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International Trade: Determinants of Patterns and Policy Impacts

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Abstract

International trade is shaped by various factors affecting firms— the main trade actors— and the economic environment in which they operate. This economic environment may relate to country and country-pair specific factors and policies; the formation and deformation of economic agreements; and the global factors and policies that affect the overall functioning of the trading system. Changes in factors affecting firms and their economic environment can affect trade patterns directly and indirectly, interacting with the rest of the economy. The research presented in this thesis analyzes the relevance of factors at different scales (firm level, country level, economic partnership level, and global level) in shaping international trade patterns and their consequences beyond trade impacts. It also introduces several theoretical, methodological, and data contributions that advance such analyses. Overall, this research highlights that factors at different scales may relate to firms' fixed and variable costs and product prices. Changes in those factors, as long as they are aligned with firms' profitability, can increase firms' trade activities. As firms increase their trade activities, their performance measures may improve. This involves impacts on the environment in which firms operate.

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Abbreviations

ACRONYM	Definition
AVEs	Ad-valorem equivalents
BREXIT	British exit Europe
CETA	Canada-EU trade agreement
CGE	Computable general equilibrium
COVID-19	Corona virus disease 2019
EU	European Union
FTA	Free trade agreement
FDI	Foreign direct investment
GATS	General agreement on trade in services
G-RDEM	GTAP-based recursive dynamic economic model
GTAP	General trade analysis project
IQ	Institutional quality
NTMs	Non-tariff measures
PE	Partial equilibrium
RTA	Regional trade agreements
SSA	Sub-Saharan African
TRQs	Tariff-rate quotas
TTIP	Transatlantic trade and investment partnership
WTO	World trade organization

1. Overview

International trade patterns of countries refer, among other things, to the size of trade with other countries (trade values/volumes) and in comparison to their domestic sales (trade intensity), how many trade links they have per country and per product (extensive margin of trade), the amount of trade value per trade link (intensive margin of trade), how long their trade relationships persist (stability of trade relationships), and the extent of diversification along the extensive and intensive margins of trade and across markets and products (resiliency of trade relationships). These patterns of international trade are shaped by a multitude of characteristics at different scales, which may relate to firms, countries, trading partners, economic partnership agreements, and the global factors that affect the overall functioning of the trade network and/or (segments of) global value chains.

The changes in factors at different scales can affect trade patterns directly and indirectly and involve consequences to and from the rest of the economy because of multiple channels that link the trade structure of the economy with other economic variables. Changes in factors that have an immediate link with trade, such as trade policy measures, can affect trade patterns directly, which, in turn, may involve changes in socioeconomic variables such as economic growth, welfare, poverty, and income distribution, and may impact the environment. Indirect impacts on trade patterns may arise when there are changes in factors/policies that are not immediately linked to trade but through multiple linkages with the rest of the economic system. For example, changes in domestic support measures, implementation of agri-environmental policies, or perturbations in the global economic environment such as COVID-19 may result in changes in the demand- and supply-side structures of the economy and their macroeconomic condition, which, in turn, trigger impacts on the patterns of international trade. Both the relevance of multiple factors at different scales to affect trade patterns and the linkages of the trade structure of the economy with other economic

variables result in complexity in the analysis of the determinants of trade patterns and their consequences beyond trade impacts. Insights into such considerations are relevant for decision-makers at various stages of the global supply chain when formulating policies or identifying strategies.

This thesis is a collection of 13 chosen publications by the author (and others) that examine the impacts of various factors that influence trade patterns and their effects beyond trade variables. In this respect, it analyzes the trading behavior of firms as key entities that perform trade activities (Bernard, Jensen, and Lawrence 1995; Melitz 2003; Bernard et al. 2003; Bernard et al. 2007; Melitz and Redding 2014) and the relevance of the economic environment in which firms operate. It also introduces several cutting-edge methods as well as a database for such analyses. Specifically, this study (i) brings insights into the relationship between firms' performance measures and their international trade behaviors, (ii) evaluates the role of countries' institutional environments and domestic policies concerning economic sustainability, and that of trade partners, on their trade patterns, (iii) highlights the impact of (de)formation of economic agreements on countries' trade patterns, (iv) explores how changes in the global economic environment impacts international trade patterns, (v) discusses consequences of the changes on countries socioeconomic and environmental conditions, and (vi) introduces several innovative approaches concerning theory and methodology and offers a new database for conducting such analyses.

Several theories highlight the role of firms and the environment in which they operate to explain observed trade patterns. Following the empirical observations that only a small percentage of firms involve in trade activities (Bernard, Jensen, and Lawrence 1995; Bernard et al. 2003), several theories of heterogeneous firms trade initiated by Melitz (2003) explain the behavior of firms in international trade. These models are complementary to the older trade theories that highlight the

importance of the environment in which firms operate (Bernard, Redding, and Schott 2007). The business environment factors of firms may relate to countries and their trading partners, economic agreements involving changes in trade costs and mobility of resources for a trade link on which countries trade, and the global economic environment, which may change because of natural or policy factors (Bernard, Redding, and Schott 2007).

Several empirical approaches rely on trade theories to explain international trade relationships and to study how changes in the economy affect trade. Econometric approaches, mainly those based on gravity models of international trade models, and partial and general equilibrium models are the widely used approaches. Other widely used approaches, bringing further insights, are applications of network analysis onto trade data, and the analysis of trade indicators and diversification measures.

This habilitation thesis and its constituent papers contribute empirically and technically to the international trade literature in several ways, providing avenues for a more comprehensive understanding of international trade flows and the design of policies/strategies at various stages of supply chains. First, it analyzes the behavior of firms in international trade; primarily, it identifies the causal relationship between firms' export decisions and the price-marginal cost margins of firms (i.e., their markups), where the direction of causality is not clear, and both variables are affected by the interaction of factors that influence firms' production and product demand (De Loecker and Warzynski 2012; De Loecker 2013; De Loecker et al. 2016; Bellone et al. 2016; Kiliç 2019).

Second, it analyzes how changes in the business environment of countries and their trading partners, the similarity of their business environments, and their unilateral domestic and trade policy measures impact international trade patterns. Specifically, it analyzes (i) the impact of exporting countries' Institutional Quality (IQ) environment, and its similarity with importers (along

different IQ dimensions) on the stability of trade relationships, and (ii) the impact of countries' implementation of sustainability measures, such as unilateral efforts to reduce food waste through domestic policies or to enhance sustainability practices in trading partner countries through trade measures, on trade patterns.

Third, it analyzes the impact of the (de)formation of economic partnership agreements on the intensive and extensive margins of trade and overall trade values/volumes. The analysis considers different dimensions of de(formation) of economic agreements, including changes in tariff and Non-Tariff Measures (NTMs) affecting trade in commodities and services, and changes in rules on the mobility of capital and labor across nations. The analysis also investigates the importance of product coverage and the relevance of trade agreements for different components of the supply chain of commodities, including the demand, and fixed and variable cost components of their trade.

Fourth, it highlights the importance of changes in the global economic environment (global level factors) for trade patterns. In this respect, it investigates the evolution of the trade network's structure (integration and resiliency) in concordance with the major developments in global factors linked to the trading system. Moreover, it analyzes changes in trade indicators and diversification of trade activities during the recent pandemic. It also brings insights into the impacts of some of the future pathways for global economic development on trade patterns.

Fifth, it highlights the impacts of changes in factors at different scales beyond trade impacts. In this respect, it analyzes the impacts of changes in trade patterns on several socioeconomic and environmental variables. This includes the analysis of the impacts on economic growth, sectoral outputs, welfare (of various interest groups), poverty, income distribution (across different types of households), deforestation, peatland destructions, greenhouse gas emissions, etc. Moreover, it analyzes the role that trade patterns may play in achieving desired sustainability outcomes in

domestic economies and/or economies of trade partners through the (unilateral and globally coordinated) domestic and trade policy measures.

This thesis also introduces several sets of technical contributions that concern theory and econometric analyses, enhancing the application of partial and general equilibrium models, advancing the tools to analyze trade networks and trade diversification, and developing a database on ad valorem equivalents of barriers against foreign suppliers of services in 11 service sectors and 103 countries.

Concerning theory and econometric analyses, it proposes strategies for improving the estimation of firms' production functions, by addressing possible biases in output measurement resulting from deflating revenues with industry-wide price deflators, therefore improving the estimation of firms' unobserved productivities. It offers an approach that surpasses the classic methodologies that, in estimating firm-specific markups, assume perfect competition in input markets. It advances econometric exercises to identify the causal relationships associated with the simultaneity of firms' performance measures and trade behaviors.

Concerning the partial and general equilibrium models, the thesis presents two approaches to adequately capture the impact of changes in tariff and Tariff-Rate Quota (TRQ) policies, respectively, at the detailed product level. This prevents the biases that may arise from aggregating tariffs, TRQs, and trade data at the product level into an aggregate sector as typical in standard Computable General Equilibrium (CGE) exercises. This thesis also presents advances in the representation of heterogeneous firm models of international trade into CGEs, focusing on enhancing numerical stability. It introduces different ways to adequately capture NTMs' impact in CGE models. It presents a simplified framework to link investment changes to the capital stock in CGEs. It introduces advances in constructing the baseline models in dynamic CGEs, considering

global structural changes. It advances the representation of households in CGEs and develops a regionally extended CGE model. It develops a Partial Equilibrium (PE) model linking trade, output markets, input markets, related domestic and trade policies, and environmental outcomes.

Concerning the analysis of trade network and diversification, the thesis introduces an approach to performing a network analysis of trade along the extensive margin of trade. It also offers new ways to measure the diversification/concentration of trade activities at regional and global levels. Finally, this thesis offers a quantified measure of NTMs against foreign suppliers of services in the most important service sectors in 103 countries.

In the following sections, I first introduce the fundamental ideas and problem statements related to the relevance of factors at different scales that shape the patterns of international trade and their consequences beyond trade impacts. Then, I describe the theoretical, methodological, and database advancements introduced in the constituent papers. Then, in the last section, I present the main findings, policy implications, and recommendations for future research.

2. International trade: relevant factors at different scales

The interaction of several factors at different scales involving firms (firm level factors), countries and their trade partners (country level factors), (de)formation of economic agreements (economic partnership level factors), and the global economic environment (global level factors) determines the patterns of international trade. Figure 1 depicts the relationship between various level factors and international trade. The interaction of elements at different scales has consequences that go beyond trade impacts on socio-economic variables and the environment.

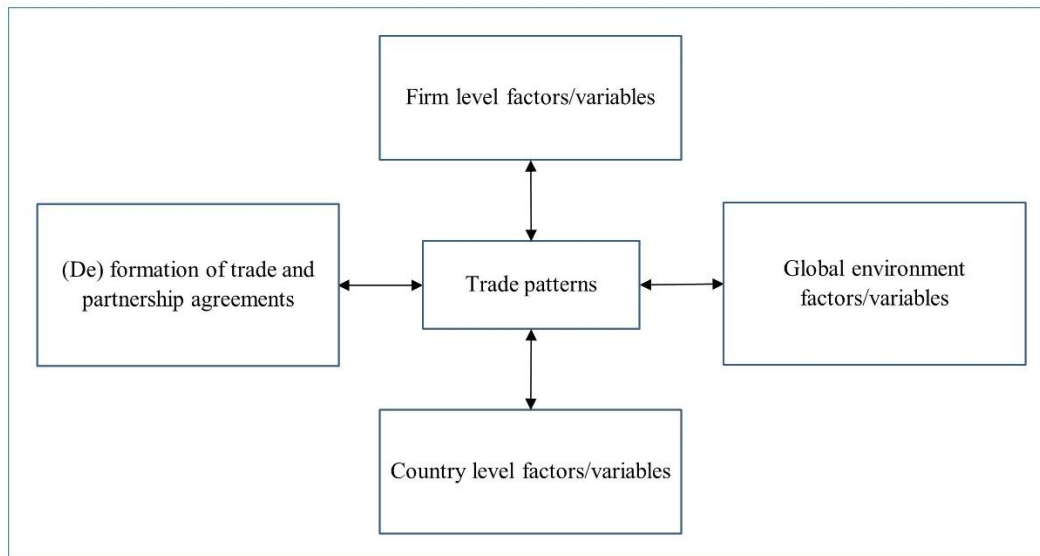


Figure 1: Different level factors and international trade

2.1 Firm-level factors and international trade

The appearance of rich micro-level datasets in the mid-1990s revealed two important empirical relationships. First, the ratio of price over marginal costs of firms, that is their markups, affects export behavior. Firms with relatively low marginal costs or higher product quality have higher markups and are more likely to enter export markets (Bernard et al. 2003; Melitz and Ottaviano 2008). Second, the experience of exporting may contribute to firms' learning and improve their productivity or product quality, which can increase their markups (Bernard and Jensen, 1995; De

De Loecker et al. 2016). Together these results show that the relationship between firm markups and export behavior is complex, with simultaneous causality that may widen the differences in markups between exporters and non-exporters. This relationship is of key interest for firms' strategic orientation in competitive industries as well as for policymakers seeking to formulate measures that promote competition and welfare (e.g., De Loecker et al. 2016; Ponikvar and Tajnikar 2011). However, the empirical evidence on export–markup relationships is limited. An important challenge in determining this relationship is the simultaneity between firms' exports and markups; this arises from the interaction of several factors that affect production and demand (De Loecker et al. 2016; De Loecker and Warzynski 2012; De Loecker 2013; Bellone et al. 2016; Kiliç 2019). In Jafari et al. (2022), we disentangle this simultaneous relationship using exogenous factors such as firms' legal form and age as instruments. First, we explore the impact of firms' markups on the decision to export and the resulting export intensity. Second, we analyze the impact of firms entering and staying in the export market for at least two consecutive years, that is, we investigate the effect of firms' export experience on markups. Finally, we evaluate the differences in markups for exporters and non-exporters. Using a double hurdle control approach, while addressing the simultaneity, we show that higher markups increase participation in export markets and lead to a higher export intensity. Moreover, using the Extended Regression Model instrumental variable approach, we show that markups increase upon entry, and markups increase further if export activities continue for at least two consecutive years. According to these results, there is a widening gap between exporters and non-exporters in their ability to exercise market power. As firms with higher markups tend to self-select into export markets, they are able to increase their markups even more. In theory, higher markups are related to differences in productivities, which affect marginal costs, and in prices. Similar results hold (albeit in lower magnitude) when we control firms' productivity differences to study the export–markup relationship. This suggests that the export–

markup relationship and markup differences across firms are also influenced by factors other than their productivity, such as product quality and demand-side conditions. Based on the observed relationship, firms can increase markups, by relying on internal adaptation, and participate in export markets. The markups may increase further when firms begin exporting. This implies that using firm-specific resources and participating in export markets can be consistent ways for them to increase markups. Additionally, the results suggest that trade policies aimed at enhancing firms' export participation, including limiting border restrictions, could counteract domestic competition policies that target price-cost margins.

2.2 Country level factors and international trade

The literature extensively covers the impacts of countries and country-partner characteristics on trade. Significant advances include (i) analyzing factors that affect trade beyond traditional gravity variables, and (ii) analyzing factors on different dimensions of international trade patterns, such as extensive and intensive margins, duration of trade, and diversification of trade links. Despite the observed trade disruptions and their consequences on supply chains, the literature that analyzes the determinants of the stability of trade relationships is still scarce. Bilateral trade relationships across sectors can have a short duration, indicating that certain factors prevent their continuance (Besedeš and Prusa 2006; Nitsch 2009; Hess and Persson 2011; Bojnec and Fertő 2018). Recent developments in modeling the dynamics of decisions of heterogeneous firms to enter costly export markets place an emphasis on the importance of trade costs (Melitz 2003) and uncertainty on the duration of bilateral trade links (Rauch and Watson 2003; Segura-Cayuela and Vilarrubia 2008; Bernard, Jensen, and Schott 2009). The IQ environment of trading partners affects both trade costs and uncertainties (North 1991; Martínez-Zarzoso and Márquez-Ramos 2019) and can have an impact on the duration/stability of trade relations. IQ elements can be crucial for firms choosing

trade partners to lessen uncertainties as well as for policy planners looking to improve the stability of trade relations and/or to modify their institutional environment. Stable trade relations have welfare implications on both sides of the trade relationship since they affect the revenue of producers in exporting countries and the availability and variety of products in importing countries. In Engemann, Jafari, and Heckelei (2022), we examine the effect of exporters' IQ and its similarity with that of importers on the stability of trade relationships using a discrete-time duration model. We concentrate on the agri-food exports from Sub-Sahara African (SSA) nations to the European Union (EU) and consider three dimensions of IQ: "efficiency of policy formulation and implementation," and "respect of citizens and state for institutions," and "government selection, monitoring, and replacement." We find that the duration of SSA exports to the EU lasts longer when exporters' IQs are higher and trading partners' IQs are more similar. The biggest impact of exporters' IQ is related to "government selection, monitoring, and replacement." When considering the similarity of trading partners, "respect of citizens and state for institutions" has the most substantial influence on trade durations. These results imply that fostering nations' IQ may increase the stability of trade relations. Furthermore, the similarity of trading partners IQs contributes to the stability of trade relations and should be carefully considered when establishing new trade links.

Countries' international trade may also be affected by several other country-specific factors such as domestic policy measures pursuing sustainability concerns in the domestic economy and trade policy measures seeking sustainability concerns in the domestic economies of their partners. How these policies impact a country's trade depends on the impact of policies on the competitiveness of the country in or toward which such policies are implemented and the ability of the countries to shift their trade partners. In Jafari et al. (2017), we use a PE model to analyze the impact of EU import restrictions on the overall Indonesian trade of palm oil. We show that the unilateral trade restriction policies introduced by the importing countries against their trade partners due to

sustainability concerns do not importantly affect trade values in those partner countries unless there is some global coordination of such policies. Similarly, in Jafari et al. (2020), using a CGE framework, we show that unilateral domestic sustainability measures like the EU efforts to reduce food waste may reduce the competitiveness of countries' trade in favor of their trading partners, therefore adversely affecting trade of those countries. Such results imply that pursuing sustainability concerns requires enhancing the commitment of countries at the global level and/or more targeted actions with low costs to domestic policies.

2.3 Economic partnership level factors and international trade

Numerous economic agreements between countries have been negotiated, or are in the negotiation process, and a number of existing contracts are deformed or weakened. Before formulating their policies, policymakers are concerned about the consequences of their policies, and following the implementation, they seek to understand the decisions' strengths and weaknesses. A major concern is the effect of (de)forming economic agreements on trade patterns. The impacts may substantially differ depending on a number of factors. Impacts may vary depending on the product and service coverage of the (de)formation of economic agreements because countries have different levels of competitiveness and trade protection across products. Impacts may also differ depending on the depth of the agreement, that is, the type and strength of policy changes involved. For example, (de)formation of economic agreements may involve, to different extents, increased (or decreased) tariffs, NTMs, and mobility of labor and capital across countries; this involve different impacts on firms' production and trade costs and their demand. Moreover, the impacts depend on the economic ties of partners before the (de)formation of economic cooperation. We bring insights along these dimensions in several works on the impact of Free Trade Agreements (FTAs).

In our analysis of the Transatlantic Trade and Investment Partnership (TTIP) (Jafari and Britz 2018), we show that trade policies that reduce fixed costs have a greater impact on increasing the number of active firms on a trade link (i.e., the extensive margin of trade), whereas those that reduce variable costs primarily increase traded quantities per firm (i.e., the intensive margin of trade). Overall, change in traded quantities (the net effect on the extensive and intensive margin of trade) is more sensitive to policies that affect the variable cost than those that affect fixed trade costs by the same percentages. In another analysis of TTIP (Jafari, Britz, and Beckman 2018), we show that lowering tariffs and NTMs create trade price effects, thereby leading to an increase in the intensive margin of trade. In this respect, the impacts are more substantial when NTMs are reduced. Moreover, the increased liberalization reduces firms' average productivity on the trade link between the United States and the EU, leading to an increase in the number of firms operating on that trade link, increasing the extensive margin of trade. Overall trade increases due to this FTA but at the expense of a reduction in trading with other countries (trade diversion effect). In the application of the Canada-EU Trade Agreement (CETA) (Jafari et al. 2021b), we show that the type of products that are subjected to trade liberalization significantly impacts trade flows. In particular, we show that the inclusion/exclusion of sensitive products (those with high rates of protection) in trade agreements has a significant impact on the changes in overall trade values. In yet another application of CETA (Jafari et al. 2021a), we show that the expansion of TRQs results in increased trade, but the simulated trade impacts are expected to stay below the post-quota level, and therefore the out-of-quota tariff rates should not be much concern in trade negotiations. In our analysis of Brexit (Jafari and Britz 2020), we identify different dimensions of the economic deformation, including the restoration of tariff and NTMs, restrictions on the movement of workers, and restrictions on the movement of Foreign Direct Investments (FDIs) between the United Kingdom and the EU, among other dimensions. We show that higher negative trade impacts are

associated with the reduced labor force, while restoring the most favored nation tariffs has the lowest impact. The restoration of the NTMs and restrictions on FDIs yields an almost equally considerable impact.

2.4 Global level factors and international trade

International trade of countries may also be affected by the changes in factors that affect the functioning of the overall trade network. The international trade system has been subjected to various changes over time (Maluck and Donner 2015), which may be associated with the multitude of factors and policies that affect the cost of production and the ability of firms to produce specific products, trade costs, and demand preferences (Kim and Shin 2002; Fagiolo, Reyes, and Schiavo 2010; Benedictis and Tajoli 2011; Shatters and Muneeppeerakul 2012). Studying the evolution of the structure (integration and resiliency) of the trade network concerning natural shocks and major global socio-economic changes and identifying the barrier to further integration helps to better understand the directions in which the structure is moving and to discover the potentials of and threats to the network. Hence, several of our works consider the analysis of (possible) changes in trade networks concerning past, current, and future global structural changes and identifies some barriers to the further integration of the trading system.

Using network analysis, in Jafari, Engemann, and Zimmermann (2022), we investigate the structure and evolution of the international agri-food trade network from 1995 to 2019 in terms of connectivity and vulnerability. We show an enhanced integration of the agri-food trade network along with the extensive margin of trade and overall trade values with major changes from 1995 to 2007, and only slight integration of the network after this period. Along with the increased integration, the number of core-periphery structures has increased, but the dominance of cores has decreased. Moreover, we show that the trading network generally turned more stable from 1995 to

2007; after that, there are no strong signs of its higher resiliency. The observed changes may relate to the sharp increase in the number of trade agreements between 1995 and 2007, the fast economic growth that characterizes this period, and the relatively high decline in transport and communication costs compared to subsequent periods. The setback from further integration and resiliency may relate to the 2008/2009 financial crisis and the weakened aggregate demand amid the economic turmoil in many high-income countries during the 2014–2015 period (WTO 2022). We conclude that there are still significant heterogeneities in the contribution of individual countries to the overall integration of trade networks, which could potentially lead to instabilities in the trading network.

In Engemann and Jafari (2022), we analyze the changes in the observed agri-food trade (values, extensive and intensive margins, and diversification) during the pandemic at the global and regional levels. We measure changes in some of the trade network measures (trade indicators and diversification measures) and associate them with changes in a number of COVID-19-related factors, such as deaths, infections, policy stringency, mobility restrictions, and industrial production output, which are either directly related to the virus or are induced by policies intended to contain it. We demonstrate that changes in trade remained constrained to short-term disruptions that predominantly occurred at the extensive margin of trade and, in particular, at the peak of policy stringency, mobility reductions, and the general decline in economic output. Trade in staples was most resilient, whereas that in other agri-food products drastically decreased. In general, the inter-regional trade of Asia, Africa, Latin America, and the Caribbean turned out to be more resilient than these regions' intra-regional trade; the reverse holds for the intra-regional trade.

In Britz et al. (2022), we forecast the evolution of the average shares of imports on total domestic consumption and the shares of exports on total domestic production across countries and over time

using a nonlinear panel regression with random effects that identifies a historical trend component. Our results highlight a clear path toward increased trade integration for selected countries in our analysis (Albania, Bolivia, Ethiopia, Malawi, Nicaragua, and Vietnam). However, the path to increased trade integration evolves somewhat differently across three considered sectors—agriculture, extraction, and manufacturing. The manufacturing sector is expected to experience higher integration and the agricultural sector is likely to experience comparatively less integration, and extraction somewhere in the middle.

In Jafari and Tarr (2017), we identify barriers to the integration of the international trade network for the service sectors, given the growing role of these sectors in the economy and overall trade and their role in reducing uncertainties associated with trade in commodities. Service trade has grown faster than merchandise trade: in 2014, service trade accounted for 23% of total trade, based on the balance of payment, compared to 19% in 1995. However, once different “modes” of services trade are considered, services trade constitutes almost 50% of the total trade. We provide a new database covering the estimates of the Ad-Valorem Equivalents (AVEs) of the barriers for 11 of the most important service sectors in international trade in 103 countries. We point toward important restrictions against foreign services suppliers that vary substantially across countries. Among the potential reasons are that members of the World Trade Organization (WTO) have uneven commitments to the General Agreement on Trade and Services (GATS) and FTAs, which cover service sectors. The uneven commitments relate to countries’ service sectors coverage and their depth of commitments. Combining these two dimensions, as articulated in Roy (2019), the average incidence of the commitment level is rather limited. Another potential reason is that although various members in service Regional Trade Agreements (RTAs) undertake GATS+ commitments, i.e., they go beyond and above GATS commitments, the extent to which WTO

members engage in service RTAs is uneven, and the new RTAs only cover a portion of global service trade.

2.5 Trade patterns and their linkages with socioeconomic and environmental characteristics and outcomes

International trade structure has linkages with output and factor markets. Therefore, changes in trade structure can affect these markets and involve changes in socioeconomic and environmental characteristics and outcomes. Despite numerous studies in respect to these issues, the empirical evidence is still inconclusive (Cerra, Lama, and Loayza 2021). International trade may have a differential impact in terms of the direction and magnitude across countries, economic sectors, and different groups of people.

Perhaps one of the relatively most conclusive pieces of evidence from the literature relates to the direction of the impact of trade on economic growth and welfare. Countries are likely to increase their economic growth and welfare by increasing trade; but if such trade is driven by lowering the trade barriers between countries, it may exert a reduction in trade with other nations (trade diversion impact), resulting in lower welfare in those other countries. However, the extent of such impacts is uncertain as it depends on the economic structure of countries, including their trade structure. In several studies where we carry out FTA analysis (Jafari and Britz 2018; Jafari, Britz, and Beckman 2018; Jafari et al. 2021a; Jafari et al. 2021b), we show that increased trade driven by FTAs increases the economic welfare and growth of countries involved but the impacts differ on the third party countries. Impact varies significantly across countries and sectors depending on the type of trade agreement, its coverage, and its depth.

The impact of trade on poverty and income distribution has also been subject to a myriad of analyses. Yet, findings are inconclusive (Cerra, Lama, and Loayza 2021) and impacts can vary

across countries (David, Dorn, and Hanson 2013), sectors, and households (Pavcnik 2017). The main reason is that the channels exerting influence are many and complex (Winters, McCulloch, and McKay 2004). In Britz et al. (2022), we construct a recursive-dynamic CGE model with household details to analyze the impacts of deeper trade integration on poverty and income inequality until 2050 with a focus on six developing countries: Albania, Bolivia, Ethiopia, Malawi, Nicaragua, and Vietnam. We show that accelerated trade integration increases income gaps in all six countries and increases relative poverty. However, by 2050, absolute poverty would be eliminated in almost all six nations.

International trade structure is also related to decreased or increased pressure on environmental resources (Zimmermann et al. 2018), either directly or by its impact on policies implemented to pursue sustainability concerns. Enhanced trade may directly affect transport, consumption, production, and factor input use; and the literature provides mixed evidence on the environmental impact (Zimmermann et al. 2018). Trade structure may also play a role in weakening the impact of policies that aim to enhance sustainability practices, depending on the level of coordination of the policies among countries (Britz et al. 2019). In Jafari et al. (2017), we use a PE framework to show that the EU efforts to reduce deforestation and conserve peatlands in palm-oil-producing countries, by implementing private standards that result in import restrictions, may significantly reduce trade on bilateral links. However, the alternative trade relationships may mean that the overall impact of such policies would be negligible unless globally coordinated efforts are followed. Moreover, in Jafari et al. (2020), we use a CGE model to show that while technological advancements in Europe to prevent food waste may decrease the pressure on natural resources and the environment in Europe, this will not have global benefits due to trade leakage effects partially or completely offsetting the expected benefits.

3. Methodological advances and database developments

Analysis of the determinants of international trade patterns, like other (economic) analyses, involves concerns about the right choice of methodology and accessibility to rich data. The choice of methodology depends on multiple factors such as data availability, scope of analysis in terms of the country and sectoral coverages, purpose of the study, uncertainties associated with economic and policy variables, and researchers' taste. There are also circumstances where different types of analyses can be performed to complement each other. This thesis introduces advances to some of the approaches widely used for analyzing determinants of international trade patterns and highlights the technical and data advances that the constituent papers of the thesis have introduced to the literature. These include theoretical and methodological advances concerning econometric analyses, partial and general equilibrium analyses, trade network analyses and diversification measures, and database development.

3.1 Econometric approaches

Econometric approaches are one of the types of approaches that are frequently used to assess the effects of different factors and policies on trade patterns when sufficient historical data exist. One of the significant challenges with econometric estimations in trade research, like that of many other fields, is tackling the bias associated with the correlation of the explanatory variables with the error terms, that is the endogeneity bias. There exist different sources of endogeneity, including errors in the measurement of variables, reverse causality between the right and left-hand side variable(s), and omission of variables in the specification of regressions (Wooldridge 2010). Endogeneity may result in incorrect causal inferences of the relationship between variables (Wooldridge 2010).

Strategies to address measurement error

Recent trade research has extensively analyzed the relationship between firms' performance measures and trade behavior. There exist essential shortcomings when it comes to dealing with the endogeneity issue both when estimating the firm performance measures, such as estimations of firms' productivity and markups from a production function (De Loecker and Warzynski 2012; De Loecker 2013), and when exploring the relationship of these variables with the trade behavior of firms (De Loecker and Warzynski 2012; De Loecker 2013; Bellone et al. 2016; Kilinc 2019).

Measuring firm performance measures often involves estimating the production function; while the physical output quantities are not available, the output values are. A classic approach to deal with this issue is to deflate the firm output values with industry-wide price deflators, which may result in measurement bias (Foster, Haltiwanger, and Syverson 2008). In Jafari et al. (2022), we enhance the production function estimation by addressing possible biases in output measurement that are caused by deflating revenues with sector-wide price deflators. We employ price indices that reflect the weighted average of prices in both domestic and export markets, whereas the weights capture the sale shares in different markets. Additionally, to account for the firm-specific deviations from the weighted average industry prices, when estimating the production function, we use firm-specific dummies. Given this more accurate production function estimation, the firms' performance measures obtained from the production function estimates are more reliable.

Some of the firm performance measures like productivity can be directly obtained from the production function estimates, but others like markups of firms, require additional steps (De Loecker and Warzynski 2012). The measurement issue might arise when the latter is not adequately addressed. For example, due to the firm-level database's availability, many studies follow De Loecker and Warzynski (2012) to estimate firms' markups. In this approach, firms' markups are

calculated as the production elasticity of the variable input multiplied by the inverse of its revenue share. This approach has been widely used to estimate firms' markups as it does not call for any assumptions regarding how competition takes place in output markets, and it needs less data than the New Empirical Industrial Organization approaches, which rely on the demand-side approach. However, this approach assumes that input markets are perfectly competitive. In Jafari et al. (2022), we go beyond the classic methodology of De Loecker and Warzynski (2012) and take into account the potential imperfections in both input and output markets when estimating firm-specific markups.

Strategies to address simultaneity

Simultaneity is another source of endogeneity that does not allow causal inferences. This is omnipresent when analyzing the relationship between firm performance measures and trade behavior. For this reason, researchers interpret their results as the correlation among the variables (De Loecker and Warzynski 2012; Kilinc 2019). A challenge is to disentangle this simultaneity. In Jafari et al. (2022), we evaluate the relationship between firms' markups and export behavior by employing exogenous characteristics of firms such as firm legal structure and age as instruments. Relying on these instruments, we employ a double hurdle control function technique that separates the initial export decision from the export intensity and also captures the zero export observations as meaningful observations (Cragg 1971; Wooldridge 2010; García 2013; StataCorp 2017) to analyze the impact of firms' markups on export participation and export intensity. We also use an Extended Regression Model Instrumental Variable approach (Stata Press 2019) to determine whether markups are impacted by the decision of firms to start exporting and to remain in the export market for at least two consecutive years. In some cases, the reverse causality issue is less severe and can often be addressed by using a lag of variables suspected to involve reverse causality. For example, in studying the impact of IQ factors on the stability of trade flows (Engemann, Jafari,

and Heckelei 2022), we use a lagged value of institutional quality factors to address the potential reverse causality.

Strategies to address biases from the omission of relevant variables

Endogeneity associated with omitted variables correlated with a right-hand side variable is often removed by including fixed effects, that is, including dummy variables for the missing or unknown characteristics. This approach is a common practice in estimating the gravity model of trade and other econometric estimations involving trade variables. For example, in our analysis of the impact of institutional quality on export duration using a gravity trade mode (Engemann, Jafari, and Heckelei 2022), we use country-fixed effects. Likewise, in Jafari et al. (2022), we use firm and industry dummy variables to assess the relation between firms' markups and export behavior.

3.2 General and partial equilibrium models

Econometric models are trustworthy tools for estimating the impact of policy changes empirically. These models, however, necessitate a significant amount of detailed historical data and do not explicitly consider the interlinkages of trade with consumption and production. The former may render the econometric models unsuitable for analyzing the trade impact of the most recent or prospective changes. The latter may limit the analysis of impacts on the variables considered in the regression.

Equilibrium-based models with explicit equilibrium conditions in the model representations, including CGEs and PEs, are other widely used approaches in analyzing trade relationships and the impact of different factors or policies on trade. In contrast to econometric models that rely on rich historical data, equilibrium-based models often require data for a single year and explicitly represent linkages between markets; as a result, they are preferable tools when data are scarce and/or when a simultaneous policy impact analysis requires taking into account the linkages (Jafari

and Othman 2016; Jafari et al. 2017). When the sector under policy reform has close linkages with the rest of the economy, CGEs models are ideally suited to consider all the economic sectors and their linkages simultaneously. However, there are circumstances where the analysis is related to a relatively small sector of the economy, but more tractable and focused results are required; in such cases, PE models, which generally consider a single sector in isolation from all other sectors, are preferable. Both CGE and PE models may complement each other in policy analysis, but despite their widespread use in trade policy analysis, both types of models have several shortcomings. The results of CGEs are sensitive to the choice of the model's configuration, and the methodological and data deficiencies may result in an ill-posed imposition of policy shocks to the model. PE models also may ignore the linkages between the input and output markets (or between downstream and upstream activities) and therefore miss various constraints that apply to multiple factors of production. Below I review some of the shortcomings concerning the application of CGE and PE models and offer technical and data advances in regard to these.

Modeling heterogeneous firms in CGEs

The simulated trade and welfare impacts from CGE models may significantly differ depending on the features of industrial organization (Armington assumptions and features of popular Melitz model) incorporated in the model (Balistreri, Hillberry, and Rutherford 2011; Balistreri and Rutherford 2013; Balistreri and Tarr 2022; Jafari and Britz 2018; Jafari, Britz, and Beckman 2018; Jafari and Britz 2020). Since Armington (1969) suggested treating domestic and imported varieties of the same goods as imperfect substitutes, applied CGE analysis has mostly followed this methodology. It offers a strong yet manageable framework for analyzing international trade policy and can reproduce any observable pattern of international trade along the intensive margin of trade. The Armington model, however, does not allow for changes in the number of imported varieties on a trade link because preferences for each origin in the Armington model are constant and not

linked to the imported varieties (Akgul, Villoria, and Hertel 2016). As a result, it ignores potential variations at the extensive margin of trade, such as trade flows with new partners and in new products, which are determined to be essential in empirical studies (Hummels and Klenow 2005; Chaney 2008). The ground-breaking research by Melitz (2003) addresses this issue. It incorporates heterogeneity in firm productivity to Krugman's (1980) framework of monopolistic competition and allows firms to self-select new export markets based on their productivity level. That is, it allows constant preference parameters in the Armington approach to vary in the number of firms. This allows the analysis of the changes in trade along both the intensive and extensive margins. Accordingly, the Melitz model can be seen as an expansion of the Armington technique, which permits changes in the extensive and intensive margins of trade (Hosoe 2018). Numerous papers use the Melitz model and replicate important trade patterns observed at the firm/plant level (Bernard et al. 2007; Eaton, Kortum, and Kramarz 2004). There have therefore been several efforts to include the features of the Melitz model into CGEs (Zhai 2008; Balistreri, Hillberry, and Rutherford 2011; Akgul, Villoria, and Hertel 2016; Dixon, Jerie, and Rimmer 2016; Oyamada 2017; Jafari and Britz 2018). Because the Melitz model is more complicated than the Armington model, these attempts in published applications consider CGEs with a modest sectoral and regional resolution. Melitz-based CGEs can be challenging to solve and might end up infeasible partly due to convexity problems. To illustrate this, assume that a firm's demand is reducing because of increased imports driven by an FTA. This results in a reduction in outputs, which leads to two counterfactual effects. First, the average industry productivity increases because less productive firms will leave the industry and the trade link, resulting in a decreased average variable cost of firms. Second, the average fixed cost for firms in the domestic industry increases. The latter may dominate the former effect. If this occurs, the cost for firms that use domestic industry's output in their production increases. This reduces the demand for a given firm's industry output being

substituted by imports or other inputs. The reduced demand for firms' industry output results in a vicious cycle that may lead to the exit of all firms in that sector and therefore the disappearance of that sector. That is, the model may enter corner solutions because the solver encounters infeasibility caused by non-negativity bounds becoming binding, in addition to the equations of the standard model, thereby rendering the system of equations non-square. In Jafari and Britz (2018), we focus on numerical stability to facilitate the use of the Melitz model in CGE analysis when dealing with many sectors and regions. We introduce three strategies to prevent the vicious circle that results in ever-increasing costs for firms. The first strategy rises price feedback from factor markets by making the non-depreciated portion of the capital sector-specific. Second, we offer an aggregation of the bilateral and domestic intermediate input demand by the different sectors such that the share of imports across sources and the percentage of import composition and domestic intermediate demand stays identical. The first and second strategies to some extent prevent the vanishing of sectors. In the third strategy, we specify a maximum cost share for domestic intermediate demand in a given industry's output. In our application, if the cost share exceeds the specified maximum cost share, then the bilateral demand equation will be replaced by the standard Armington formulation in the benchmark. In our application of the impact of TTIP (Jafari, Britz, and Beckman 2018), we show that trade and welfare impacts of policy shocks are more significant when considering the sectors under Melitz compared to Armington.

Modeling NTMs in CGEs

The way different NTMs are addressed in CGEs is also tied to the type of CGE model (Armington vs. Melitz type models) and impacts its results. Three general trade effects are associated with NTMs (Andriamananjara, Ferrantino, and Tsigas 2003; Walkenhorst and Yasui 2005; Fugazza and Maur 2008; Jafari and Britz 2018). These are trade cost impacts, supply shifting impacts, and demand shifting impacts. Trade cost impacts describe a change in bilateral trade costs, such as

tariffs and certification fees. Supply shifting effects are associated with costs in production for an export market, such as those needed to comply with technical trade barriers. Demand shifting impacts happens when measures such as product labeling standards impact consumer behavior. Trade cost effects and demand shifting effects of NTMs may be captured similarly in Armington and Melitz type models but modeling the supply shifting of NTMs is related to the choice of the model (Jafari and Britz 2018; Akgul, Villoria, and Hertel 2016). In Armington-based models, the fixed costs are not present; therefore, all the production costs associated with the NTMs are modeled as variable costs; technically speaking, they affect iceberg costs. In the Melitz model, the costs may be allocated to the fixed and variable costs of trade depending on the fixed and variable cost component of NTMs (Akgul, Villoria, and Hertel 2016; Jafari and Britz 2018). The differentiation between fixed and variable costs in Melitz-type CGE models allows a more realistic quantitative assessment of NTMs. In Jafari and Britz (2018), we implement the NTMs in different ways and show that the change in trade quantities is more sensitive to bilateral variable costs. In contrast, welfare increases are driven more by reduced fixed costs, reflecting the love-of-variety effect.

Extension of CGEs to detail product levels

In trade agreements, sensitive products often receive only a partial tariff elimination, but CGE assessments often make the simplifying assumption of complete bilateral tariff elimination or underrepresent exemptions for sensitive products. If CGE analyses ignore the exemptions, they likely overestimate trade impacts (Jafari et al. 2021b). When tariff exemptions for sensitive products are considered, tariff changes for individual tariff lines are aggregated outside the model to larger sectors. Still, the aggregation of trade and tariff data pre-model presents problems. High tariff rates tend to reduce traded volumes more than lower tariffs; therefore, tariff aggregators can lead to systematic bias that underestimates the average level of border protection (Bach and Martin

2001; Anderson 2009; Himics and Britz 2016). The related bias typically rises with greater initial tariff dispersion and larger tariff cuts. The absence of commodity details in the model might also result in aggregating bias because it ignores the substitution possibilities between detailed products falling under an aggregate sector. Pre-model aggregation might also underrepresent trade competition among partners. As an example, take two exporters who are not directly competing with one another in weak product substitutes such as butter and cheese. Considering that the data aggregates the two into a single sector called the “dairy product” sector, these exporters could be seen as competitors at the aggregate sectoral level. Recent developments attempt to mitigate these problems by iteratively linking CGE models to a detailed PE model (Grant, Hertel, and Rutherford 2007) or by extending the model structure to tariff lines for a single or small number of sector(s) (Narayanan, Hertel, and Horridge 2010; Beckman and Arita 2017; Chepeliev et al. 2019). In both cases, consumption, production, and bilateral trade information must be available and rendered consistent with a larger database, which is often challenging (Hertel 2013). In the end, neither the iterative PE-CGE link nor the partial disaggregation scale up well as it is numerically challenging to apply them to many or all commodities (Himics and Britz 2016). These approaches also require substantial amounts of data from various sources, which causes issues with data harmonization. Additionally, these methods significantly expand the size of the entire model, making it computationally difficult to dis-aggregate sectors comprising many tariff lines while at the same time considering regional detail. In Jafari et al. (2021b), we offer a tariff line module that only extends the two-stage constant elasticity of substitution/transformation found in the trade structures of CGE models to the tariff line level for selected trade links. This module functions as an endogenous tariff aggregator across tariff lines and allows for the substitution of commodities across tariff lines. At the same time, it reduces data needs and computational burden.

Modeling TRQs in CGEs

TRQs are crucial for trade negotiations since they rarely undergo full liberalization and frequently present barriers to negotiations. TRQs are typically simplified in CGEs due to the complexity of modeling and data collection. One aspect often simplified is the representation of TRQs by AVEs, which is an attempt to express TRQs by a single percentage of the value of a commodity. Specifically, AVEs represent the impacts of TRQs on a commodity as a percentage tariff levied on the cost-insurance-freight price. Typically, AVEs are first calculated at the level of individual tariff lines and then aggregated to the sectoral resolution in the CGE. As such, crucial information might be missed. The conversion of the TRQ to an AVE facilitates their implementation in global CGE models by summarizing information on inside and outside quota tariff rates and fill rates, defined as import quantities over predefined quotas (Narayanan, Hertel, and Horridge 2010). However, determining the AVE of a TRQ after liberalization involves an assumption about the future fill rate. Another aspect relates to the implementation of TRQs at an aggregate sectoral level. Detailed products might be subject to an aggregate TRQ, where the initial TRQ regimes differ across products or some products are even not traded under a TRQ regime. Furthermore, substitution possibilities in trade between detailed products are ignored. Therefore, TRQs require proper implementation in CGEs. In Jafari et al. (2021a), we build on the approach for bilateral trade modeling at the tariff line from Jafari et al. (2021b) and offer an approach to introduce TRQs as a mixed complementary problem (Rutherford 2003) at the tariff line. With this approach, the TRQ regime is endogenously represented, and the simulated marginal tariff depends on the endogenously simulated quota fill rate. It also allows for modeling of TRQs at the detailed product level that can take into account the differences in inside quota tariff rates, outside quota tariff rates, and quota rents. Furthermore, it prevents situations in which trade not subject to a TRQ becomes

subject to an aggregate TRQ and considers substitution possibilities in trade between products belonging to the same aggregate sector in the CGE model.

Modeling dynamics in CGEs

Considering time elements, CGE models are divided mainly into comparative static and dynamic models. In comparative static models, producers and consumers make optimal decisions at a specific time, with no consideration for the future (Devarajan 2001). Time dynamics are captured variously in CGEs. In forward-looking CGE models, agents may have perfect/limited foresight and optimize their intertemporal objective functions (Babiker et al. 2009). In Recursive dynamic models, investment decisions are made based on a set of exogenously determined rules, but agents still maximize their objective functions with respect to the budget constraints in that year. Comparative static models are most suitable when the economic structure (exogenous parameters of the model) is not expected to change over the years. The calibration of the parameters of these models is relatively easy compared to dynamic models because, generally, comparative static models have lower parameterization requirements than dynamic models (Weitzel, Balistreri, and Ren 2016). When considering the dynamics, the use of forward-looking CGEs and recursive dynamic models have trade-offs (Weitzel, Balistreri, and Ren 2016). On the one hand, high sectoral and regional detail is desirable; but on the other hand, stricter adherence to economic theory and allowing for intertemporal optimization are favored. Allowing for intertemporal optimization of investment and consumption decisions increases the computational burden because the model can no longer be easily split into smaller problems that can be solved faster and more reliably. Models that analyze longer-term pathways of trade policy and include intertemporal optimization usually do so at the cost of abstracting from higher spatial, sectoral, or temporal resolution. Models with considerably more sectoral or regional detail are typically run in a recursive dynamic manner that

determines investment decisions based on an exogenous rule and not based on impacts from a policy affecting the future.

CGE models that rely on comparative static simulations compare the economy by taking two snapshots before and after shocks, without considering the path to the simulated results. One of the shortcomings of comparative static models is that they do not consider the impact of agents' investments on economic output even though gross investments are supposed to increase capital. Dynamic models take this into account by allowing for capital accumulation over the years. Still, these models also need further assumptions and data for their parameterization. In Jafari and Britz (2020), we follow the reasoning of the vintage capital module in ENVISAGE and introduce a simple capital accumulation framework within a comparative static model to overcome the limitations of these models and, at the same time, remove the extensive data needs and further assumptions in dynamic CGEs. This approach divides the capital into old (immobile) capital that can be depreciated and new (mobile) capital that increases by gross investment. Therefore, the total capital stock is endogenous in the comparative static mode.

Construction of baseline for dynamic CGEs

Recursive dynamic models are still the main approach when the variables that are important to observe change over time. However, these models require calibration of a baseline trend. As parameters in the model are calibrated on past data found in social accounting matrices, a standard CGE formulation cannot adequately capture long-term structural changes with regard to economic growth, technology, preferences, saving propensities, etc. To overcome these deficiencies, new ways to construct long-term scenarios have emerged (Dellink, van der Mensbrugghe, and Saveyn 2020; Bekkers et al. 2020; Ho et al. 2020). The General Trade Analysis Project (GTAP)-based recursive dynamic economic model, known as G-RDEM (Britz and Roson 2019; Roson and Britz

2021), is a model in this class that extends the standard GTAP model (Hertel 1997) by adding some key drivers of long-run structural change. This model has received attention in the literature and has been applied in several studies. In Britz et al. (2022), we develop a dynamic general equilibrium model of the global economy based on the dynamic features following G-RDEM. The model allows for simulating the impacts of some of the global economic development pathways, including the middle-of-the-road scenario of shared socio-economic pathways, and an accelerated scenario of trade integration.

Extension of CGEs to a detailed household level

In Britz et al. (2022), we extend the constructed dynamic model to a detailed representation of households to capture the impacts on poverty and income distribution across different types of households (male- and female-headed households, urban and rural, and households of different income levels: below the poverty level, middle income, and rich) in six countries: Albania, Bolivia, Ethiopia, Malawi, Nicaragua, and Vietnam. This allows for an analysis of the impact of possible global economic pathways on income distribution and poverty in those countries.

Extension of CGEs to regional levels

CGE models are often aggregated at the national level, ignoring differences in the composition of outputs across regions, the availability of resources, the populations, etc. They also ignore the interregional interlinkages. One approach is to split the underlying CGE data into subnational levels and introduce the regional interlinkages in the CGE model (see Rutherford and Schreiber 2019). The model application requires substantially rich data on the sub-national demand-side and supply-side structures and their interlinkages. In Jafari et al. (2020), we offer a framework that uses nests of constant elasticity of substitution and constant elasticity of transformation functions to break down economic production activities from the national to sub-national level. This approach

considers sub-national differences in production structures and allows the distribution of economic activities and mobile resources across regions.

Developing PEs with linkages to input markets and the environment

PE models are a better choice than CGEs when the purpose is a tractable and focused analysis of how a small number of variables are influenced by the imposition of policy changes. A critical direction in PE modeling is the explicit linking of trade, output, and factor markets. In this respect, one of the types of PE models is the market (equilibrium) displacement model, established by Muth (1964) and Floyd (1965) and popularized by Gardner (1987) in his textbook in the field of agricultural economics. The idea was used by Hertel (1989) to develop a single-country PE model that explicitly treats factor markets. Gunter, Jeong, and White (1996) extended Hertel's model to a multi-country framework. Since then, these models and their extensions have been used in a variety of applications (see, e.g., Salhofer 1996; Alston and James 2002; Othman 2003; Ciaian and Swinnen 2006; Jafari and Othman 2015, 2016). Building on these concepts, in Jafari et al. (2017), we develop a comparative static, single-commodity model of the Indonesian palm oil sector with extensions to environmental outcomes to account for the effects of a shift in export demand for Indonesian palm oil on its trade, output, and factor markets, and on deforestation and peatland destructions.

3.3 Approaches to the analysis of trade networks and diversification

Some specific inferences can be drawn from trade patterns and their relationship with other economic variables using other methodologies, including network analysis and quantification of trade indicators and diversification measures. The choice of methodology depends on the study's objectives (Plummer, Cheong, and Hamanaka 2011; Bardach and Patashnik 2019).

Network analysis is recognized as one of the major approaches for analyzing the trade network structure because it entirely considers the dependencies of countries on each other within the trade network (Kali and Reyes 2007). It allows for an exploration of trade structure that is not possible with classic or modern trade theories, dealing with single/some factors at a country-level, gravity models, which deal with first-order trade relationships, or the equilibrium-based models, which work at relatively aggregate sectoral resolution. For these reasons, the application of network theory to international trade data has attracted researchers in recent years (Benedictis and Tajoli 2011). Trade literature often analyzes the trade network from the participation or trade intensity perspectives. To provide insights related to the partnership of countries in the trade network, the literature suggests using the trade participation network, which inquires whether or not countries trade with each other at the aggregate agri-food sector level or for a specific commodity. To provide insights into the network of trade values, the literature considers the trade intensity network, which shows trade values among nations. Both approaches are complementary to each other. In these respects, the literature suggests a binary network approach to analyze the trade participation network and a weighted network approach to analyze the trade intensity network. In Jafari, Engemann, and Zimmermann (2022), to provide insights related to the extensive margin of trade, we suggest looking at the trade network from the perspective of the trade participation intensity, which shows the number of traded commodities among nations. In this approach, we suggest using the weighted trade network analysis and the number of trade commodities as a weight. This offers a way to analyze the trade network from the perspective of the extensive margin of trade.

Calculating some trade indicators and diversification measures is another alternative. The main advantage of such an approach is that data requirements are minimal, so this method is easy to implement. Trade literature use a wide range of measures, such as Theil, Herfindahl, and Gini, to analyze the diversification/concentration of trade activities (see e.g., Cadot, Carrère, and Strauss-

Kahn 2011). In Engemann and Jafari (2022), we modify these indices to calculate trade diversification in terms of trade values and along intensive and extensive margins of trade at different spatial scales, including country, regional, and global levels. Comparison of the trade diversification measures across time scales allows drawing insights into the changes in the resiliency of the trade network.

3.4 Database development

Analyses of international trade patterns are also related to developing databases, one of which is quantifying NTM-related costs. Estimates of the AVEs of NTMs are the starting points for determining what the trade negotiations might offer. This is relevant for NTMs that affect commodity and service trades, but the latter has received much less attention than the former. Estimates of the AVEs of barriers against foreign service suppliers can be categorized into two methodological groups: estimates based on the gravity model; and estimates that rely on collecting information on the regulatory barriers against foreign suppliers of services, converting that information into restrictiveness indices and then using those indices in econometric regressions to obtain AVEs. The gravity approach has been used by many researchers, including Francois and Hoekman (1999), Walsh (2006), Kimura and Lee (2006), and Francois, Hoekman, and Woerz (2007). One limitation of the econometric approaches is that the estimations are based on cross-border trade in services. However, in the service sector, it is often sales through FDI that are more important. Furthermore, as Francois and Hoekman (2010) point out, a well-known limitation of the gravity-based approach is that the AVE is not related to any specific regulatory barrier. Therefore, unless the researcher can identify specific regulatory barriers that explain the AVE in particular sectors, in-country officials are often skeptical or unpersuaded of such estimates. When specific barriers can be mentioned, the story typically becomes convincing.

The second approach has been employed in single sectors for many countries by Findlay and Warren (2000), Kang (2000), and Kalirajan et al. (2000), and Nguyen-Hong (2001). Using this method, AVEs of barriers in multiple sectors and for many countries are also estimated by Doove (2001), Dihel and Shepherd (2007), and Copenhagen Economics (2005). The Australian Productivity Commission pioneered work along these lines, and many of the studies it supported are collected in Findlay and Warren (2000). The authors above generally estimate AVEs of the service barriers in less than 30 countries because of the lack of information on the regulatory regimes in services for most countries.

In Jafari and Tarr (2017), we produce estimates of the AVEs of the barriers for 11 of the most important service sectors in international trade for 103 countries. This is based on a database on the barriers faced by foreign suppliers of services produced by the World Bank, building on the methodology and publications supported by the Australian Productivity Commission. Compared to available estimates in the literature based on assessments of country and sector-specific barriers to service providers, our study expands the set of sectors and more than triples the set of countries for which estimates of the AVEs of the service barriers are available.

4. Lessons learned and future research directions

International trade patterns of countries can be explained by the interaction of a range of factors and policies at different institutional scales, including firm, country, economic partnership, and global levels. In this respect, institutional factors and policies at each level and across scales may reinforce or counteract each other, thereby affecting the trading behavior of firms as key entities that perform international trade activities. This involves impacts on the firms and the environments in which they operate.

Even within narrowly defined sectors in a given country, firms have substantial differences in performance measures. Firm characteristics that involve firms' lower fixed costs, lower marginal costs, and higher ability to exert markups results in firms' increased participation (extensive margin of trade) and increased trade on each trade link (intensive margin of trade). Once firms start to operate in the international trade market, the learning effects from operating in foreign markets may increase firms' productivity and product quality and overweigh the reduced prices because of induced competition, therefore increasing firms' profitability. This two-way positive relationship may imply that when some firms trade internationally the profitability gap widens between exporting and non-exporting firms. The two-way relationship suggests that firms can rely on firm-specific resources to reduce marginal costs, and increase product quality; once firms begin to export, their productivity, quality, markups, and profitability increase further. The induced gap between exporters and non-exporters due to the two-way relationship may then be reduced if non-exporters develop strategies to enhance their competitiveness or if the formulation of policies at a higher scale supports non-exporters to begin exporting.

Country-level characteristics and policies may increase firms' participation in international trade if they involve lowering the costs and/or increasing the firms' product quality. However, if such

characteristics and policies result in firms' costs being higher than what consumers are willing to pay for those products, they might adversely affect trade values. Moreover, the country-specific factors that lower the uncertainties in the business environment of firms and/or reduce the differences in the business environment of trading countries may increase the stability of trade relationships.

International trade patterns may also be affected by the (de)formation of economic partnership agreements. The impact depends on the different dimensions of policy changes that may affect different components of the product supply chain. Generally, changes in NTMs, particularly those implemented by developed countries, are expected to affect trade values far more than the changes in tariff measures. Our experience with the analysis of Brexit shows that policies that affect the movement of capital have a comparable impact with NTM. Still, a much higher impact is expected when labor movements are restricted. Additionally, policies that affect the fixed trade costs more than variable trade costs tend to affect the extensive margin of trade more than the intensive margin of trade but have a lower impact on the overall trade values. In contrast, an increase in the extensive margin of trade through changes in fixed costs of trade increases the welfare impact of trade more than the equivalent variations in variable trade costs. In terms of product coverage, reducing or removing tariffs for products with high tariffs but low trade values, which are mainly under the agri-food sector and some textile products, can importantly affect the trade of the partners.

Global structural changes may also affect the firms' performance measures by affecting either the production of firms or the demand they face. Depending on which part of the supply chain is affected, which commodities are affected, and the extent of the impacts, disproportional changes may occur to countries' international trade patterns. This results in changes in the overall

integration of the trade network, the structure of integration, and therefore, the resiliency of the trade network.

The overall changes in trade patterns involve important changes beyond trade including the impacts on socio-economic and environmental conditions and outcomes. Such impacts may substantially differ across countries depending on the domestic economic structures. Initial trade structures are also important in determining the impacts of trade and domestic policies because trade patterns may change to mitigate the impacts of shocks.

Analysis of the patterns of international trade and its relationship with performance measures of firms and their external environment involves various types of methodologies. The widely used approaches are econometric analyses, partial and general equilibrium analyses, network analyses, and the analyses of trade indicators and diversification measures. The choice of methodology relates to, among other things, the purpose of the analysis, the technical deficiencies associated with the models, the limitations of the data, the uncertainties associated with changes in trade and economic environments, and the taste of the researcher.

There are important directions to the key themes of the research. At the firm level, one of the major limitations is that firm-level data might not be readily available for many countries. When it exists, it may not be sufficient to estimate the major firm-level performance indicators such as firms' productivity, markups, and product quality. This is because firm-level databases typically do not include firm prices and quantities, but rather the sale values. Efforts to compile such databases will help improve the accuracy of firm performance measures. The analysis of the relationship between firm performance measures and trade is confined by some limitations. A rich dataset showing firms' export to specific destinations would offer considerable scope for future research. In this respect, important discoveries are promised on the impact of demand-side factors, such as the size

of the export destination markets, the income level, etc., on firm performance measures. Moreover, firm performance measures are determined by the interaction of several factors that affect the firm supply side, and several factors on the firm demand side; firm performance measures themselves are also related. The important direction in this regard is to analyze the relationship between different components of firm performance measures and international trade measures. For example, firm markups are affected by productivity, quality, and firm pricing strategy; how these factors are individually related to trade and how they relate to each other is an interesting area of research.

At the country level, in light of the recent disruptions in supply chains, more efforts may be directed toward factors that affect trade link stability along the extensive and intensive margins of trade, which relates, respectively, to the volume and variety of product availability. Our experience in analyzing the role of countries' IQ (with different dimensions) on trade patterns points toward the need to perform the analysis in greater policy detail, i.e., considering different dimensions of policy changes and the interaction of different policy dimensions. Moreover, while countries may formulate unilateral trade and domestic policies to pursue a more sustainable economy, the efforts may have only minor global impacts. The way forward for future research is to identify more targeted actions with low costs and to provide approaches for countries to embrace a common set of sustainability standards that include the components of transparency, legal compliance, environmental responsibility, and respect for individual and community rights.

At the economic partnership level, identification of the different dimensions of the (de)formation of an agreement, and analyses of the different dimensions are crucial. This is particularly important because substantial literature is produced just before and during the negotiation phase of the (de)formation of economic agreements. Concerning the formation of economic agreements, the main difficulty is to foresee the types of policy changes and what sectors will be affected; in the

case of the deformation of economic agreements, this might be even more difficult because of the (possible) availability of various options for trade parties after deforming the existing agreement. In this regard, researchers may perform the impact assessments in close collaboration with policymakers and also perform various sensitivity analyses to discover the various important aspects of the impacts. Moreover, the impact assessments may also need to take into account more of the emerging issues, including the impacts on various indicators of sustainable development goals. Future analyses should also consider the analysis of policies in relation to the prospected global structural changes and consider the adjustment costs associated with policies.

Concerning the global economic structure and trade system and in light of recent disruptions in the trading system, future research may be directed toward analyzing the evolution of the structure (integration and resiliency of trade network) and the impact of changes in characteristics of the trading system on its resiliency. This may bring insights into the weakness and strengths of the trading system in pursuit of formulating global policies to increase the benefits of integration into the trade network and, at the same time, increase its resiliency. The interdependence of the global value chain also means that approaches need to be developed at the global institutional level to enhance countries' collaboration in a fight against regional and global shocks to the trading system.

Considering the relationships of trade patterns with countries' socioeconomic and environmental conditions and outcomes, our experience reveals that within-country impacts are pretty much contingent on the economic structures of countries; hence, impact assessments should be rendered for individual countries. Nonetheless, trade relationships and transboundary impacts associated with environmental issues mean that other countries are affected and might consider this in their policy formulation. Thus, the analysis of the impact should consider the policy responses of other countries.

Future studies may consider further advancing the literature in terms of methodological aspects and data developments. Simultaneity and measurement errors are two of the main issues in econometric studies of the relationship between trade patterns and factors at different scales. Identifying the causal relationships and adequately measuring the variables at each scale remain challenging mainly because of data limitations.

Equilibrium-based simulation models complement econometric approaches, but they also face several data and technical deficiencies. Properly capturing the impacts in equilibrium-based models requires improved quantification of the shocks, proper technical implementation of shocks, the right choice of the industrial organization structure to represent the market structure in the model, and improved model parameterization. Quantifying the trade measures, particularly NTMs, and identifying their demand, rent, and cost-generating impacts are the natural points for measuring the shocks in trade policy analyses. Importantly, a more detailed database underlying the equilibrium-based models can importantly overcome other issues. The GTAP database is the primary data underlying such analyses; the GTAP database currently covers 64 sectors and 141 regions. Policies affecting sectors are rather heterogeneous and in order to be implemented in equilibrium-based models either the policies should be aggregated or the databases need to be disaggregated. The former may bias results because of the aggregation bias from policy shock. For this reason, there have been several efforts, such as those to introduce tariffs and TRQ aggregators, to enhance the technical implementation of policy shocks. The latter may be taken at the heart of the modeling when possible because it provides more accurate analysis and may eliminate technical deficiencies. Moreover, disaggregation of the underlying modeling data may remove model infeasibilities that are caused by ever-increasing costs to firms in a vicious cycle; reduction in firms' output demand increases their fixed costs, results in reduced demand from their industry outputs, and leads to a vicious cycle where a sector will completely vanish. Removing such infeasibilities facilitates the

implementation of the features of modern trade theories into the equilibrium-based models and increases the accessibility of those equilibrium-based models to modelers.

The application of network analysis to the international trade field is still in its infancy. The analyses provide important discoveries regarding the structure of the trade network from different perspectives including intensive and extensive margins of trade and trade values. Research in these directions does not consider the weights associated with each network dimension in the analysis. Assigning the weights to each of these dimensions provides more comprehensive analyses, but the methodological advancements to consider the appropriate weights are still in their early stages. Future research may consider the possibility of weighing different aspects of the trade pattern in explaining the integration and resiliency of the trade network. Moreover, the use of the network measures that explain the overall integration of countries to the trade network as an alternative to multilateral resistance terms in gravity models may be seen as an alternative to complement the analysis of econometric studies. This is because network measures may consider different orders of integration to the trade network in contrast to multilateral resistance terms that may only consider the first-order integration of countries in the network.

5. Included research papers

- Jafari, Y., Engemann, H., Zimmermann, A., 2022. The evolution of the global structure of food and agricultural trade: Evidence from network analysis. *Background Paper for The State of Agricultural Commodity Markets (SOCO) 2022*. Rome, FAO. <https://doi.org/10.4060/cc4145en>.
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The evolution of the global structure of food and agricultural trade: Evidence from network analysis

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Abstract

The outbreak of the COVID-19 pandemic in 2020 and the war in Ukraine, which began in February 2022, have tested the resilience of the food and agricultural trade network at a global level. The global dimension of these crises meets a policy landscape in which multilateral trade negotiations have largely stalled and regional approaches to trade integration are proliferating rapidly. Based on network analysis, this paper explores the evolution of the integration of the network of food and agricultural trade since the World Trade Organization (WTO) Agreement on Agriculture (AoA) in 1995, the network structure and their implications for resilience to trade shocks. Food and agricultural trade evolved rapidly and countries worldwide became more connected to global markets in the period 1995-2007, but progress has since been limited. While countries are connected globally, trade intensity is usually higher in specific regional clusters, which have become firmer over time. Increased connectivity among countries boosted their resilience to trade shocks, but vulnerabilities remain and evidence suggests slight tendencies of disintegration in recent years.

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1 Introduction

The outbreak of the COVID-19 pandemic in 2020 and the restrictions imposed worldwide to contain the spread of the virus have tested the resilience of the food and agricultural trade network at a global dimension and almost simultaneously across all countries. The war in Ukraine, which started in February 2022, affects agricultural production and export capacity of two main players in the network and, in contrast to the globalized shock of the COVID-19 pandemic, poses a localized shock to the network but with a high risk of sending shock waves through the whole network through transmission effects and potentially self-propagating trade disruptions.

On average, and despite the multiple challenges, the food and agricultural trade network proved remarkably resilient to the shock posed by the outbreak of the COVID-19 pandemic. The only visible effects at global level were short-lived disruptions of trade at the beginning of the pandemic and when worldwide restrictions on movement were imposed during the March-April 2020 period (Arita *et al.*, 2022; Engemann and Jafari, 2022; FAO, 2021; Schmidhuber and Qiao, 2021). Due to high dependencies of some countries on imports of specific products, the war in Ukraine is expected to have more disruptive effects on food and agricultural trade. This raises questions about the stability of the network of food and agricultural trade and how to strengthen its resilience. For this, it is important to understand the structure of the current network and how it has evolved.

In the early 2000s, food and agricultural trade expanded rapidly, the share of low- and middle-income countries in global trade increased and global value chains in food and agriculture evolved (Dellink, Dervisholli and Nenci, 2020; FAO, 2020). However, this process has largely stalled since the 2008 financial crisis. One of the catalysts of the globalization process in the 2000s was the implementation of the 1995 World Trade Organization (WTO) Agreement on Agriculture (AoA), which, for the first time, ensured the explicit inclusion of agriculture as a sector in the multilateral liberalization process, reduced tariffs and other trade barriers (Daugbjerg and Swinbank, 2008; Grant and Boys, 2012). Since the 1990s, inspired by and often based on the set of rules defined by the General Agreement on Tariffs and Trade (GATT) and the WTO, a plethora of preferential and regional trade agreements (RTAs) followed or were negotiated in parallel to foster trade liberalization and deepen economic integration of countries in regional and global markets. Together, and reinforced by rapid technological progress that improved transport and communication, these trade agreements led to an unprecedented wave of globalization.

Although the WTO agreements, including the AoA, have succeeded in promoting trade by making it freer, fairer and more predictable, further progress in improving these rules has been limited (Beghin and O'Donnell, 2021; Kerr, 2021). The latest round of multilateral negotiations, the Doha Round, which was launched in 2001, stalled at the end of the first decade of the twenty-first century for many reasons, including divergent views on issues related to agriculture among negotiating members (Beghin and O'Donnell, 2021; Kerr, 2021). With limited progress in multilateral trade negotiations, RTAs have emerged even more rapidly (Ahcar and Siroën, 2017). By limiting the number of countries involved and focusing on their strategic interests, RTAs can be more targeted and can be concluded more easily than multilateral negotiations, where a large number of negotiating countries and divergent views preclude achieving consensus. While the WTO has taken some significant steps towards behind-the-border convergence in regulations, many RTAs envisage much deeper levels of integration among their signatories (Crawford and Laird, 2001; Hofmann, Osnago and Ruta, 2019).¹

Over the last decades, most countries have concluded trade agreements both within the multilateral framework of the WTO and regionally, and multilateralism and regionalism are thought to have advanced together (Baldwin, 2016). While governments come together at the WTO to negotiate the “rules of globalization” (Staiger, 2021), this process has been complemented and reinforced by an increasing number of RTAs. Since 1990, and in parallel to the multilateral trade negotiations, the number of regional trade agreements (RTAs) in force grew from fewer than 25 to more than 350 in 2022 (WTO, 2022).² The deadlock in WTO negotiations and the proliferation of RTAs have led to renewed interest in the question whether, after the wave of globalization in the 2000s, food and agricultural trade is now fragmenting into regional blocs.³

¹ Recent trade agreements no longer emphasize market access but instead focus on behind-the-border regulatory issues, including domestic policy coordination in a much broader sense (Bown, 2017; Maggi and Ossa, 2021). These agreements are often very complex as they tend to pursue economic objectives and provisions targeting social and environmental sustainability outcomes (Maggi and Ossa, 2021; Rodrik, 2018).

² This number includes only RTAs in force that have been notified to the WTO.

³ The agricultural sector appears to be increasingly included in RTAs and is progressively being treated similarly to other sectors, although many agreements still exclude some agricultural products from specific provisions. In agriculture, RTAs may facilitate deeper integration by harmonizing NTMs, including technical and food safety standards and domestic regulations, in areas in which multilateral negotiations have made little progress as preferences across countries worldwide diverge widely. However, RTAs usually do not address

The question whether RTAs are building blocks of, or stumbling blocks to, multilateralism has generated a rich discussion in the literature (e.g. Bhagwati, 1991; Krugman, 1989; overview provided by Baldwin, 2008), but has largely focused on tariff liberalisation (Baldwin, 2008). While regionalism and multilateralism have probably both contributed to freer trade overall (Baldwin, 2008; Summers, 1991), today's deep trade agreements raise new questions about their interaction with multilateral approaches and their impact on trade. The overlapping of RTAs (Bhagwati's "spaghetti bowl"; Bhagwati, 1995) can pose significant challenges for compliance and transparency due to multiple rules with respect to tariffs, non-tariff measures (NTMs) and rules of origin⁴, which can differ by agreement, trading partner and product, and can even lead to conflicting regulatory standards across different trading blocs, thus raising trade barriers and costs (Bhagwati, 1991, 1993; Pomfret, 2021; Thompson-Lipponen and Greenville, 2019). Negotiating and implementing an RTA requires considerable resources, which could be beyond the reach of many countries (Crawford and Laird, 2001). As a result, especially developing countries appear to have accepted provisions in RTAs that they resist at WTO level (Baldwin, 2008).

Empirical studies have found mixed evidence on the impact of RTAs on trade (Grant and Lambert, 2008; Sarker and Jayasinghe, 2007). Based on more than 60 agreements, Grant and Lambert (2008) found that the increase in trade among RTA signatories was much larger in agriculture compared to non-agriculture. The researchers attributed this to the larger gains from liberalization due to relatively high levels of protection in agriculture before the RTA entered into force. The effects were also found to differ across specific agreements and were subject to the length of their phase-in periods. In fact, the impact of RTAs on trade depends on the provisions of the agreement and the characteristics of the countries involved (Mujahid and Kalkuhl, 2016). The degree to which governments negotiate comprehensive and deeper trade agreements appears to be positively related to their level of economic development – the richer a country, the deeper its trade agreements. RTAs are also deeper when more WTO members are involved in the agreement, as provisions contained in RTAs usually build on existing WTO policies. Indeed, WTO members appear to use RTAs not to undermine or circumvent WTO rules, but rather to build on trade-promoting policies embedded in the multilateral system (Kohl, Brakman and Garretsen, 2016; Thompson-Lipponen and Greenville, 2019). However, the evidence of the effects of deep RTAs on trade is mixed in general and scarce in agriculture (Ahcar and Siroën, 2017; Mattoo, Mulabdic and Ruta, 2017). Although RTA trade provisions that are also part of the WTO's mandate and those that enhance institutional quality are generally trade promoting, this does not need to be the case for deeper provisions beyond the scope of the WTO (Kohl, Brakman and Garretsen, 2016). There are also concerns about the welfare implications of special interests and lobbies that engage in deeper RTA negotiations.

In general, there is scope and reason for both global (i.e. interregional) and intraregional trade. Global trade in food and agriculture is fostered by the fact that food and agricultural production depend on agroclimatic conditions and natural resource endowments, which are unevenly distributed across the world and, together with differences in technology, shape trade flows. Both feature prominently as drivers of trade in the traditional trade theories, with the Ricardian model emphasizing technological differences and the Heckscher-Ohlin model stressing differences in factor endowments

(potentially trade-distorting) domestic support to agriculture (Grant and Lambert, 2008; Thompson-Lipponen and Greenville, 2019).

⁴ Rules of origin refer to criteria to establish where a product was made. They are important in identifying whether goods qualify for preferential treatment within an RTA because they originate in one of the RTA signatory countries and are not re-exported (FAO, 2022).

(Krugman, 1987). Demand for food is increasing fastest in regions where population and income growth are strongest, as in emerging economies and developing countries in Africa and Asia (FAO, 2020). However, in many of these regions, agricultural productivity is relatively low and countries may be challenged to produce sufficient food for their growing population. Globally, trade can help balance food supply and demand by moving food from surplus to deficit areas. It also contributes to ensuring dietary diversity and responds to consumers' 'love of variety' (Dixit and Stiglitz, 1977) as foods that cannot be produced domestically can be imported from other countries (Aguiar *et al.*, 2020; Geyik *et al.*, 2021; Remans *et al.*, 2014; Wood *et al.*, 2018). The increasing risks to agricultural production from climate change reinforce the role of global trade in ensuring food security and nutrition (FAO, 2018; Janssens *et al.*, 2020).

At the same time, most empirical evidence shows that countries that are similar in terms of economic size or are located close to each other tend to trade more among each other, as compared with countries of different relative sizes or countries that are geographically more remote (see for example Anderson and van Wincoop, 2003; Feenstra, 2015). Trade is proportional to the economic size of a country, reflecting production capacity and economies of scale, but also purchasing power and preferences associated with income levels (Anderson, 2011; Bergstrand, 1989; Krugman, 1980). Trade costs tend to increase with distance, favouring trade between countries that are nearer each other. Infrastructure is linked and trade procedures are often similar among neighbouring countries, and these countries are often closer in terms of culture and preferences, which leads to more trade between them (Anderson and van Wincoop, 2004; Pomfret and Sourdin, 2010).

The evolution of trade patterns and their distribution over the world has implications for the resilience of the network of food and agricultural trade. Increased connectivity among countries can strengthen the buffer capacity of the global food and agricultural trade network. Countries that are well-integrated in the global market and have many trade links with other countries can benefit from trade by leveraging their comparative advantage globally. This would promote food security, a greater diversity of foods supplied and economic growth, alleviating pressure on the natural resource base. Higher connectivity would contribute to resilience to domestic production shocks and localized shocks in exporting countries.

For a country, domestic food production shocks, such as those arising from extreme weather events or geopolitical crises, can be effectively buffered by adjustments in the quantities traded, ensuring food security (Cottrell *et al.*, 2019). In this way, shocks that are specific to individual countries or regions can be partly cancelled out at the global level. Trade is, therefore, a potentially powerful engine to even out supply fluctuations across the world and, as a result, to reduce price volatility. Nevertheless, there are also concerns that, with increasing import-dependency, greater connectivity between countries through trade may also act as an avenue to transmit negative shocks and increase vulnerability, rather than contribute to resilience (Allouche, 2011; Remans *et al.*, 2014; Sartori and Schiavo, 2015). The effects on importing countries can be aggravated and lead to self-propagating trade disruptions if other countries in the network react by imposing export restrictions or other measures, thus exacerbating price spikes (FAO, 2018; FAO *et al.*, 2011; Puma *et al.*, 2015; Torreggiani *et al.*, 2018). Still, countries with a high dependency on food and agricultural imports from only a few major trading partners are more vulnerable to shocks impacting one of their partners than are those countries that are better connected and which can more easily source foods from other places (Kummu *et al.*, 2020).

At the global level, the extent to which countries are vulnerable to external trade shocks depends on many factors. An important determinant is the structure of the trade network. If a few large players dominate the network and many other countries are connected to these hubs, but are not connected among each other, shocks affecting these large players can easily transmit through the whole network and possibly be magnified by global value chains. A shock to the system can dissipate when all (or many) countries in the network are connected to many trade partners (Acemoglu *et al.*, 2012; Acemoglu, Ozdaglar and Tahbaz-Salehi, 2015; Lucas, 1977; UNCTAD, 2019).

This paper sets out to understand the evolution of food and agricultural trade since the establishment of the WTO and the WTO AoA in 1995, assess globalization and regionalization tendencies and the impact on the resilience of the trade network.

The next section provides an initial exploration of major changes in food and agricultural trade at global level. This is followed by the description of methodology and data used for the main analysis. Based on network analysis, the results section first explores the integration of countries in the global network of food and agricultural trade and its evolution. Second, it analyzes the evolution of the structure of integration, that is, the extent to which similar countries trade with each other along different dimensions: regional proximity, income similarities, and number of trading partners. Third, it explores the vulnerability of the trading system to shocks based on the heterogeneity in the level of countries' integration into the trade network and the way it evolved. The final section concludes.

2 A glimpse of the evolution of food and agricultural trade

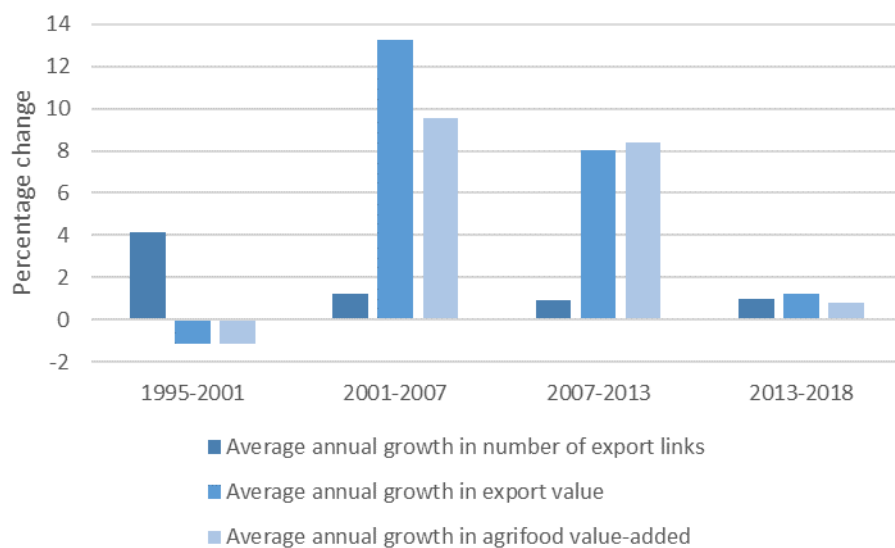
Since 1995, food and agricultural trade has increased in terms of volume traded and number of trade partnerships (or links) formed among countries. The total number of trade links between country pairs rapidly increased between 1995 and the early 2000s, after which newly formed trade partnerships have expanded more slowly (Figure 1). By contrast, the value of global food and agricultural trade grew strongly between the early 2000s and the early 2010s, but its growth rate has since been stagnant (Figure 1). The globalization in food and agriculture during this time period thus appears to have evolved in two steps. First, countries formed more trade links (1995-2001), followed by a rapid expansion of trade intensity through these trade links (2001-2007). As an indicator of globalization, the value of food and agricultural products traded expanded much more rapidly in the 2000s than the global value-added generated by the food and agricultural sector (Figure 1), a process that has largely stalled since the beginning of the second decade of the new millennium.

In terms of both the expansion of trade links and value traded, globalization has been mainly driven by a greater participation of emerging and developing countries in global markets. Between 1995 and 2019, the number of export links established by the group of low- and middle-income countries grew at an average annual rate of 2.1 percent, while this rate was 1.1 percent for the group of high-income economies. Low- and middle-income countries expanded their value exported at an average annual rate of 6.4 percent, while for high-income countries this rate was 4.6 percent.

Traditionally, countries in some regions have traded more with partners within the same region, while others have been more globally oriented. At continental level, these relationships still hold, but some shifts have occurred in the global versus regional orientation of countries' trade (Figure 2). African countries tend to trade more globally, with the majority of their food and agricultural exports (almost 40 percent in 2019) destined for Europe. Still, between 1995 and 2019, the share of intra-

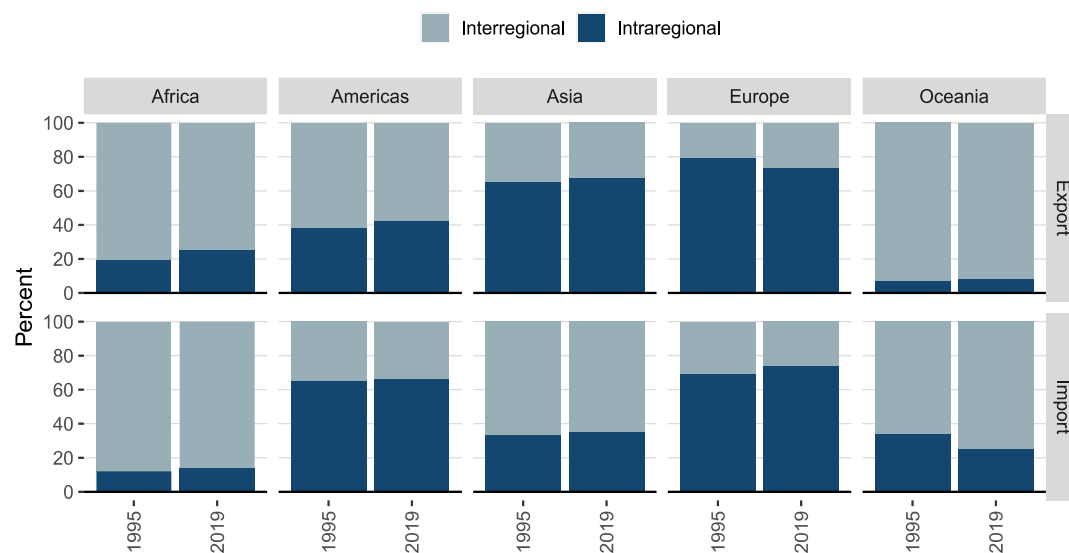
African trade increased. The share of intra-regional trade increased also in the Americas and in Asia, while the pattern is mixed across imports and exports in Europe and Oceania.

Figure 1 Growth rates in global food and agricultural export links, export value and value-added, 1995-2018



Source: Based on FAOSTAT.

Figure 2 Food and agricultural trade within and between regions, 1995 and 2019



Source: Based on FAOSTAT.

3 Data and methodology

3.1 Network analysis

The specific patterns in which countries trade with each other give rise to a ‘network’ of trade which reflects the relative position of each country but also important features of the global market. An increasing number of studies rely on techniques borrowed from network analysis to analyse the patterns of trade flows and connectivity among countries. Network analysis is a well-known field of mathematics and it has a long tradition in sociology and political sciences.⁵ More recent examples of the application of network analysis in trade include the analysis of integration and regionalization in merchandise trade (Vidya, Prabheesh and Sirowa, 2020), the analysis of trade networks of various food and agricultural products (Chung *et al.*, 2020; Gutiérrez-Moya, Adenso-Díaz and Lozano, 2021; Torreggiani *et al.*, 2018) and the analysis of specialization patterns and transmission of shocks in food and agriculture (Campi, Dueñas and Fagiolo, 2021; Distefano *et al.*, 2018).

Network analysis comprises a set of techniques that are applied to analyse complex systems. It aims to depict relations among actors, in this case countries (or nodes in network terminology), and to analyse the structures that emerge from these relations (Chiesi, 2001). A multitude of network measures can be used to describe the connectivity patterns of countries, their relative importance within the network, how many other countries they are connected to, how close their relationships with other countries are, or whether they are intermediaries between others (Marsden, 2015).

In general, there exist two main approaches to analyse the trade network that complement each other: binary and weighted network analysis. Early studies investigating the properties of networks of international trade usually employed binary network analysis, where binary variables (defined as either zero or one) represent zero or non-zero trade flows (Garlaschelli and Loffredo, 2005; Serrano and Boguñá, 2003). Binary network analysis provides information on trade links (or trade relationships) between countries, but ignores trade intensity and is therefore prone to underestimate heterogeneity across trade relationships. Generally, the intensity of trade, as measured by the value of trade, is highly concentrated in a few trade links (Cepeda-López *et al.*, 2019) alongside a majority of trade links with relatively low trade intensity (Bhattacharya *et al.*, 2008). Weighted network analysis complements binary network analysis by weighting each trade link with its (deflated) trade value (export, import, or export plus import). The statistical properties of the weighted trade network considerably differ from the binary/unweighted network (Fagiolo, 2010). Drawing a complete picture of the trade network requires consideration of both binary and weighted approaches. However, methods that take into account both the intensity (strength) and the number of country-specific trade links are still in their early stage of development (Opsahl, Agneessens and Skvoretz, 2010). In addition to analyzing trade links and values, we look at the trade network from an additional perspective, by weighting each bilateral trade link with the number of products traded through it.

We apply network analysis to identify the evolution of connectivity in the global network of food and agricultural trade, detect signs for a possible fragmentation of food and agricultural trade into regional blocs, and assess the resilience of the trade network to shocks to the system. The

⁵ Social network analysis has been developing since the beginning of the 20th century, owing to the efforts of sociologist, psychologists, and anthropologists. It is built on graph theory, a well-recognized branch of mathematics since the 18th century. See Scott (2017) for the origin of social network analysis and Wasserman and Faust (1994) for a general overview.

following subsections briefly introduce the network measures applied in the analysis of each of these fields.

3.1.1 Measures to assess countries' connectivity to the global network of food and agricultural trade

The overall network integration can be analyzed by different measures. The density of a network is one of the simplest measures of global integration (De Benedictis and Tajoli, 2011; Kali and Reyes, 2007; Kim and Shin, 2002). It is defined as the number of observed trade links over the maximum theoretically possible trade links across countries. As this measure shows the proportion of actual connections over potential connections, it reflects the probability of the presence of a link between any two countries.⁶ In a completely integrated network, the density is equal to one indicating that each country is linked to (trades with) all other countries.

We use several measures of connectivity at individual country level, each showing different aspects of country-level integration into the global trade network (see Table 1 for an overview). The most basic measure at country-level is the degree/strength of connectivity. The degree indicates the total number of trade links of a country and is identified based on binary network analysis. Strength indicates the total number of traded products or the trade value associated with each aggregate trade flow, it is derived from weighted network analysis. Outdegree/outstrength refer to export flows, indegree/instrength refer to import flows. For better comparability, these indices are often normalized.⁷

Both in- and out-degree/strength show the direct (first-order) connectivity of countries in the trade network. Countries are also indirectly linked by second or higher orders, which can constitute important ties in the economies (Bartesaghi, Clemente and Grassi, 2022). We follow Acemoglu, Akcigit and Kerr (2016) and define the second-order degree/strength as the sum of the first-order degree/strength of all direct trade partners.⁸ While these measures focus on specific (first and second) orders of connectivity, other network measures consider also linkages at higher orders. The eigenvector connectivity has a similar interpretation as the first- and second-order degree connectivity measures, but also considers all higher-order degrees.⁹ Eigenvector connectivity of a country thus shows its direct and indirect linkages with all countries in the network and can indicate whether a country is central or peripheral in the trade network.

Other connectivity measures focus on different aspects of the trade network. Closeness connectivity indicates how “close” a country is to all other countries in the network. The higher the closeness connectivity, the more central a country is located in the network and the “closer” it is to all other countries. Closeness connectivity of a country is defined as the inverse of the average network geodesic distance of that country to all other countries, where geodesic distance is the shortest path (definition below) of moving from one country to another in the network. The measure can be understood as a country's access efficiency to other countries. The higher the closeness connectivity, the more direct the connection to other countries and the lower the

⁶ This measure is primarily used in unweighted network analysis.

⁷ In our analysis, the in-/out-degree of a country is normalized by the total number of theoretically possible degrees. In the directed network, the total possible number of degrees (links) is: $(\text{number of countries} - 1) \times 2$. The in-/out-strength of a country is normalized by dividing by the highest observed in-/out-strength across years.

⁸ Second-order degrees are calculated by multiplying the binary trade matrix with itself (Acemoglu *et al.*, 2012; Sartori and Schiavo, 2015). Product- and trade value-weighted trade matrices are multiplied by the transpose of the normalized first-order instrength matrix. Both second-order indegree and instrength are normalized by their maximum across years.

⁹ The highest order is the number of countries in the network minus one.

number of links a country needs to take to trade with another country (“small-world property”). The computation of the geodesic distance differs in binary and weighted approaches. Referring to trade links (binary), the geodesic distance between two countries is the lowest number of links that connect two countries, i.e. the shortest path between them. There can be more than one such path. In the weighted network (either by product or by trade value), a weight is assigned to each trade link to calculate the geodesic distance. The weight for each trade link is obtained by dividing the average number of products traded per link by the number of traded products associated with each link (in case of weighting by the number of traded products) or dividing the average trade value per link by the trade value associated with each link (in case of weighting by trade value). The shortest path is defined as the strongest link, either in terms of highest number of products traded or in terms of highest trade intensity, that connects two countries.

We measure the global connectivity of the network using arithmetic averages of the individual network connectivity measures including first- and second-order indegree/instrength, eigenvector and closeness connectivity.¹⁰

Within the global network, individual countries can be connected (or clustered) in different forms which constitute the intermediate features or structure of integration in the network. Countries may tend to open up to trade unilaterally or engage in bilateral, trilateral, or any higher order of trade relationships such as with a group of countries (Wasserman and Faust, 1994).¹¹ The existence of specific types of trade relationships that occur frequently is not random (Gutiérrez-Moya, Adenso-Díaz and Lozano, 2021), and the analysis of these relationships can identify subnetworks within the global network (Chung *et al.*, 2020). We show the frequency of unilateral and bilateral trade relationships, as well as hierarchical trade relationships.¹² Bilateral and trilateral relationships can be thought of as the smallest unit on which the network builds or the micro-level connectivity. The closer these relationships, the denser the network.

3.1.2 Measures to assess the structure of the food and agricultural trade network

While the assessment of bilateral and trilateral trade relationships can give an indication of the micro-level features of countries’ integration in the global food and agricultural trade network, other network measures can be used to identify broader structures, such as trade hubs, decentralization tendencies and fragmentation into trade clusters. We use a measure of “betweenness” to identify trade hubs and a clustering approach to detect important trade structures within the global network. Measures of assortativity and modularity provide additional insights into the significance of trade clusters.

The betweenness connectivity of each country in the network shows how many times a given country connects to other countries that are not directly connected with each other (Freeman, 1978). The higher the value of the betweenness measure, the more important the role of the country as a trade hub. Countries with low betweenness are peripheral countries in the network. In terms of trade links, the betweenness connectivity of each country is the total number of shortest paths in the network that go through a given country over the total possible number of

¹⁰ Because the size of the network is constant across years we do not explicitly calculate network centralization measures that provide estimates of the normalized global connectivity with respect to the star network.

¹¹ In network analysis, a subgroup of countries that have local trade relationships is called motif or clique. Any type of trade relationship between two partners is called dyad; trade relationships involving three or four partners are called triad and tetrad, respectively; and so on.

¹² In a subgroup of three countries, trade relationships are hierarchical when two countries extend ties to one other country. In a sub-group of four countries, the existence of a hierarchical relationship is defined if two or three countries extend ties to one or two other countries; and so on.

shortest paths. In the weighted approaches, a weight is assigned to each shortest path, where the weight is the value of trade or the number of products that are traded through this shortest path.

Countries do not trade at the same intensity with all other countries in the world, but tend to form trade clusters/communities in which they trade relatively more. These trade clusters/communities can be of varying size, they can be regional or encompass countries in different parts of the world. Trade clusters/communities are identified by community detection algorithms and assortative mixing measures. Community detection algorithms are theory-free mechanisms to identify different trade clusters based on observed trade relationships. Assortative mixing measures show the extent to which similar countries trade with each other. These measures are consistent with the network theory of homophily¹³ and a plethora of empirical studies in trade, which show that similar countries tend to trade more with each other than dissimilar ones. For example, in the empirical trade literature using the gravity model, it is often found that trade intensity is higher between countries of similar economic sizes than with other countries and that trade intensity also tends to be higher between neighbouring countries and countries with a common history (Feenstra, 2015). In contrast to the endogenous features of community detection, the calculation of assortative mixing measures requires the exogenous classification of country groups.

We use the Louvain method (Blondel *et al.*, 2008) for the identification of trade clusters, a well-known and widely applied method in the field of international trade (Bernard and Moxnes, 2018). The method endogenously identifies both clusters and the number of clusters by maximizing the density of intragroup connectivity against the density of intergroup connectivity. The significance of the detected communities is then determined based on a modularity index indicating the difference between degree of connectivity inside the detected communities and the degree of connectivity expected in a random graph.¹⁴ A modularity index above 0.3 indicates a significant community structure. A modularity index close to zero implies that no significant community structure could be found.¹⁵

Assortativity indices range from 1 showing that similar countries trade with each other (assortative network) to -1 showing the reverse (disassortative network). We use the assortativity coefficient following the reasoning of Newman (2003). The similarity dimension based on which countries trade needs to be determined and was chosen based on theoretical considerations. We classify countries by income group and region for the calculation of the assortativity indices. This is consistent with trade theories that underline the importance of the economic size (income) and proximity of countries in explaining trade patterns (Tinbergen, 1962). We use undirected trade matrices (see section 3.2) when detecting trade communities and

¹³ See Jackson (2010) on the related notion of homophily.

¹⁴ The significance of a community can be measured using the Z-modularity measure. It varies from -0.5 (a non-modular clustering) to 1 (fully modular) clustering. Thus, the positive (negative) value of Z-modularity implies that the fraction of links within communities is greater (less) than the expected fraction of such links in a random graph.

¹⁵ A negative modularity index indicates disassortativity, implying that between-community interactions are more significant than within-community interactions. The community detection method groups the observation without prior assumptions, the number of groups and the composition of groups are endogenous. It is a bottom-up approach based on the greedy optimization method that groups the nodes in successive stages to maximize the modularity and build a hierarchy of networks. At the lowest level, each node is taken as a community and then the method takes a node and adds it to a community if it increases the modularity. During the process of grouping the nodes, if joining nodes do not contribute positively to the modularity, the process starts again from the lower level and is repeated until the modularity of the overall network is maximized (Blondel *et al.*, 2008).

assortativity because we are not interested in the direction of trade, but rather in the existence of a trade link between two partners.

3.1.3 Measures to assess the resilience of the food and agricultural trade network

Changes in the stability and resilience of the trade network depend on changes in global connectivity and the distribution of connectivity across countries. We graphically analyse the distributions of countries' connectivity in terms of trade links among countries, trade links by country and product and value traded. We also show measures of tail heaviness reflecting different aspects of the distributions of country connectivity measures. The heavier (fatter) the tails of the distribution of the connectivity measures and/or the more uneven the distribution of the connectivity measures, the larger the probability of large cascade effects threatening the resilience of countries in the event of negative shocks affecting their trading partners (Sartori and Schiavo, 2015).

The comparison of the highest and lowest percentiles of a distribution provides information on the heterogeneity of the distribution and the existence of fat tails. The thickness/heaviness of the tail of a distribution can also be shown by the percentage of out-of-interval observations (observations with mean $\pm$ two standard deviations) (Sartori and Schiavo, 2015). Skewness and kurtosis provide further information on the shape of the distribution. Skewness indicates the asymmetry of the distribution relative to the symmetric bell-shaped Gaussian (normal) distribution. In a normal distribution, the skewness is zero. In presence of a right (left) fat tail, the skewness is positive (negative). Kurtosis compares the extent to which data cluster to the tails or the peak of the distribution relative to the normal distribution. A kurtosis lower than the reference level for a Gaussian (normal) distribution, which is three, suggests the presence of a thin tail.¹⁶ The obesity index delivers additional information on the tailedness of the distribution (Cooke, Nieboer and Misiewicz, 2014). It is based on the heuristic that in the case of heavy tail distributions, larger observations lie further apart than smaller observations. Considering that the individual centrality measures $\{X_1, X_2, X_3, X_4\}$ are independent and identically distributed values that are randomly sampled from the data¹⁷, the obesity index is the probability that the sum of the largest and the smallest of four observations is larger than the sum of the other two observations.¹⁸

3.2 Data and construction of the world trade matrix

To calculate the network measures, we use data on international bilateral trade of food and agricultural products from the FAOSTAT database.¹⁹ Our analysis considers snapshots of world trade of 190 countries²⁰ in the years 1995, 2007, 2013, and 2019. We select 1995 as the year in which the WTO was established, 2007 as the year when the global food price crisis started and before the financial crisis, 2013 as the year when further growth in the value of global food and

¹⁶ Data is considered to be normal if the skewness is between -2 and +2 and the kurtosis between -7 and +7.

¹⁷ Our index is based on 10 000 random samples of four observations.

¹⁸ It is computed as $OB(X) = P(X_1 + X_4 > X_2 + X_3 | X_1 \leq X_2 \leq X_3 \leq x_4)$.

¹⁹ Our definition of food and agricultural trade products follows the definition of FAO covering 425 individual products.

²⁰ Geopolitical changes led to variations in the number of countries over time. For the analysis, a balanced panel of 190 countries was used.

agricultural trade had already plateaued, and 2019 as the most recent year for which data was available at the time the analysis was conducted.

We construct the trade matrix using data on bilateral import flows as these are often more reliable than export data (Cadot et al. 2011). In general, import and export links (see Figure A 1 in Appendix A) and import and export values (see Figure A 2 in Appendix A) are highly correlated, allowing for some generalization to overall trade patterns. Each entry of the matrix is set to one if there exists a trade flow between exporter (in rows) and importer (in columns), and zero otherwise. The constructed matrix is known as adjacency matrix. This matrix is used to analyse the trade links between countries, where each trade link indicates an aggregate trade flow (aggregated over all products) between two countries. For some results, binary values are weighted with the number of products traded on each link or with actual trade values - the matrix becomes a weighted trade matrix. A directed (asymmetric) trade matrix includes information on the direction of trade flows (from exporter to importer). An undirected (symmetric) trade matrix determines the existence of a trade relationship between two countries, regardless of its direction.

When import values were not available, but respective exports were reported by partner countries, we mirror export values to represent import values.²¹ Trade values are expressed in USD and deflated using the 1995 United States of America Consumer Price Index (e.g. Rose, 2004). We use this trade matrix for the entire analysis except for the community detection. The community detection is based on a symmetric trade matrix based on the arithmetic averages of bilateral export and import values for each trade link.

4 Results

4.1 The evolution of the global network of food and agricultural trade

On average, the connectivity of countries to the global network of food and agricultural trade has increased in almost all dimensions, i.e. across several network indicators and in terms of both trade links and value traded (Table 1). The network density increased, indicating that more countries trade among each other. In terms of both trade links and trade intensity, the first-order, second-order and eigenvector connectivity increased, on average across all countries. Countries are also closer connected among each other and overall better integrated in the trade network, as indicated by the closeness connectivity. Most of the global integration took place between 1995 and 2007, with a slower rate of change between 2007 and 2019.²²

The number of active trade relationships including both asymmetric (one-way trade links) and mutual trade relations (two-way links) between countries increased from 7 084 in 1995 to 10 454 in 2019, with the most significant changes having occurred between 1995 and 2007 (Table 2).²³ Given the same network size over years, the share of actual trade relationships over total possible trade relationships increased from 39 percent in 1995 to 58 percent in 2019. The share of asymmetric (mutual) trade relationships slightly decreased (increased), with most of the trade

²¹ See also Konar *et al.* (2011) for tackling discrepancies of import and export matrices.

²² For the analysis, all import links have been taken into account, including those with very small trade values. Excluding links with trade values smaller than 0.5 or 1 percent of the overall trade value of a country leads to systematically lower estimates of connectivity, but general patterns regarding the evolution of connectivity hold. These results are shown in Appendix B.

²³ Here, the count of trade relationships is irrespective of the type of trade links, that is, each of the mutual (two-way trade links) and asymmetric trade relations (one-way trade links) are counted as one single trade relationship. The number of trade relationships is therefore lower than the number of import links reported in Table B 1 in Appendix B.

relationships being mutual, ranging from 60 percent to 63 percent of all trade relationships across years.

The number of trilateral trade relationships involving three countries (triads) increased significantly. The share of actual triads of all possible triads (the intensity of triads) increased from 40 percent in 1995 to 56 percent in 2007, it remained at around 60 percent in 2013 and 2019 (Table 2). Theoretically, trade relationships of three countries can form 16 different types of triads, 13 types of which involve all three countries (see Figure A 3 in Appendix A). In 1995 and 2007, the most frequent types of triads formed in the global food and agricultural trade network were intransitive triads (labelled as 201 and 111D in Figure A 3, respectively), that is triads in which countries interact through intermediaries. In 2013 and 2019 the most frequent triad type (labelled as 300 in Figure A 3) was transitive with reciprocal trade between all three countries. Overall, the share of transitive (multi-way) trade relationships increased from 19 percent in 1995 to 30 percent in 2019, while the share of intransitive trade relations decreased. This implies much stronger trade relationships between countries and between larger groups of countries in 2019 than in 1995, a clear sign of increased connectivity.

Overall, the connectivity of countries in the global network of food and agricultural trade has increased between 1995 and 2019. Most of this change happened between 1995 and 2007, while changes between 2007 and 2019 remained marginal. The network became much denser, with countries being closer connected among each other both at micro-level and from global perspective.

Table 1 Global connectivity measures from different perspectives of the food and agricultural trade network

	Trade links				Trade intensity			
	1995	2007	2013	2019	1995	2007	2013	2019
Network density	0.32	0.44	0.46	0.47	-	-	-	-
First order indegree connectivity	0.33	0.46	0.49	0.5	0.67	0.72	0.74	0.75
Second order indegree connectivity	0.87	0.93	0.94	0.94	0.89	0.9	0.91	0.92
Eigenvector connectivity	0.45	0.47	0.48	0.48	0.04	0.05	0.05	0.05
Closeness connectivity	0.64	0.69	0.7	0.7	0.84	0.88	0.89	0.89

Note: Global connectivity measures are the arithmetic average of the country indicators.

Table 2 Structure of bilateral and trilateral trade relationships

	1995	2007	2013	2019
<i>Structure of bilateral trade relationships</i>				
Active trade relationships	7084	9877	10383	10454
Share of active bilateral trade relationships over total possible ones (%)	39	55	58	58
Share of mutual relationships (%)	61	60	60	63
Share of asymmetric relationships (%)	39	40	40	37
<i>Structure of trilateral trade relationships</i>				
Actual number of triads	446310	633492	675494	680616
Share of actual triads over total possible ones (%)	40	56	60	60
Most frequent type	201 (24.28%)	111D (17.70%)	300 (18.59%)	300 (20.48%)
Share of transitive (%)	19	27	29	30
Share of intransitive (%)	58	45	43	43
Share of mixed (%)	15	20	20	20
Other (021D,021U) (%)	8	8	8	7

4.2 The structure of the food and agricultural trade network

The increased connectivity, the expansion of food and agricultural trade and the emergence of new players in global markets have changed the structure of the trade network. In terms of betweenness (Figure 3), we observe a heavily right-skewed distribution of both trade links and trade values (trade intensity). This implies that a large part of connectivity of the network depends on a few countries. These countries serve as trade hubs that connect to many partners and through these trade hubs smaller partners (indirectly) connect to the global network. Over time, the number of hubs increased, implying that the network depended on more but less dominant hubs in 2019 compared with 1995.

Figure 4 depicts the network of food and agricultural trade based on betweenness indices of individual countries. In terms of trade intensity, the United States of America was the most significant hub in 1995 and remained so in 2019. Following its accession to the WTO in 2001 and the rapid growth it experienced, China evolved from being a relatively small hub in 1995 to the second largest hub in 2019, moving from the periphery of the network to become one of its central players (Tombe and Zhu, 2019). Several Northern and Western European countries that were among the top ten hubs in 1995 reduced in relative importance and gave way to emerging economies such as India, the Russian Federation and South Africa (Figure 4). Emerging economies became more globalized and, at the same time, developed as important regional hubs, linking smaller countries in their regions to the global market (Chen and De Lombaerde, 2014; Iapadre and Tajoli, 2014). Indeed, as measured by the assortativity index, hub countries with many links and high trade intensity tend to trade more with countries with lower connectivity than with other hub countries (assortativity by degree/strength in Table 3), thus confirming their role in connecting peripheral countries to global markets. In 1995, the trade network had a pronounced core-periphery structure with few traders in the core and many less connected countries in the periphery. With more, though less dominant, trade hubs, there was a change to a more balanced structure, characterized by smaller core-periphery sub-networks (Figure 4). Similar structural changes characterized by a tendency towards decentralization have also been observed by Sartori and Schiavo (2015) for food and agricultural trade and in the merchandise trade network (Vidya, Prabheesh and Sirowa, 2020).

The assortativity index by region suggests that countries within a region tend to trade more with each other than with countries in other regions (Table 3). On average, countries within the same region have relatively more trade links with each other and the intensity of trade between them is higher than with countries outside the region. Possibly reflecting regionalization tendencies fostered by RTAs worldwide, the analysis suggests that during the 1995–2019 period not only globalization, but also the tendency of countries to trade with partners within the same region increased (when measured in terms of trade intensity). When globalization came to a halt after 2008, countries appeared to trade more within their regions.

Income levels also play a role in determining trade intensity. Countries with similar income per capita tend to trade more among each other because income levels can reflect similar tastes and preferences. High-income countries also tend to trade with rich partners due to a comparative advantage in the production of high-quality goods (Hallak, 2006). In 1995, the food and agricultural trade intensity of countries within the same income group was higher than the trade intensity of countries in different income groups (Table 3). However, with the increasing participation of low- and middle-income countries in global food and agricultural markets, this relationship between similar income levels and trade has weakened over time. In 2019, countries were much more likely to have a high trade intensity with countries of a different income group than in 1995.

Income levels, geography, differences in natural resource endowments and technology, and trade policies, all influence the choice of a trade partner. Within the global food and agricultural trade network, different trade clusters within which countries tend to trade more are identified using the Louvain method (see section 3.1.2). These clusters may be regional or can expand to include trade partners across regions. During the period 1995–2019 and in terms of trade intensity, the analysis suggests that countries traded within a pronounced cluster structure. Over time, some clusters became even firmer, as trade increased within them. Some clusters remained regional and stable in terms of country participation, while others expanded across regions with a country composition that changed frequently (Figure 5).

For example, a stable cluster includes the signatories of the North American Free Trade Agreement (NAFTA) and its successor the United States of America–Mexico–Canada Agreement (USMCA) and some of their trade partners across Latin America and the Caribbean. The intensity of food and agricultural trade between the three signatories of the agreement was already high in 1995 and remained significant to 2019. In 1995, this cluster already included Central American countries beyond Mexico. Over time, trade links of significant value were formed with South American countries and the cluster expanded to include Northern America and countries from Central America and South America except Argentina, Brazil, Paraguay and Uruguay, which are members of the Southern Common Market (Mercosur) and, together with countries in Eastern Asia, South-eastern Asia and Oceania, tend to trade globally rather than within the region (Figure 5). Other mainly regional clusters include the European Union, where the Common Market has led to high levels of trade intensity among members and a cluster based on strong trade ties between former Soviet Union countries.

Africa did not form a stable regional cluster during the 1995–2019 period, instead African countries were shown to have a high rate of entries into and exits from other clusters (Figure 5). In 1995, the cluster around the European Union also included many Northern African and several sub-Saharan countries. In 2007 and 2013, the food and agricultural trade links of African countries with other countries across the southern hemisphere became more evident. In 2019, countries located at the eastern parts of Northern Africa and of sub-Saharan Africa formed relatively strong trade links with the Eastern European and Central Asian cluster and countries in Western and Southern Asia. These changes in trade cluster participation may not necessarily imply a re-orientation of food and agricultural trade of African countries. Instead, they might reflect the fact that the trade intensity of African countries is generally low, their trade relationships are often less stable, and trade of African countries also tends to be underreported (Besedeš and Prusa, 2011; Bouët, Tadesse and Zaki, 2021). These characteristics could confound the identification of clear trade patterns, but the lack of a stable regional cluster in Africa still suggests that the intensity of intra-regional trade is low and that countries in the region tend to form many trade links outside Africa, despite various economic communities that have been established between countries in the region to promote integration.

The modularity index, which is calculated based on the identified clusters, shows that these clusters became indeed more pronounced (Table 3), with the trade intensity among countries within clusters increasing relatively stronger than the trade intensity among countries in different clusters. However, in terms of trade links, the cluster structure is not very significant and countries link to many countries inside and outside their own clusters.

Overall, clusters shaped by regional proximity and trade agreements are clearly evident.²⁴ There also appears to be a trend towards a rise in regionalization with trade intensity increasing faster within than between regions (also indicated by Table 3).

Figure 3 Distribution of betweenness connectivity across countries

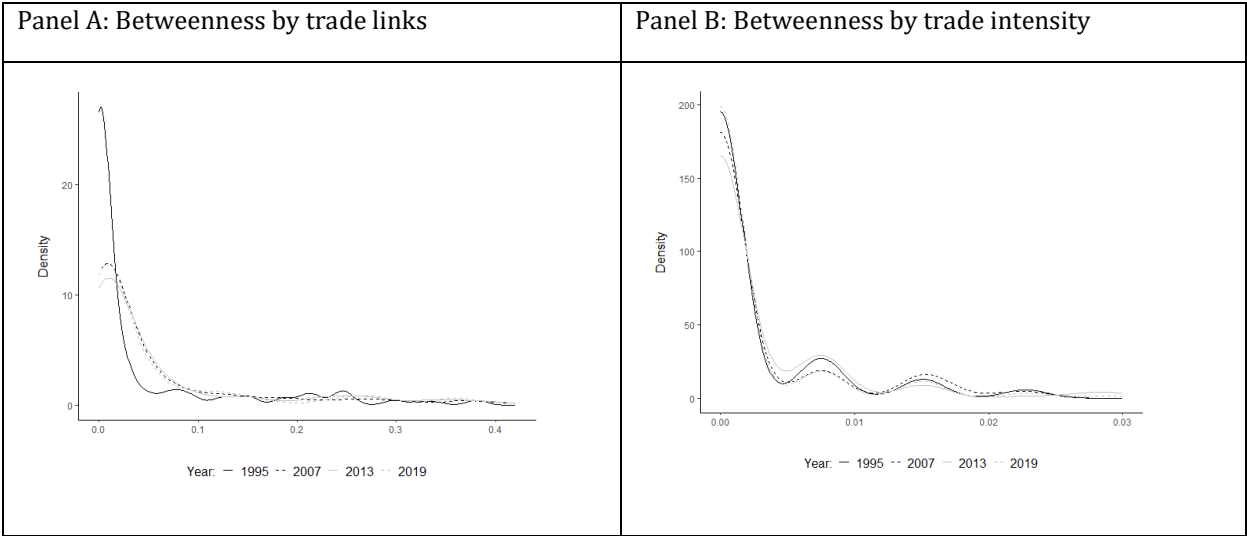
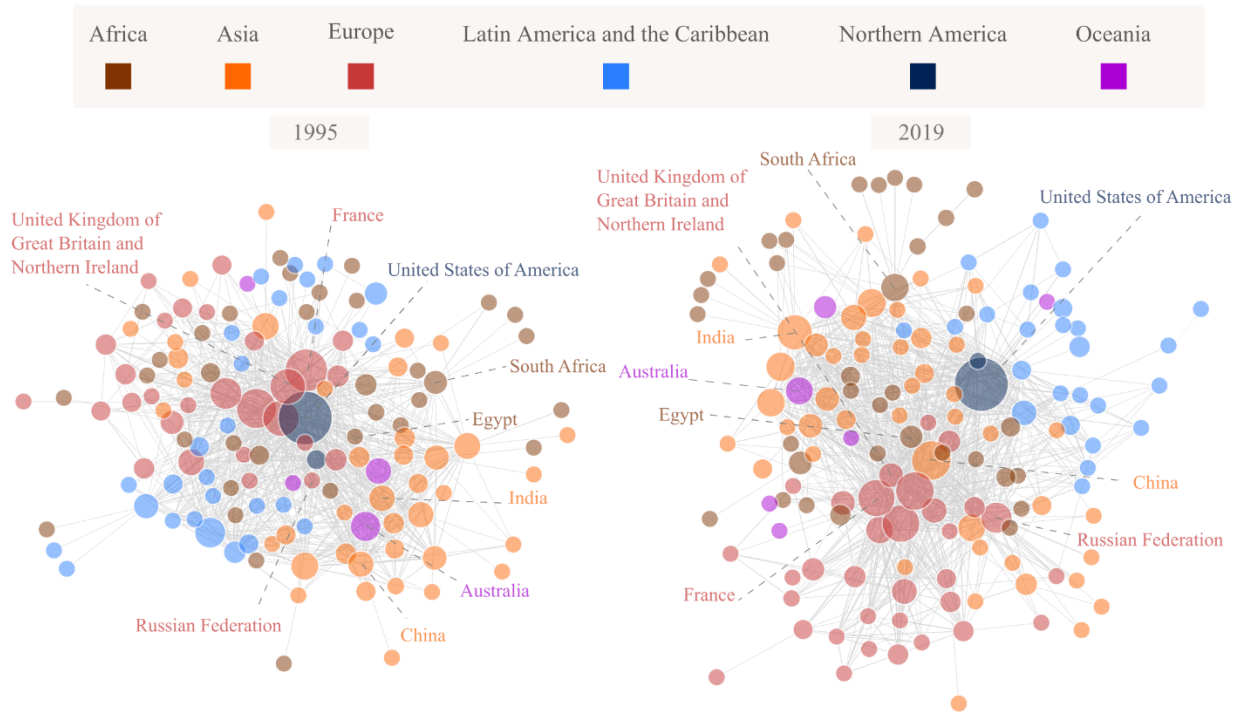
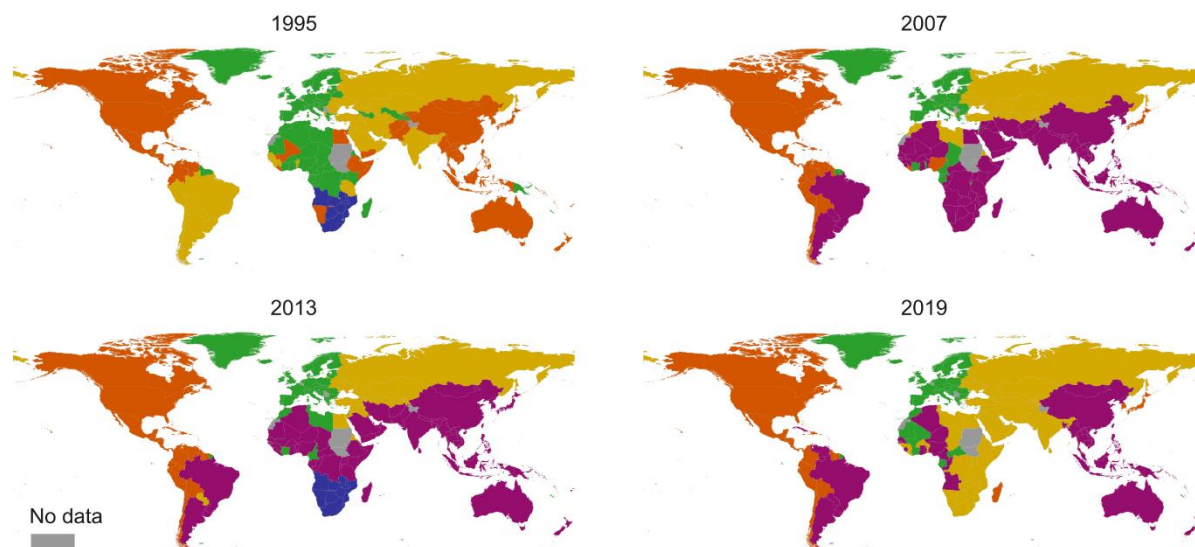


Figure 4 The food and agricultural trade network and trade hubs, 1995 and 2019



Note: Based on trade intensity.

²⁴ Clusters formed on the basis of regional proximity and regional trade agreements have also been identified in an analysis of global meat trade networks by Chung *et al.* (2020); and for several food and agricultural products independently by Torreggiani *et al.* (2018).

Figure 5 Regional food and agricultural trade clusters, 1995-2019

Note: Based on trade intensity. Trade communities have been identified based on total food and agricultural trade defined as (exports + imports)/2.

Table 3 Assortativity and modularity in the food and agricultural trade network

	Trade links				Trade intensity			
	1995	2007	2013	2019	1995	2007	2013	2019
Assortativity by degree/strength	-0.46	-0.32	-0.33	-0.35	-0.14	-0.1	-0.1	-0.1
Assortativity by country income group	-0.05	-0.02	-0.02	-0.02	0.08	0.04	0.04	0.03
Assortativity by regions	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.02
Modularity	0.08	0.08	0.07	0.07	0.30	0.32	0.33	0.34

Note: Income classification according to World Bank 2019; regional classification distinguishes Africa, Asia, Europe, Latin America and the Caribbean, Northern America, and Oceania; modularity index refers to trade communities as identified in Figure 5.

4.3 Implications for the resilience of the food and agricultural trade network

Network analysis can shed light on the extent to which the global food and agricultural trade network is vulnerable to shocks by assessing the connectivity of countries and the distribution of connectivity across the world.

Considering both connectivity and its distribution, one can distinguish between the following pathways the trade network could move to: (I) higher connectivity and a more even distribution of connectivity across countries, (II) higher connectivity overall, but a more heterogeneous distribution of connectivity across countries, (III) lower connectivity overall, but a more even distribution of connectivity across countries, and (IV) lower connectivity and more heterogeneous distribution of connectivity across countries (Arriola *et al.*, 2020; Korniyenko, Pinat and Dew, 2017). The first

pathway would be ideal to improve resilience of the network, while the fourth pathway represents the worst case scenario. There are trade-offs between the two intermediate pathways.

We analyse both countries’ direct connectivity with trade partners and their indirect connectivity. Indirect connectivity is assessed based on second-order and eigenvector connectivity. The distribution of different direct and indirect connectivity measures provides insights on the short- and medium-term impact of shocks originating from network cores. The distribution of countries’ direct connectivity can give an indication on the spillover effects of shocks in the short term, as direct trading partners would be immediately affected. Higher order connectivity measures can provide an indication on the impacts over a relatively longer time period and on more countries. If countries are connected with countries that themselves are connected with more trading partners, shocks from network cores can more easily transmit through the network, especially if global value chains are affected that span across several countries. However, the spread across the network would take longer than the immediate effects experienced by direct trade partners. At the same time, both higher direct and higher indirect connectivity would also mean that alternative suppliers could more easily substitute missing imports if only specific countries were affected by the shock, as respective trade relationships would already exist.

The number of direct trade links per country increased from an average of 60 in 1995 to 90 in 2019, indicating an enhanced connectivity among countries (see Figure A 4 in Appendix A and Table B 1 in Appendix B). At the same time, the distribution of trade links across countries became more even, with the majority of changes having occurred between 1995 and 2007. In 1995, the distribution of direct trade links by countries was strongly right-skewed as shown in Figure 3 Distribution of betweenness connectivity across countries

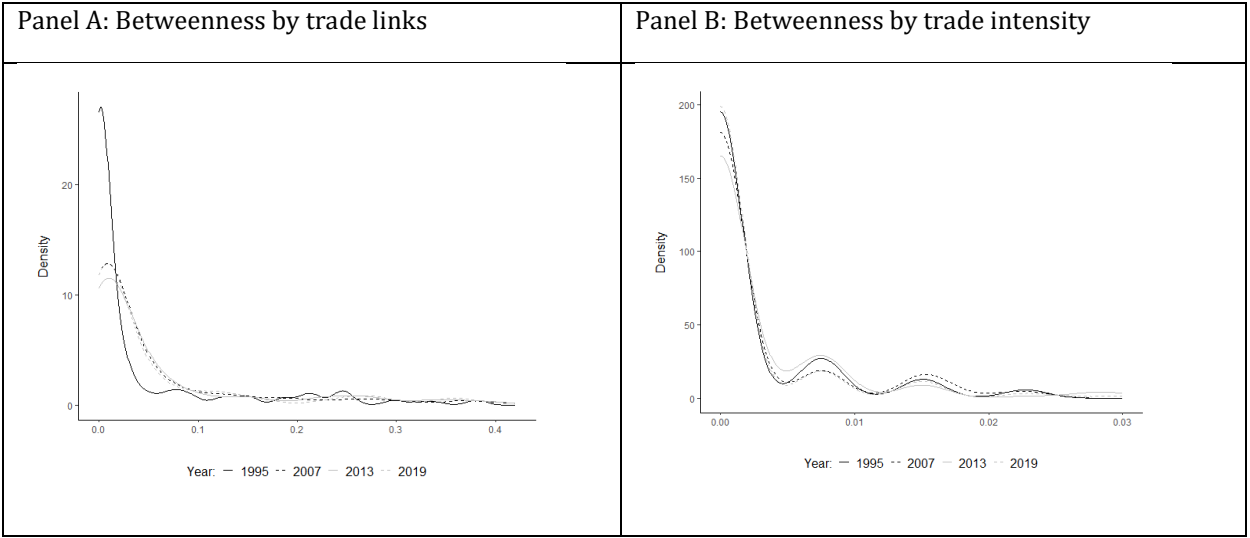


Figure 4 (panel A). In this year, only a few countries were highly connected to the global trade network (10 percent of the countries had more than 121 import links). Most countries were not well-integrated into global markets and remained in the periphery of the network (50 percent had below/above 48 import links and 10 percent had less than 19 import links) (Table B 1 in the appendix). Over time, the distribution became more symmetric. Skewness and kurtosis decreased (Table 4) and the distribution shifted to the right, showing that the number of countries with which

the average country is connected increased over time. In 2019, 10 percent of the countries had more than 148 import links, 50 percent had below/above 86 import links and 10 percent had below 36 import links (Table B 1 in the appendix). The value of the obesity index was always below the theoretical value of an exponential distribution (0.75) and generally decreased over time (Table 4). Similarly, the percentage of observations outside the interval of mean $\pm$ standard deviation decreased, indicating a lower number of countries with both very high and low connectivity, which results in a thinner tail of the distribution. Overall, the network moved from a core-periphery structure to a more symmetric structure with more but less dominant cores. This is related to Pathway I: higher connectivity and a more even contribution of countries to the overall connectivity. The result is also consistent with the findings of Sartori and Schiavo (2015) and Konar et al. (2011). Both studies observed that the distribution of first-order degree connectivity shifted rightward and that the tails of the distribution became thinner over time.

At the aggregate level of trade links for all food and agricultural products, resilience to disruptions in a major exporter can be better balanced through increased imports from other countries than at the individual product level. For a single product, such as wheat, only a few countries have a comparative advantage and are main exporters, which may imply a high dependency of other countries in the network on these key exporters (d'Amour *et al.*, 2016; Gutiérrez-Moya, Adenso-Díaz and Lozano, 2021; Karakoc and Konar, 2021; Puma *et al.*, 2015; Soffiantini, 2020). The distribution of trade links weighted by the number of products imported (

Figure 7) is much more imbalanced than the distribution of trade links at the aggregate level (Figure 6). Although significant imbalances still exist in 2019, indicating that many countries import a narrow range of products from a small number of trade partners (see also Figure A 4 and A 5 in Appendix A), the distribution of connectivity by country and product became less concentrated since 1995, with the largest change having occurred between 1995 and 2007. During the whole period 1995 to 2019, the number of trade links by country and product more than doubled and the share of actual trade links over the number of total possible trade links increased from 1.4 percent in 1995 to 3.2 percent in 2019. Similar to the distribution of trade links per country and product, also the distribution of trade intensity, measured as trade links weighted by trade values is strongly right-skewed. Still, the connectivity of countries in terms of trade intensity increased and the distribution became more symmetric.

The distribution of connectivity at detailed product level and the distribution of trade intensity indicate increasing connectivity overall and a more even distribution of connectivity across countries, a process that evolved mainly between 1995 and 2007 (Table 4). While the average connectivity still increased between 2007 and 2019, though at a slower pace, the tail-heaviness of the distributions showed an increasing trend between 2013 and 2019. Both kurtosis and skewness decreased between 1995 and 2007, but increased thereafter. This would suggest a development reflecting Pathway II: higher connectivity, but a more uneven distribution of connectivity across countries, indicating that the resilience of the network increased between 1995 and 2007, with little progress since then.

Similar patterns as for the direct connectivity are found for indirect connectivity measured as second-order and eigenvector connectivity. With the rising number of trade links among countries, also the indirect connectivity of countries as indicated by the second-order and the eigenvector connectivity increased. The body of the distributions generally shifted rightwards (Figure 6,

Figure 7, and Figure 8, panels B and C), indicating an increase in the average connectivity, particularly between 1995 and 2007. The measures of tail-heaviness for second-order connectivity (Table 4) suggest a slight reversal of the trend towards a more evenly distributed trade integration between 2013 and 2019. Since 2007, the distribution of trade links by country at second and higher orders of connectivity has tended to be left-skewed (Figure 6, panel B and C): the network moved from a state in which a small fraction of highly connected countries coexist alongside a large number of countries with few connections to a state in which only a small fraction of countries has a low level of indirect connectivity, implying that still some countries lag behind in terms of connectivity. The distribution of the second-order indegree and the eigenvector connectivity of trade links by country and product and trade intensity (

Figure 7 and Figure 8, panels B and C) is less skewed than their first-order connectivity, suggesting that the indirect connectivity of marginal countries could be conducive to reducing their vulnerability to shocks in the system.

As shown by Figure 9, the connectivity of countries is distributed unevenly across the world. Northern American, Eastern Asian, Oceanian and European Union countries, and partly South Africa and countries in Northern Africa, were already well-connected in 1995. By 2019, the connectivity of most countries had improved, especially the connectivity of countries of the former Soviet Union. Connectivity of countries in Africa remained low and, in general, African countries are least connected in the world.

Beyond the global distribution of connectivity, also trade clusters are important (see section 4.2), as they affect how a shock in one country could spread within the global network of trade. For example, if the epicentre of a shock is within a regional cluster, countries in that cluster would be more directly affected than outside countries as they would face reduced supply from their trading partners and higher prices. Countries outside the epicentre cluster would be indirectly affected through increasing international prices and possible trade interventions by their own trading partners (Torreggiani *et al.*, 2018).

Figure 6 Distribution of connectivity of trade links by country

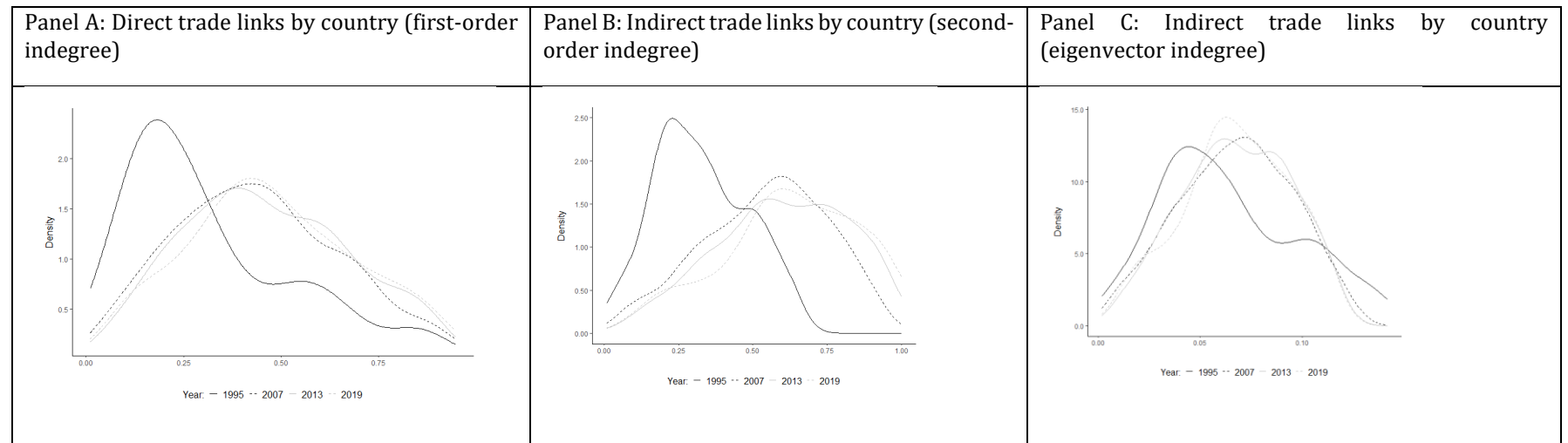


Figure 7 Distribution of connectivity of trade links by country and product

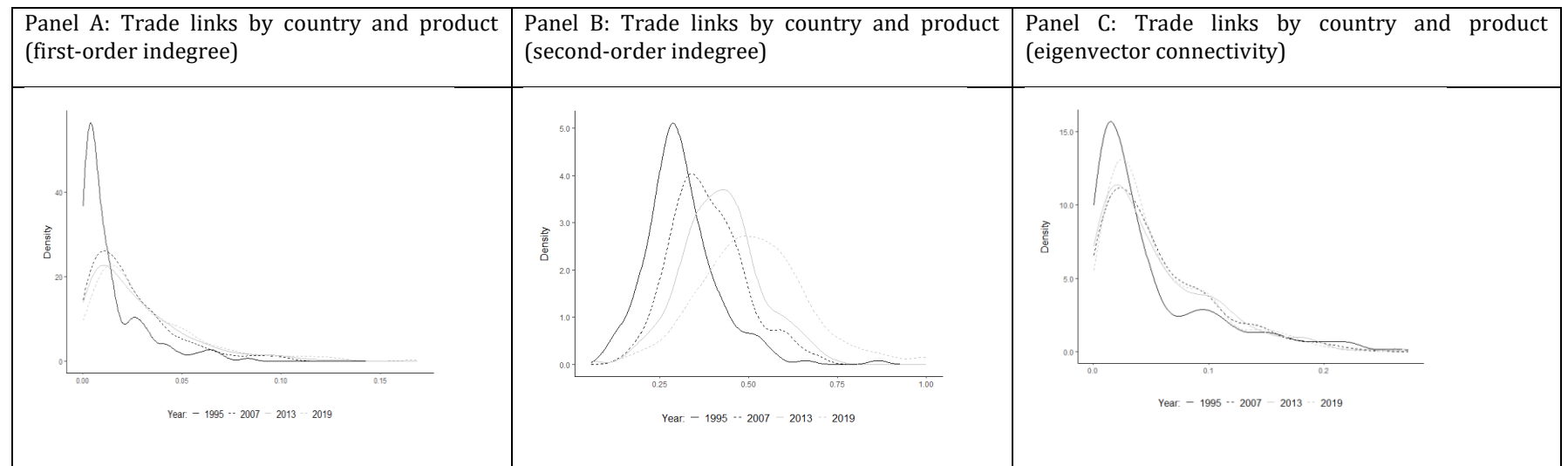
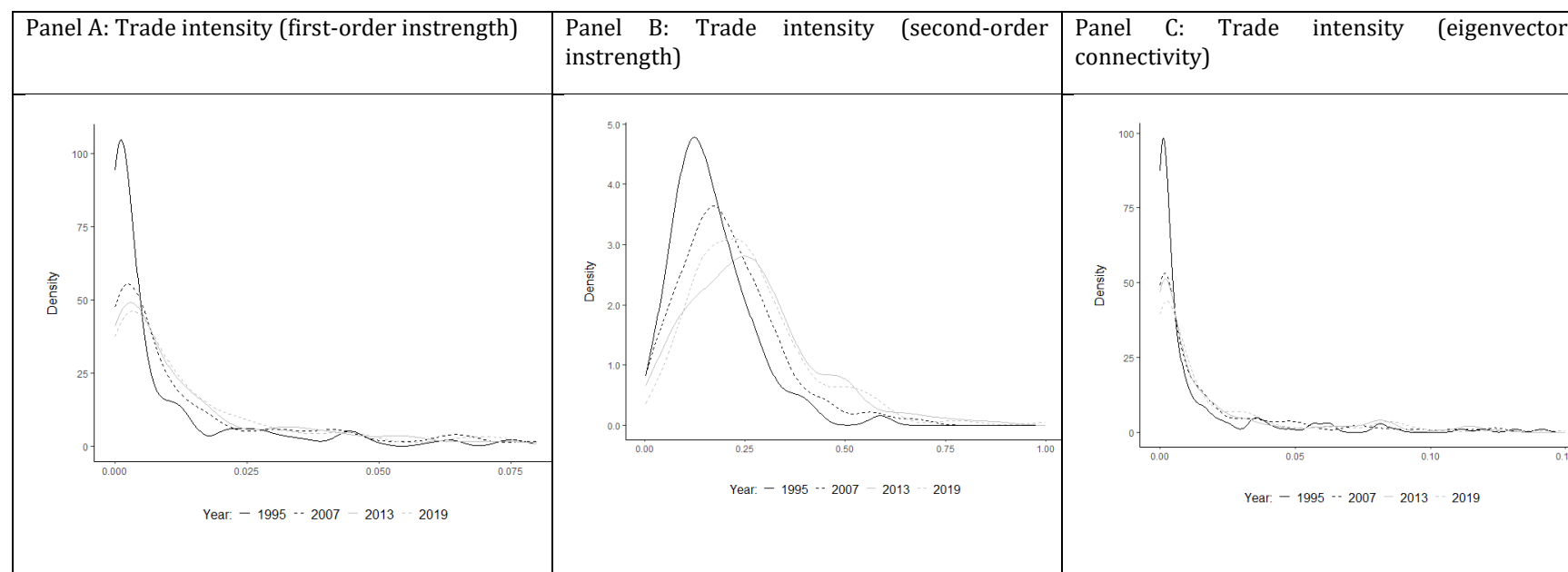
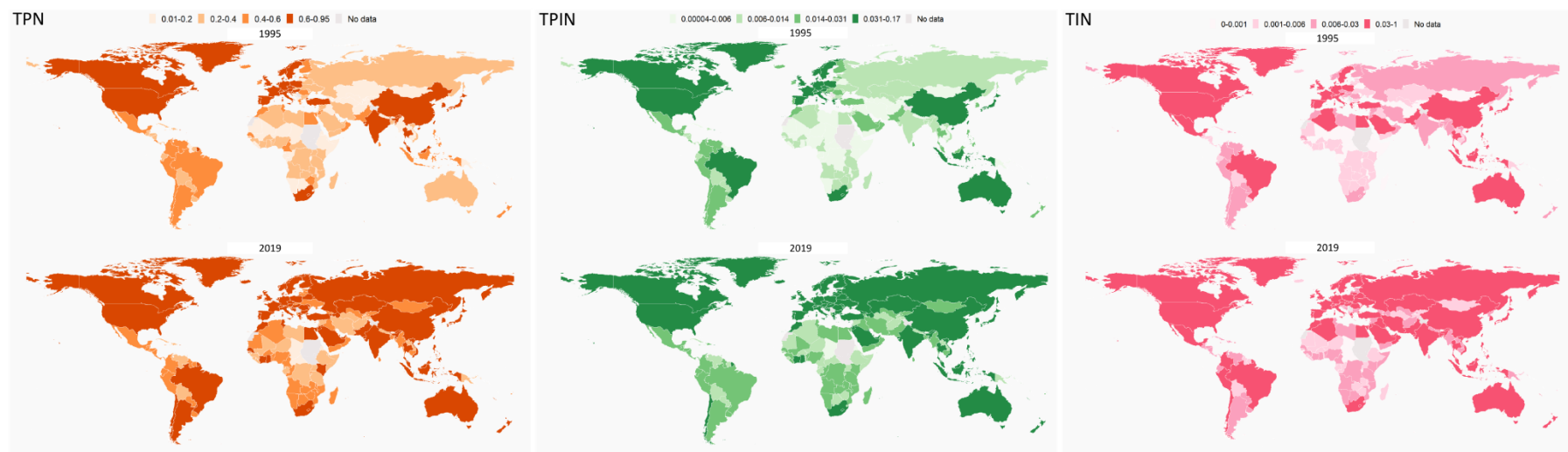


Figure 8 Distribution of connectivity of trade intensity**Table 4 Measures of tail-heaviness**

	Trade links by country				Trade links by country and product				Trade intensity by country			
	1995	2007	2013	2019	1995	2007	2013	2019	1995	2007	2013	2019
	<i>First order connections</i>											
First order indegree connectivity	0.33	0.46	0.49	0.5	0.67	0.75	0.76	0.79	0.67	0.72	0.74	0.75
Percentage of observations out of interval	6.32	4.02	1.72	2.87	5.79	5.79	5.79	5.26	3.68	4.74	4.74	3.68
Obesity index	0.71	0.54	0.54	0.55	0.82	0.73	0.74	0.77	0.91	0.89	0.9	0.89
Kurtosis	2.78	2.33	2.2	2.31	6.51	5.22	5.27	7	26.92	24.28	26.05	33.91
Skewness	0.87	0.19	0.13	0.15	1.91	1.49	1.48	1.83	4.7	4.34	4.48	5.09
	<i>Second order connections</i>											
Second order indegree connectivity	0.87	0.93	0.94	0.94	0.87	0.89	0.9	0.93	0.89	0.9	0.91	0.92
Percentage of obs out of interval	1.72	2.87	2.87	3.45	4.74	6.32	5.26	5.26	4.74	4.21	4.21	4.21
Obesity index	0.57	0.45	0.45	0.48	0.59	0.58	0.53	0.55	0.64	0.61	0.61	0.64
Kurtosis	2.18	2.46	2.37	2.57	7.12	3.26	3.29	3.79	5.62	4.74	4.37	6.24
Skewness	0.23	-0.31	-0.3	-0.31	1.25	0.56	0.1	0.49	1.25	1.09	0.99	1.39

Figure 9 Connectivity to the global food and agricultural network by country



Note: The darker colours indicate countries with high connectivity. A lighter shade indicates countries with lower connectivity. Conforms to Map No. 4170 Rev. 19 United Nations (October 2020).

5 Conclusions

Based on network analysis, this paper explored the evolution of connectivity within the network of food and agricultural trade since 1995, its structure and implications for resilience to trade shocks. Food and agricultural trade evolved rapidly and countries worldwide became better connected to global markets in the period 1995-2007, but progress has since been limited. Between 1995 and 2007, countries formed closer ties among each other both at the micro-level and from a global perspective. Emerging economies became important players and link smaller and less-connected countries to the global market. The connectivity of countries increased globally and the network of food and agricultural trade became more balanced and resilient, although vulnerabilities and dependencies remain in the trade of specific products. Also, despite the emergence of new players and a more even distribution of connectivity across the world, still not many countries account for most of the value traded.

Since the 2008 financial crisis, the process of further trade integration has largely stalled, but evidence suggests that countries have continued deepening their trade intensity with partners in dedicated trade clusters, which are often shaped by regional proximity and trade agreements. The distributions of connectivity among trade partners and with partners of trade partners indicate a reversal of the trend towards a more even and balanced trade network between 2013 and 2019, which may imply a loss in resilience in the future, were this trend to continue.

Developments in recent years give rise to concerns over a fragmentation of global food and agricultural trade and reduced resilience of the network to shocks, which may pose a risk to countries' food security and dietary diversity. A fragmentation of the global market into regional trading blocs could prevent countries from fully leveraging the gains from trade and may imply less efficient outcomes in terms of production allocation and resource use.

Further research could deepen the discussion on the contribution of regional trade agreements and regional trade integration to these processes, for example, by exploring the features of regional trade clusters and modelling their interaction within the multi-layered system. This could shed light on the impact of geopolitical shifts on the global network of food and agricultural trade and help explain the impact of deep trade agreements on global trade integration and the risk of excluding countries from the integration process more specifically.

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Appendix A

Figure A 1 Correlation between import and export links, 2019

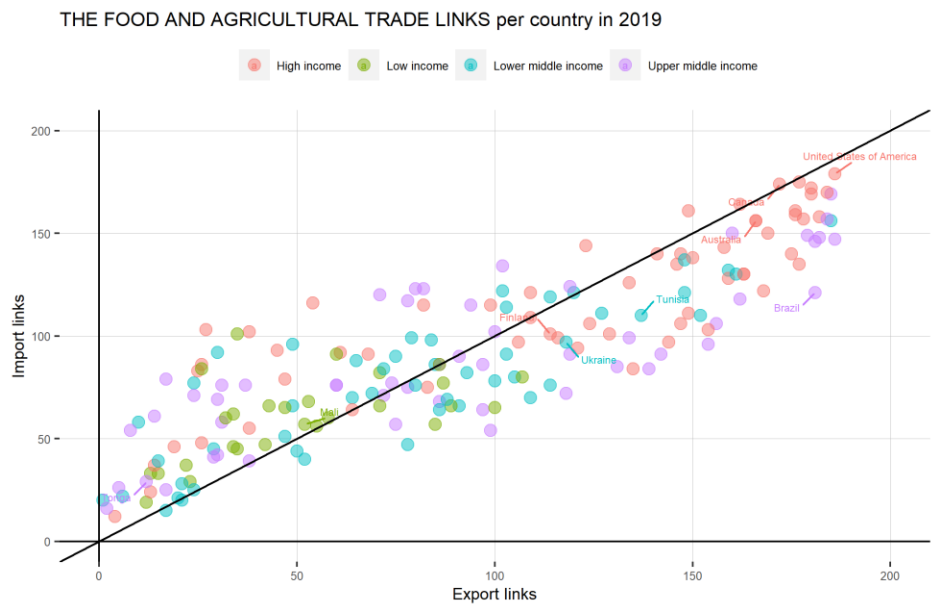


Figure A 2 Correlation between import and export values, 2019

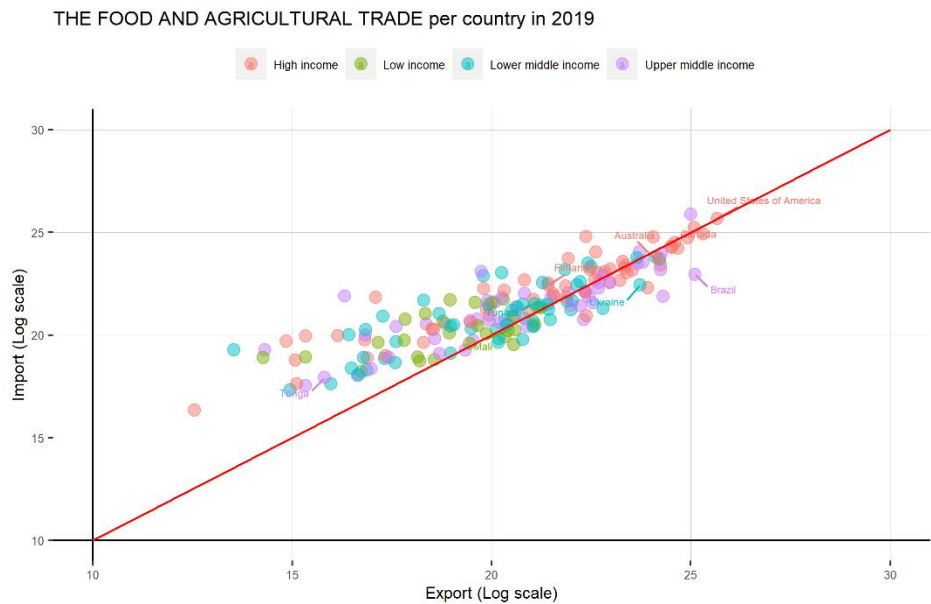
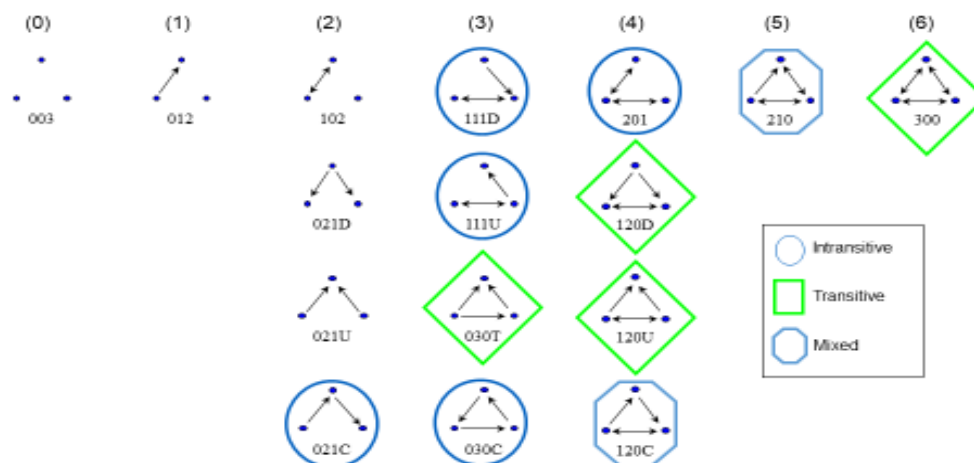


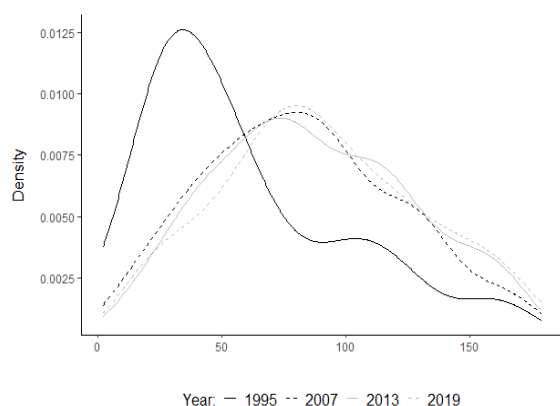
Figure A 3 Triad isomorphism classes (following James Moody)



Note: In a triad, countries can be related in sixteen different types. Thirteen types of triads indicate some form of connection among the three actors, which means 13 different motifs are observed. Each type is labelled according to the three digits MAN scheme. The first digit shows the number of observed mutual (M) trade relationships, the second digit shows the number of observed symmetric (A) trade relationships and the third one shows the number of null (N) trade relationships. If two triad types have an equivalent number of dyads, the fourth digit is used to distinguish the triads further based on edge directions (U: up and D: down), cyclicity (C: cyclic), and transitivity (T: transitive).²⁵

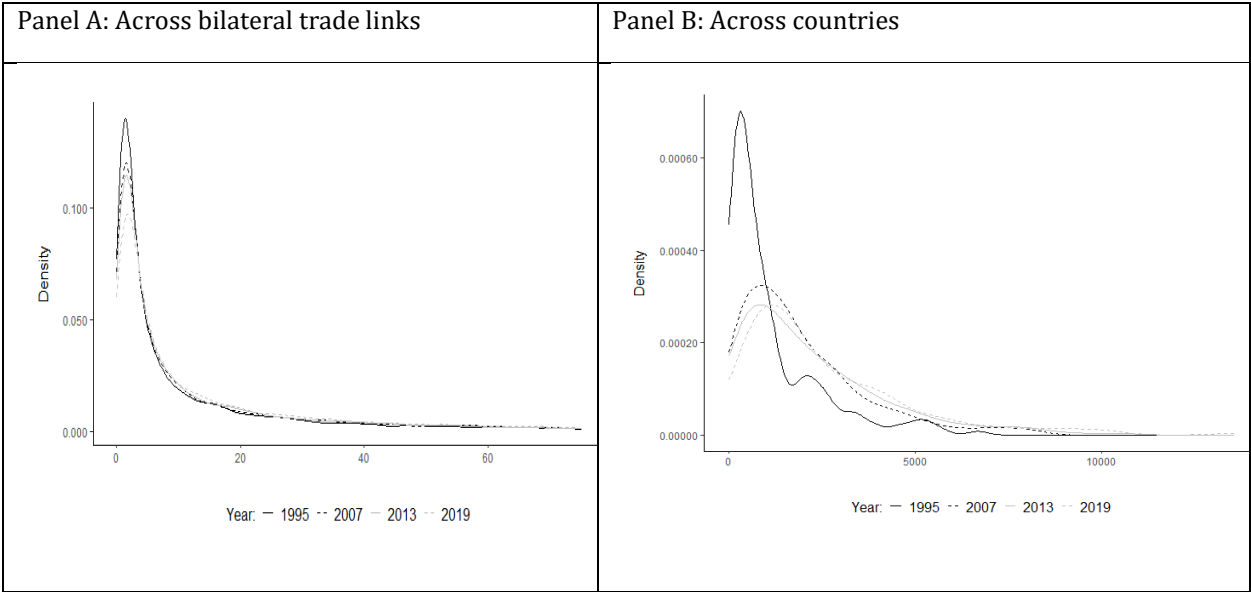
Source: Moody, J. Introduction to networks: Methods and measures. Duke Network Analysis Center, Department of Sociology.

Figure A 4 Distribution of the number of trade partners per country



²⁵ A triple of nodes i, j, k is cyclic if $i \rightarrow j, j \rightarrow k, k \rightarrow i$; it is transitive if $i \rightarrow j$ and $j \rightarrow k$ implies $i \rightarrow k$; and intransitive if $i \rightarrow j$ and $j \rightarrow k$ but $i \nrightarrow k$.

Figure A 5 Distribution of the number of traded products



Appendix B

Many trade relationships occur with very small trade values. Once the small trade values are ignored the analysis can deviate significantly (Kali and Reyes, 2007). For this reason, some studies considered trade values only above a certain threshold as non-zero trade values. There is no consensus on the value of this threshold. For example, Kim and Shin (2002) use cut-off values of USD 1 million and USD 10 million and thus remove the trade of many small countries from the sample. Kali and Reyes (2007) use different levels of thresholds defined as shares of a country's bilateral exports from the country's total exports. If the share is below a certain level (0.5 percent, 1 percent and 2 percent) the observed trade relationship is ignored. Once taking out import values below 0.5 percent and 1 percent of the overall import value of each importing country, the number of active trade links declines to almost a third compared to the case when all data reported by the countries are considered (Table B 1). While absolute values differ significantly when applying different cut-off thresholds, the patterns of change over time remain the same, with distributions shifting rightward between 1995 and 2007, suggesting higher direct and indirect connectivity overall and a more even distribution of connectivity across countries (Figure B 1 and B 2).

Table B 1 Distribution of trade links considering different cut-off thresholds

	0-percent threshold				0.5-percent threshold				1-percent threshold			
	1995	2007	2013	2019	1995	2007	2013	2019	1995	2007	2013	2019
Active Links	11 395	15 768	16 635	17 016	3 356	3 792	4 026	4 157	2 480	2 709	2 867	2 924
Average number of links per country	60	83	88	90	18	20	21	22	13	14	15	15
10th percentile of links	19	32	38	36	8	10	13	12	7	7	9	9
Median links	48	80	83	86	16	21	22	23	13	15	15	15
90 th percentile of links	122	136	147	148	28	28	29	31	19	20	21	22

Figure B 1 Normalized first-order indegree distribution by cut-off threshold

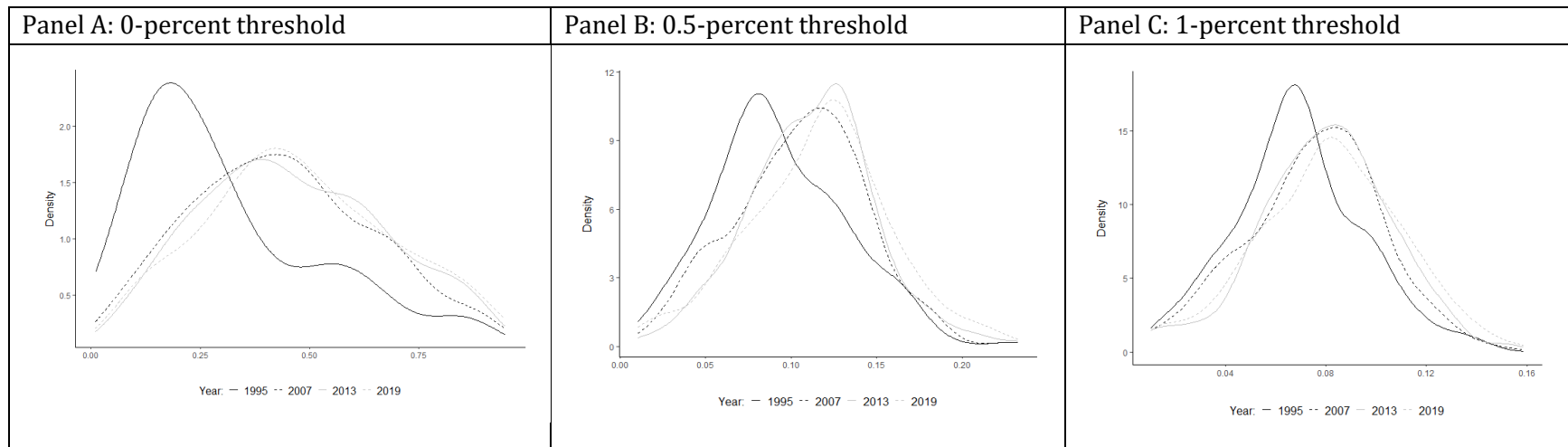
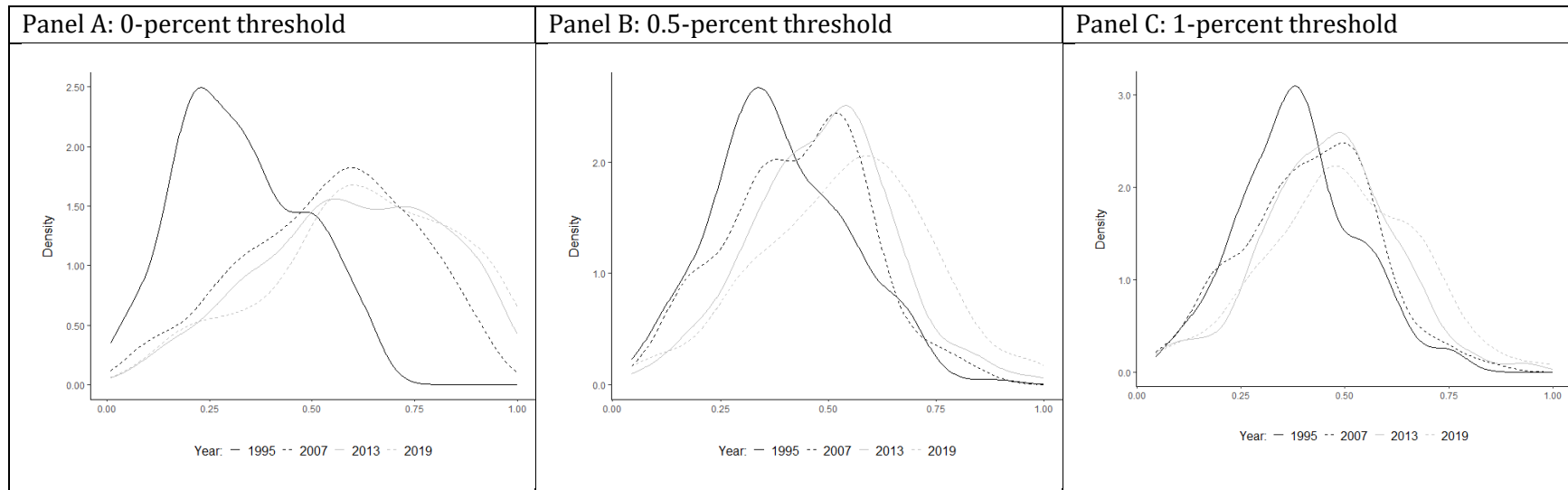


Figure B 2 Normalized second-order indegree distribution by cut-off threshold



Assessing Inequality and Poverty in Long-Term Growth Projections: A General Equilibrium Analysis for Six Developing Countries

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Highlights:

1. We analysed the impact of some long-term projections of economic growth on income distribution and poverty.
2. We extended a recursive dynamic CGE model with data from household surveys to obtain 12 distinct household classes in six developing countries.
3. A reference scenario of economic development (SSP2) generally entails widening income inequality.
4. Accelerated trade integration only marginally amplifies the impact on income inequality, but contributes to eradicating absolute poverty.
5. Increasing capital incomes and decreasing agricultural earnings are key drivers of the increased inequality.

Abstract

Most projections of long-term economic development, such as the shared socioeconomic pathway (SSP) scenarios in climate change research, do not quantify future effects on income distribution and poverty. To address this knowledge gap, we present some numerical simulations based on a recursive-dynamic general equilibrium model with household details, focusing on relative and absolute poverty in six developing countries: Albania, Bolivia, Ethiopia, Malawi, Nicaragua, and Vietnam. The results under the SSP2 reference scenario suggest that the exogenously projected gross domestic product (GDP) and population growth, combined with long-term structural change, produce lower absolute but higher relative poverty. An alternative scenario of stronger trade integration further amplifies the impact on income inequality. Indeed, more international trade tends to increase capital income, which mainly benefits rich households, but generally decreases agricultural earnings, which are important for rural poor households.

Keywords: income distribution, poverty, economic growth, trade, shared socioeconomic pathways.

JEL Codes: C68, E17, F17, I32, O11, O15, O41.

1. Introduction

Despite the inherent difficulties of projecting the evolution of the economy much beyond the short term, it is often necessary to consider scenarios of long-term economic development. The integrated assessment modelling of climate change policy and subsequent effects provides an example with so-called shared socioeconomic pathways (SSPs). These are scenarios of projected socioeconomic global changes up to 2100 introduced by the Intergovernmental Panel on Climate Change¹ (IPCC; Riahi et al., 2017). The SSPs provide narratives describing alternative socioeconomic developments. The underlying storylines provide each SPP with a qualitative description that relates the different elements of the narratives to each other under a common thematic umbrella.

The scenarios are:

- SSP1: Sustainability (Taking the Green Road)
- SSP2: Middle of the Road
- SSP3: Regional Rivalry (A Rocky Road)
- SSP4: Inequality (A Road Divided)
- SSP5: Fossil-fuelled Development (Taking the Highway)

Not surprisingly, most analyses have been based on the intermediate case (SSP2), whose qualitative description is provided in the following:

The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceed unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward, but make slow progress in, achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements, and overall, the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly, and challenges to reducing vulnerability to societal and environmental changes remain.

In regard to numerical economic modelling, the only available quantitative details that define the SSP2 scenario relate to demographics, urbanisation, education level, and gross domestic product (GDP) obtained from aggregated macroeconomic models, such as ENV-growth (Dellink et al., 2017). This is often insufficient. For instance, in estimating future emissions of greenhouse gases, it is not only aggregate growth that matters, but also the sectoral composition of the economy, with higher or lower shares of polluting industries. Furthermore, the SSP2 narrative mentions the persistence of income inequality as one of its distinguishing traits, yet the available projections on GDP per capita allow only for assessing inequality in broad terms and between countries.

To overcome these limitations, one sensible strategy is to employ a disaggregated macroeconomic model such as a global multiregional computable general equilibrium (CGE) model, forcing it to follow a predefined growth path of population and national income, as stated in SSP2. In this way, the CGE model

¹ <https://www.ipcc.ch/assessment-report/ar6/>

would generate a series of global, temporal equilibria, thereby providing detailed information about future economic structures and trade patterns that are internally consistent and simultaneously coherent with the exogenously imposed path of development.²

On the other hand, CGE models were not designed for this purpose. Because the parameters in the model are calibrated on past data found in social accounting matrices (SAMs), a standard CGE formulation cannot adequately capture long-term structural changes in the economy since technology, preferences, and saving propensities are typically considered static.

To overcome these deficiencies, a new generation of recursive-dynamic CGE models, explicitly designed for the construction of long-term scenarios, has emerged (Dellink, van der Mensbrugghe and Saveyn, 2020; Bekkers et al., 2020; Ho et al., 2020). G-RDEM (Britz and Roson, 2019, Roson and Britz 2021) is a model in this class, and it is employed for the exercise illustrated in the following.

The G-RDEM model extends the standard GTAP model (Hertel and Tsigas, 1997) by adding some key drivers of long-term structural change, namely, (1) variations in household consumption patterns, giving rise to non-linear Engel curves; (2) differentiated sectoral productivity growth; (3) debt accumulation generated by trade imbalances; (4) variable savings rates, influenced by population and income dynamics; and (5) time-varying and income-dependent industrial input–output parameters.³

The exercise was conducted by coupling this dynamic general equilibrium model of the global economy with detailed micro data on household income in six countries: Albania, Bolivia, Ethiopia, Malawi, Nicaragua, and Vietnam. We selected these six countries to achieve good coverage of cases on different continents, as well by considering the quality and quantity of available survey data provided by the United Nations (UN) Food and Agriculture Organization (FAO). Albania is representative of low-income European countries, Bolivia and Nicaragua are representative of South and Central America, Ethiopia and Malawi are representative of Africa, and Vietnam provides an example of an Asian developing economy.

We found that long-term structural change, as simulated by the model, has different impacts on income inequality across the countries, but accelerated trade integration widens income gaps in all six countries compared to the reference scenario. Relative poverty increases in both the baseline and the larger trade volume case. Nonetheless, absolute poverty would be eradicated in almost all countries by 2050.

The paper is structured as follows. In the next section, we summarise some key findings from the literature on trade and poverty. We explain our modelling strategy in the third section, focusing on the overall logic of the methodology employed. We ran the model under SSP2 (Riahi et al., 2017) until 2050, which informs us about future national GDP and demography. We did not address issues of realism in these projections but rather explored, through our model, their implications in terms of income distribution in the six developing countries. The results of the SSP2 baseline model are presented and discussed in Section 4. Subsequently, in Section 5, we introduce an alternative scenario of accelerated international trade integration. We first consider recent tendencies in the degree of openness of the six economies, noting that lower trade friction (the principal explanatory factor in neoclassical trade theory) cannot account for the observed rise in international trade volumes. We then turn to an alternative explanation based on the higher quality (and variety) of exchanged goods. We simulated this kind of effect in our numerical model,

² CGE models are not the only numerical models that could be used to assess impacts on poverty and inequality. For example, Kaplan, Moll, and Violante (2018) presented a DSGE model with heterogeneous agents, yielding distributions of household wealth. Those models would not be suitable for our objective due to their limited sectoral detail and the difficulty of forcing the system to follow a predetermined growth path, which involves a swap between endogenous and exogenous variables.

³ A concise description of the G-RDEM model is provided in Appendix A.

and further elaborated its implications in terms of poverty. The results are presented in Section 6. The concluding section discusses the key insights of our research, its limitations, and what remains to be examined.

2. Related Literature

Trade has played a major role in reducing poverty in the past. A better global allocation of resources and exploitation of comparative advantages have led to significant productivity and thus income increases, and in many countries, large groups of people have been lifted out of poverty. However, trade has not been universally inclusive. Vulnerable groups are at risk of being left behind, and income inequality is on the rise in many countries (Cattaneo and Dodd, 2007). However, even though international trade is often indicated as a key driver of inequality, recent empirical research indicates that other factors are more important, such as financial globalisation and foreign direct investment (FDI) (Asteriou, Dimelis and Moudatsou, 2014) or technological progress (Jaumotte, Lall and Papageorgiou, 2013). Huang et al. (2022), in a meta-analysis combining results from 494 comparable studies, found the overall effect of trade on income inequality to be negative or close to zero.

Neoclassic theory stipulates that trade liberalisation is welfare increasing in the aggregate, at least in terms of potential Pareto improvement, with income transfers (McGuire, 2012; Grafton, 2012). Nonetheless, not all regions (Autor, Dorn, and Hanson, 2013; Saad, 2021), sectors, or households benefit from globalisation (Pavcnik, 2017).

There is a vast body of literature that has investigated, from different angles, the nexus between economic development, international trade, and poverty (or income distribution). The literature is so large that we refrain from providing a comprehensive summary here (Cerra, Lama and Loayza, 2021). However, we can state that the key questions in this field address the relations between the corners of the triangle of growth–trade–inequality. For instance: Is growth conducive to more trade (or vice versa)? Does higher growth imply more inequality (or vice versa)? Is trade integration bringing about more (or less) inequality?

The main message is that the channels influencing the mutual interrelationships are many and complex (Winters, McCulloch and McKay, 2004). Theory provides a strong presumption that trade liberalisation, through its impact on growth, will alleviate poverty in the long run, on average; this is supported by empirical evidence.⁴ Marrero and Servén (2021), for instance, using a panel of 158 countries between 1960 and 2010, found that the correlation of growth with poverty was consistently negative.

Nonetheless, since trade liberalisation tends to not uniformly increase opportunities for all economic activities, it can very easily widen income inequality while simultaneously reducing absolute poverty. The adverse effects of import competition appear to be highly geographically concentrated (Autor, Dorn, and Hanson, 2013) and long-lasting in developing and developed countries alike (Pavcnik, 2017).

One major issue in the literature is the possible ambiguity of concepts. When we talk about poverty, for example, are we (perhaps implicitly) referring to income per capita? Or, should we better consider the risk of becoming unemployed, which is actually related to market instability (Santos-Paulino, 2012)? Should we focus on the individual or the household? How can informal markets, self-employment, and subsistence consumption be properly accounted for? Haughton and Khandker (2009) illustrated the many

⁴ For example, Shahbaz (2012) and Mustafa et al. (2017) pointed out the role of trade in stimulating economic growth in Pakistan and a group of developing Asian economies, but Eriş and Ulaşan (2013) did not find evidence when considering many countries globally at different levels of development.

difficulties related to the empirical measurement and definitions of various concepts of poverty and inequality.

Even the notion of higher trade integration contains ambiguity. The conventional approach is framed in terms of lower trade frictions: tariff and non-tariff barriers, transport, communication, and cost margins. As technological progress lowers mobility costs, on the one hand, and international agreements lower tariffs and other normative barriers on the other, the gross volume of international trade should expand proportionately over time more than global GDP (Brahmbhatt, 1998). However, Feenstra (1998) argued that falling tariffs and transportation costs ‘are only partial explanations, leaving three-fifths of the growth in trade relative to income unexplained’. Furthermore, ‘when countries become more similar in size, they import more product varieties from each other. This hypothesis, linked to the economic size of trading partners, has found considerable empirical support for the OECD [Organisation for Economic Co-operation and Development] and non-OECD countries’ (Hummels and Levinsohn, 1995). The bottom line is that not only the volume of trade matters, but also its nature and composition.

A recent strand of literature has linked trade to knowledge spillovers and endogenous growth, indicating that this mechanism could bring about trade benefits much larger than those suggested by conventional theory (Hsu, Riezman, and Wang, 2019). This argument is relevant for income distribution to the extent that heterogeneous workers sort themselves into different activities in such a way that more trade produces effects similar to skills-based technological progress (Grossman and Helpman, 2018).

Our research naturally relates to previous studies, where disaggregated, general equilibrium CGE models have been employed to analyse impacts on poverty and inequality of trade policies (for a survey, see Cockburn, Decaluwé and Robichaud, 2008). However, we depart from the typical comparative-static perspective of these exercises, which essentially entails comparing a baseline equilibrium state with a short-term, counterfactual one where the effects of some (trade) policies are simulated. For instance, Acharya, Hölscher, and Perugini (2012) examined the effects of trade liberalisation on inequality in Nepal. Liyanaarachchi, Naranpanawa, and Bandara (2016) combined CGE and microsimulation modelling for Sri Lanka. Mahadevana, Nugrohob, and Amir (2017) explored the impact of protectionism in the form of import tariffs and export taxes through a dynamic CGE model for Indonesia.

One distinguishing feature of all these exercises is that the overall impact on poverty and inequality is crucially determined by some closure assumptions introduced in the model. For instance, much depends on whether budget neutrality in the public sector is assumed (Mahadevana, Nugrohob, and Amir, *ibid.*), or whether fixed or variable exchange rates are adopted (Acharya, Hölscher and Perugini, *ibid.*).

3. Modelling Strategy

We employed a recursive-dynamic global CGE modelling framework based on the flexible, open-source and open-access platform CGEBox (Britz and van der Mensbrugghe, 2018). Specifically, we based our exercise on the G-RDEM model for the construction of future scenarios and the simulation of structural change (Britz and Roson, 2019, Roson and Britz, 2021), integrated with some elements of the GTAP-E (McDougall and Golub, 2007), GTAP-AGR (Keeney and Hertel, 2005) and GTAP-AEZ (Lee, 2005) models.

The G-RDEM model extends the standard GTAP model (Hertel and Tsigas, 1997) by adding some key drivers of long-term structural change, namely, (1) variations in household consumption patterns, giving rise to non-linear Engel curves; (2) differentiated sectoral productivity growth; (3) debt accumulation generated

by trade imbalances; (4) variable savings rates, influenced by population and income dynamics; and (5) time-varying and income-dependent industrial input–output parameters.⁵

During the baseline construction, real GDP, demography, and workforce projections are provided exogenously, in this case from the SSP2 scenario, at each time step t . The model is solved for a simultaneous equilibrium in all commodity and factor markets, globally, at each period t . As is typical of recursive-dynamic models, net investments from step t update the capital stocks at $t+1$, while savings rates and input–output coefficients are also modified between periods. During the process, sector-specific productivity shifters adjust to obtain the aggregate total factor productivity needed to align the model with the given trajectory of real GDP.

The G-RDEM model, as the standard GTAP model, normally considers only one representative consumer in each country or region. Here, we instead exploited information from a set of household surveys (FAO, 2017) to obtain 12 distinct household categories for the six countries considered. We distinguished among male- and female-headed households, urban and rural, poor (below the poverty level in 2011), middle income (between the poverty level and the mode of income distribution), and rich (the rest).

To model each household category, we needed to define its various sources of income and specific consumption pattern in such a way that the data would be consistent with aggregated factor incomes and consumption in the GTAP SAM. Each household is assumed to own property rights to primary factors (labour, land, capital, natural resources), which are allocated to the different sectors to maximise revenue. The constant elasticity of transformation (CET) function allocates the household-specific endowments of primary resources to the various production activities, which is different from assuming full factor mobility. In addition to factor income (the net of taxation and capital depreciation), households also receive public and private transfers and remittances.

Because of differences in quality, classifications and methods, the integration of household data into the accounting framework of the CGE model is a difficult task.⁶ The number of variables collected in the FAO household national surveys differs due to the specificity and time of the diverse data collection processes. The number of surveyed households also changes across countries. Furthermore, one must consider that a substantial portion of household income in developing countries comes from informal activities, especially among poor rural households.

Households in our model exercise are characterised by (1) their per capita endowments of primary factors; (2) from which sectors they draw factor income; (3) transfers from the government, other households, and abroad; and (4) their consumption bundle. While income per capita and its composition are informed by household surveys, the consumption bundle needs to be estimated. To do so, we relied on the Engel curves underlying the empirically estimated AIDADS demand system in the G-RDEM model.

From the per capita income of the different representative households, we estimated per capita demand based on the Engel curves while ensuring that the reported national totals would be matched. The parameters of each household's demand system were then simultaneously adjusted to match the per capita demand vector of the average aggregate households in each country, as reported in the SAM. The non-linear curves, which might differ from country to country, drive the budget shares of the different households in the dynamic simulation. To capture cross-price effects for closer substitutes, we introduced CES subnests for cereals, meats, and energy carriers. We also estimated savings rates for each household group, such that richer households would spend less on total consumption in relative terms.

⁵ A concise description of the G-RDEM model is provided in Appendix A.

⁶ Data inconsistency between surveys and national accounts is a known issue when coupling the CGE and microsimulation models (van Ruijven et al., 2015).

We updated the endowments of each household between different simulation periods as follows. The supply labour stock follows the national change in population, such that we did not consider changes in labour participation rates. Capital and land endowments follow the national variations in capital and land stocks. Natural resource stocks (services) are assumed to be fixed.

To link households to production sectors, we used information about where wages are earned from the household surveys (and on self-employed earnings), which allowed us to identify income shares by endowment and sector. We assumed sluggish factor mobility through the household-specific CET function. This means that households would allocate their labour, capital, and natural resource endowments according to relative returns in the various production sectors.

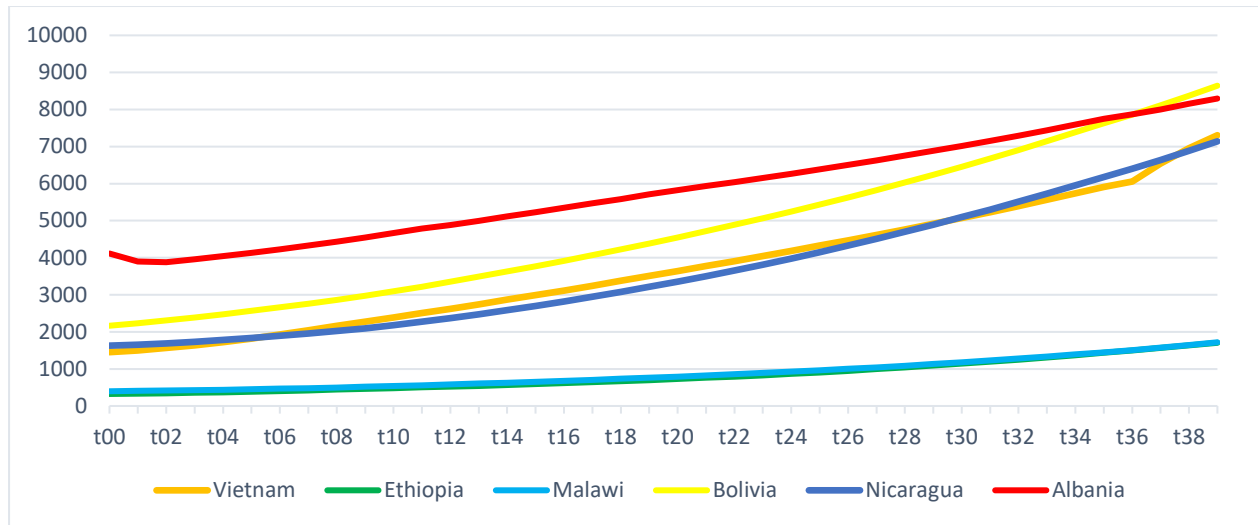
According to van Ruijven et al. (2015), household heterogeneity in CGE models can be modelled based on three aspects: (1) differences in factor endowments; (2) differences in wage rates and/or return rates to capital, possibly linked to labour market participation; and (3) differences in preferences and savings. We fully captured aspects 1 and 3 in our model. We do not have explicitly variable labour participation rates, but average returns on primary resources do differ, as they depend on how the different households allocate their assets across industries. Equally, the household survey informs us about household size (and thus to some degree about the overall available labour), total income, and the share of labour income by sector, which implicitly also captures information on labour participation.

4. Insights from the Baseline Scenario

Before more directly considering the role of trade in poverty and income distribution, it is necessary to scrutinise the implications of the assumed baseline scenario SSP2, which is the intermediate ‘middle of the road’ one in the set of IPCC SSPs. A data repository is maintained at the International Institute for Applied Systems Analysis (IIASA)⁷, containing baseline information for each country and up to the year 2100 about demography, urbanisation rates, education level, and GDP (three estimates generated by different models). From this source, we extracted data about national or regional GDP and demography, which are hence taken here as a given. Our G-RDEM model works as a sort of ‘multiplier of scenario variables’ in the sense that it generates a sequence of global general equilibrium states consistent with information from SSP2, but including details at the level of industrial production, trade flows, and consumption patterns. Furthermore, because of the model’s extension with finer disaggregation for household classes, we could explore the consequences of the chosen baseline in terms of income distribution.

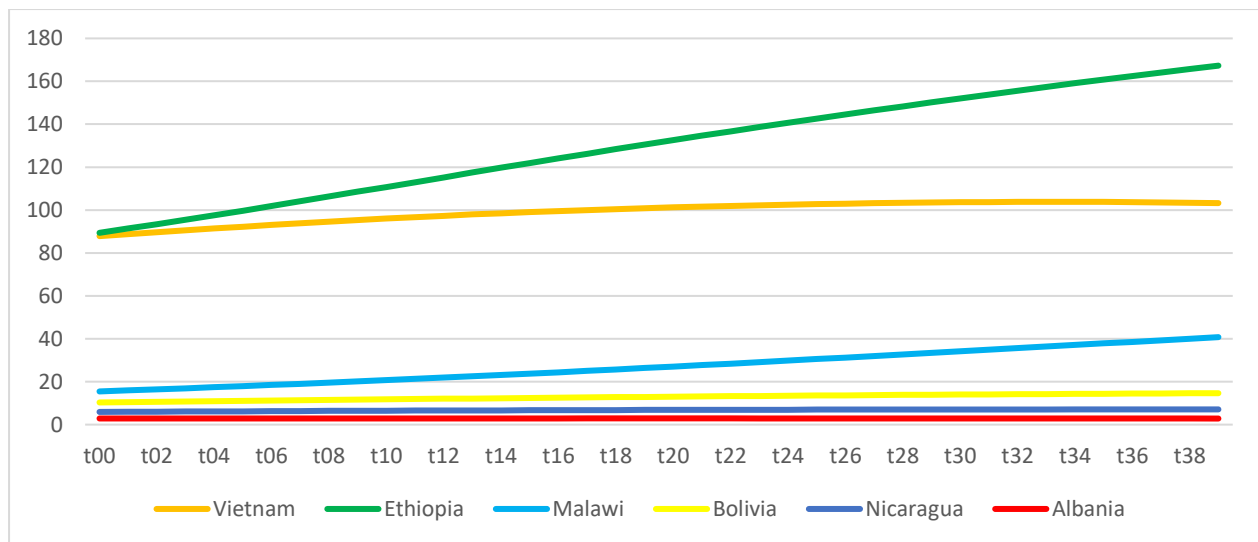
Perhaps the most frequently used metric of economic development is income per capita. Figure 1 shows the exogenously projected evolution of this variable (in real terms, purchasing power at constant 2011 USD) for the six countries considered. Since the starting point is quite different, the figure may mask the underlying hypotheses of growth. The given growth in real income per capita over the whole 2011–2050 period is posited at 134% for Albania, 309% for Bolivia, 480% for Ethiopia, 378% for Malawi, 377% for Nicaragua, and 413% for Vietnam. Thus, Ethiopia and Malawi are moving quickly, but due to their initial handicap, they only marginally catch up.

⁷ <http://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about#v2>

Figure 1. Time profile of per capita real income (constant 2011 USD), from 2011 (t00) to 2050 (t39)

Source: Our own elaboration.

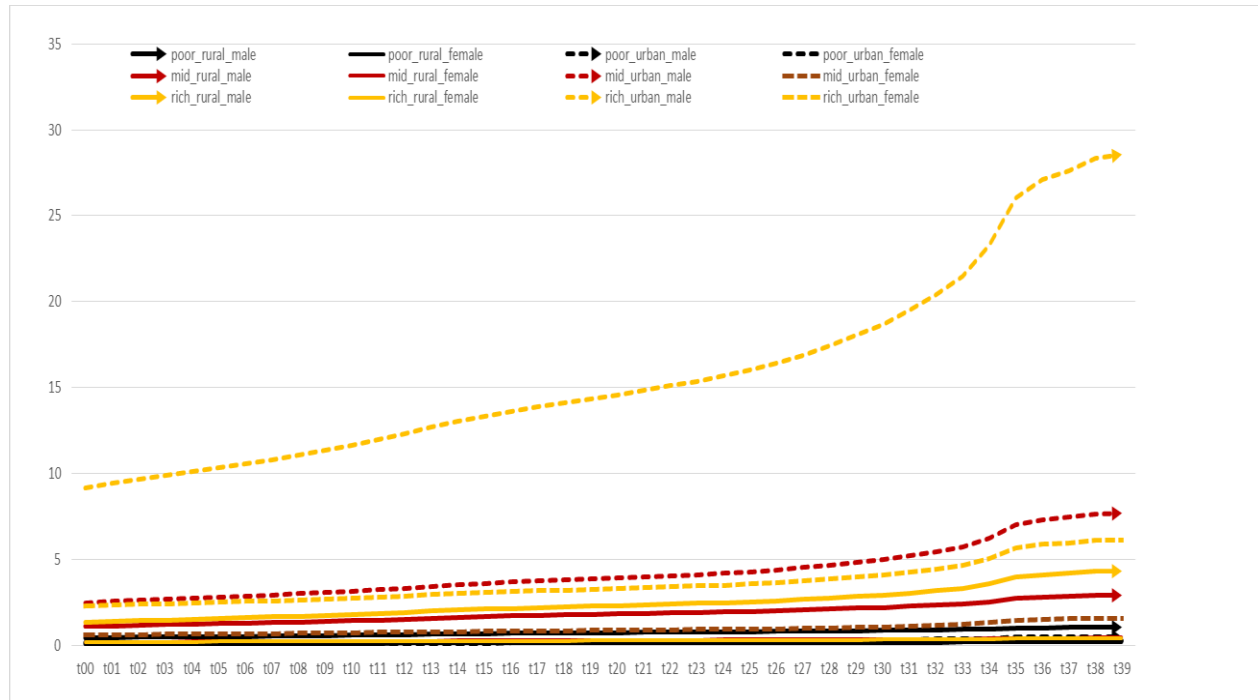
Per capita income or GDP is itself a ratio and is therefore dependent on the combined assumptions of growth in GDP and in population, which are totally exogenous. Figure 2 depicts the assumed growth in population.

Figure 2. Population time profile from 2011 (t00) to 2050 (t39)

Source: Our own elaboration.

The national population is not assumed to grow very much, except for the two African countries. Therefore, the SSP2 scenario is very optimistic about economic growth in Africa (for an alternative view, see Müller, Stock and Watson, 2019), although the per capita effect is curbed by the contemporary increase in the population.

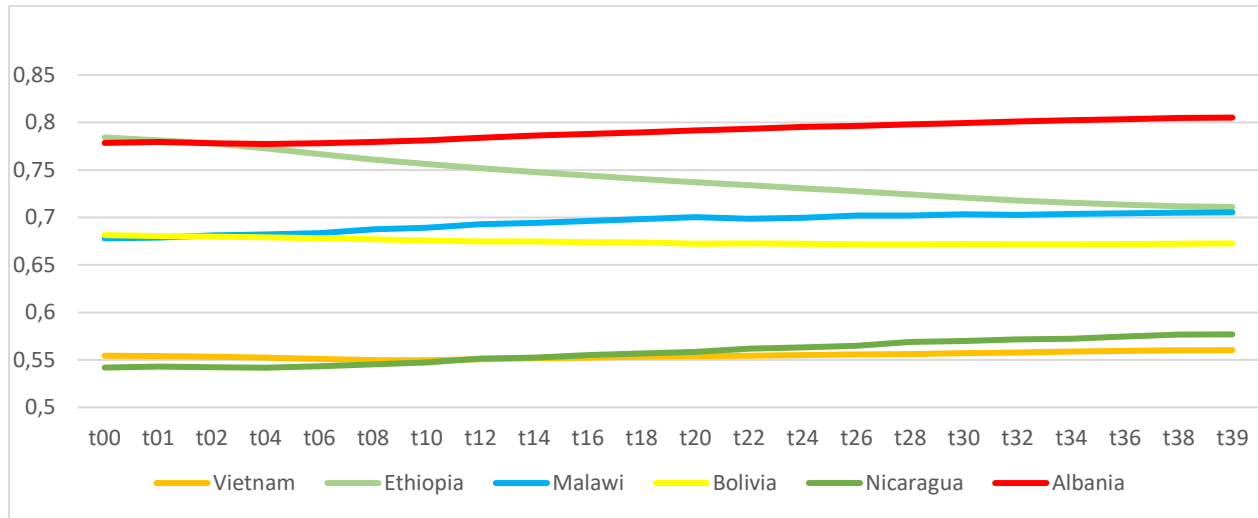
What about income at the level of household category? By way of illustration, Figure 3 displays the evolution of nominal income in Bolivia for the 12 representative households (male/female, urban/rural, poor/mid/rich).

Figure 3. Households' income over time in Bolivia

Source: Our own elaboration.

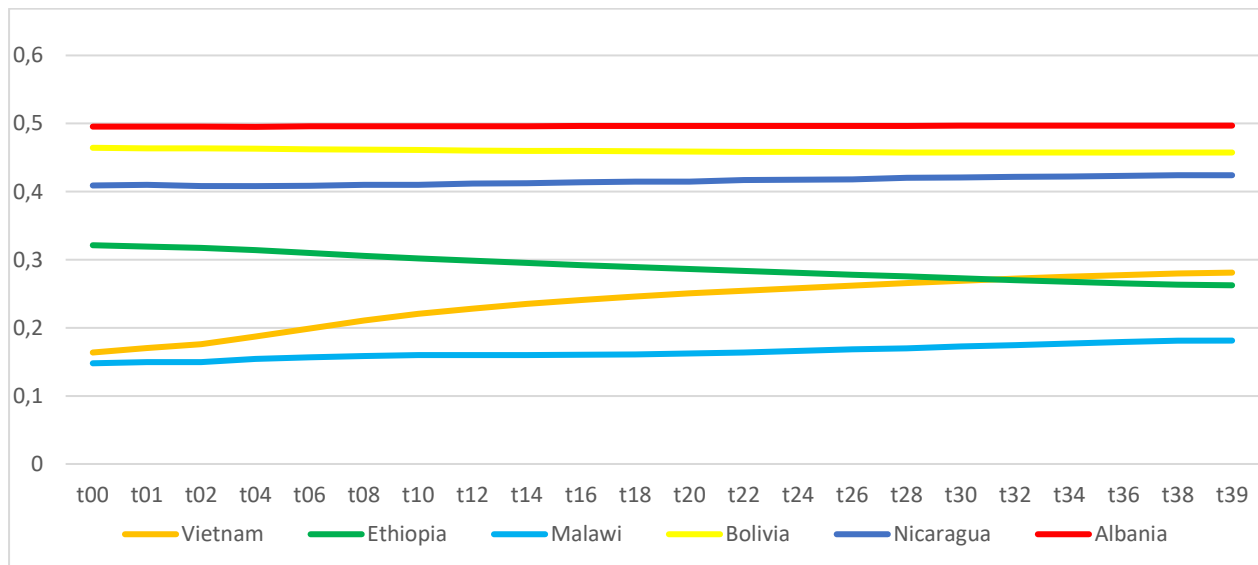
One absolute measure of inequality (the standard deviation of income distribution) increases substantially over time, not only in Bolivia (see Figure A1). However, the evolution of relative inequality (measured here by the Gini index) can be quite different (Figure 4). The Gini index ranges from 0, indicating complete equality (when income is distributed equally across the different household categories), to 1, implying extreme inequality (one category receives all the income). According to this measure, relative income inequality does not vary significantly over time for Bolivia and Vietnam, decreases considerably for Ethiopia, and increases in the other three countries (Albania, Malawi, and Nicaragua). Albania stands out as the country experiencing the largest increase in income inequality, measured this way.⁸

⁸ Of course, others, possibly more informative indices of income inequality could be considered, e.g. the decile dispersion ratio, generalised entropy, or Atkinson's measures (Haughton and Khandker, 2009).

Figure 4. The Gini index of income inequality across different households

Source: Our own elaboration.

We also computed a second Gini index to gauge inequality between two aggregated household types: poor versus non-poor (Figure 5). The main reason behind the differences observable in figures 4 and 5 is related to the fact that (Figure A3) in all countries, income differentials between poor households decrease, while the opposite is observed among non-poor households.

Figure 5. The Gini index of income inequality between poor and non-poor households

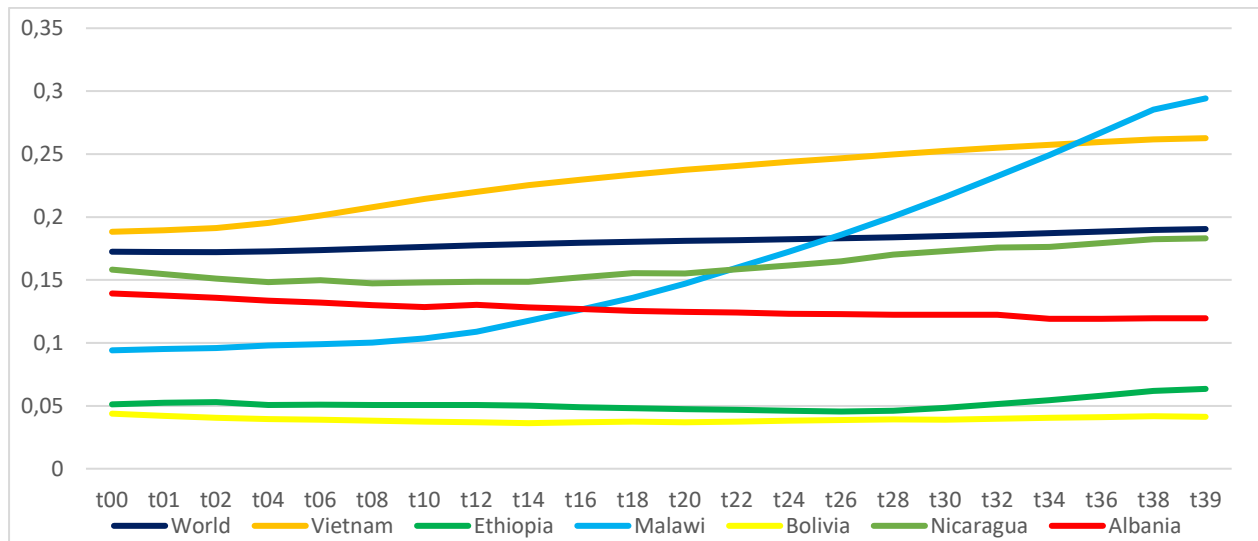
Source: Our own elaboration.

Why did we observe changes in income distribution over time? The answer in our model is quite simple. Households obtain income from the ownership of primary resources: capital, land, labour of different types, and natural resources. Better off households are those that own larger shares of factors where returns grow more. Higher growth for a factor can stem from changes in relative returns, such as when returns to capital grow stronger than wages, or from faster growing general stocks, such as in the case of

capital accumulation. For example, we can imagine that rich households possess large shares of capital and skilled labour. If income from capital and skilled labour grows faster than, say, income from land and unskilled labour, then these households will become relatively richer.

As we shall better understand in the following, this is also related to the bigger volume of trade, which is generated already in the baseline scenario. This is confirmed by Figure 6, which shows how the ratio of imports to GDP increases over time. In other words, the volume of trade would grow faster than GDP.

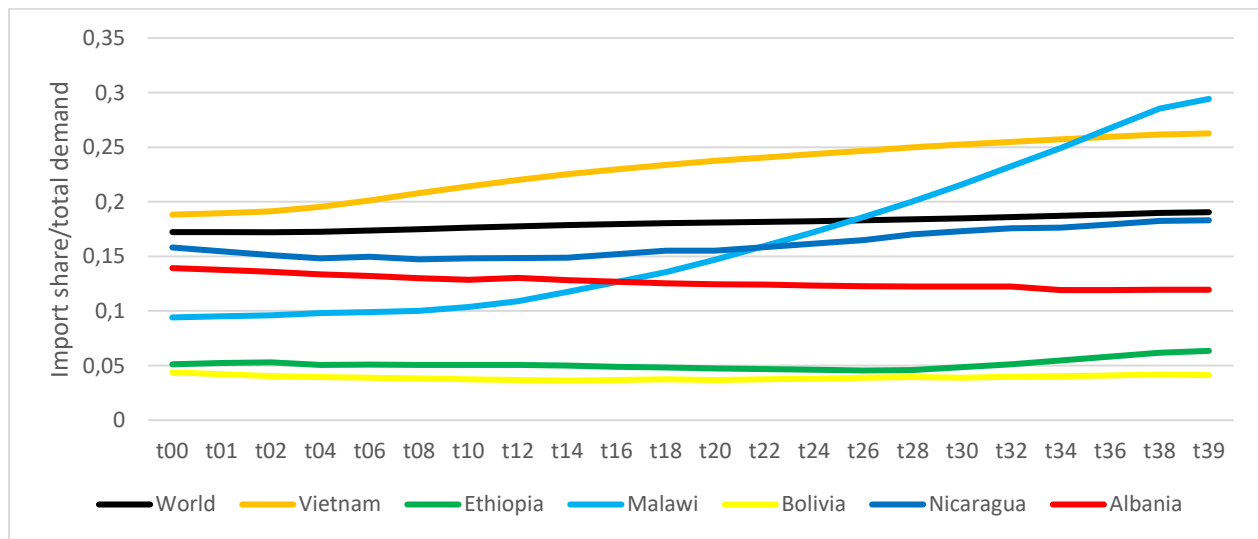
Figure 6. Evolution of the imports/GDP ratio



Source: Our own elaboration.

Let's take a closer look at trade in agricultural products, both because agricultural goods account for the largest share in the consumption basket of the poor, and because this provides us with information about the degree of agricultural self-sufficiency in the six developing countries we are studying. Figure 7 displays the shares of imported grains and crops over total domestic demand for the same commodities.

Figure 7. Shares of imported grains and crops over time



Source: Our own elaboration.

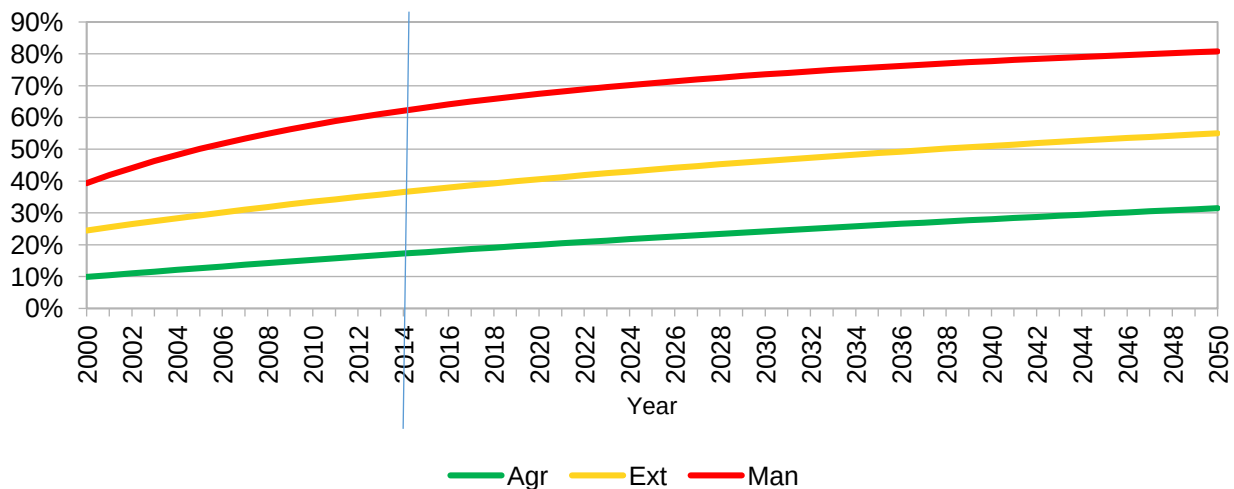
Over time, Malawi becomes more dependent on imports of grains and crops from the rest of the world. Something similar occurs in Vietnam (which is already quite import-dependent in 2011) and, to a lesser extent, in Nicaragua. Bolivia and Ethiopia do not import much, and they will retain low volumes of imports in agricultural products in 2050.

5. An Alternative Scenario of Increased Trade Integration

The global economy has experienced several decades of increased integration. This long-lasting trend can only be partially explained in terms of reduced trade friction (Feenstra, 1998; Brahmabhatt, 1998). Gravitational models of trade have been proven successful in explaining the amount of trade between countries, and they are today the empirical workhorses in applied international economics. Interestingly, Mussa (2000) noted that ‘if trade between two countries tends to rise proportionately with respect to each of their economic sizes and diminish with the distance between them, then the suggestion is that doubling the size of both economies should raise their bilateral trade by a factor of four rather than by a factor of two’. This observation is quite relevant for our modelling exercise, since here, the baseline scenario is driven by exogenous assumptions about GDP growth and therefore about the future size of national economies.

To check whether the globalisation trend is affecting (and to what extent) the six developing countries under consideration, we carried out a preliminary analysis based on recent historical data. First, for the six countries and for three sectors (agriculture, extraction, manufacturing), we built a panel dataset (1995—2013) of import and export shares, combining different data sources. More precisely, we estimated the shares of imports in total domestic consumption and the shares of exports in total domestic production. Subsequently, we performed a non-linear panel regression with random effects to identify a historical trend.⁹ Figures 8 and 9 display the simulated and forecasted evolution of the *average* (over countries) import and export shares. The vertical line divides the periods between historical past and forecasted future.

Figure 8. Simulated average import shares



Source: Our own elaboration.

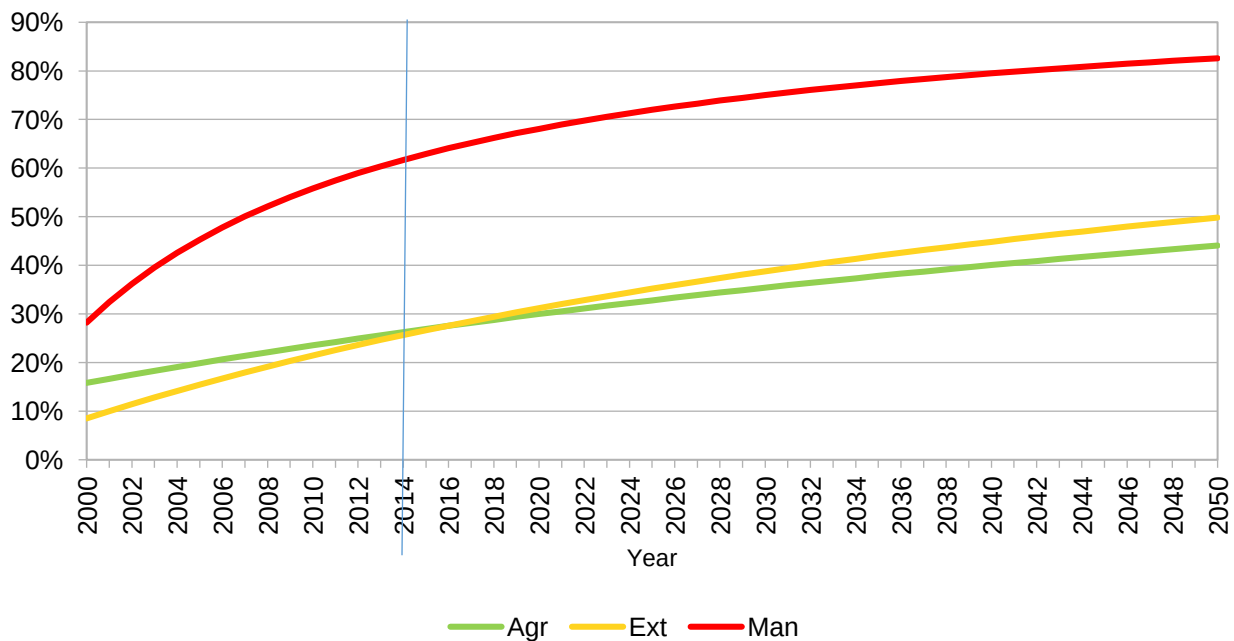
⁹ Details of the exercise are provided in Appendix B.

Our econometric results highlight the existence of a clear trend toward increased trade integration for the six countries, which affects the sectors in a rather different way. Higher trade integration mostly involves the manufacturing sector, whereas the agricultural sector is comparatively less affected. Because of the paucity of data, we could not obtain more sectoral detail. Additionally, and despite the use of random error effects (which partially capture country- and time-specific idiosyncratic shocks), we could not single out the potential factors influencing the trend, such as reduced friction, changing preferences, and the variety or quality effects.

Given the limited time span considered, the high level of aggregation, and the low quality of the data employed in our econometric experiment, this study is only intended to highlight a broad tendency in the countries under investigation; for this reason, we did not force our dynamic CGE model to produce results fully consistent with the econometric projections. Rather, we were interested in assessing under what conditions (i.e. based on what parameter variations) the model generates an evolution in import and export shares akin to the one observed in figures 7 and 8.

To this end, we first carried out a conventional simulation of trade liberalisation by halving all import tariffs in all industries around the world in the period of 2011–2050. The effect on trade shares is minimal. This is likely due to the already rather low initial level of tariffs, especially for manufactured goods.

Figure 9. Simulated average export shares



Source: Our own elaboration.

We looked for some alternative factors, possibly driving the trend of increased globalisation and trade openness. Modern international trade theories suggest that more exchanges with the rest of the world make more goods, at higher quality, available to consumers and firms. This could be interpreted as an increase in the productivity of the bundle of traded goods and services in the sense that more utility or output is obtained from a physically equivalent aggregate of exchanged items.

To simulate this effect in our model, we considered the CES demand layer, steering the choice in demand between imports and domestic products, which has the following structure:

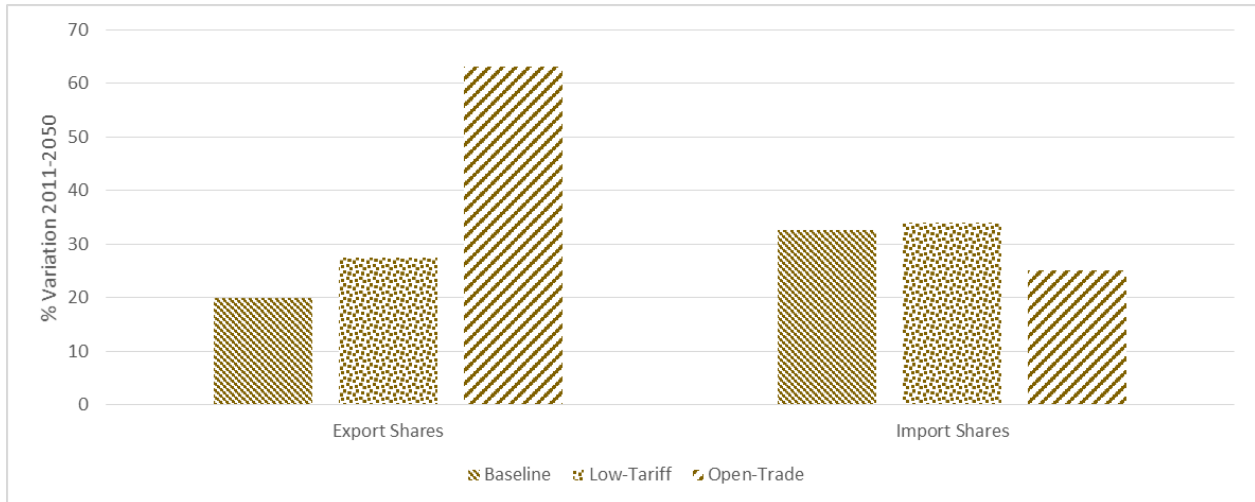
$$\frac{\lambda M}{D} = \alpha \left(\frac{\lambda P_D}{P_M} \right)^\sigma \quad (1)$$

where M represents imports, D denotes domestic products in the same industry, σ is the elasticity of substitution, P refers to price indices, and the remaining symbols are parameters. The parameter λ , initially set to 1, expresses the relative productivity/quality of imports over domestic products, such that λM expresses imports in efficiency units. When the model is calibrated at the initial year, prices are normalised to 1; therefore, the value assigned to the structural parameter α depicts the share of imports in total demand.

When λ rises, two opposing effects occur. First, there is a direct productivity effect by which one needs to import lower quantities to obtain the same utility level. Second, there is a substitution effect because imports become more convenient, which is equivalent to a reduction in the price index P_M . It is straightforward to show that the substitution effect prevails over the direct productivity effect if the elasticity of substitution is larger than 1 (as is the case in our model).

Consequently, one way to generate larger import shares (and export shares, since imports by one country correspond to exports by other countries) is to set higher values for the parameter λ in the model. Figure 10 presents the total export and import shares for the whole set of six countries in the three cases: baseline, trade liberalisation through lower tariffs (low tariff), and higher productivity/quality (open trade).

Figure 10. Trade shares in three different scenarios



Source: Our own elaboration.

Lower tariffs do not vary the shares much, whereas the higher productivity of globally traded goods boosts exports but also shrinks import shares. This seeming contradiction can be explained by the fact that the model generates, under the open trade scenario, a real devaluation of the currencies (on average) in the six countries. Indeed, whereas the balance of trade for the six countries turns out to be negative by the year 2050 at baseline (-469 M USD) and in low tariff (-397 USD) states, it becomes a surplus when trade productivity is increased (+258 USD). This devaluation makes imported goods less convenient, counteracting the substitution effect associated with the greater relative productivity of imports.

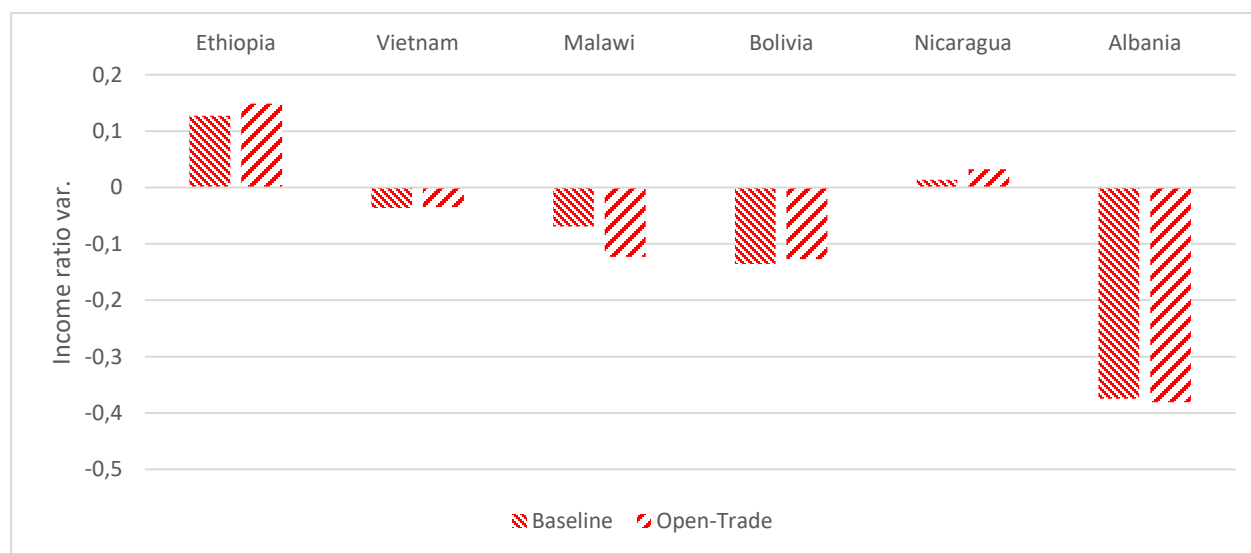
Nonetheless, we can conclude that, net of the endogenous devaluation mechanism, the scenario based on higher values for the productivity parameter λ , succeeds in simulating an increase in the degree of trade openness. For this reason, we adopted it as a contrasting case with respect to the baseline, mainly

to investigate the implications of such an accelerated globalisation scenario on income distribution and poverty.

We started by considering the variation in relative income with regard to the initial year separately for female- versus male-headed households, rural versus urban households, and poor versus non-poor households. Thus, a negative variation should be interpreted as worsening income inequality in the corresponding dimension.

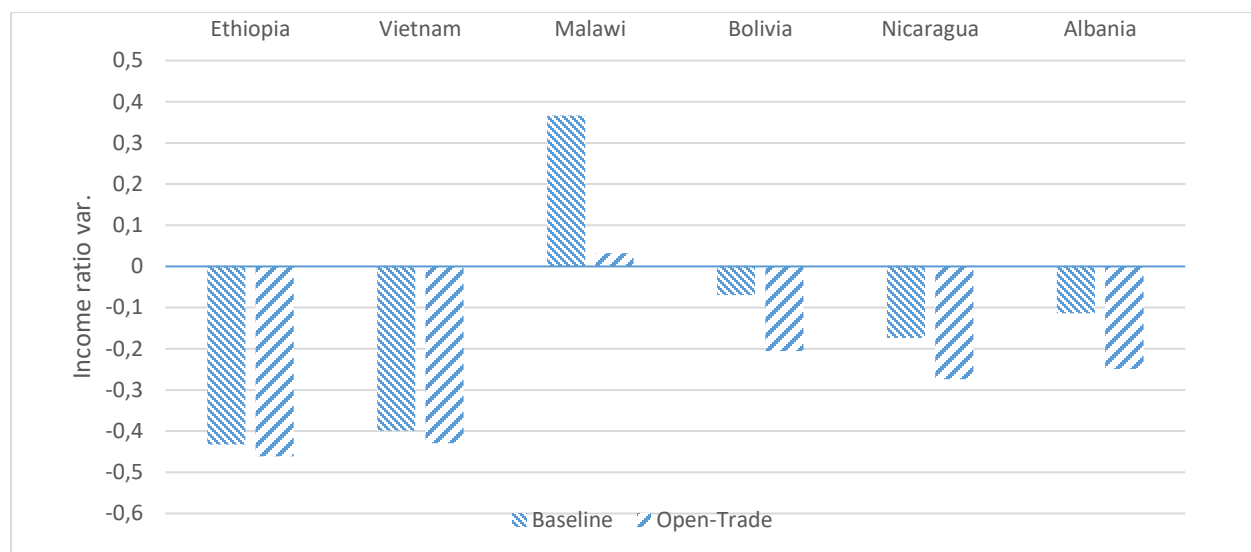
Figure 11 traces the evolution of inequality between male- and female-headed households in the six countries. Much of the income gap is already generated in the baseline, most notably in Albania and, to a lesser extent, in Malawi and Bolivia, whereas Ethiopia goes in the opposite direction. More trade does not add very much to the picture, exacerbating inequality in Malawi but improving it somewhat in Bolivia, Nicaragua, and Ethiopia.

Figure 11. Variations (2011–2050) in relative income (male/female)



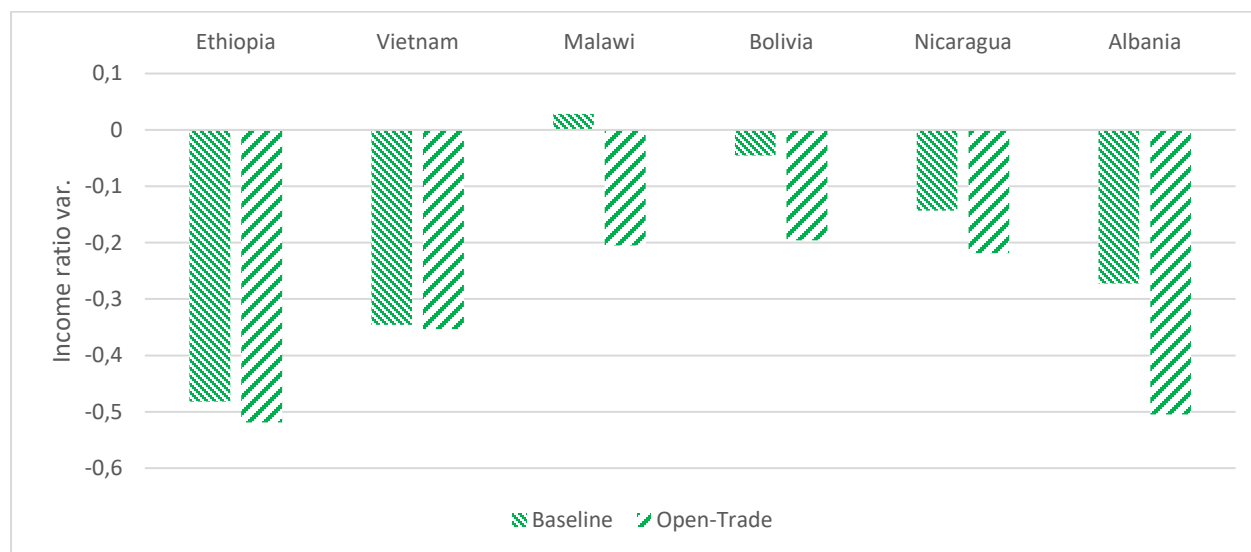
Source: Our own elaboration.

Figure 12 presents a similar kind of analysis, but this time considering the relative income of rural and urban households. We can see a very different picture here. First, inequality does not vary in the same direction in all countries at baseline. Rural/urban income inequality is narrowed (in the sense that rural income accrues more than urban income) in Malawi but widened in all other countries. Accelerated trade integration does make a difference here, clearly worsening income inequality with regard to the baseline, most notably in Malawi, Bolivia, Nicaragua, and Albania.

Figure 12. Variations (2011–2050) in relative income (rural/urban)

Source: Our own elaboration.

Finally, Figure 13 considers income differentials in terms of relative poverty (relative income: poor/non-poor). The growth paths embedded in the baseline are generally characterised by the exacerbation of relative poverty, which is especially evident in Ethiopia, Vietnam, Nicaragua, and Albania. More international trade further worsens relative poverty, especially in Malawi, Bolivia, and Albania.

Figure 13. Variations (2011–2050) in relative income (poor/non-poor)

Source: Our own elaboration.

6. Analysing the results in terms of absolute and relative poverty

We now consider the main determinants of changes in relative poverty, expressed as percentage variations in ratio I of the incomes of the poor (I_p) and non-poor (I_n) household groups. We focused on the

factor of income only, which is income derived from the ownership of primary factors, neglecting other elements such as taxes or transfers.¹⁰ Using lowercase letters to indicate percentage variations (approximately, changes in logarithms), then:

$$r = i_P - i_N \quad (2)$$

We can further break down the change in income by source (land L , capital K , unskilled labour U , skilled labour S , natural resources R) as follows:

$$i_P = S_P^L i_P^L + S_P^K i_P^K + S_P^U i_P^U + S_P^S i_P^S + S_P^R i_P^R \quad (3)$$

$$i_N = S_N^L i_N^L + S_N^K i_N^K + S_N^U i_N^U + S_N^S i_N^S + S_N^R i_N^R \quad (4)$$

where S denotes the shares of each source in the total factor income of the household category.

Plugging (3) and (4) into (2), and grouping:

$$\begin{aligned} r &= i_P - i_N = \\ &= (S_P^L i_P^L - S_N^L i_N^L) + (S_P^K i_P^K - S_N^K i_N^K) + (S_P^U i_P^U - S_N^U i_N^U) + (S_P^S i_P^S - S_N^S i_N^S) + (S_P^R i_P^R - S_N^R i_N^R) \end{aligned} \quad (5)$$

As such, the components in parentheses express the contribution of diverse sources of income to the overall variation in relative poverty.

To better appreciate the decomposition above, consider that the percentage variations in income by source are *approximately* the same for the two groups. This is because income is the product of factor quantity and price. In our model, ownership shares are given so that group-specific factor endowments move proportionally. On the other hand, prices are price indices because they depend on how households allocate their resources among the different sectors. Without a major reallocation of resources, however, the two price indices will be characterised by variations of comparable magnitude.

This implies that the contribution of a specific source to relative poverty is driven by two elements: (a) the (similar) variation in source income and (b) the difference in shares S . For example, if land income rises significantly and/or poor households obtain most of their income from land ownership, then land would contribute to narrowing the relative poverty differential.

In Table 1 below, we summarise the main findings of the relative poverty impact decomposition for all six countries using the methodology described above. More detailed regional outcomes are presented in Appendix C. We consider two variations in the relative income of the poor: the change in the baseline (2011–2050) and the change in 2050 between the two scenarios (baseline and open trade). Hence, the first variation refers to the assumptions employed for long-term growth, whereas the second one gauges the incremental effect of accelerated trade integration. Alongside both variations, we identified the most important factor in terms of impact on the relative income of poor households, which is the one having the largest change in absolute value.

¹⁰ These other elements are considered in Figure 13.

Table 1. Analysis of changes in the relative income of poor households

	Var. 2011–2050 BL	Most imp. factor	Var. 2050 OT-BL	Most imp. factor
Albania	-10%	Capital (-7%)	-45%	Land (-25%)
Bolivia	-15%	Capital (-14%)	-8%	Land (-11%)
Ethiopia	-32%	Capital (-36%)	+9%	Capital (+7%)
Malawi	9%	Land (+25%)	-13%	Land (-21%)
Nicaragua	-12%	Capital (-20%)	-3%	Land (-6%)
Vietnam	-53%	Capital (-55%)	+18%	Capital (+23%)

Source: Our own elaboration. BL: Baseline, OT: Higher trade openness scenario

A quick inspection of Table 1 reveals some interesting points. First, our growth baseline scenario generally exacerbates relative poverty (except in Malawi). This effect is generally driven by increases in capital income, which is an important source for non-poor households. Second, higher international trade generally worsens relative poverty (except in Vietnam and Ethiopia). This time, the key driver is land because higher trade openness tends to reduce the value of land, which is a very important asset for poor households (e.g. Mallick, 2014).

We now turn to analysing the findings in terms of absolute poverty, which in the FAO household surveys is defined as the daily average expenditure below the threshold level of 1.9 USD in the reference initial year. The incidence of absolute poverty is especially relevant in the two African countries (Ethiopia: 82.5%, Malawi: 70.8%), but also in Vietnam (54.1%).

To estimate absolute poverty levels for the year 2050 in the baseline scenario, we obtained the regional variations from the model in income by source, already employed for the assessment of relative poverty. These variations have been divided by the corresponding GDP deflator to convert income in 2050 to equivalent purchasing power in 2011. Using household data, which inform us about the income structure of each unit, we were therefore able to roughly estimate what household income would be in the final year 2050, expressed in terms of 2011 USD, which makes it comparable with the conventional poverty line. This kind of elaboration could be considered the implementation of a simple accounting or ‘non-behavioural’ microsimulation framework (van Ruijven et al., 2015).

Table 2 presents the share of households below the absolute poverty threshold in 2011 and 2050. The key insight from Table 2 is that absolute poverty would be eradicated in all countries except Malawi.¹¹ Combining these findings with those summarised in Table 1, we can conclude that our scenario implies a substantial improvement of average living conditions, associated with more inequality in the six countries.

¹¹ We do not regard the outcome of Albania as very reliable. There is no reported information in the FAO survey for poor Albanian households (only 12 units) in terms of capital and unskilled labour income (see Table C1). Factor income is seemingly obtained in equal proportion from land and skilled labour, which explains the figures in Table 2.

Table 2. Share of households below the absolute poverty threshold

	% HH poverty 2011	% HH poverty 2050
Albania	0.86	7.86
Bolivia	11.89	0.00
Ethiopia	82.49	1.64
Malawi	70.77	10.01
Nicaragua	20.33	0.00
Vietnam	54.07	0.00

Source: Our own elaboration.

7. Concluding remarks

The SSPs provide a reference for medium- to long-term scenarios of economic development and are extensively employed in integrated assessment models of climate change, as well as in other fields. They are based on narratives and quantitatively expressed through a limited set of macroeconomic variables. To overcome informational limits, a new generation of multiregional recursive-dynamic CGE models, specifically designed to capture long-term structural changes in economic systems, is now being developed and used to obtain a more detailed picture of the global economy in the distant—albeit hypothetical—future.

In this paper, we showed how a dynamic CGE model of this type could be employed for this purpose, coupled here with household micro data, to obtain more information about income inequality in different dimensions for six developing countries. To the best of our knowledge, this is the very first exercise of this kind. Indeed, whereas we focused on the long-term future, econometric-based analyses in the literature, dealing with growth–trade–inequality–poverty, are based on past data. On the other hand, CGE models, sometimes coupled with microsimulations, deal with short-term impacts.

Understanding the possible evolution of income inequality associated with a given SSP scenario is very important from a practical angle. A robust finding in climate economics is that global warming will exacerbate inequality within and between nations (Islam and Winkel, 2017; King and Harrington, 2018). Adaptation and mitigation policies critically rely on distributional considerations and conditions (Rao et al., 2017; Taconet, Méjean and Guivarch, 2020). Elaborating policies based on some reference scenarios, but without knowing what those scenarios entail in terms of inequality, may render the policies ineffective, inappropriate, or politically unacceptable.

We confirm the finding that structural change, as simulated in our model, has direct consequences for the distribution of income. For instance, as the share of services in intermediate and final consumption increases and productivity in the production of services improves at a slower rate than in other sectors, the relative price of services is bound to rise.¹² As a result, even the price of primary factors for which the services are intensive (e.g. skilled labour) will follow the same path. Income distribution would then also

¹² This is known as Baumol's cost disease. See, e.g. Hartwig and Krämer (2019).

vary because of the diverse ownership shares of primary factors ascribed to the various population groups (Mallick, 2014.).

There is a vast amount of literature dealing, on the one hand, with the link between inequality and growth, and on the other with the connection between growth and structural change. Surprisingly, very few studies have directly approached the relationship between structural change and income distribution or poverty, as we have done in this paper, and none, to our knowledge, have referred to future scenarios. Cook and Uchida (2008) came to some conclusions, confirming the key findings of our modelling exercise, even though their study and ours are rooted in completely different methodologies and approaches. They noted that industries with the highest impact on growth (such as high tech) have the greatest potential for exacerbating income distribution in developing countries. However, income inequality effects could be offset if the growth effects are large enough and therefore help to reduce poverty by raising average incomes.

A distinguishing feature of our exercise is the disaggregation of final consumption demand in 12 distinct household classes, thereby departing from the standard CGE setting, having a single representative consumer. Multiple household CGE models for the assessment of poverty and income distribution do exist (Cogneau and Robilliard, 2000; Cockburn, 2006; Cockburn, Decaluwé and Robichaud, 2008), but more often, a macro CGE model and a microsimulation household model are kept separate and soft-linked (Ahmed and Cathal, 2007).

Furthermore, almost all studies of this type have a comparative static nature. This is because the typical research question addresses the impact on the distribution of income of some fiscal reform or some change in international prices (e.g. Dartanto and Usman, 2011). There are only a few dynamic CGE models with multiple households (e.g. Annabi et al., 2005; for a review see van Ruijven, 2015). However, contrary to our G-RDEM model, the typical dynamic CGE model does not account for long-term structural adjustment processes.

When reconciling data from the SAM used to calibrate our CGE model and data from household surveys in the six countries, we decided to give preponderance to the SAM (to keep all accounting balances), whereas information from the surveys was only employed to infer a set of disaggregation weights. More generally, we were unable to model interhousehold dynamics, such as rural households migrating to the city, thereby moving from one group to another. We acknowledge that this is a limitation in our model, which could possibly be overcome in the future when more data will hopefully allow for introducing specific behavioural assumptions. Equally, we could not address dynamics in household size.

Aizenman, Lee, and Park (2012) identified five time-varying channels that influence the relationship between structural change and inequality: (1) economic incentives; (2) technological changes; (3) capital accumulation; (4) social changes; and (5) political changes. Our empirical exercise, constrained by data and the availability of modelling tools, only partially addresses the first three aspects. On the other hand, it does account for various drivers of structural adjustment in the economic system, considering their implications for income distribution for the very first time.

Keeping these caveats in mind, we believe that the insights obtained by our modelling exercise are sufficiently robust. We have found that long-term structural change generally widens income inequality in all six developing countries. Accelerated trade integration amplifies the effect further, but most of it is already generated in the baseline scenario. A decrease in the relative value of land property and an increase in the relative value of capital ownership appear to be key determinants.

We have divided the income differentials into three dimensions. Structural change worsens the income gap between male- and female-headed households, especially in Albania, but the additional impact of trade is minimal. The effect of structural change is not uniform across countries when the income of rural households is contrasted with that of urban households, yet more trade reduces relative rural income. Relative poverty increases in both the baseline and the larger trade volume case. However, we found that absolute poverty would be eradicated in almost all countries by 2050.

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Appendix A: A Concise description of the G-RDEM model

G-RDEM is a computable general equilibrium model, designed for the construction of internally consistent and sufficiently detailed scenarios of long-run economic development (Britz and Roson, 2019). The model is a recursive dynamic extension of the GTAP standard comparative static model, with the inclusion of five distinguishing features, meant to capture some key adjustment processes in the long run.

The structure of the GTAP model is fully described in Hertel and Tsigas (1997), although some minor changes have been introduced recently (Itakura and Hertel, 2001; Corong et al., 2017). Most basic assumptions in the model are canonical for a general equilibrium setting: industries are modeled through representative, cost-minimizing firms with constant returns to scale and zero profits; households maximize utility under a budget constraint; revenues are obtained by selling services of primary factors; all macroeconomic identities hold, etc.

Some other assumptions are less common, in particular:

- Utility of the representative household is implicitly defined as a Constant Differences in Elasticity (CDE) function (Hanoch, 1975). This function allows for (rather limited) differences in income elasticities among consumed goods and services.
- Aggregate savings are a constant share of national income. Savings are virtually collected by a global bank and redistributed as physical investments, without the need to match national savings to investments, therefore to have the trade balance in equilibrium.
- Trade and transport margins in international commerce are handled similarly, by means of virtual global transport and trade agents.

Although a dynamic variant of the GTAP model does exist (Ianchovichina and Walmsley, 2012), the simplest way of making the model dynamic is by framing it as a chain of temporal general equilibria. This can be simply done by making the (exogenous) capital stock at time t dependent on (endogenous) investments at time $t-1$. When there is no intertemporal optimization, this approach is often termed “recursive dynamics”. In general, that extension alone will not generate a realistic path of economic growth.¹³ This is why the usual methodology for the calibration of this kind of models entails the generation of a “baseline” path, obtained by imposing GDP levels at each period (obtained, e.g., by a macroeconometric model or by a given scenario), while making endogenous some factor productivity parameter. Counterfactual simulations are then obtained by setting the resulting productivity parameter back to exogenous, while over-imposing shocks, possibly time-dependent, to other parameters. This means that the model dynamics is partly endogenous (capital accumulation) and partly exogenous (productivity growth).

G-RDEM introduces five additional features into the recursive system:

1. The GTAP CDE utility function is replaced by an AIDADS demand system.¹⁴ The AIDADS is An Implicit, Directly Additive Demand System (Rimmer and Powell, 1992). It can be understood as a generalization of a Linear Expenditure System, where marginal budget shares are not fixed, but are a combination of two vectors, depicting the budget structure at very low and very high utility (income) levels. The reason for replacing CDE with AIDADS is that the latter can account for more effects driven by differences in income elasticity, which is important when variations in per-capita income are large, as it is typically the case in the long run.

¹³ There are several reasons for this. One reason, for example, is the assumption of exactly one year lag for the transformation of investments in fresh new capital, which may not hold in the real world.

¹⁴ The parameters of the demand system has been estimated in a cross-sectional analysis by, based on global data by the International Comparison Network (ICP).

2. Total factor productivity is allowed not to vary uniformly among industries and sectors. Indeed, differential productivity growth is one key factor of structural change in the economic systems, and probably the most important one (Swiecki, 2017). In G-RDEM, a function of the GDP growth rate is used, expressing the variation of productivity in Agriculture and Manufacturing relative to the one in the Services. The latter is endogenously computed during the generation of the baseline dynamic path, to get consistency with the imposed trajectory of growth.
3. The national, aggregate saving rate (marginal propensity to save out of the national income) can change over time, mainly as a consequence of variations in the demographic structure. The saving rate is expressed as a function of: (a) Population composition by age group; (b) per capita GDP growth and its growth. Parameters for this relationship have been estimated through a cross-section econometric regression.
4. Interest payments on cumulated past foreign debt are considered in the model. To this end, an equation is introduced, which computes the debt stock.¹⁵ The given interest payments on the stock of foreign debt enter the equation defining the regional income, in addition to the factor and tax income. They are positive for a country which was in the past a lender and negative for past debtors.
5. Parameters of the production function, applied to the representative firm in each regional industry, are calibrated on the observed cost structures of the base year SAM, but in G-RDEM they are allowed to vary. This is because, as the economy grows, the average industrial cost structure may vary even if the production technologies for individual goods stay the same. The relevance of the composition effect is a purely empirical question, which is addressed in the model by checking for the existence of a relationship between cost shares and an index of per-capita income¹⁶. It is found that, out of the 65 input-output coefficients with a cost share of at least 1%, more than 40 turn out to have a highly significant relation with per capita income. The estimates have therefore been introduced in G-RDEM as functions, updating input-output coefficients (parameters of the industrial production functions), from one time period to the next.

¹⁵ This is usually assumed to be zero in the starting year.

¹⁶ Economies are not closed in our system. Therefore, the index was built through trade weighted aggregation of per-capita incomes.

Appendix B: A panel estimation of trade shares evolution

Estimates of gross industrial production are not regularly produced by national accounts agencies. We therefore built our own estimates, starting with sectoral value added data obtained from the UNData search engine (<https://data.un.org/>). Value added is available for seven industries in the period 1995-2013 and for the seven developing countries under consideration. However, data on international trade is accessible for only three of them: Agriculture, hunting, forestry, fishing (ISIC A-B, termed Agriculture in the following); Mining, Manufacturing, Utilities (ISIC C-E, termed Extraction in the following); Manufacturing (ISIC D).

We employed data from the GTAP9A data base (<http://gtap.org>), to get two different pieces of information. First, time series of export and import flows, by sector and country. Second, from the global Social Accounting Matrix of the year 2004 (central year in our time window), we obtained the ratio between gross output and value added. We made the (strong) assumption that this ratio stays approximately constant along the period 1995-2013, so that we could convert value added to production volumes.

Table B1. Output/VA ratios

	Albania	Bolivia	Ethiopia	Malawi	Nicaragua	Vietnam
Agriculture	2.17	2.65	1.39	2.06	2.20	2.32
Extraction	2.13	2.74	3.33	3.12	5.63	2.29
Manufacturing	3.04	3.98	10.22	3.64	3.00	5.69

Table B1 shows the ratios used for the conversion. The lower the value, the lower the employment of intermediate factors in the production processes. You can notice that Ethiopia stands out as an outlier, which casts some doubts about the quality of data for this country.

The difference between gross output and export gives domestic absorption of national products. The ratio between imports and the sum of imports and absorption (total internal demand) provides the share of demand, which is satisfied through imports. Conversely, the ratio of export over gross production right away informs about the share of production, which is directed abroad. In a scenario of increased international trade integration, we expect that both import and export shares increase over time.

To identify a trend component in the evolution of import and export shares, we ran a panel regression with random effects, using the plm package of the R software. Since shares s are constrained to stay within the $[0,1]$ interval, the regression is performed in terms of the transformed variables $s/(1-s)$, whose domain is $[0, \text{infinity}]$. More precisely, the estimated model is:

$$\frac{s_{c,t}}{1-s_{c,t}} = \alpha + \beta(t - 1995) + u_c + v_t + e_{c,t}$$

Where s are import or export shares of country c in year t , and u , v , e are random variables. Table B2 below presents the estimated values for the α and β coefficients.

Table B2. Estimated coefficients

Shares	α	β
Agriculture, imports	.07530	.00655
Extraction, imports	.2335	.0185
Manufacturing, imports	.2943	.0711
Agriculture, exports	.1277	.0122
Extraction, exports	.00295	.01755
Manufacturing, exports	-.0424	.087

Appendix C: Regional relative poverty impact analysis

Table C1. Income structure poor/non-poor in Albania

	Poor	Non-Poor	Diff.
Factor Income - Land	12.5%	3.3%	9.2%
Factor Income - Capital	0.0%	27.1%	-27.1%
Factor Income - UnSk Labor	0.0%	5.6%	-5.6%
Factor Income - Skill Labor	12.5%	23.5%	-11.0%
Factor Income - Nat.Res.	0.0%	1.3%	-1.3%
Direct taxes	-0.1%	-7.1%	7.0%
Remittances received	6.1%	1.3%	4.8%
Remittances sent	-0.1%	-0.3%	0.2%
Govern transfers	56.4%	33.9%	22.5%
Private transfers	12.7%	11.5%	1.2%
Total	100.0%	100.0%	0.0%

Table C2. Income structure poor/non-poor in Bolivia

	Poor	Non-Poor	Diff.
Factor Income - Land	22.9%	3.4%	19.5%
Factor Income - Capital	34.3%	33.2%	1.1%
Factor Income - UnSk Labor	4.9%	13.2%	-8.3%
Factor Income - Skill Labor	50.7%	37.9%	12.8%
Factor Income - Nat.Res.	3.3%	3.9%	-0.6%
Direct taxes	-0.4%	-1.3%	0.9%
Remittances received	0.9%	2.3%	-1.4%
Remittances sent	-1.4%	-1.2%	-0.2%
Govern transfers	0.0%	7.3%	-7.3%
Private transfers	-15.3%	1.4%	-16.7%
Total	100.0%	100.0%	0.0%

Table C3. Income structure poor/non-poor in Ethiopia

	Poor	Non-Poor	Diff.
Factor Income - Land	7.4%	4.5%	2.9%
Factor Income - Capital	40.4%	52.9%	-12.5%
Factor Income - UnSk Labor	11.2%	18.5%	-7.3%
Factor Income - Skill Labor	56.0%	45.2%	10.8%
Factor Income - Nat.Res.	0.8%	0.9%	-0.1%
Direct taxes	-1.6%	-0.5%	-1.1%
Remittances received	0.1%	0.2%	-0.1%
Remittances sent	-0.3%	-0.3%	0.0%
Govern transfers	2.1%	0.5%	1.6%
Private transfers	-16.2%	-22.4%	6.2%
Total	100.0%	100.0%	0.0%

Table C4. Income structure poor/non-poor in Malawi

	Poor	Non-Poor	Diff.
Factor Income - Land	8.6%	3.9%	4.7%
Factor Income - Capital	27.6%	34.5%	-6.9%
Factor Income - UnSk Labor	7.4%	12.7%	-5.3%
Factor Income - Skill Labor	47.3%	47.6%	-0.3%
Factor Income - Nat.Res.	1.8%	3.6%	-1.8%
Direct taxes	-8.7%	-4.0%	-4.7%
Remittances received	1.7%	1.7%	0.0%
Remittances sent	-0.5%	-0.5%	0.0%
Govern transfers	3.9%	1.8%	2.1%
Private transfers	10.9%	-1.2%	12.1%
Total	100.0%	100.0%	0.0%

Table C5. Income structure poor/non-poor in Nicaragua

	Poor	Non-Poor	Diff.
Factor Income - Land	14.9%	4.8%	10.1%
Factor Income - Capital	24.3%	31.9%	-7.6%
Factor Income - UnSk Labor	5.4%	16.1%	-10.7%
Factor Income - Skill Labor	46.0%	35.6%	10.4%
Factor Income - Nat.Res.	0.0%	0.6%	-0.6%
Direct taxes	-0.1%	0.0%	-0.1%
Remittances received	0.0%	0.1%	-0.1%
Remittances sent	-1.0%	-0.9%	-0.1%
Govern transfers	4.8%	9.4%	-4.6%
Private transfers	5.8%	2.3%	3.5%
Total	100.0%	100.0%	0.0%

Table C6. Income structure poor/non-poor in Vietnam

	Poor	Non-Poor	Diff.
Factor Income - Land	14.3%	4.9%	9.5%
Factor Income - Capital	12.6%	28.7%	-16.0%
Factor Income - UnSk Labor	2.8%	7.8%	-5.0%
Factor Income - Skill Labor	30.6%	39.8%	-9.2%
Factor Income - Nat.Res.	2.1%	5.0%	-2.9%
Direct taxes	-3.7%	-4.0%	0.3%
Remittances received	9.4%	5.0%	4.4%
Remittances sent	0.0%	-0.1%	0.0%
Govern transfers	17.0%	18.6%	-1.6%
Private transfers	14.9%	-5.7%	20.7%
Total	100.0%	100.0%	0.0%

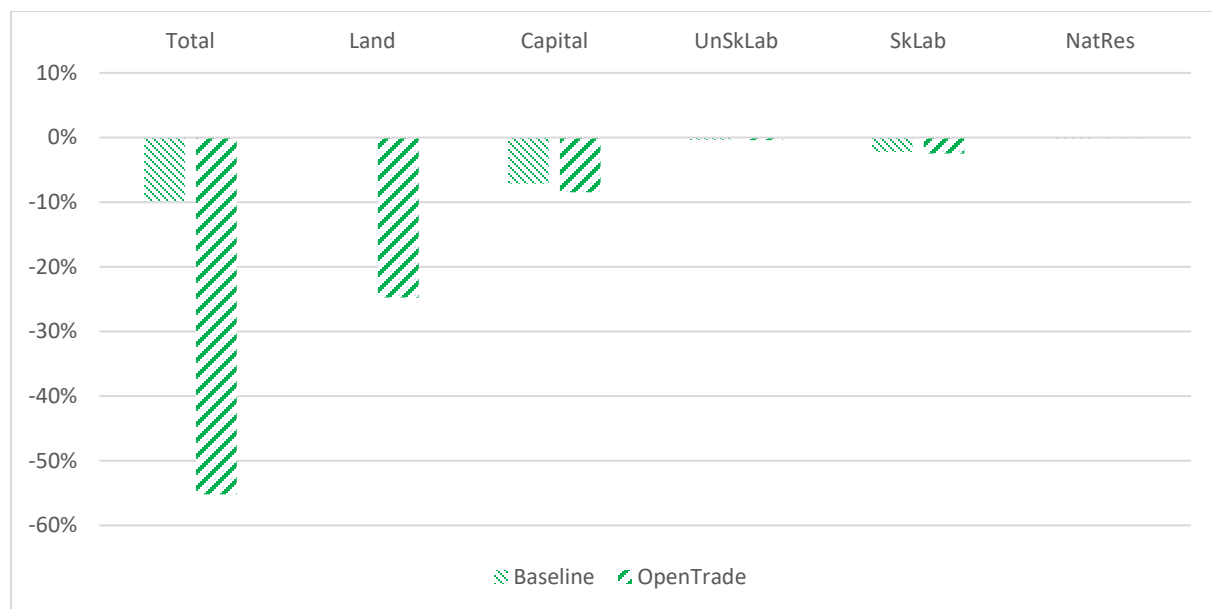


Figure C1. Variations 2011-2050 in relative factor income poor/non-poor, by source, Albania.

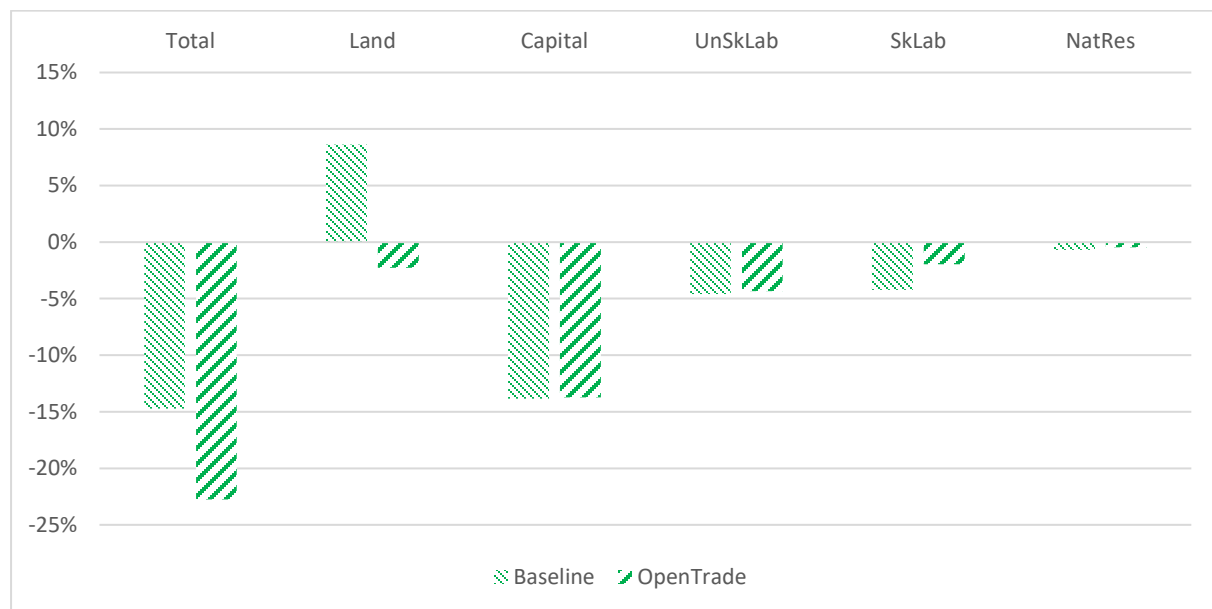


Figure C2. Variations 2011-2050 in relative factor income poor/non-poor, by source, Bolivia.

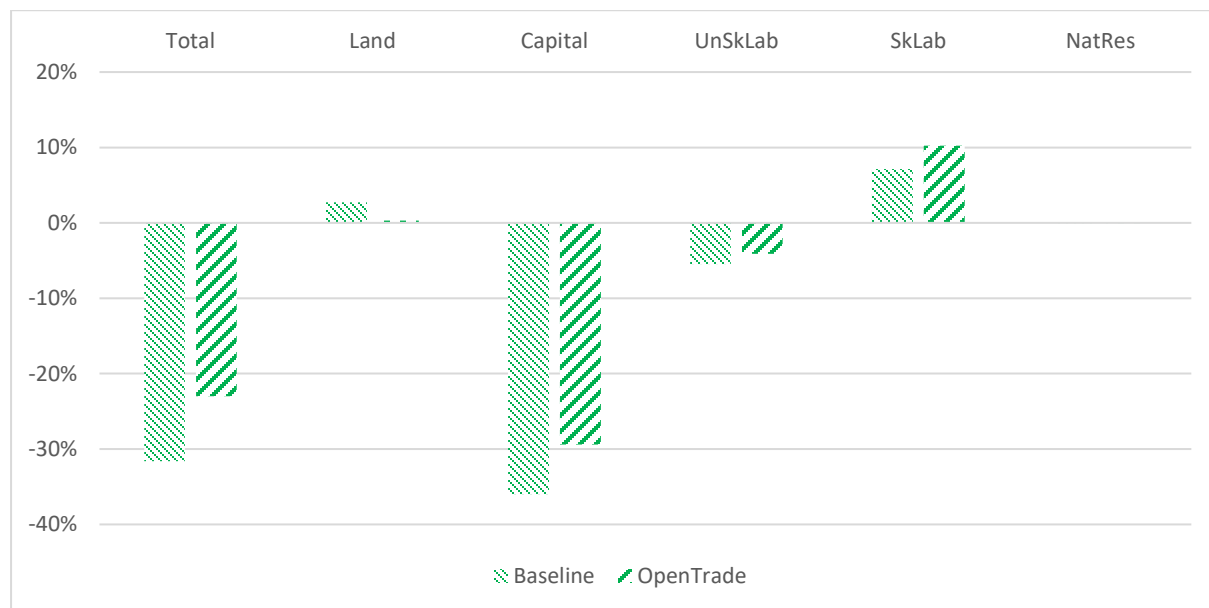


Figure C3. Variations 2011-2050 in relative factor income poor/non-poor, by source, Ethiopia.

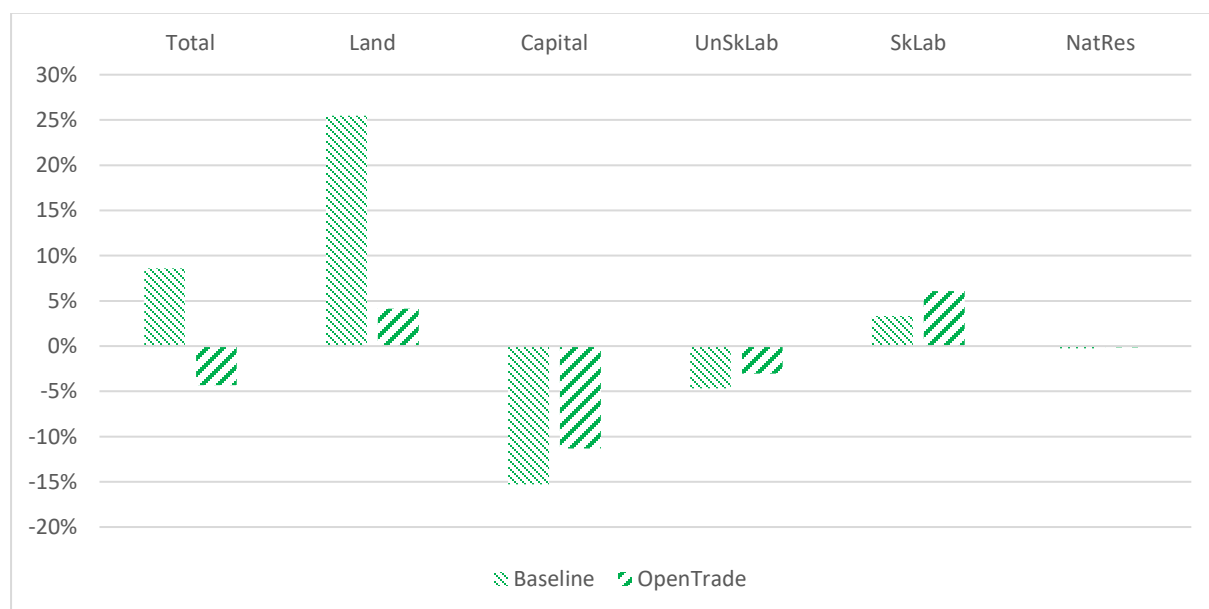


Figure C4. Variations 2011-2050 in relative factor income poor/non-poor, by source, Malawi.

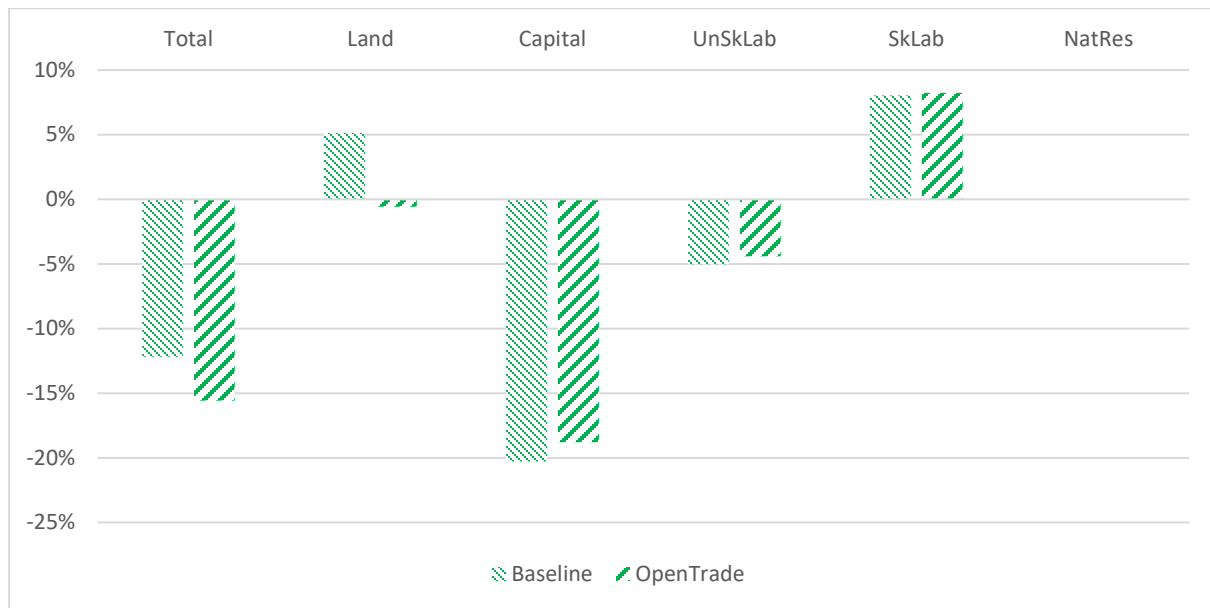


Figure C5. Variations 2011-2050 in relative factor income poor/non-poor, by source, Nicaragua.

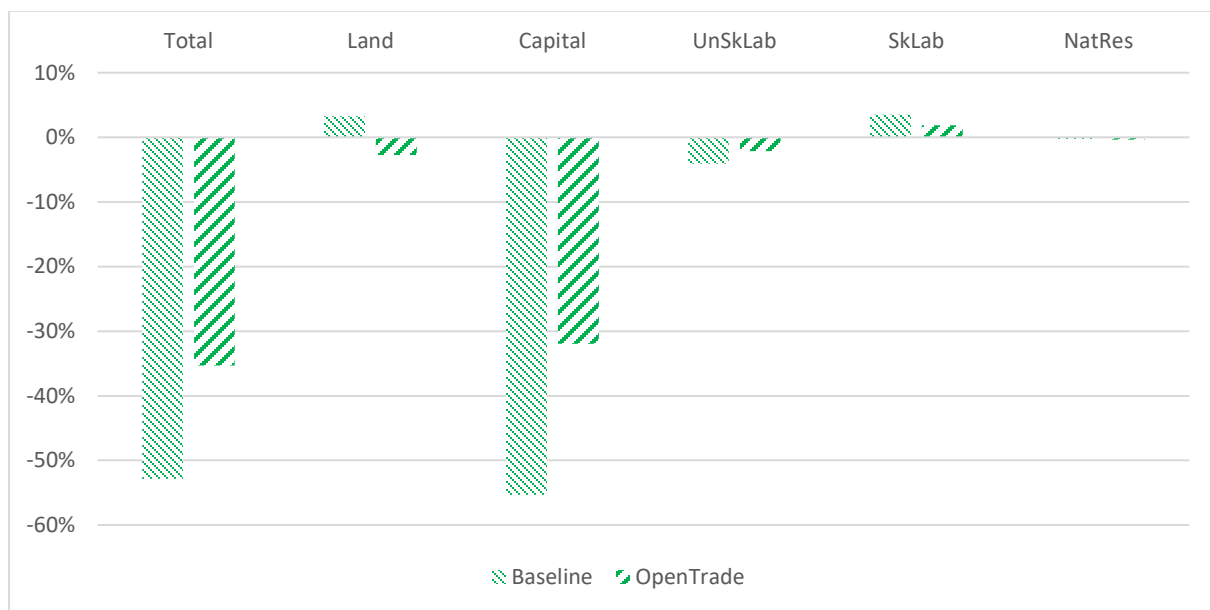


Figure C6. Variations 2011-2050 in relative factor income poor/non-poor, by source, Vietnam.

ARTICLE

Markups and export behavior: Firm-level evidence from the French food processing industry

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Abstract

The relationship between a firm's markups and its export behavior is highly relevant to individual firms' strategic decisions as well as to governments' policies regarding competition. We investigate the impact of markups on firms' decisions to export and resulting export intensity in the French food processing industry. Moreover, we assess the effect of entry into and remaining in the export market on firms' markups and evaluate differences in markups between exporters and non-exporters. Our results suggest that higher markups lead to both increased participation in the export market and greater export intensity. In addition, we find that firms obtain higher markups by entering and remaining in the export market. Finally, our results suggest that exporters generate higher markups, on average, than non-exporters. Similar results are found when controlling for differences in firms' productivity. Our findings suggest that trade policies designed to increase firms' participation in export markets, such as limits to border restrictions, may counteract domestic competition policies targeted at price–cost margins.

KEYWORDS

export behavior, firm-level markups, food processing industry

JEL CLASSIFICATION

D22, F14, L11, L66, Q18

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1 | INTRODUCTION

Food processing industries worldwide enjoy strong protection against competition from foreign trade.ⁱ However, recent trade reforms have made foreign markets more accessible to (potential) exporters (Curzi et al., 2015; FAO, 2019). This fosters firms' export activity that can influence their ratio of price over marginal costs, that is, markups. At the same time, countries employ various measures to encourage domestic firms to adopt advanced technologies and to produce higher quality products (FAO, 2019). Such measures also involve changes in markups that can in turn affect export participation and intensity. Consequently, the relation between markups and export behavior is of direct interest to policy makers and firms seeking to successfully align their policies and competitive strategies, respectively (e.g., De Loecker et al., 2016; Ponikvar & Tajnikar, 2011). This article investigates this simultaneous relationship using the example of the food processing sector in France.

One challenge in identifying the relationship between export decisions and markups is that both result from the interaction of factors that affect production and demand.ⁱⁱ We disentangle this simultaneity using exogenous characteristics such as firm age and legal form as instruments. First, we analyze the impact of firms' markups on the decision to export and on export intensity. Second, we explore the impact of (i) entering and (ii) remaining in the export market for at least two consecutive years, that is, the effect of export experience on markups. Finally, we evaluate the differences in markups for exporters and non-exporters.ⁱⁱⁱ

Theory predicts that firms with relatively low marginal costs and/or higher product quality, that is, larger markups, enter the export market and adjust their product prices depending on the level of competition they expect to encounter at the export destination (Bernard et al., 2003; Melitz & Ottaviano, 2008). Furthermore, markups can change through learning by exporting (LBE) for firms remaining in the export market for a number of years (Bernard & Jensen, 1995). However, the empirical evidence on the relationship between exporting and markups is limited. De Loecker and Warzynski (2012) (hereafter DLW) were the first to empirically study the relevance of firms' export behavior for markups using the Slovenian manufacturing sector as a case study. DLW estimated firm-specific markups based on an extended version of the production function approach in Hall (1988).^{iv} The DLW approach is attractive as it does not require assumptions about how firms compete in output markets. It also has lower data requirements compared to New Empirical Industrial Organization approaches (De Loecker & Scott, 2016). Later studies, such as Bellone et al. (2016) and Kilinc (2019), show the relevance of export destination characteristics for markups of companies in France and Luxembourg. However, these results should be understood as a correlation analysis as the authors did not control for the reverse causality between markups and export behavior.

This study adds to the literature in several ways. First, we go beyond the classic DLW methodology, that assumes perfect competition in input markets, when estimating firm-specific markups as a measure of output market power. In this respect, we take into account the potential imperfect competition in the labor input market. Furthermore, to obtain more reliable markup estimates, we improve the estimation of the production function by addressing potential biases in output measurement caused by deflating revenues with industry-wide price deflators. Instead, we use a price index that considers the weighted average of prices in domestic and export markets. Moreover, we account for the firm-specific deviations from the weighted average industry prices in the estimation of the production function. This results in more reliable estimates of production function parameters, which are required for the calculation of markups.

Second, we add to the understanding of the impact of firms' markups on both the probability of participating in an export market and on conditional export intensity. We use a double hurdle control function approach that separates the initial export decision from the conditional intensity while addressing the simultaneity between markups and export decisions based on suitable instrumental variables (IV) (Garcia, 2013). To the best of our knowledge, this impact has not yet been investigated empirically at the firm level.^v

Third, we follow DLW and test whether markups are affected by the firm's decision to begin exporting and stay in the export market for at least two consecutive years. Moreover, we follow DLW and estimate differences in markups between exporters and non-exporters. Results of previous studies in this area are inconclusive, especially for developed countries (DLW). To obtain our estimates, we deviate from DLW by accounting for the simultaneity of firms' markups and export behavior using an extended regression model IV approach. Therefore, our results offer more reliable evidence on this issue.

We also control for differences in firms' productivity, which can play an important role in the markup–export behavior relationship (De Loecker & Goldberg, 2014; Foster et al., 2008; Greenway & Kneller, 2007). This provides evidence regarding the importance of factors other than productivity that drive the markup–export relationship, such as output quality and demand-side conditions. After controlling for differences in productivity, markups contain information that can be relevant for policy makers in formulating policies affecting domestic competition and for firms in designing strategies for product quality and pricing (De Loecker & Goldberg, 2014).

Our analysis uses a sample of 10,927 firms operating in the French food processing sector over the period 2011–2019. With a 20% market share, France is the largest contributor to total EU food industry turnover, followed by Germany and Italy. Moreover, the food processing sector constitutes the largest manufacturing subsector in France, contributing 17% (€178 billion) of total manufacturing sales in the country (Eurostat, 2019a). The food sector in France is characterized by high market saturation, strong competition along the supply chain, and a high degree of retailer concentration, all of which puts food processors under pressure (European Commission, 2014; Wijnands et al., 2007). In addition, the sector is known as one of the most diverse in the world^{vi} with a variety of globally recognized products that provide firms with promising export opportunities (CNIEL, 2015). Accordingly, approximately 24% of French agri-food products are exported, with an emphasis on grain products and beverages whose export rates are 49% and 30%, respectively (FMOAF, 2021). Consequently, the French food processing industry presents an interesting opportunity to examine the relationship between markups and firms' export behavior.

The remainder of this article is structured as follows. We first review earlier studies examining the link between firms' export behavior and markups. Next, we describe the empirical strategy used to estimate markups that accounts for potentially imperfect input markets. We then outline regression specifications for analyzing markup–export relationships, present the data, and discuss the results. Finally, we offer some conclusions.

2 | BACKGROUND AND DERIVED HYPOTHESES

Theoretical and empirical studies on the relationship between trade and markup gained attention following the emergence of trade models of monopolistic competition (see Jacquemin, 1982). In parallel, the literature on this relationship gained in popularity with the introduction of intra-industry trade in homogenous goods into the reciprocal dumping models in Brander (1981) and Brander and Krugman (1983) that allow firms to differentiate between domestic and export markets (see Gullstrand et al., 2014).^{vii} Later, the appearance of rich microlevel datasets in the mid-1990s led to three main insights: First, markups affect firms' export behavior. Second, entering and/or staying in export markets may involve changes in firm markups. Third, this two-way relationship can result in differences in markups between exporters and non-exporters.

2.1 | The impact of a firm's markup on export participation and intensity

The influence of markups, that is, the ratio of output price over marginal cost and its components, on firms' export participation and intensity has received considerable attention in the literature. A

firm's physical productivity—which determines its marginal cost—has been identified as one of the key determinants of export participation and intensity. Melitz (2003) uses a monopolistic competition model to illustrate that a firm's decision to serve one or multiple foreign market (s) depends on its productivity. Because a firm has to pay fixed export entry costs to access new markets, its productivity must be strong enough to offset this outlay.^{viii} Chaney (2008) and Helpman et al. (2008) use Melitz-type models to show that a firm's expected export share is higher when bilateral trade frictions are relatively low.^{ix} Although these models predict that productivity will have a positive impact on export intensity, defined as the ratio of export sales over total sales, a reverse effect is also possible (Arkolakis, 2012). Given that firms with a given level of productivity can reach a certain fraction of consumers in both domestic and export markets, improved productivity enables them to increase the fraction of consumers they reach in both markets. If the positive impact of productivity improvements on domestic sales exceeds the positive impact on export sales, productivity, and export intensity will be inversely related.

Output prices are the second component of markup and superior product quality has been identified as a major driver of higher prices (Baldwin & Harrigan, 2011; Bellone et al., 2016; Johnson, 2012; Kugler & Verhoogen, 2012; Manova & Zhang, 2012). Products destined for export must offer an output quality premium over what is available in the domestic market. Consequently, exporters realize higher output prices and higher markups than non-exporters even though they use higher quality, and therefore more costly, inputs (Kugler & Verhoogen, 2012) or technologies that result in higher marginal costs (Antoniades, 2015; Eaton & Fielser, 2019; Hallak & Sivadasan, 2013; Johnson, 2012).^x Nonetheless, if export markets have a different appreciation for product quality compared to domestic markets, the impact of the product quality component of markups on exports could be negative (Crino & Epifani, 2012). For example, firms located in countries with high domestic quality standards that produce high-quality products are less likely to export to markets with lower quality standards (Crino & Epifani, 2012).

Previous studies have investigated the relationship between the individual components of markups and the decision to export, but we are not aware of any empirical study that analyzes the causal impact of firm markups on the decision to export and resulting export intensity.

Based on these theoretical concepts, we develop Hypothesis 1a: higher markups increase the likelihood of export, and Hypothesis 2a: higher markups lead to higher export intensity, conditional on export participation. We also hypothesize that rising markups after controlling for productivity differences increase the likelihood of export (Hypothesis 1b) and lead to incremental increases in export intensity (Hypothesis 2b).

2.2 | The impact of firms' export entry and continuation on markups

We now turn to the effect of a firm's entering into and remaining in export markets on its pricing and marginal costs, and therefore on its markups. Theoretical models suggest that exporters adjust their prices to the price level in the export destination (e.g., Bernard et al., 2003; Melitz & Ottaviano, 2008). Accordingly, an exporter's price depends on rivals' marginal costs in the export market. If exporters' domestic prices are higher (lower) than prices in the export market, their markups will, *ceteris paribus*, decrease (increase) when they enter the foreign market. Market size in the export destination also affects exporters' markup. Competition is stronger in large, integrated markets, which implies relatively small markups (Melitz & Ottaviano, 2008). Therefore, depending on the level of competition in the export market, a firm's markup may increase, decrease, or remain constant upon entering a foreign market. In addition, firms choosing to begin exporting may reduce their markups strategically, to increase market penetration, enabling them to compete while they attempt to gain a certain share of the market (Dean, 1976). Firms may also upgrade product quality upon entering an export market^{xi} or may benefit from economies of scale (DLW), both of which have a positive impact on markups. In that respect, De Loecker et al. (2016) and McQuoid and

Rubini (2019) find that decreased marginal costs as a consequence of trade liberalization are incompletely passed through to prices in India and Chile, respectively. As noted earlier, the food sector is highly competitive (Wijnands et al., 2007); therefore, we do not expect food processors in France to attempt to gain a significant share in the destination market by strategically undercutting their rivals' prices when they enter an export market. Instead, we conjecture that as the French food sector is rather specialized and has many differentiated products (CNIEL, 2015), these products have relatively high prices in export markets. Thus, we formulate the following hypotheses: firm markups increase upon export entry (Hypothesis 3a) and that the effect is robust when we control markups for productivity (Hypothesis 3b).

Furthermore, the literature on exporting and firm performance suggests that firms benefit from learning when they remain in an export market for consecutive periods, that is, they experience LBE (Bernard & Jensen, 1995; Baldwin & Wulgong, 2005; DLW). Potential gains can arise through different channels, such as increased efficiency due to competitive pressures, or the ability to use new technology thanks to international contacts (Baldwin & Wulgong, 2005; Baldwin & Yan, 2015; De Loecker, 2013). In addition, firms that continue to export after entering foreign markets shift their product mixes toward their best-performing products, leading to overall productivity improvements (Mayer et al., 2014). Therefore, we can expect lower marginal costs and, *ceteris paribus*, higher firm markups for firms that remain in an export market for consecutive periods. DLW's examination of the Slovenian manufacturing sector yielded evidence to support this mechanism. Exporters may also learn to recognize consumer preferences in foreign markets and observe foreign rivals to improve product quality (De Loecker, 2007; De Loecker, 2013). Therefore, we expect that remaining in an export market for consecutive years has a positive impact on markups (Hypothesis 4a) and that this effect is robust when controlling for productivity (Hypothesis 4b).

2.3 | Markup differences between exporters and non-exporters

Differences in markups are likely to arise between exporters and non-exporters (DLW) as firms with higher markups may participate in export markets and benefit from learning effects of participation, which in turn influences their markups. Bellone et al. (2016) investigate differences in markups between exporters and non-exporters by introducing product quality into the framework proposed in Melitz and Ottaviano (2008). They assume that productivity can increase product quality, and therefore markups, leading to participation in export markets. In this framework, the difference between markups of exporters and those of non-exporters depends on the quality-enhancing impact of productivity and the price effects of competition on the export market (Bellone et al., 2016). The authors applied their model to the French manufacturing industry and found that exporters' markups exceed those of non-exporters by 0.013 units because the quality-enhancing impact of productivity exceeds the downward price pressure from competition. However, they do not control for simultaneity in markups and export participation; thus, their estimates may be biased.

We therefore derive Hypothesis 5a, which states that exporters in the food processing sector have higher markups than non-exporters, and Hypothesis 5b, which states that this holds for markups after controlling for productivity.

3 | MEASURING MARKUPS

We adopt the DLW approach and augment it to account for input market power (e.g., see De Loecker & Scott, 2016; Mertens, 2020; Morlacco, 2019) to recover markups of price over marginal cost. We present the approach here briefly and refer the reader to an online Appendix for details. Based on the firm's first-order condition of cost minimization, market power in the output market, that is, markup (μ), is defined as revenue (PY) over the firm's expenditures for a variable input

j ($W_j X_j$) multiplied by the elasticity of output with respect to input j (θ_j) adjusted for market power in j 's input market, that is, markdown of j (ψ_j),

$$\mu = \frac{PY}{W_j X_j} \theta_j / \psi_j. \quad (1)$$

Although ψ_j is unique for each input j , μ is not. No matter which one of the j inputs we use, Equation (1) will always produce the same markup μ (DLW). Hence, we can equate the right-hand side of Equation (1) using different variable inputs so that.

$$\frac{\psi_k}{\psi_j} = \frac{W_j X_j}{W_k X_k} \frac{\theta_k}{\theta_j}, j \neq k. \quad (2)$$

Although we have estimated the output elasticities and can observe both input expenditures and revenue, we still have $j + 1$ unknowns, indicating that the system of j equations is under-determined (we must identify ψ for each j , and μ). However, if we are willing to assume that for some variable inputs, such as intermediate inputs, ψ equals one, that is, there is no market power in input market (the input market is perfectly competitive), we can solve for μ , and for ψ for all variable inputs on which we do not impose perfect competition.

We estimate the following gross output production function to obtain estimates for θ :

$$y = \beta_k k + \beta_l l + \beta_m m + \beta_{kk} k^2 + \beta_{ll} l^2 + \beta_{mm} m^2 + \beta_{kl} kl + \beta_{km} km + \beta_{lm} lm + \omega + \varepsilon. \quad (3)$$

Here y , k , l , and m denote the logs of output, capital, labor, and material, respectively. ω captures firm-specific productivity and ε is a random error component. Although data on physical quantities of labor and capital are available, this is not the case for output and materials. Deflated revenues are frequently used as a measure of output, just as input expenditures are used as a measure of physical input quantities. However, this leads to biased estimates of production function parameters (see e.g. Bond et al., 2020; Morlacco, 2019).

Our strategy for dealing with the bias caused by the absence of output prices is closely related to our theoretical considerations. We assume that exporters and non-exporters typically charge different prices. Therefore, we deflate the revenues of all non-exporters by the same domestic price index, whereas exporters' domestic sales are deflated by the domestic price index, and their export sales are deflated by an export price index. We then assume that most of the deviations from these price indices are firm specific and that these firm-specific deviations change little over time. Therefore, we use firm-specific fixed effects (G_i) to account for firm-specific deviations from average industry prices. The use of firm-specific effects also captures variations in input prices (De Loecker et al., 2016) and accounts for product differentiation in the food sector by picking up unobserved price differences related to product differentiation (c.f. Bonnet & Bouamra-Mechemache, 2016; Richards et al., 2018).^{xii} The production function is then specified as

$$y_{it}^* = G_i + \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it}^* + \beta_{kk} k_{it}^2 + \beta_{ll} l_{it}^2 + \beta_{mm} m_{it}^{*2} + \beta_{kl} k_{it} l_{it} + \beta_{km} k_{it} m_{it}^* + \beta_{lm} l_{it} m_{it}^* + \omega_{it} + \varepsilon_{it}. \quad (4)$$

The only remaining unobservable is ω , which we proxy using material demand (Levinsohn & Petrin, 2003).^{xiii} We define material demand as a function of productivity (ω), capital, the firm's lagged export status as well as firm-fixed effects (G_i). Our parameter identification follows Akerberg et al. (2015) and De Loecker (2013) who apply a two-step generalized method of moments (GMM) approach (see the online Appendix for details).

Once the GMM estimates have been identified, we can compute the output elasticity with respect to any of the inputs. Here, we are interested in labor and material, that is, the variable inputs in the production process. We use the output elasticity and the expenditure share of materials in

Equation (1) to identify markups by assuming that $\psi_M = 1$. The markup estimates from materials can then be used to identify the divergence from perfect competition in the labor market by plugging μ into Equation (1) specified for labor and solving for ψ_L .

4 | REGRESSION SPECIFICATIONS AND ESTIMATION TECHNIQUES

In this section, we first specify regressions to test Hypothesis 1 and Hypothesis 2, that is, to investigate the impact of markups on export participation and export intensity. Because only a small percentage of firms engage in exporting, the dataset contains a large number of zero trade values. Nevertheless, these zeros must be treated as meaningful observations (Helpman et al., 2008) as they represent the optimal choice for these firms. Therefore, we employ the Cragg hurdle regression (Cragg, 1971; Garcia, 2013; StataCorp, 2017; Wooldridge, 2010b).^{xiv} The hurdle model is based on $EI_{it} = s_{it} * EI_{it}^*$ where EI_{it} denotes export intensity, whereas s_{it} is a latent variable capturing export participation defined as:

$$s_{it} = \begin{cases} 1 & \text{if } \alpha_0 + \alpha_1 \ln \mu_{it} + \mathbf{X}_{it} \boldsymbol{\gamma} + \epsilon_{it} > 0 \\ 0 & \text{otherwise} \end{cases}, \quad (5)$$

where μ_{it} reflects estimated markups.^{xv} The control variables and their corresponding coefficients are defined by the vectors $\mathbf{X}_{it}$ and $\boldsymbol{\gamma}$, respectively. We control for labor, capital, and material (all in natural log form) to capture differences in factor intensity and size. We also consider year and industry dummies (at the four-digit NACE level) to account for trend and subsector-specific aggregate effects in the dependent variable, respectively. ϵ_{it} is a standard normally distributed error. EI_{it}^* is a continuous latent variable that is observed only if $s_{it} = 1$; it is specified in exponential form as:

$$EI_{it}^* = \exp(\beta_0 + \beta_1 \ln \mu_{it} + [\mathbf{X}_{it}, \text{Lag} EI_{it}] \boldsymbol{\gamma} + \nu_{it}). \quad (6)$$

Hence, the hurdle model allows us to explore a firm's two-stage decision process (export participation and intensity) using the same explanatory variables for each decision stage but adding the lag of export intensity ($\text{Lag} EI_{it}$) at the second stage to control for possible dynamic impacts of export intensity (e.g., see Damijan & Kostevc, 2006).^{xvi} In Equations (5) and (6), markups are potentially endogenous to export behavior due to the simultaneity described above. We use a control function approach to deal with the potential correlation between $\ln \mu_{it}$ and ν_{it} , and consider three instrumental variables for this purpose. We use the lag of capital and the firm's legal form, both of which correlate strongly with revenue productivity, and therefore markups (see e.g. De Loecker, 2007).^{xvii} We also add firm age as an instrument as it can explain differences in revenue productivity as an important component of markup (Diego & Rogerson, 2008; Hsieh & Klenow, 2009). Moreover, markups vary systematically with firm age (Peters, 2020).

The LBE-related hypotheses (H3 and H4) are tested by investigating whether there is a significant difference between markups of firms that (i) were never active on an export market or left the export market following a period of export activity; (ii) starters, that is, firms that enter the export market following a non-exporting period; and (iii) continuers, that is, firms that are exporting and have been doing so for at least two consecutive years. We estimate the model as:

$$\ln \mu_{it} = \lambda_0 + \lambda_1 \text{Entry}_{it} + \lambda_2 \text{Continue}_{it} + [\mathbf{X}_{it}, \text{Lag} \ln \mu_{it}] \boldsymbol{\gamma} + \nu_{it}, \quad (7)$$

where Entry_{it} is a dummy variable equal to one if a firm is an exporter during t but was not an exporter in $t-1$, whereas Continue_{it} is a dummy variable equal to one when a firm exports during both t and $t-1$.^{xviii} Consistent with earlier literature on the LBE effect, we also include the lagged

dependent variable ($Lagln\mu_{it}$) on the right-hand side to capture the difference in markups due to entering and staying in the export market (e.g., see Fernandes & Isgut, 2005; Van Biesebroeck, 2005). The constant term reflects the average markup for firms in the base group that have either never entered an export market or do not export during t . We are interested in the coefficients λ_1 and λ_2 that measure differences in markups between starters and continuing exporters compared to the firms in the base group.

In Equation (7), *Entry* and *Continue* are potentially endogenous due to their being simultaneously determined with markups and are therefore correlated with the error term, leading to biased estimates for λ_1 and λ_2 . For this reason, we use an extended regression model estimator (Stata Press, 2019). This approach uses maximum likelihood estimation to determine the parameters of a joint distribution of an endogenous continuous dependent variable and binary endogenous covariates conditional on exogenous covariates. The likelihood function is defined as the product of the marginal distributions of error terms v_i with variance σ^2 , $\phi(v_i, \sigma^2)$, and the cumulative joint distributions of the error terms in the reduced form equations for b endogenous binary covariates with lower limits $\mathbf{l}$ and upper limits $\mathbf{u}$ for each binary covariate and the adjusted correlation matrix of reduced form errors $\sum_{i,b|1}$, $\Phi_b^*(\mathbf{l}_i, \mathbf{u}_i, \Sigma_{i,b|1})$ (Bartus & Roodman, 2014; Roodman, 2011; Stata Press, 2019):

$$LnL = \sum_{i=1}^N \xi_i Ln \{ \phi(v_i, \sigma^2) \Phi_b^*(\mathbf{l}_i, \mathbf{u}_i, \Sigma_{i,b|1}) \}, \quad (8)$$

where ξ_i are weights.

This approach requires instrumental variables for the endogenous covariates that are correlated with *Entry* and *Continue* in the reduced form models, but uncorrelated with v_{it} in the structural model. We rely on the same set of instrumental variables (i.e., age, lagged capital and ownership) that we used above for markups, as the same underlying process simultaneously drives the firms' markups and export variables.

Hypothesis 5, "Exporters have higher markups than non-exporters," is tested empirically by relating estimated markups to firms' export status as follows:

$$ln\mu_{it} = \delta_0 + \delta_1 Export_{it} + [\mathbf{X}_{it}, Lagln\mu_{it}] \boldsymbol{\gamma} + \nu_{it}, \quad (9)$$

where $Export_{it}$ denotes a binary variable equal to one if firm i is an exporter in period t and zero otherwise. Its associated coefficient δ_1 reflects the percentage markup performance premium for exporters. Because export status is likely endogenous to markups, we use the same identification and estimation strategy as in Equation (8) with the difference that in Equation (9), the cumulative distribution of errors terms is associated with only one endogenous binary covariate, $Export_{it}$, rather than a joint distribution of two endogenous covariates.

In the regressions specified in Equations (5)–(7) and (9), we assess whether our results are robust to controlling markups for productivity. This involves regressing markups on productivity estimates so that the resulting residuals measure the part of markups that are unrelated to productivity. These "productivity-adjusted" markups are then used in Equations (5)–(7) and (9) in place of the original markups. Instruments and estimation techniques remain unchanged.

5 | DATA AND DESCRIPTIVE STATISTICS

We use firm-level data from the ORBIS database provided by Bureau van Dijk (Bureau Van Dijk, 2020). ORBIS contains financial data for firms in all European countries and economic sectors. The database also contains information on firms' export participation and total export sales. We

TABLE 1 Comparison of the sample and population of food processors in France, by firm size

	Sample	Population [as of 2015]
Total number of firms	11,104	59,757
Percentage share of firms per size class		
Small firms	91.30	97.59
Medium firms	6.36	1.87
Large firms	2.34	0.54

Note: Small: <50 employees; medium: 50–249 employees; large: >249 employees. Shares for the population are calculated based on Eurostat (2019c).

selected all French firms involved in manufacturing food or beverages as defined by NACE codes 10 and 11 in the years from 2011 to 2019. Although information on other countries is readily available in ORBIS, France is the only country where the number of firms that publish their export revenues is sufficient to support an empirical analysis in line with the objectives of our study. There are a total of 28,618 observations in our sample comprising 11,104 firms, where each observation refers to a legal entity publishing its financial information in a specific year. Table 1 compares our sample with the population with respect to size categories. We see that the sample reflects about 18.6% of the total number of firms (59,757) in French food processing industry and adequately represents the distribution of the population with respect to size (Table 1). Note that small firms are slightly under-represented due to lower requirements with respect to financial information disclosure for companies with fewer than 10 employees (European Commission, 2013). Table A1 of the online Appendix provides descriptive statistics for the firm-level variables. Labor is defined as the number of employees used to estimate the production function. We use deflated material costs for materials and the value of fixed assets for capital. The production function is estimated by deflating material costs and capital using the respective industrial producer price indices with base year 2015 (Eurostat, 2019a). Revenue is deflated to obtain a measure of physical output. Although the domestic price index is the harmonized index of consumer prices (Eurostat, 2019b), we construct an industry-specific price index for exports using data on country-level export quantities and prices from PRODCOM (Eurostat, 2020). The overall sample shows considerable variations in firm revenues, input variables, export intensity (only applicable to exporters), and firm characteristics, such as age and ownership (cf. Table A1 of the online Appendix). These variables also tend to differ between exporters and non-exporters, with exporters having higher average revenues and input use. Moreover, exporters tend to be older firms compared to non-exporters.

Several studies show that estimates of production function coefficients and regression coefficients may be affected by outliers or faulty observations in firms' reported data (see for example, Cainelli et al., 2015; De Loecker et al., 2016; Demirer, 2020; Hirsch, Lanter, & Finger, 2020a; Hirsch, Mishra, et al., 2020b). Therefore, we apply the BACON algorithm that identifies multivariate outliers using Mahalanobis distances (Billor et al., 2000; Weber, 2010). This reduces the number of firms (firm-year specific observations) to 10,203 (24,594). Accordingly, we use two sets of observations for our analysis. We use "all observations" including outliers as our baseline data then repeat the estimations using the "observations excluding outliers" as a robustness check.

6 | RESULTS AND DISCUSSION

We present the mean of the estimated markups for all observations and compare the 10th, 50th, and 90th percentiles in Table A3 of the online Appendix.^{xx} Our estimates show that 10% of firms charge markups of less than 1.03 (i.e., a price that is no more than 3% above marginal cost), 50% charge markups below/above 1.84 (i.e., a price that is less/more than 84% above marginal cost), and 10%

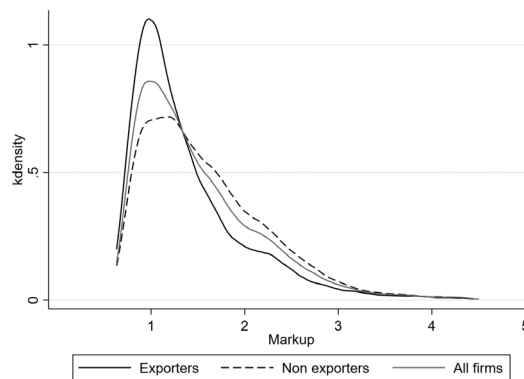


FIGURE 1 Firms markup distributions

charge markups greater than 2.75 (i.e., a price that is 175% above marginal cost). These results indicate a positively skewed distribution (see Figure 1) and substantial variation across firms, supporting previous findings of firm-level heterogeneity in markups (e.g. Curzi et al., 2020; Garrone & Swinnen, 2018; Karagiannis et al., 2018; Vancauteran, 2013).^{xxi} The arithmetic mean of markups across all firms is 1.97; however, given the heterogeneity in firm size and the skewed distribution of markups, we calculate an average industry markup as the sales-weighted average of markups and obtain a value of 1.29. This lies within the range of estimated average markups of 1.02 to 1.70 previously reported for the food processing sector (see Garrone & Swinnen, 2018; Karagiannis et al., 2018; Lopez et al., 2018; Vancauteran, 2013; Wilhelmsson, 2006). Our results also show substantial variation in wage markdowns, suggesting the importance of considering firms' market power in the labor market (see Table A3 of the online Appendix). There is also considerable heterogeneity in markups among firms operating in different subsectors of the food industry, as supported by the Bartlett test that rejects equality of variance, and hence means and medians, between almost all pairs of subsectors. This highlights the need for subsector dummy variables in our regression analysis.

6.1 | The impact of markups on firms' export participation and intensity

The results of the hurdle model in capturing the impact of markups on export participation and intensity as specified in Equations (5) and (6) are reported in Table 2. The statistical significance of the coefficients on the reduced form residuals in both stages of the structural model shows the endogeneity of markups and ensures the other parameters are estimated consistently in this case.^{xxii} The coefficient for markup in the export participation equation is positive for both datasets ("all observations" and "observations excluding outliers"). Because markups are measured in logarithmic form we derive the marginal effect of markups on levels.^{xxiii} The results are reported at the bottom of Table 2 and reveal that a 1% increase in markups increases the probability that a firm will participate in export markets by 0.018 (all observations) and 0.006 percentage points (observations excluding outliers), on average. Table 2 also reveals that controlling for productivity lowers the positive effect of markups on the probability firms will participate in export markets, producing marginal effects of 0.016 and 0.006 for all observations and observations excluding outliers, respectively. This suggests that output quality and demand-side conditions influence firms' export decisions. These findings confirm Hypothesis 1 and Hypothesis 2, and are in line with recent theories of trade (e.g., Melitz & Ottaviano, 2008) in terms of providing evidence that firms with higher markups and high-quality products self-select into export markets.

TABLE 2 Impact of markups on export participation and export intensity

Export status	All observations		Observations excluding outliers	
<i>LnMarkup</i>	4.070*** (0.692)		4.436*** (0.491)	
<i>LnL</i>	−0.957*** (0.194)	−0.711*** (0.192)	−0.938*** (0.129)	−0.940*** (0.139)
<i>LnM</i>	1.624*** (0.243)	1.018*** (0.177)	1.768*** (0.176)	1.276*** (0.132)
<i>LnK</i>	−0.293*** (0.050)	−0.230*** (0.049)	−0.345*** (0.043)	−0.341*** (0.045)
<i>LnMarkup (adjusted)</i>		2.838*** (0.611)		3.839*** (0.458)
<i>Residual from reduced form equation</i>	−3.888*** (0.694)	−2.676*** (0.612)	−4.237*** 0.494	−3.692*** 0.461
<i>Constant</i>	−12.032*** (1.618)	−5.643*** (0.685)	−12.351*** (1.120)	−5.823*** (0.473)
Export intensity				
<i>LagExpInt</i>	5.727*** (0.128)	5.738*** (0.127)	5.831*** (0.182)	5.838*** (0.182)
<i>LnMarkup</i>	4.598*** (1.218)		2.346** (0.997)	
<i>LnL</i>	−1.238*** (0.339)	−1.227*** (0.337)	−0.734*** (0.263)	−0.789*** (0.285)
<i>LnM</i>	1.628*** (0.427)	1.188*** (0.312)	1.012*** (0.358)	0.804*** (0.269)
<i>LnK</i>	−0.266*** (0.089)	−0.259*** (0.087)	−0.147* (0.089)	−0.161* (0.094)
<i>LnMarkup (adjusted)</i>		4.047*** (1.077)		2.211** (0.938)
<i>Residual from reduced form equation</i>	−4.708*** (1.216)	−4.144*** (1.075)	−2.253** 1.000	−2.111** 0.940
<i>Constant</i>	−14.681***	−8.539***	−10.989***	−7.734***
<i>Observations</i>	14,944	14,944	12,177	12,177
<i>LR Chi2</i>	9449.25***	9434.64***	5347.67***	5333.23***
<i>Log likelihood</i>	3421.281	3414.076	1432.890	1425.668
Marginal impacts on export participation				
<i>LnMarkup</i>	1.828*** (0.502) {0.018}		0.586** (0.256) {0.006}	
<i>LnMarkup (adjusted)</i>		1.609*** (0.444) {0.016}		0.553** (0.240) {0.006}

(Continues)

TABLE 2 (Continued)

	All observations	Observations excluding outliers
Export status		
<i>Marginal impact on export intensity</i>		
<i>LnMarkup</i>	1.705*** (0.368) [9.4]	0.677*** (0.161) [3.8]
<i>LnMarkup (adjusted)</i>	1.419*** (0.323) [7.8]	0.611*** (0.150) [3.3]

Note: *LnMarkup (Adjusted)* refers to *LnMarkup* controlled for *LnProductivity*; Standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Numbers in {} refers to the approximated average change in the probability of export participation caused by a marginal increase of 1% in markups. Numbers in [] refer to the average percentage change in export intensity caused by a marginal change of 1% in markups (see footnotes 23 and 24). Sector and year dummies are included as explanatory variables.

The estimated coefficients that measure the effect of markups on export intensity are also positive. A 1% increase in markup before controlling for productivity leads to an increase in export intensity of 9.4% (all observations) and 3.8% (outliers excluded); after controlling for productivity the increases are 7.8% and 3.3%, respectively.^{xxiv} This suggests that export intensity has an elastic reaction to improvements in markups and quality.

6.2 | The impact on markups of firms' export entry and continuation

Here we assess the change in markups caused by entering into export markets. The results from the reduced form equations are shown in Table A4 of the online Appendix and indicate that the ownership variable affects entry, and that both ownership and age influence the decision to continue export activities, in particular when outliers are removed from the data sample. Table 3 shows the result of estimating the regression specified in Equation (7). The null hypothesis of "no endogeneity" is only rejected in the case of the *Continue* variable and when markups are not controlled for productivity, as indicated by the significant correlation of the error terms of the structural and reduced form equations in these cases. We use instruments for *Entry* and *Continue* but subsequently perform a robustness check to compare the results with the case where no instruments are used. The coefficient of the *Entry* variable measures the markup premium or deduction in the first year of exporting. Although there is no evidence that entry has any effect on markups when all observations are used, the influence becomes clear when outliers are excluded; here, entry is associated with a 2.4% increase in markups. Similarly, when controlling for productivity differences, a firm's first year after starting to export is associated with a 2.5% increase in markups. This result is in line with DLW and suggests that when a firm enters an export market, its markup performance improves. This may be due to the firm upgrading the quality of its products to be competitive in the export market or to a decision to export to markets where the level of competition is lower than in the domestic country. As the difference between the markup premiums when entering the export market before and after controlling for productivity are almost equal, we infer that the markup premium is associated with price or quality variations.^{xxv} Thus, our results support Hypothesis 3, that is the presence of an immediate learning effect that leads to improved efficiency and quality, but only when outliers are removed from the data.

The coefficient of the *Continue* variable obtained with the dataset containing all observations suggests that firms that export for at least two consecutive years charge markups that are 2.1% higher than markups charged by firms that either exited the export market or never exported at all. This result is robust when outliers are excluded from the data, resulting in an increase in markups of

TABLE 3 Learning by exporting

Variables	All observations		Observations excluding outliers	
	Markups	Markups controlled for productivity	Markups	Markups controlled for productivity
<i>LnL</i>	0.067*** (0.004)	0.063*** (0.004)	0.057*** (0.004)	0.052*** (0.005)
<i>LnK</i>	0.019*** (0.002)	0.018*** (0.002)	0.022*** (0.002)	0.020*** (0.002)
<i>LnM</i>	−0.090*** (0.005)	−0.063*** (0.004)	−0.089*** (0.006)	−0.057*** (0.004)
<i>Lag.LnMarkup</i>	0.756*** (0.012)		0.762*** (0.013)	
<i>Enter</i>	0.013 (0.009)	0.011 (0.010)	0.024** (0.011)	0.025** (0.011)
<i>Continue</i>	0.021*** (0.006)	0.015** (0.006)	0.017*** (0.006)	0.013** (0.006)
<i>Lag.LnMarkup (adjusted)</i>		0.796*** (0.011)		0.811*** (0.012)
<i>Constant</i>	0.495*** (0.033)	0.153*** (0.024)	0.469*** (0.036)	0.106*** (0.027)
<i>Correlation of error terms of structural and reduced form for Entry</i>	0.008 (0.014)	0.008 (0.015)	−0.0128 (0.019)	−0.0117 (0.020)
<i>Correlation of error terms of structural form and reduced form for Continue</i>	−0.017** (0.007)	−0.005 (0.005)	−0.0203** (0.009)	−0.011 (0.009)
<i>Observations</i>	14,944	14,944	14,944	14,944
<i>Log pseudo Likelihood</i>	−1187.222	−1430.699	1838.646	1606.674
<i>Wald chi2</i>	117834.18***	82410.17***	1082790.2*	79195.46*

Note: *LnMarkup (adjusted)* refers to *LnMarkup* controlled for *LnProductivity*; Heteroskedasticity robust standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Sector and year dummies are included as explanatory variables.

1.7%. When controlling for productivity differences the estimated coefficients are lower, with markups increasing by 1.5% for all observations and 1.3% for the sample that excludes outliers. These results indicate that continuing to export is related to marginal costs and price changes induced by learning effects that lead to improvements in productivity and product quality. Thus, our results support Hypothesis 4, that is, the LBE hypothesis conditional on continuous exporting. The results are also consistent with the finding in DLW that by entering the export market firms can benefit from learning effects if they remain committed to exporting for at least two consecutive years.

In addition, as a robustness check we follow DLW by analyzing the effect of entering the export market and continuing to export without instrumenting these variables (see Table A5 of the online Appendix). As in DLW, we use OLS but also apply between effects (BE) estimation.^{xxvi, xxvii} Moreover, because we reject the null hypotheses that markups and the natural log of markups are normally distributed based on a Shapiro–Wilk test, we use a novel and robust 0.5-quantile regression estimator for panel data that is particularly well-suited to handle the strong skewness and extreme values observed in estimated markups (Baker et al., 2016).^{xxviii} This allows us to assess the extent to

which the coefficients of entry and continuation are affected by the skewness of markups. Table A5 of the online Appendix shows that our results are robust to both the use of instruments and the skewed distribution of markups. More precisely, when using OLS and quantile estimation we find that firms' entry is associated with an increase in markups, whereas remaining in the export market for at least two consecutive years is associated with higher markups across all estimators (Table A5, online Appendix).^{xxix}

6.3 | Markup differences: Exporters versus non-exporters

Finally, in Table 4 we present the results from estimating the regression in Equation (9) to show the difference in markups between exporters and non-exporters. The null hypothesis of “no endogeneity” with respect to export status is rejected (i.e., there is significant correlation between the correlation of the error terms in the structural and reduced form equations), except for the case where outliers are not excluded and markups are not controlled for productivity differences.^{xxx} The coefficient of the binary export variable suggests a markup premium of 2.0% and 2.2% for exporters compared to non-exporters, based on datasets that include and exclude outliers, respectively. This result is consistent with DLW's study of firms in Slovenian manufacturing sectors and also with recent theories of international trade, such as those proposed by Bernard et al. (2003), Melitz and Ottaviano (2008), and Bellone et al. (2016), which suggest that exporters on average have higher markups than non-exporters. When we control for productivity the estimated coefficients are lower

TABLE 4 Difference between exporters and non-exporters markup performance

Variables	All observations		Observations excluding outliers	
	Markups	Markups controlled for productivity	Markups	Markups controlled for productivity
<i>LnL</i>	0.067*** (0.004)	0.063*** (0.004)	0.057*** (0.004)	0.052*** (0.005)
<i>LnK</i>	0.019*** (0.002)	0.018*** (0.002)	0.022*** (0.002)	0.020*** (0.002)
<i>LnM</i>	−0.090*** (0.005)	−0.063*** (0.004)	−0.089*** (0.006)	−0.057*** (0.004)
<i>Lag.LnMarkup</i>	0.756*** (0.012)		0.762*** (0.013)	
<i>Export status</i>	0.020*** (0.005)	0.015** (0.005)	0.022*** (0.006)	0.017*** (0.006)
<i>Lag.LnMarkup (adjusted)</i>		0.796*** (0.011)		0.811*** (0.012)
<i>Correlation of error terms in structural and reduced form</i>	−0.003 (0.0073)	−0.015** (0.007)	−0.0284** (0.008)	−0.0174** (0.008)
<i>Constant</i>	0.494*** (0.033)	0.153*** (0.024)	0.471*** (0.036)	0.108*** (0.027)
<i>Observations</i>	14,944	14,944	12,177	12,177
<i>Wald chi2</i>	117838.90***	82413.92***	108254.57***	79180.83***
<i>Loglikelihood</i>	313.194	68.401	2787.680	2555.187

Note: *LnMarkup (adjusted)* refers to *LnMarkup* controlled for *LnProductivity*; Heteroskedasticity robust standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.05$; Sector and year dummies are included as explanatory variables.

but still result in positive markup premiums of 1.5% and 1.7%, respectively. These results imply that exporting firms either have superior productivity and higher quality products and/or that the demand conditions they face allow them to charge higher prices. As a robustness check, we estimate Equation (9) using OLS, BE and quantile regression and continue to find that exporters have higher markup performance (see Table A6 of the online Appendix). Consequently, our results also generally support Hypothesis 5.

7 | CONCLUSION

This article investigates the relationship between firms' export behavior and markups for the case of the food processing sector in France, based on a dataset of 11,104 firms over the period from 2011–2019. The analysis of this relationship in the food sector is particularly relevant for firms' strategic orientation in competitive food markets as well as for understanding the impact of trade and domestic policies. Trade barriers in the food sector are higher than in other sectors of an economy, implying that trade policies could have direct implications for firms' markups and consumer welfare. Moreover, policies designed to improve firm efficiency and eradicate welfare losses due to market power could influence firms' export behavior.

We evaluate the relationship between firms' markups and export behavior focusing on (i) the impact of markups on export participation and intensity, (ii) the effect of entering the export market and of continuing to export for at least 2 years on markups, and (iii) differences in markup performance between exporters and non-exporters. We estimate firm-specific markups using a modification of DLW's production function approach, allowing for the possibility of imperfections in both output and input markets. Subsequently, we apply various regression specifications that address the reverse causality between firms' markups and export variables to evaluate the firm export–markup relationship.

Our results suggest that on average, firms in the French food processing industry charge prices that exceed marginal costs by 29%. Average markups differ significantly across and within subsectors. We also find that the distribution of markup values, both for the entire sample and for individual subsectors, exhibit a positive skew.

With respect to the impact of markups on export participation and intensity, our analysis reveals that higher markups increase the likelihood that a firm will engage in exporting and will also exhibit a higher export intensity. Our investigation of the effect of export market entry shows an immediate markup increase upon entry. Moreover, we detect that the markup increases further if export activities continue for at least two consecutive years. Finally, our findings indicate that exporters and non-exporters differ in terms of their ability to exercise market power, as firms with higher markups self-select into export markets. This enables them to charge even higher markups.

We also control for productivity differences to study the relationship between firm markups and export behavior. Theoretically, higher markups could be associated with differences in both marginal cost (i.e., productivity) and price. When we control for cost differences across firms we obtain similar results, albeit of lower magnitude. This suggests that factors other than productivity, such as product quality and demand-side conditions, are also important in explaining markup differences across firms and also affect the markup–export relationship. The observed relationship—even after controlling for productivity differences—highlights the importance of product quality and/or differentiation to a firm's choice of export destination markets when designing an export strategy.

The results have some important implications. The uneven distribution of markup values within the food industry in France—even within subsectors—suggests that domestic policy measures that are common to all firms may have adverse effects on domestic prices. These may be anti-trust policies but could also take the form of quality standards, for example, that increase the cost of production for most firms. In this setting low-markup firms are most likely to exit the market first so that

the supply curve shifts upward, leading to higher prices. Secondly, downward pressure on prices in the domestic market due to domestic policy measures incentivizes firms to participate in export markets, further reducing domestic supply.

The observed relationship between markup and export behavior suggests that firms can rely on internal adaptation to increase markups and participate in export markets. Once firms begin to export, markups may increase further. This implies a consistency in firms' decisions to increase markups by relying on firm-specific resources and to participate in export markets.

The observed positive relationship also implies that policies intended to promote exports, particularly policies promoting border trade, may induce firms to charge higher prices in domestic markets. This is supported by our findings as firms' markups increase with experience in the export market. Hence, a policy promoting exports may have an adverse impact on domestic consumer welfare. Policymakers should consider these adverse effects carefully when weighing domestic anti-trust and/or export promotion measures.

There are some limitations to the research presented here. Despite our careful strategy to use firm-specific deflators to obtain a measure of firms' physical output, there could still be some unobserved variation in firm prices that affects the estimated markups. Therefore, the estimated markup values should be interpreted with caution. Data limitations meant that we could not attribute price differences to their potential sources, that is, output or input qualities, and it was likewise not possible to differentiate demand-side conditions by market size, consumer preferences, or income levels. Accordingly, the markups here are the average of the markups in domestic and export markets. However, export pricing strategies, and thus markups, depend heavily on the destination market. Therefore, these results should be viewed with a degree of caution. Progress in this respect would require a richer dataset that includes firm-specific domestic production quantities and sales, as well as export quantities and prices differentiated by destination. A richer dataset would offer considerable scope for future research.

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ENDNOTES

ⁱ At the global level the food sector's Most Favored Nation status and applied tariffs weighted by trade shares are 31% and 22%, respectively (World Bank, 2017).

ⁱⁱ The overall markup-export relationship can be explained by the correlation between individual components of markups and firm export behavior (see Bellone et al., 2016; De Loecker, 2013; De Loecker, 2016; De Loecker & Warzynski, 2012; Kilinc, 2019). Firm markups are linked with factors that affect production costs, such as productivity, input prices and quality, firms' oligopsonistic (input buyer) power, and variations in those factors that influence product prices, such as product quality, trade costs, and demand-side conditions (market size, consumer preferences, income levels) (see e.g. Hottman et al., 2016). These factors can be firm, product, or market specific, and their variation is affected by and/or has an impact on a firm's export behavior. This reflects the idea that the relationship between firms' markups and export behavior is the combination of production- and demand-side factors affecting cost and product prices.

ⁱⁱⁱ There is evidence for the presence of significant firm- and industry-level markups in the food sector (e.g. Curzi et al., 2020; Garrone & Swinnen, 2018; Karagiannis et al., 2018; Koppenberg & Hirsch, 2021; Lopez et al., 2018; Sexton & Xia, 2018; Vancauteran, 2013; Wilhelmsson, 2006). Firms' ability to charge markups is partly due to their export behavior and can partly explain that behavior (Bellone et al., 2016; De Loecker, 2013; Kilinc, 2019).

- ^{iv} Similarly, Zhang and Zhu (2017) investigate the relevance of firms' export behavior to markups in China.
- ^v Note that although our study considers the firm markup and export relationship, several other studies have assessed the relationship between the individual components of markups, such as firm productivity and product quality, with export market participation and export intensity (see e.g. Bellone et al., 2016; Bernard et al., 2007; Curzi & Olper, 2012; Eickelpasch & Vogel, 2009). See also, Melitz and Redding (2014) for a review.
- ^{vi} For example, over 1500 different dairy products are produced by food processors in France (CNIEL, 2015).
- ^{vii} A recognition of the relationship between trade and markups dates back to traditional dumping theory that analyzes monopolistic price discrimination between national markets (i.e., the formal theory of dumping) (see Ethier, 1982; Tarr, 1979). Schwartzman (1959) was the first to empirically show that market structures (i.e., price over average cost margin) of individual industries differ depending on their level of involvement in trade activities (see Caves, 1980, 1985 for a review).
- ^{viii} Using a Ricardian model with geographic barriers, Eaton and Kortum (2002) show that firms' exports increase with productivity due to marginal cost advantages over their competitors. However, the model is based on perfectly competitive markets (i.e., firms do not charge markups).
- ^{ix} Chaney (2008) shows that bilateral fixed and variable costs of trade are important factors in determining the role of a firm's productivity in its participation in export markets (extensive margin of trade) and subsequent export quantity (intensive margin of trade): The higher the bilateral fixed and variable costs, the lower the extensive margin of trade; the higher the variable cost the lower the intensive margin. Similarly, Helpman et al. (2008) show that bilateral trade frictions between countries influence firms' exports to different destinations and their export values. These models have been widely used in empirical analyses with gravity models. For example, see the application of Chaney (2008), and Helpman et al. (2008) on the impacts of bilateral frictions on food trade in Chevassus-Lozza and Latouche (2012), and Eum et al. (2021), respectively.
- ^x These references are based on the insights in Sutton (2007) and employ different functional forms to link sources of product quality with cost and price components of markups.
- ^{xi} Quality upgrading occurs in response to customer demand in foreign markets, product quality of rivals (De Loecker, 2007), and to the greater incentive to invest in quality upgrading when supplying a larger market (Hallak & Sivadasan, 2013).
- ^{xii} Note: the authors used fixed effects to capture product differentiation when estimating a demand system.
- ^{xiii} Here we also refer to Curzi et al. (2015) who use intermediate input as a proxy for unobserved productivity in the food sector.
- ^{xiv} Note: we use a hurdle model, rather than modern gravity models that consider both the participation and decision to export, as the firm trade data in our study is not destination specific. The hurdle model is also more flexible than a simple Tobit model as export participation and export intensity decisions are determined by different processes, which implies that the impact of the same variable may differ.
- ^{xv} We consider the logs of markups because markups have highly skewed distributions.
- ^{xvi} Note: We are not interested in interpreting the coefficient of the lagged dependent variable and therefore ignore its possible correlation with the error term. Moreover, the Cragg hurdle model assumes that errors for the participation decision (first stage) and the quantity decision (second stage) are uncorrelated. However, the results are not sensitive when this assumption is relaxed (Ricker-Gilbert et al., 2011).
- ^{xvii} Note: De Loecker (2007) uses these instruments in a matching treatment approach to analyze the relationship between firms' productivity and export status. See also Gagné et al. (2015) for the importance of ownership structure on firm export behavior.
- ^{xviii} In addition to the highly skewed distributions observed for markups, an important advantage of using log markups as a dependent variable is that even if all variable inputs that are considered in computing markups are subject to adjustment costs, results of the regression analysis are unchanged as long as the export status is not related to those costs (DLW).
- ^{xix} Consider the correlation of error terms in structural and reduced form models as $\Sigma = \begin{bmatrix} \Sigma_b & \sigma_b \\ \sigma'_b & \sigma^2 \end{bmatrix}$ where Σ_b is the correlation of errors in reduced form models, σ^2 is the variance of errors in structural model, and σ is the correlation of error terms in each reduced form model with the error terms in structural model. The adjusted correlation matrix of reduced form model errors is defined as $\Sigma_{i,b|1} = \Sigma_b - \frac{\sigma_b \sigma'_b}{\sigma^2}$. Accordingly, the cumulative joint distribution of the error terms in the reduced form equations is $\Phi_b^*(\mathbf{l}, \mathbf{u}_b, \Sigma_{i,b|1}) = \int_{l_1}^{u_1} \dots \int_{l_d}^{u_d} \phi(\mathbf{e}, \Sigma_{b|1}) d\mathbf{e}_1 \dots d\mathbf{e}_d$. For details on the likelihood function, see also Stata Press (2019).
- ^{xx} The production function coefficients associated with the markup estimation obtained from all observations is presented in Table A2 of the online Appendix. The estimated coefficients indicate the importance of labor, capital, and material inputs as well as the complementarity of labor and material inputs on firms' gross output.
- ^{xxi} This resembles findings for the distribution of productivity across firms (e.g., Gabaix, 2008).

- xxii The results from the reduced form equations are shown in Table A4, Column 1 of the online Appendix. It can be observed that the instruments significantly impact firm markups, particularly when the outliers are removed, which speaks for the suitability of instruments.
- xxiii Note: the average marginal effect (AME) of markup on export participation is $AME = \Delta P / \Delta L \eta \mu$ where P is the probability of export participation. We use a linear approximation of $\Delta P / \mu$ as follows: $\Delta P = AME * (L \eta \mu_2 - L \eta \mu_1) \Rightarrow \Delta P = AME * L \eta \left(\frac{\mu_2}{\mu_1} \right)$. Accordingly, a 1% rise in markup results in $\Delta P = AME * L \eta (1.01)$. This indicates that a 1% increase in markups raises the probability of export participation by ΔP percentage points, on average.
- xxiv As in footnote 23, $\Delta EI = AME * L \eta (1.01)$. Accordingly, the percentage change in export intensity is approximated by dividing ΔEI by the average export intensity of firms as reported in Table 1A of the online Appendix.
- xxv As DLW postulate, the small productivity differences shown here could also be related to measurement bias associated with productivity measurement.
- xxvi We refrain from estimating Equations (7) and (9) using firm-fixed-effects as a large number of firms (>90% of exporters) in the dataset do not change their exporting status over time.
- xxvii Due to the asymptotic normality of the estimators, inference based on OLS and panel estimators is possible even in the absence of a normally distributed dependent variable (Wooldridge, 2010a). A sample of 1500 observations is large enough to assume that the central limit theorem will hold (Wooldridge, 2010a), and our dataset comprises more than 15,000 observations.
- xxviii See Hirsch et al. (2020b) for a recent application of quantile regression to agribusiness firm-level data.
- xxix Note: we do not interpret the results from OLS, BE and quantile as causal relationship, as endogeneity is not controlled.
- xxx The results from the reduced form equations are shown in Table A4 of the online Appendix and reveal that both age and ownership structure impact firms' exporting behavior.

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SUPPORTING INFORMATION

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Institutional quality and the duration of agri-food trade flows

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Abstract

Recent trade disruptions and their consequences on supply chains show the importance of stable trade relations for exporters' economic planning and importers' supply security. Both instability in trading partners' economic and institutional environment and differences between them are likely to exacerbate these disruptions. We investigate the role of exporters' institutional quality (IQ) and its similarity with importers' IQ in the stability of trade links. We focus on the trade links of agri-food products exported from sub-Saharan African (SSA) countries to the European Union (EU-28) and consider three dimensions of IQ: 'government selection, monitoring, and replacement'; 'efficiency of policy formulation and implementation'; and 'respect of citizens and state for institutions'. Using a discrete-time duration model, we show that the duration of SSA exports to the EU-28 increases with higher exporters' IQ and similarity of trading partners' IQ. The strongest impact of exporters' IQ is associated with 'government selection, monitoring, and replacement'. In terms of the similarity of trading partners, 'respect of citizens and state for institutions' has the largest impact on trade durations. Our findings suggest that the improvement of countries' IQ may boost the stability of trade relationships. Moreover, the similarity of IQs between trading

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partners supports the stability of trade links and should be carefully considered when establishing new trade relations.

KEYWORDS

Agri-food trade, discrete-time model, institutional quality, trade duration

JEL CLASSIFICATION

F14; P48; Q17; Q18

1 | INTRODUCTION

Given the substantial costs of establishing new trade relationships, the successful maintenance of existing trade relationships, that is, their long-term survival, is crucial for the success of exporters and importers. Stable trade relations contribute to the income of producers in exporting countries and the availability of product varieties in importing countries, which have welfare implications on both sides of the trade relationship. However, bilateral trade links across sectors can be short-lived, suggesting that specific factors hinder their continuity (Besedeš and Prusa, 2006a; Bojnec and Fertő, 2018; Hess and Persson, 2011; Nitsch, 2009). Recent advances in modelling the dynamics of heterogeneous firms' decisions to engage in costly export markets emphasise the role of variable trade costs (Melitz, 2003) and uncertainty in explaining the stability of bilateral trade relationships (Rauch and Watson, 2003; Bernard et al., 2009; Segura-Cayuela and Vilarrubia, 2008). The institutional environment of trading partners also has an impact on both uncertainties and variable costs (Martínez-Zarzoso and Márquez-Ramos, 2019; North, 1991), and can affect the stability of trade relations. Consequently, the role of institutional quality (IQ) factors can be important for firms' selection of trade partners to reduce uncertainties and for policy planners seeking to boost the stability of trade relations and/or to adjust their institutional environment.¹

We investigate the impact of trading partners' IQ on the stability of trade relationships along the extensive margin of trade. We use the information on agri-food export flows from sub-Saharan African (SSA) countries to the individual European Union (EU-28) countries, as an example. More specifically, we analyse the impact of exporters' IQ and the similarity of IQ between partner countries on the duration of trade (the time from the start of a trade relation to its end). We also examine the impact of different attributes of exporters' IQ and their similarity with that of importers on the duration of trade. The attributes we identify are: 'government selection, monitoring, and replacement'; 'efficiency of policy formulation and implementation'; and 'respect of citizens and state for institutions'. Finally, we rank the importance of these attributes with regard to their impact on trade duration.

We focus on agri-food exports from SSA countries to the individual EU-28 members for several reasons. In many countries in SSA, the agri-food sector has the largest share in GDP and trade, indicating the importance of this sector. The EU-28 and even several individual EU-28 countries are major destinations for SSA agri-food exports (WITS, 2021; World Bank, 2021a; World Bank, 2021b)² whereas the duration of these trade relationships are low

¹Countries worldwide have recently implemented institutional reforms as the drawbacks of institutional instabilities are evident (Boudreaux and Holcombe, 2018; Kanani and Larizza, 2021). Countries are also concerned about the stability of their trade relationships (WTO, 2018; Huang et al., 2020).

²The Netherlands, the UK and France are the top three destinations of food products from SSA (WITS, 2021).

with, on average, 2.5 years.³ Moreover, the majority of countries located in SSA are least developed countries with low levels of IQ (see [Appendix S1](#)), but are trying to improve their IQ (AFDB, 2021). The EU-28 countries have, on average, higher IQs leading to substantial differences between IQs of the country-pairs involved in EU-SSA trade relationships. Consequently, the SSAs' export flows to the EU-28 countries are interesting for the analysis of the impact of IQ of exporters and its similarity with that of importers on trade duration.

Trade relations are initiated when both exporters and importers expect benefits from the exchange of goods over a sufficiently long period of time so that at least the costs of establishing a trade link are covered (Besedeš and Prusa, 2011). Upon successful entry, firms may revise their decisions at any time, depending on the changes in operating profits and the level of uncertainty they face. Reducing uncertainty is the major contribution of functioning institutions, which can help create stability for human interaction (North, 1991). In exporting countries, IQ is related to uncertainties associated with bilateral trade frictions, production and demand conditions, and the non-market factors that increase the firms' risk of exiting the export market (Nguyen, 2012; Besedeš and Prusa, 2011). Further, the similarity of IQ between trading partners is important. A greater similarity in the institutional environment leads to more confidence among economic agents due to partners' comparable formal procedures, behavioural norms and levels of trust in conducting business (Groot et al., 2004). This might reduce uncertainties regarding trading partners' mutual expectations. The IQ environment also affects fixed and variable costs relevant for trade through several channels such as contracting, investment, productivity, comparability, trust and transparency (Martínez-Zarzoso and Márquez-Ramos, 2019). (Unexpected) changes of these costs carry further implications for export participation and continuation (see Chaney, 2008; Helpman et al., 2008).

Empirical evidence on the role of IQ of trading partners and institutional similarity in trade duration is limited. A study by Bojnec and Fertő (2012) is to our knowledge the only research that examines the impact of exporters' IQ on the duration of exports. They find that IQ increases the duration of the EU agri-food exports. However, further empirical studies investigate the impact of IQ on the quantity of trade (Álvarez et al., 2018; Nunn and Trefler, 2014; Martínez-Zarzoso and Márquez-Ramos, 2019). These show that higher IQ reduces trade barriers, for example, due to greater transparency and reduced uncertainty between trading partners.

We contribute to the literature in two ways. First, we show the impact of different IQ indicators on the duration of trade. Compared to Bojnec and Fertő (2012), who analyse the impacts of the EU enlargement on its agri-food exports, we explore the relative importance of different dimensions of IQ with a focus on the exports of SSA countries to the EU-28. Second, we examine the effect of institutional dissimilarity between exporters and importers on the duration of bilateral trade for different dimensions. We use the trade flow information from 1996 to 2017 for each SSA country to the individual EU-28 countries at the HS 6-digit level to perform a duration analysis using the Kaplan–Meier survivor function that shows the probability of exports surviving a certain number of years. To analyse the impact of trading partners' IQs on trade durations, we use discrete-time analysis (Hess and Persson, 2012) as trade relationships are reported in discrete units of yearly length.

The remainder of this paper is structured as follows. Section 2 reviews relevant theoretical and empirical literature on IQ and the duration of trade relationships. Section 3 presents the methods used for analysing the impact of institutional factors on trade duration. Sections 4 and 5 present the data description and results, respectively, and Section 6 concludes.

³See also Rudi et al. (2012), who find low survival rates of exports from Africa.

TABLE 1 Institutional quality indicators

IQ dimension	WGI (World Bank)	Explanation
(A) Government selection, monitoring and replacement	Voice and Accountability	Citizens' ability to participate in government selection, freedom of expression, freedom of association and freedom of media
	Political Stability and Absence of Violence/ Terrorism	Likelihood of government destabilisation by politically motivated violence and terrorism
(B) Efficiency of policy formulation and implementation	Government Effectiveness	Quality of public services, quality of civil service and its degree of independence from political pressures, quality of policy formulation and implementation, and credibility of the government's commitment to such policies
	Regulatory Quality	Government's ability to formulate and implement sound policies and regulations that permit and promote private sector development
(C) Respect of citizens and state for institutions	Rule of Law	Agents' confidence in abiding by the rules of society (quality of contract enforcement, property rights, the police and courts) and likelihood of crime and violence
	Control of Corruption	The extent of exercising public power for private gain (petty and grand forms of corruption) and capture of the state by elites and private interests

Note: The annual indicators are created by Kaufmann and Kraay using an unobserved component model (UCM). They are based on 31 data sources and are available from 1996.

Source: Own illustration based on Kaufmann et al. (2010).

2 | BACKGROUND AND DERIVED HYPOTHESES

Duration of trade is defined as the number of consecutive years with uninterrupted trade flows of a specific product between two trade partners. Recent studies reveal short trade durations across sectors, with means between 2.7 and 5.7 years and medians of 1 and 2 years (e.g., Besedeš and Prusa, 2006a; Peterson et al., 2017; Hess and Persson, 2011).⁴ Although no specific theory explains the duration of trade, different trade theories, including those on firms' export behaviour and buyers' behaviour in the export destination markets, suggest reasons for (non-)continued trading on an already established trade link.

An exporting firm's decision on initiating, continuing or terminating a trading activity is inherently a decision under uncertainty. Assuming risk-neutral firms, a firm exports if the associated expected profit over the planned period is at least as large as the fixed costs of establishing an export link (see e.g., Melitz, 2003). Since expected profits are not always earned, firms revise their expectations once they enter the export market or during their ongoing trade relation (Nguyen, 2012; Besedeš and Prusa, 2011). One reason for unexpected changes in profits is the uncertainty of market and non-market conditions in exporter countries, importer countries, or both (Fera et al., 2017; Bodt and van Wassenhove, 1983), which can lead to changes in production costs and domestic demand conditions (see Esteves and Rua, 2015 for a review), in the export market's competition level (see Bernard et al., 2009), or in trading costs due to changing tariff and non-tariff measures (see Chaney, 2008; Helpman et al., 2008). The revision of exporters' expectations is based on changes in uncertainty and actual market conditions.

Trade links are also established and (dis-)continued at the discretions of buyers, that is, importers, taking uncertainty into account. Buyers search for the supplier with the lowest price among all possible sellers of the desired product with a certain quality (Rauch and Watson, 2003). Once a suitable supplier, that is, exporter, is found, they bear the costs of establishing a trade relationship and revise the trade decision every time unexpected changes occur.⁵ Importers establish new trade relations if these costs are lower than their expected operating profits. Their decision to continue trading with an exporter or to shift to another supplier depends on the ability of sellers to meet their expectations (Peterson et al., 2017).

IQ plays a crucial role in the entry and continuation decisions through its impact on uncertainty and costs for importers and exporters. IQ relates to how authority in a country is exercised. IQ has been more specifically defined by Kaufmann et al. (2010) as: 'the process by which governments are selected, monitored, and replaced'; 'the capacity of the government to effectively formulate and implement sound policies'; and 'the respect of citizens and the state for the institutions that govern economic and social interactions among them' (Kaufmann et al., 2010, p. 4; see Table 1). These dimensions of IQ affect trade duration through different pathways and cost elements (see Álvarez et al., 2018; Bojnec et al., 2014; Lin et al., 2019; Martínez-Zarzoso and Márquez-Ramos, 2019).⁶ Better IQ (1) facilitates contracting between companies; (2) leads indirectly to investment and firms' productivity

⁴For example, Besedeš and Prusa (2006a) find an average duration of 2.7 years and a median of 1 year for the US imports from 160 countries, and an especially low survival rate of exports from Africa (48% survive after 1 year of trade). Later, Besedeš and Prusa (2011) study the export survival of 46 countries and find that more than 50% of the relations fail in the first 2 years. Hess and Persson (2011) and Nitsch (2009) find an average import duration of 3.3 years and medians of 1 and 2 years, respectively. In addition, Rudi et al. (2012) find a mean export duration of 5.7 years for fresh fruits and vegetables trade.

⁵Since agri-food products are subject to numerous product standards, buyers might face relatively high costs for finding the trading partners meeting such standards or training them to comply with those standards (Bojnec et al., 2014; Peterson et al., 2017). We note that these training and time costs vary between products depending on product differentiation, which affects the ease of switching to another trade partner and, therefore, the trade duration (Besedeš and Prusa, 2006b).

⁶See also Anderson and Marcouiller (2002); Bojnec et al. (2014); Berden et al. (2014); Besedeš and Prusa (2002); Levchenko (2007); Márquez-Ramos (2011); Nguyen (2012).

improvements; (3) facilitates custom procedures; and (4) increases transparency and comparability. The IQ dimensions further differ in their impact on uncertainty, that is, how they (5) enhance trust between trading partners⁷ and (6) stabilise factors that affect firms' business environment.⁸ Although IQ dimensions are interlinked, dimension (A) may relate most to channels 2 and 6, dimension (B) to channel 1, and dimension (C) to channels 3, 4 and 5. The direction of IQ dimensions on trade duration could also differ. For example, higher voice and accountability (dimension A) may be associated with bargaining power of workers and through channel 2 reduce trade duration, but better control of corruption (dimension C) increases domestic investment through channel 2 and may increase trade duration (Berden et al., 2014).⁹

Bojnec and Fertő (2012) create one IQ indicator applying Principal Component Analysis to different dimensions of IQ, that is, all six World Bank Worldwide Governance Indicators (WGI), and integrate this composite into an extended Cox proportional hazard model (Cox, 1972) to estimate the impact of IQ on the survival rate of trade links. Their findings show that an overall measure of IQ increases the duration of EU agri-food exports. Nonetheless, there is a lack of an empirical analysis of the impact of individual dimensions of the institutional environment on trade duration. Literature that focuses on other determinants affecting trade duration find that in general, factors that reduce trade costs lead to lower failure rates and, consequently, to longer bilateral trade duration (e.g., Bacchetta et al., 2012; Besedeš and Prusa 2006b; Hess and Persson 2011; Nitsch 2009). Since higher IQ can reduce trade costs, (Anderson and Marcouiller, 2002; Álvarez et al., 2018) this might lead to an increase in trade duration. Against this background, we hypothesise (H1a) that a higher IQ of SSA exporters leads to longer bilateral trade duration. Additionally, because of the different impact pathways of IQ dimensions, we hypothesise (H1b) that the various dimensions of IQ have different effects on the trade duration.

Trade relationships are affected by both countries' IQ and the similarity of importers' and exporters' IQ (Álvarez et al., 2018; Fiankor et al., 2019; Yu et al., 2010). Similarity of IQs can affect transaction costs and the uncertainty related to trade links. It may reduce the transaction cost but its impact on uncertainty may depend on the absolute level of IQs of both partners involved. With respect to the transaction costs, Álvarez et al. (2018) argue that similarity among trading partners reduces trade costs due to familiarity regarding their institutional environment. For example, Horsewood and Voicu (2012) analyse the impact of importers' and exporters' corruption levels on trade flows between Romania and Bulgaria. They show that countries with similar business ethics and mutually acceptable practices for cross-border transactions tend to trade more. With regard to the uncertainty component of IQ similarity, trading with low IQ partners may increase the risk of deviations from expectations (Martínez-Zarzoso and Márquez-Ramos, 2019). Further, Ben Ali and Mdhilat (2015) suggest that countries with high ethical standards would risk reputation when trading with a corrupt country. Consequently, countries with high IQ might prefer partner countries with same IQ standards, and, for example, increasing corruption in one partner country could lead to the termination of the trade link to avoid reputational

⁷For example, Bojnec et al. (2014) indicate the role of IQ for meeting standards, which are particularly high for food consumed in the EU (European Commission, 2021), as better IQ increases transparency and reduces uncertainty.

⁸See also Horsewood and Voicu (2012) and Ben Ali and Mdhilat (2015).

⁹We note that the mentioned studies empirically analysed IQ impacts on trade values but not on the trade duration. Anderson and Marcouiller (2002) and Jansen and Nörðas (2004) identify market competition, legal security and corruption as the most important impact factors on trade values. Álvarez et al. (2018) find stronger effects of countries' regulatory quality, governmental effectiveness and rule of law compared to the voice and accountability, political stability and control for corruption. Lin et al. (2019) conclude that voice and accountability is relevant for the degree of cooperation in the production process and workers' bargaining, government effectiveness mainly affects the ability of contract enforcement, and monitoring is generally important for both the production process and trade relations.

damage. The overall impact of IQ similarity and its different dimensions on trade duration depends on the combined effect through transaction cost and uncertainty channels. Considering that EU-28 countries have generally high IQs, they would trade more with SSA countries of high IQs to reduce both the associated uncertainty and transactions costs. In this context, we hypothesise (H2a) that the greater the similarity of IQs between SSA countries and their EU-28 trading partners, the greater the probability of a longer bilateral trade duration. Finally, we hypothesise (H2b) that the various dimensions of similarity in IQ differ with respect to their effects on the trade duration.

3 | METHODOLOGY

We apply the Kaplan–Meier survivor function to perform a descriptive duration analysis of the SSA-EU agri-food trade and use different discrete-time regression models to identify the effects of IQ and its various dimensions on the duration of trade.

Survival analysis estimates the expected time until one or more events happen, which we apply in the context of trade duration. We define an event as the failure of a trade relation after one or several successive years of trade (e.g., Besedeš and Prusa, 2006a; Besedeš and Prusa, 2006b; Hess and Persson, 2011; Nitsch, 2009; Peterson et al., 2017; Rudi et al., 2012). We follow Besedeš et al. (2016) and define the term ‘trade relation’ as the trade of a specific product between two countries. For each trade relation, the time from the first trade flow in any given year until the year, in which the trade stops, is called a ‘spell’ (Hess and Persson, 2011, p. 666). When two countries re-start trading a specific product, the trade relation has ‘multiple spells’ (Hess and Persson, 2011, p. 671). The number of consecutive trade years of a spell is the ‘length of spell’ representing the trade duration of that spell (Hess and Persson, 2011, p. 666).¹⁰

To calculate the probability of a spell of length k , we estimate the survival function $\hat{S}(t)$ using the non-parametric Kaplan–Meier (KM) survival estimator of the hazard function. Thus, we calculate the probability of spells' survival in period t , given that the length of spell lasted until k using (Kaplan and Meier, 1958; Nicita et al., 2013).

$$\hat{S}(t) = \prod_{t(k) < t} \frac{n_k - d_k}{n_k} \quad (1)$$

The KM estimator is a standard measure in survival analysis and robust to censoring; however, it does not capture any functional relationship between trade survival and its covariates (Besedeš and Prusa, 2006a). We complement the analysis with a model that allows us to investigate the effects of IQ indicators and other factors on the duration of SSA–EU trade relations. Studies on trade duration widely use the Cox (1972) proportional hazard model (Besedeš and Prusa, 2006b; Rudi et al., 2012). However, Hess and Persson (2012) argue that the application of the Cox hazard model is unsuitable for analysing the determinants that affect trade duration because, first, the data are grouped into discrete units, while the Cox hazard model relies on a continuous-time specification leading to biased estimations. Second, it is difficult to properly control for unobserved heterogeneity using the Cox approach, which can create spurious negative duration dependence of the estimated survivor functions and biased parameters. Third, the Cox hazard model restricts the independent

¹⁰For example, Ghana exported eggplants to the UK in 1994 and 1995. Thus, the length of the first spell is 2 years. As Ghana exported eggplants again to the UK from 2003 to 2011, this trade relation reveals an example for multiple spells. In our analysis, we consider multiple spells.

variables from having a constant effect on the hazard rate across a spell, but this is not expected for many explanatory variables (see for further discussion Hess and Persson, 2012). Following Hess and Persson (2012), we use the discrete-time model for our impact analysis on trade duration.

In the discrete-time hazard model, export duration is estimated as a conditional probability that the export of one specific product will terminate in a particular time interval $[t_k, t_{k+1}]$, whereas $k = 1, 2, \dots, k_{max}$, and $t_1 = 0$, given that the export of this specific product already lasted until this time interval. In this model, the estimated conditional probability is explained by independent variables x_{ik} . Consequently, the discrete-time hazard rate h_{ik} , that is, the probability of termination of a specific spell i at time interval k , can be defined as (Hess and Persson, 2012).

$$h_{ik} = P(T_i < t_{k+1} | T_i \geq t_k, x_{ik}) = F(x'_{ik}\beta + \gamma_k), \quad (2)$$

where T_i is a non-negative continuous random variable denoting the length of the spell. x'_{ik} denotes a vector of time-varying explanatory variables, and β refers to their corresponding coefficients. An appropriate distribution function $F(\cdot)$ ensures that the hazard rate h_{ik} lies in the range from zero to one for all i and k . γ_k refers to a function of time allowing the hazard rate h_{ik} to vary over time (Hess and Persson, 2012) captured in our discrete-time model by year-specific dummies.

The discrete-time hazard model can be estimated using the log-likelihood function,

$$\ln \mathcal{L} = \sum_{i=1}^n \sum_{k=1}^{k_i} [y_{ik} \ln(h_{ik}) + (1 - y_{ik}) \ln(1 - h_{ik})], \quad (3)$$

where y_{ik} is a binary variable equal to one if the spell i ends in the time interval k , that is, if the trade relation fails, and zero if trade occurs.

We follow Hess and Persson (2012) and assume that the hazard rate has a normal distribution and estimate Equation (3) using the probit model. To test the sensitivity regarding this assumption, we re-estimate Equation (3) with a logit model, which underlies the assumption of a logistic distribution (Hess and Persson, 2011). With regards to the hazards assumption, the probit model imposes non-proportionality, whereas the logit model only slightly deviates from the proportional hazards assumption of the Cox (1972) model (Hess and Persson, 2012).

Specifically, we estimate the hazard rates of exports using

$$y_{odpk} = \delta_0 + \delta_1 IQ_{o(k-1)} + \delta_2 prod_p + \tau_{od} \delta_3 + X_{odp(k-1)} \delta_4 + \lambda_o \delta_5 + \lambda_d \delta_6 + \lambda_k \delta_7 + \varepsilon_{odpk}, \quad (4)$$

where the dependent variable y_{odpk} equals one if the spell (of a specific product p between origin o and destination d) fails in k given that trade continuously occurred in previous year(s), and zero if the spell survives.

$IQ_{o(k-1)}$ denotes the IQ of exporters, that is, the SSA countries, which lags by 1 year, to reduce potential endogeneity/reverse causality where bilateral trade flows may influence IQ (Nunn and Trefler, 2014; Álvarez et al., 2018). Álvarez et al. (2018) also note that institutions likely affect trade with a time lag. With the estimate of $IQ_{o(k-1)}$, we test H1a, that is, higher IQ of SSA exporters leads to longer bilateral trade duration. We iterate the regression for the overall exporter IQ and each dimension of IQ (Table 1).

The binary variable $prod_p$ refers to the classification into agricultural commodities (zero; less differentiated) and processed food products (one; more differentiated), which we expect

to influence the costs of establishing trade links and hence trade duration (Besedeš and Prusa, 2006b; Rauch and Watson, 2003). Given that switching between different suppliers, from a buyers' perspective, is easier in the case of homogeneous commodities than with differentiated products, we anticipate longer trade durations for processed food products (Besedeš and Prusa, 2006b). The vector τ_{od} in Equation (4) captures several trade cost variables such as countries' landlock status as well as trading partners' colonial ties, language conformity and bilateral distance. Studies on trade duration show that being landlocked, having no colonial ties or a common official language, and a longer bilateral distance may increase trade costs and lead to a shorter trade duration (Bacchetta et al., 2012; Nitsch, 2009; Besedeš, 2011).

Vector $X_{odp(k-1)}$ includes time-variant control variables such as the GDPs of exporters and importers as measures of economic size and the exporters' exchange rate as a proxy for an economy's stability (Bojnec and Fertő, 2012). We consider these variables typically used in gravity models and commonly introduced in duration analyses to control for their effects on the duration of SSA agri-food exports to the EU-28 (e.g., Bacchetta et al., 2012; Besedeš and Prusa, 2006b; Hess and Persson, 2011). Better economic performance (higher GDPs) may implicate longer, more stable trade relations (Besedeš and Prusa, 2006b). A longer trade duration may involve a higher exchange rate of the exporting country as weaker currencies stimulate exports due to relatively cheaper prices for importing countries and, in turn, enhance the probability of trade survival (Krugman et al., 2011). $X_{odp(k-1)}$ also captures variables of exporters' experience, that is, the number of EU destination countries per product and the number of products traded to one destination. Greater diversification and, thus, more experience with the export of specific products and markets may lead to a longer trade duration (Brenton et al., 2010; Hess and Persson, 2011). All the time-variant covariates are included in the model with a one-year lag to reduce potential biases associated with reverse causality.

We introduce exporter-specific fixed effects (λ_o), importer-specific fixed effects (λ_d), and time dummies (λ_k). Incorporating exporter and importer fixed effects captures remaining country-specific differences that are not explicitly identified by the introduced country-specific variables. They are regularly used in the empirical gravity model specification of international trade flows, capturing the outward and inward multilateral resistance terms, that is, the exporters' ease of market access to and importers' ease of market access from all countries in the trade network, respectively (Yotov et al., 2016). The use of yearly time fixed effects controls for common shocks such as global economic booms or slowdowns in a given year (Baldwin and Taglioni, 2006). ε_{odpk} is the error term.

To examine the impact of institutional dissimilarity of trading partners on trade survival, we use Equation (4) and estimate effects of the dissimilarity of IQ (overall and different dimensions) $IQ_{o(k-1)-d(k-1)}$ instead of the IQ of exporters $IQ_{o(k-1)}$, which addresses H2a, that is, greater similarity in the IQ of an SSA country and an EU-28 country, the higher is the probability of achieving longer bilateral trade duration.

We calculate marginal effects of the regression coefficients to assess the sizes of the IQ (overall and different dimensions) effects on the probability of trade failure. Additionally, we standardise the IQ indicators' marginal effects and consider confidence intervals to evaluate the differences in the effect among the three dimensions, thereby addressing H1b and H2b, that is, the various dimensions of IQ and of the similarity in IQ differ with respect to their effects on the trade duration.¹¹

¹¹Following Menard (2004), we partially standardise the marginal effects with the standard deviations of the explanatory variables.

4 | DATA AND DESCRIPTIVE STATISTICS

For our analysis, we use annual trade data from the UN Commodity Trade Statistics Database (Comtrade) at HS 6-digit level for 1996–2017 (United Nations, 2019). The sample includes agri-food trade flows from each SSA country to each EU-28 country. [Appendix S1](#) show the SSA countries and product groups included in the analysis. We use the import data reported by the EU-28 as import statistics are more reliable than export statistics (Jacob, 2016).

The trade data are limited to a specific period, that is, censored (Verbeek, 2008), either flows/spells ongoing in 1996 or flows/spells ongoing in 2017 (Besedeš and Prusa, 2006b; Verbeek, 2008). The first (left-) censoring is problematic, leading to estimation bias, whereas we can neglect right-censoring in duration analyses (Hess and Persson, 2012). Following Peterson et al. (2017), we use the trade data available before the investigation period (limited by the data availability of the WGIs) starting from 1988 to control for left-censored spells.

We consider the six IQ indicators retrieved from the World Bank's WGI database (Kaufmann and Kraay, 2021). For assessing a country's IQ, (A) the government selection, monitoring and replacement; (B) the governmental efficiency of policy formulation and implementation; and (C) the respect of citizens and state for institutions are relevant characteristics (Kaufmann et al., 2010). [Table 1](#) describes the three dimensions (A–C) and the underlying indicators of the World Bank's WGIs. The WGIs are in standard normal units ranging from approximately -2.5 to 2.5 . The higher the value, the better the IQ (Kaufmann et al., 2010). These data are available from 1996 to 2017; however, from 1996 to 2002, they were only published for every second year, leading to three missing (1997, 1999 and 2001) observation years. We follow Lin et al. (2019) and use the values of each previous year for the missing observations. Looking at the WGI scores of all SSA and EU-28 countries in 2017 ([Appendix S1](#)) shows that the IQ of the EU-28 ($\mu = 1.02, sd = 0.54$) is higher than the IQ of SSA countries ($\mu = -0.69, sd = 0.72$).¹²

The six IQ indicators are highly correlated (see [Appendix S1](#)). To avoid the problem of multicollinearity, we aggregate the six indicators into a single index, which provides the overall impact of IQ. In addition, we examine the three major dimensions (A–C) of the World Bank's WGIs in separate regressions to identify the effects of the different aspects of IQ (following Bojnec and Fertő, 2012; Globerman and Shapiro, 2002; Asongu and Nwachukwu, 2016; Daude and Stein, 2007). For the aggregation, we employ Principle Component Analysis (PCA). We use the first components of the PCAs that suit the Kaiser–Guttman criterion as their eigenvalues are greater than one in each of the PCAs (Ismail, 2008) and capture high shares of the overall variance of their underlying indicators (see results of the PCAs in [Appendix S1](#)).¹³

The dissimilarity index is calculated as the absolute difference between the exporter and importer IQ index for the six indicators ($|IQ_o - IQ_d|$), and then we apply PCA to calculate an aggregated dissimilarity index and one for each dimension. Our main analysis consists of estimating eight regressions: the first four consider the impact of the overall exporters' IQ and the three dimensions of IQ on trade duration; the following four use the dissimilarity indices instead of the exporters' IQ indices.

[Appendix S1](#), presents an overview of our main variables, the control variables, their definitions and sources. [Table 2](#) provides descriptive statistics. The statistics of the three

¹²Finland is the country with the best IQ (WGIs range from 1.08 to 2.22) among all EU and SSA countries, whereas Somalia scores lowest (-2.31 to -1.72).

¹³For the aggregation to the three dimensions, one can alternatively calculate the mean or sum of the underlying WGIs; see Groot et al., 2004; 2005; Linders et al. (2005). We apply the sum approach as a robustness check.

TABLE 2 Descriptive statistics of the variables

Variable	Mean	Std. dev.	Min.	Max.	N
Trade relation failure (0 = survival, 1 = failure)	0.25	0.43	0	1	274,329
IQ dimension (A)	0.98	1.99	−6.05	5.37	273,094
IQ dimension (B)	−0.18	0.48	−2.37	1.98	273,094
IQ dimension (C)	−0.07	0.28	−1.45	1.06	273,094
Dissimilarity of IQ, dimension (A)	0.01	1.19	−2.13	5.11	270,997
Dissimilarity of IQ, dimension (B)	−0.02	1.27	−2.56	5.71	270,997
Dissimilarity of IQ, dimension (C)	−0.03	1.39	−3.28	4.16	270,997
Landlocked (0 = no country is landlocked, 1 = at least one trade partner is landlocked)	0.19	0.39	0	1	274,329
Colonial ties (0 = no colonial ties, 1 = colonial ties)	0.16	0.36	0	1	274,329
Common language (0 = no common language, 1 = common language)	0.21	0.41	0	1	274,329
Distance (km)	6631	1969	2183	10,487	274,329
Exchange rate (ln of LCU/USD)	4.38	2.58	−4.60	22.63	261,746
Exporter's product diversification (number of products exported to the destination)	61.52	78.90	0	488	274,329
Exporter's market diversification (number of destinations the product is exported to)	5.50	5.72	0	28	274,329
GDP exporter (billion USD constant 2010)	102.40	149.75	0.12	464.00	264,697
GDP importer (billion USD constant 2010)	16,906	73,579	11.07	44,200	272,413
Product classification (0 = agricultural commodity, 1 = food product)	0.26	0.44	0	1	274,329

Source: Own calculations based on data extracted from various databases (CEPII, 2021; United Nations, 2019; Kaufmann and Kraay, 2021; World Bank, 2021c, World Bank, 2021d).

IQ dimensions suggest heterogeneity of their underlying data, for example, the IQ (A) in terms of the government selection and monitoring in the SSA countries ($\mu = 0.98, sd = 1.99$) range from -6.05 to 5.37 across countries and time. The means of the binary variables show that for more than three-fourths of the reported trade links, countries are not landlocked, do not have any colonial ties, and do not share a common language. Additionally, there is a large gap between the GDPs of SSA ($\mu = 102, sd = 149$) and EU ($\mu = 16,906, sd = 73,579$) countries.

5 | RESULTS

Our data reveal substantial entries and exits in agri-food trade flows between SSA and EU-28 countries, with mean and median lengths of spell of 2.53 years and 1 year, respectively. The KM survivor function of these trade flows (Figure 1) shows the unconditional survival probability of trade links for every year of trade duration. The probability of trade failure increases

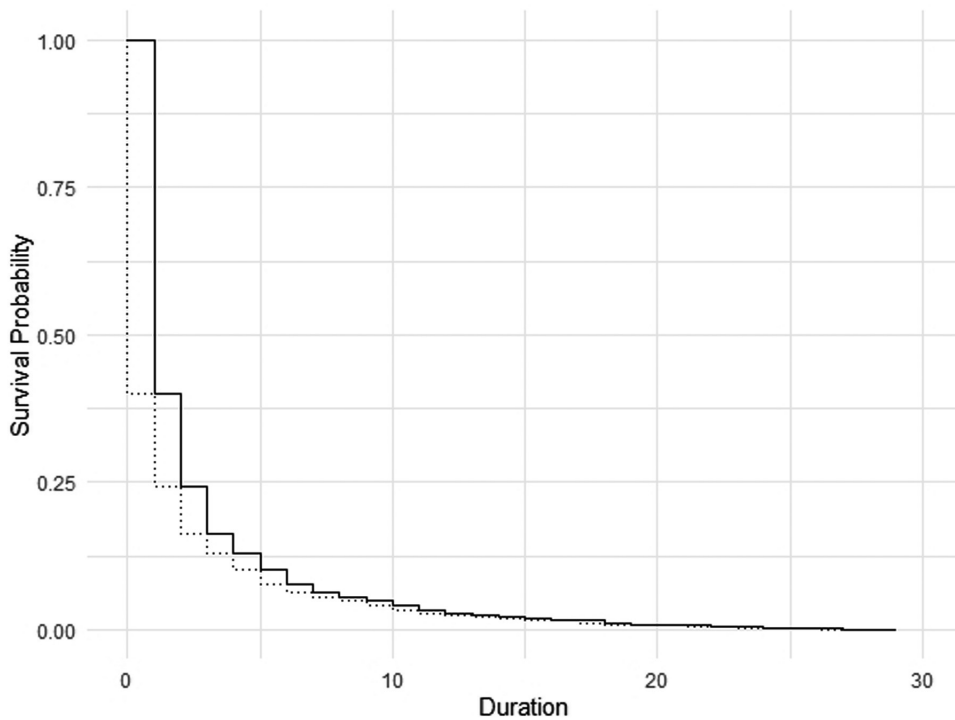


FIGURE 1 Kaplan–Meier survival function

Note: The Kaplan–Meier survival function shows the decreasing survival probability for each length of spell (i.e., the duration) of SSA's agri-food exports (see [Appendix S1](#) for SSA countries and [Appendix S1](#) for product groups) to the individual EU-28 countries from 1988 to 2017.

Source: Own calculation and illustration based on UN Comtrade data (United Nations, 2019).

with each additional year of spell length. After 1 year of trade, trade links fail with a probability of 60%. Until the end of the first 3 years, there is an 84% probability of failure. Only a small fraction of spells achieves durations longer than 10 years. We find higher failure rates and a lower mean of duration than other studies that show failure rates between 33% and 61% in the first year of trade and means of duration between 2.7 and 5.9 years (Besedeš and Prusa, 2006b; Nitsch, 2009; Rudi et al., 2012). This instability of trade relations is consistent with Rudi et al. (2012), who find particularly low survival rates of export flows from Africa.

Findings reveal that exporters with high IQ achieve longer trade durations than exporters with low IQ and, thus, support hypothesis H1a. In [Table 3](#), we show the impact of the overall indicator of exporters' IQ (column 1) and its different dimensions (columns 2 to 4) on the probability of trade failure. The marginal effect of the overall quality indicator shows a 0.78% reduction in the probability of survival of agri-food exports from SSA to EU-28. When differentiating between IQ dimensions, all dimensions (A–C) negatively impact the trade failure rate, that is, an increase in IQ reduces trade failure. A one-unit increase of the exporter's IQ dimensions decreases the probability of trade failure by 1.11 to 1.79 percentage points.

Our results ([Table 4](#)) also suggest that greater dissimilarity of SSA–EU trade partners' IQ is associated with smaller bilateral trade durations, supporting hypothesis H2a. The marginal effect (column 1) indicates that a one-unit increase in the institutional dissimilarity indicators increases the probability of trade failure by 0.29 percentage points. This is consistent with the study of Álvarez et al. (2018), who state that less familiar institutional environments in partner countries lead to a reduction in trade quantities due to higher transaction costs. Similarly, we

TABLE 3 Probit marginal effects—Exporters' institutional quality

	Overall IQ index	(A) Government selection, monitoring and replacement	(B) Efficiency of policy formulation and implementation	(C) Respect of citizens and state for institutions
Inst. quality exporter	−0.01*** [−0.01, −0.01]	−0.01*** [−0.01, −0.01]	−0.01** [−0.02, −0.00]	−0.02*** [−0.03, −0.01]
Exchange rate	−0.00 [−0.01, 0.00]	−0.01*** [−0.01, −0.00]	−0.01*** [−0.01, −0.00]	−0.01*** [−0.01, −0.00]
Product classification	−0.01*** [−0.01, −0.008]	−0.02*** [−0.02, −0.01]	−0.02*** [−0.02, −0.01]	−0.02*** [−0.02, −0.01]
Exporter's product diversification	−0.00*** [−0.00, −0.00]	−0.00*** [−0.00, −0.00]	−0.00*** [−0.00, −0.00]	−0.00*** [−0.00, −0.00]
Exporter GDP	−0.01*** [−0.01, −0.01]	0.0003 [−0.02, 0.02]	−0.02* [−0.03, −0.00]	−0.02** [−0.03, −0.01]
Importer GDP	−0.02*** [−0.02, −0.02]	−0.00 [−0.00, 0.00]	−0.00 [−0.00, 0.00]	−0.00 [−0.00, 0.00]
Exporter's market diversification	−0.02 *** [−0.02, −0.02]	−0.04*** [−0.04, −0.04]	−0.04*** [−0.04, −0.04]	−0.04*** [−0.04, −0.04]
Language	−0.02*** [−0.03, −0.01]	−0.02*** [−0.03, −0.01]	−0.02*** [−0.03, −0.01]	−0.02*** [−0.03, −0.01]
Colonial ties	−0.00 [−0.01, 0.01]	−0.01 [−0.01, 0.00]	−0.01 [−0.01, 0.00]	−0.01 [−0.01, 0.00]
Landlocked	−0.01 [−0.03, 0.02]	0.05** [0.02, 0.08]	0.03 [−0.01, 0.06]	0.02 [−0.01, 0.05]
Distance	0.03* [0.01, 0.06]	0.01 [−0.02, 0.03]	0.01 [−0.02, 0.03]	0.01 [−0.02, 0.03]
LogLik	−114,846	−116,448	−116,462	−116,460
AIC	229,903	233,098	233,126	233,123
N	238,886	238,886	238,886	238,886

Note: All time-variant variables are one-year lagged; Logarithms are taken of the distance, GDPs and the exchange rate; Estimations with importer, exporter and time FE; Lower and upper limits of 95% CI in parentheses; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Source: Own calculation based on data sources indicated in [Appendix SI](#).

TABLE 4 Probit marginal effects—Dissimilarity of institutional quality

	Overall IQ index	(A) Government selection, monitoring and replacement	(B) Efficiency of policy formulation and implementation	(C) Respect of citizens and state for institutions
Dissim. of inst. Quality	0.00 ** [0.00, 0.01]	0.00 * [0.00, 0.01]	0.01*** [0.00, 0.01]	0.01 *** [0.01, 0.02]
Exchange rate	-0.00 [-0.01, 0.00]	-0.01 *** [-0.01, -0.00]	-0.01 *** [-0.01, -0.00]	-0.01 *** [-0.01, -0.00]
Product classification	-0.01 *** [-0.01, -0.01]	-0.02 *** [-0.02, -0.01]	-0.02 *** [-0.02, -0.01]	-0.02 *** [-0.02, -0.01]
Exporter's product diversification	-0.00 *** [-0.00, -0.00]	-0.00 *** [-0.00, -0.00]	-0.00*** [-0.00, -0.00]	-0.00*** [-0.00, -0.00]
Exporter GDP	-0.01 *** [-0.01, -0.00]	-0.02 * [-0.03, -0.00]	-0.01 [-0.03, 0.00]	-0.01 [-0.02, 0.01]
Importer GDP	-0.02 *** [-0.02, -0.02]	-0.00 [-0.00, 0.00]	-0.00 [-0.00, 0.00]	-0.00 [-0.01, 0.00]
Exporter's market diversification	-0.02 *** [-0.02, -0.02]	-0.04 *** [-0.04, -0.04]	-0.04 *** [-0.04, -0.04]	-0.04 *** [-0.04, -0.04]
Language	-0.02*** [-0.03, -0.01]	-0.02*** [-0.03, -0.01]	-0.02*** [-0.03, -0.01]	-0.02*** [-0.03, -0.01]
Colonial ties	-0.00 [-0.01, 0.01]	-0.01 [-0.01, 0.00]	-0.01 [-0.01, 0.00]	-0.01 [-0.02, 0.00]
Landlocked	-0.01 [-0.03, 0.02]	0.03 [-0.01, 0.06]	0.03 [0.00, 0.06]	0.05** [0.01, 0.08]
Distance	0.03 * [0.01, 0.06]	0.00 [-0.02, 0.03]	0.00 [-0.02, 0.03]	0.01 [-0.02, 0.03]
LogLik	-113,873	-115,388	-115,385	-115,376
AIC	227,957	230,976	230,969	230,953
N	237,014	237,014	237,014	237,014

Note: All time-variant variables are one-year lagged; Logarithms are taken of the distance, GDPs and the exchange rate; Estimations with importer, exporter and time FE; Lower and upper limits of 95% CI in parentheses; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Source: Own calculation based on data sources indicated in [Appendix SI](#).

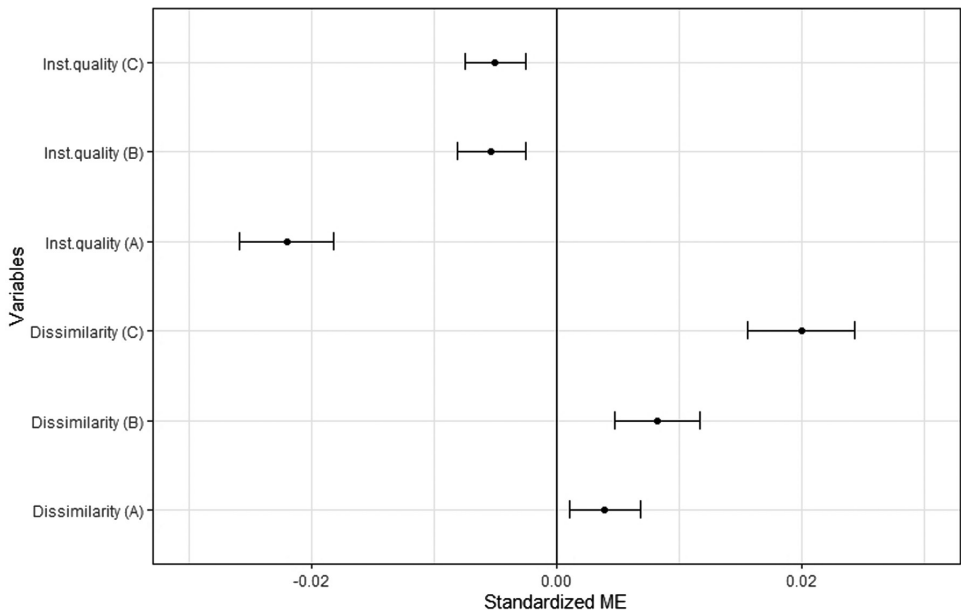


FIGURE 2 Standardised marginal effects of the different dimensions of IQ

Note: A, B, and C represent the three WGI dimensions: (A) Government selection, monitoring and replacement; (B) Efficiency of policy formulation and implementation; and (C) Respect of citizens and state for institutions; Inst. quality = IQ of exporters; Dissimilarity = institutional dissimilarity of importer and exporter; We show the standardised marginal effects with their 90% confidence intervals.

Source: Own calculations and illustration based on United Nations (2019) and Kaufmann and Kraay (2021) WGI database.

find the positive impact of institutional dissimilarity across different dimensions on the trade duration. The results indicate that a 1% increase in IQ dissimilarity of one of the three dimensions increases the probability of export failure by 0.3% to 1.4%. Businesses might resist risking a bad reputation because of on-going trade relations with a corrupt country and prefer to trade with partners having similar ethical standards in this respect.

Figure 2 shows the relative importance of the impact of each IQ dimension by standardising the marginal effects (of one SD difference). Our results partly support H1b, that is, the dimensions of IQ have different effects on the trade duration. The standardised marginal effect of dimension (A) reflecting government selection, monitoring and replacement (voice and accountability and political stability and absence of violence/terrorism) differ significantly from dimensions (B) and (C) at 90% confidence level. However, the exporters' quality in dimensions (B) and (C) show insignificantly different effects on trade duration.

The standardized marginal effects (Figure 2) of the dissimilarity of the different IQ dimensions between SSA and EU also only partly support H2b. We find that the effect of dimension (C)—the respect of citizens and state for institutions—on trade duration is statistically different from and larger than those of dimensions (A) and (B), which themselves are statistically indistinguishable. This result suggests that mutual agreements regarding the rule of law and corruption control is more important for the stability of trade links than other aspects of IQ. This is reasonable, since (C) directly represents the behaviour and legal working environment of operators involved in international trade as well as the degree of common understanding of acceptable legal practices. This might be crucial for trading partners' compliance with standards and quality requirements that play an increasingly important role in agri-food trade (European Commission, 2021; Bojnec et al., 2014). A better institutional environment in this respect might therefore increase the duration of bilateral trade relationships.

Findings underline the relevance of IQ when establishing trade relations in terms of the consideration of institutional adjustments and/or choosing the right trade partner to enhance the duration of trade relations.¹⁴ Countries can foster durations of their existing or potential trade relationships by improving their institutions and/or by trading with partners with similar IQ. From exporters' point of view, higher trade duration can result from institutional adjustments, mainly concerning governmental selection, monitoring and replacement. From both trade partners' viewpoints, the right trade partner is the one with the most similar IQ levels, mainly, along the respect of citizens and state for institutions.

Our estimation results also show the impact of further control variables on the trade duration in the context of SSA's agri-food exports. The marginal effect of the level of product differentiation reveals a positive impact on trade duration (see Table 4). This is consistent with Besedeš and Prusa (2006b) and Rauch and Watson (2003), though our estimated coefficients are lower compared to these studies, perhaps reflecting that agricultural and food products are relatively more homogeneous than the manufacturing products considered in those studies (see e.g., Brenton et al., 2010). The same official language in the two trading countries leads to longer spells, as expected. In contrast to Hess and Persson (2011), who show that being an old colony has a positive effect on the trade duration, we find no significant effects of colonial ties. Perhaps colonial ties not only contribute to countries' greater attachment but also to tensions and conflicts leading to more vulnerable trade relations (Bulhan, 2015). Moreover, as our investigated period is later than that of Hess and Persson (2011), old colonial ties might have lost importance over time. The exporter's exchange rate shows negative effects on the hazard rate of spells. An increase in nominal exchange rate (i.e., exporter's domestic currency depreciates) is associated with a lower probability of trade failure. This is also in line with Hess and Persson (2011), who conclude that a higher relative real exchange rate of non-EU exporters increases the trade duration for EU imports. The negative signs of coefficients for product and export diversification show that greater product and export market diversity reduces the trade failure rate (Tables 3 and 4), which imply that an increased trade experience, that is, the learning-by-doing effect, enhances trade duration (Hess and Persson, 2011; Besedeš, 2011; Nitsch, 2009).

As a robustness check, we re-estimate the models using the logit model. Results across all IQ dimensions only slightly differ in magnitude (Appendix S1), hence are robust against the estimation technique. We also perform a robustness check for the method of aggregating institutional indices. We sum the underlying WGIs under the three IQ dimensions (A–C) and estimate the results using a probit model (Appendix S1). In contrast to the main results, the dissimilarity in terms of (A) governmental selection, monitoring and replacement does not show an impact on the probability of trade failure. The remaining results are similar to the estimation results based on the PCA approach. Finally, instead of considering all spells, we only use the first spells to perform probit estimations of the regression with the overall exporters' IQ and institutional similarity indicators. Estimation results (Appendix S1) are largely unaffected by the consideration of the different spell types, as also pointed out by others (e.g., Bojnec and Fertő, 2018; Hess and Persson, 2011).

6 | CONCLUSIONS

The stability of agri-food trade relationships is important for importers' product accessibility and variety as well as exporters' income generation and economic development. Institutional quality (IQ) is potentially important to these relationships, and associated

¹⁴We also use the likelihood ratio test to compare our models with the (nested) model in which the IQ variables are omitted (see Verbeek, 2008), and find that the inclusion of the IQ variables significantly improves the goodness of fit and therefore contributes to explaining the duration of trade.

trade flows. We explore the duration of agri-food exports at the 6-digit level from SSA to the EU countries over the period 1996–2017, and investigate the impact of IQ factors on export flows and their duration, using the World Bank World Governance Indicators (WGI) as indicators of IQ. We use survival analysis to investigate the probability of the failure of trade links, and apply a discrete-time analysis to investigate how the IQ of exporters and the similarity with the IQs from partner countries along different dimensions affect export duration.

Our results show that, on average, export flows have a duration of 2.5 years. The probability of the failure of trade links is very high in the early years of exporting, with the probability of failure of 60% in the first year and 84% by the end of the third year. We find that higher IQ of the SSA exporters contributes to a lower failure rate in their bilateral trade links. SSA's similarity to the IQ of the EU destination country also favours longer trade duration. We distinguish between the impact of three major dimensions of IQ ('government selection, monitoring and replacement'; 'efficiency of policy formulation and implementation'; and 'respect of citizens and state for institutions') by comparing their standardised marginal effects. We show that the quality of governmental selection, monitoring and replacement (i.e., voice and accountability, political stability, and absence of violence/terrorism) in SSA countries, that is, the most related IQ dimension to enhance firms' investment and productivity and the stability of their business environment, has the largest effect on their export duration. In terms of dissimilarity, the institutional dimension evaluating the respect of citizens and state for institutions (i.e., rule of law and control of corruption) is the most important. This suggests that improving trade partners' compliance with common rules and standards are important for agri-food trade.

The positive impact of IQ and its dimensions reveals that institutional adjustments in exporting countries can enhance the stability of (potential) trade relations. The differences of the impact across different attributes of institutional adjustments suggest targeting specific attributes may be important to increase the stability of trade relationships and associated flows. Considering that levels of IQ in most SSA countries are low compared to the global average, there is substantial scope for IQ improvements. The positive impact of the similarity of the institutional environment of trading partners motivates exporters and importers to select the appropriate partner as a strategy to accomplish long-term trade partnerships, especially regarding partner countries' rule of law and corruption control. Given the significantly lower IQs of many SSA countries compared to the individual EU-28 countries, institutional adjustments can further enhance trade by increasing the common understanding of trade partners' mutual business environment.

Different dimensions of IQ might substitute or complement each other in determining the overall impact of IQ on the stability of trade relations. Considering the interaction between the different IQ dimensions (e.g., complementarity effects), and then drawing from the impact of those interactions on trade duration offers potential scope for further research. Further, the interaction of IQs with some other trade-related factors may provide insights about where the IQ measures play greater roles with regard to trade risks and uncertainty.

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SUPPORTING INFORMATION

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COVID-19 and changes in global agri-food trade

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Abstract

COVID-19 has raised questions about the resilience of agri-food trade to global shocks to the system. This paper analyses the changes in agri-food trade (values, extensive and intensive margin, and diversification) during the pandemic at global and regional levels. It also considers parallels in the changes in agri-food trade and changes of various COVID-19-related factors (infections, deaths, mobility, policy stringency, and industrial production output). The results show that changes in trade remained limited to short-term disruptions that mostly occurred at the extensive margin of trade and, primarily, at the height of policy stringency, mobility reductions, and the overall reduction of economic output. The trade of staples was most resilient, while that of other agri-food products declined considerably. Inter-regional trade of Asia, Africa, and Latin America and the Caribbean proved generally more resilient than these regions' intra-regional trade.

Keywords: COVID-19 pandemic, Agri-food trade, Extensive and intensive margin of trade, Trade diversification

JEL codes: F10, F14, Q17, Q18

1. Introduction

The rapid spread of the coronavirus disease 2019 (COVID-19) has increased morbidity and mortality rates worldwide. Countries implemented a multitude of policies to curb the spread of the virus and reduce the pressure on health systems. The pandemic's impact on public health, together with global mobility restrictions and macroeconomic impacts, has affected the supply, demand, and global trade of agri-food products. Trade policies were imposed to restrict imports and exports out of fear of contamination and to ensure the domestic availability of products, respectively. Meanwhile, trade-promoting policies, such as quota expansions and lowering non-tariff barriers, were implemented to counteract the negative impacts on food availability and access (FAO 2021a). The unprecedented shocks caused by the pandemic and the policy interventions have created concerns over the resilience of the global food system. Will countries depending on agri-food imports still be able to meet their import demand? Will agri-food exporters still be able to generate sufficient export earnings? In this regard, what is the role of the structure of global agri-food trade?

This paper analyses the changes in agri-food exports and imports and their level of diversification at global and regional levels during the first phase of the COVID-19 outbreak.

In this respect, the association of several pandemic-related factors with changes in different dimensions of the agri-food trade network is considered. Pandemic-related factors include changes in the infection rate, death rate, retail and workplace mobility measures, policy stringency, and induced macroeconomic factors. The consideration of different dimensions includes changes in total trade values and the distinction between changes in the intensive (trade values of existing trade links) and extensive (number of trade links) margins of trade. Furthermore, this paper considers the changes in trade diversification along the extensive and intensive margins and in terms of market and product portfolios.

COVID-19 has affected trade through multiple channels. The primary impact of COVID-19 on trade occurred when mortality and morbidity hit workers, leading to lower labour productivity (see e.g. [Keogh-Brown et al. 2020](#); [McKibbin and Fernando 2021](#)) and thus reduced trade values and volumes. These effects are similar to those found for outbreaks of HIV/AIDS ([Arndt and Lewis 2001](#)), SARS ([Lee and McKibbin 2012](#)), the 2009 H1N1 epidemic ([Dixon et al. 2010](#)), and Ebola ([World Bank 2014](#)). The indirect effects of the COVID-19 pandemic included a range of containment and prevention measures. These measures resulted in policy-induced shocks on demand, such as the impact of restaurant closures (see e.g. [Baldwin 2020](#); [Brodeur et al. 2020](#); [Lahcen et al. 2020](#); [Roson and van der Vorst 2021](#)), or supply, such as the impact of labour mobility restrictions (see e.g. [Lahcen et al. 2020](#); [Roson and Costa 2020](#)) or both ([Nechifor, Boysen et al. 2020](#); [Nechifor, Ferrari et al. 2020](#); [Nechifor et al. 2021](#)). Trade is also affected when policies that restrict imports and exports are directly implemented at international borders ([European Commission 2020a, 2020b](#); [OECD 2020](#)). The range of direct and indirect policy-induced impacts affects almost all segments of domestic and global value chains (GVCs) in the agri-food system. Moreover, the health impact of the pandemic and policy-related measures directly affect output, demand, and trade and can spill over to the economy and result in deepening the initial impacts. In this respect, the economic downturn in several epicentres of the pandemic (China, then Europe, then the United States) led to a steep decline in global demand and affected global trade ([FAO 2021a](#); [Laborde et al. 2021](#)).

Countries participate in international trade to ensure or increase the availability and diversity of food products in their domestic markets and to generate income earnings from their exports. In food import-dependent countries, agri-food trade ensures people's access to food at reasonable prices and to provide a variety of different types of foods to enable healthy diets ([FAO 2015](#)). In export-dependent countries, trade shocks significantly influence agri-food producers' earnings ([FAO 2015](#)), particularly in developing countries, for which an important source of income is revenues from agri-food exports ([FAO/UNCTAD 2017](#)). The literature suggests that trade increases and economic development and sustainable outcomes are promoted through participation in agricultural GVCs ([FAO 2020b](#)). Nonetheless, the impact of shocks on agricultural and food exports and imports might differ depending on the role and degree of integration into global markets and GVCs ([Koppenberg et al. 2021](#)). Although strong integration in trade networks could potentially mitigate the impacts when only parts of the global system are affected, the effect on the entire network has been the concern of the emerging literature related to COVID-19.

Most attempts to shed light on the aforementioned concerns in the early literature were carried out using descriptive analysis to identify the short-term impacts or simulation analysis to project potential mid- and long-term impacts.¹ The main finding of this body of literature is that, despite uncertainties revolving around the continuation of the pandemic, the efforts of governments and agri-food sector stakeholders worldwide have helped keep food and agricultural trade flowing ([Schmidhuber and Qiao 2020](#); [Barichello 2021](#); [Beckman and Countryman 2021](#); [FAO 2021a](#); [Hailu 2021](#)).

To analyse the relevance of COVID-19 for the agri-food trade system, this paper examines the changes in a set of trade indicators and diversification measures. The primary focus is on the first wave of COVID-19 (i.e. first half of 2020 relative to the equivalent monthly averages

of 2018 and 2019), during which the most significant changes in agricultural and food trade values are observed. The analysis is based on monthly trade data of 96 countries at the HS 6-digit commodity level. The trade indicators considered in this study are trade values, trade links, and various trade diversification measures, such as the Theil, Gini, and Herfindahl indices showing the distribution of trade values across trade links. Moreover, the Theil index is decomposed to obtain information on changes in the distribution along the extensive and intensive margins of trade. The Herfindahl index is also modified to distinguish between product and market diversification. In addition, a correlation analysis is applied to test the association of pandemic-related factors (infection rate, death rate, retail and workplace mobility measures, policy stringency, and induced macroeconomic factors) with changes in trade values and diversification at the country level.

This paper contributes to the literature in three ways. First, this paper analyses changes in the trade system during the first wave of COVID-19 in terms of both the extensive and intensive margins of trade and the diversification of trade flows along both margins. Second, this paper investigates monthly changes in the agri-food trade network at both global and regional levels and across product groups. Third, this paper analyses the association of pandemic-related factors with changes in the trade system in terms of both values and the distribution of values across trade links.

This paper is organized as follows. The next section summarizes some key features of the COVID-19 outbreak and discusses different impact channels on agri-food trade. Specific research questions are derived using this background information. Next, the approach and data for calculating the trade indicators and diversification measures are presented. Then, the results are presented and the final section concludes.

2. Background and derived research questions

On 31 December 2019, the World Health Organization (WHO) was informed of pneumonia cases with an unknown cause in Wuhan City, China. On 7 January 2020, Chinese authorities recognized as the cause of the disease a novel coronavirus that previously had not been identified in humans. On 11 March 2020, following its rapid spread outside China, the WHO declared the outbreak of COVID-19 as a pandemic (WHO 2020a, 2020b). The pandemic significantly affected health systems and resulted in the formulation of various containment measures that, in turn, reduced economic activities and resulted in reduced economic activity and affected the global trade system.

2.1 Morbidity and mortality rates

Changes in mortality and morbidity rates are factors that can interrupt the trade network. Mortality and morbidity rates directly affect labour availability. Since the outbreak of the pandemic, infection and mortality rates increased significantly since March 2020 (Panel A of Fig. 1). The increased morbidity reduced labour productivity (Bochtis et al. 2020; Petrov et al. 2021) that, in turn, resulted in a supply decrease.²

2.2 Policy responses

In response to COVID-19's direct health impacts, virus containment measures were first imposed during the first half of the year, particularly, from March to June 2020. As shown in Panel B of Fig. 1, policy stringency as reflected by the Oxford Stringency Index increased, and workplace and retail mobility rates as measured by Google Mobility indices declined substantially from March to June.

The measures implemented to curb the circulation of the virus had disruptive effects on the value chains of many products, including on agri-food markets (Hale et al. 2020; Laborde et al. 2021). On the supply side, measures such as border closures and mobility

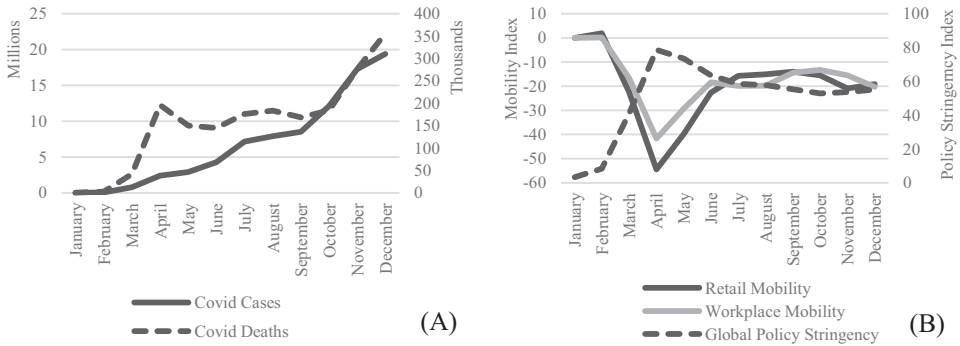


Figure 1. Evolution of global COVID-19 indicators and related factors.

Source: Own calculations based on data from John Hopkins University (Dong et al. 2020; JHU 2021), Oxford Stringency Index (Blavatnik School of Government, University of Oxford 2021), and Google Mobility indices (Google 2021).

Remark: The mobility index is normalized with respect to its value in the base month of January 2020.

restrictions led to shortages in labour, which, together with shutdowns and (partial) business closures, affected the availability of inputs, agricultural production, food industry, and the distribution of products in domestic and international markets (Bochtis et al. 2020; Larue 2020; Schmidhuber et al. 2020). To counteract supply chain disruptions, countries provided logistics and marketing support, direct transfers and loans to producers and traders (FAO 2021a). On the demand side, reduced incomes, restrictions on the movement of people, fear of infection, and widespread closures of the hospitality sector induced immediate changes in consumption patterns (Cranfield 2020; Hobbs 2020; FAO 2020a; Goolsbee and Syverson 2021; Hailu 2021).

Countries imposed a range of trade policy measures to mitigate the impacts of the pandemic and the measures to contain it on food security and food safety (see FAO 2021a). On the one hand, several countries restricted exports to ensure the domestic availability of food, particularly during the second quarter of 2020. Import restrictions, sanitary, and phytosanitary measures and additional certification requirements were applied to contain possible virus transmission through food imports. Both export and import restrictions implied direct trade disruptions. The measures also induced indirect impacts on GVCs for which traded commodities served as intermediate inputs in more downstream value chain segments. On the other hand, many countries committed to refrain from trade-restricting measures to alleviate supply chain disruptions and ensure global food security. Some exporters lowered export duties or implemented airfreight assistance programmes to support their traders in overcoming transportation and logistics disruptions. Several countries lowered import tariffs and adopted trade facilitating practices, such as the digitalization of trade-related procedures, simplified import-licensing procedures, and the establishment of green corridors to accelerate the delivery of selected food products (FAO 2021a).

Both domestic and trade measures affected trade values and the distribution of trade values noticeably across countries and products. Indeed, Arita et al. (2022) show strong impacts of policy restrictions and reduced human mobility rates on agri-food trade, whereas the effects of morbidity and mortality rates remained limited.

2.3 Macroeconomic factors and food prices

The direct health impacts and policy responses have resulted in a downturn in economic activity products, which affected the trade network (Vickers et al. 2020). Global GDP in 2020 declined by 3.41% year-on-year (World Bank 2021). Global industrial economic

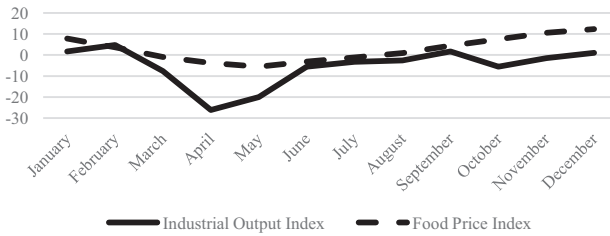


Figure 2. Global industrial output and food prices (percentage change compared with 2018/19).

Source: Own calculations based on the Monthly Index of Industrial Production (UNIDO 2021) and the Food Price Index (FAO 2021b).

output started to decline in March (when it was 15% lower than its same month average in 2018 and 2019) and further reduced in April to approximately -25% of the same monthly average value (see Fig. 2). In May, industrial output started to rebound but remained far below its 2018/2019 average (-20%). In June, industrial output rebounded to 5% less than its average monthly value. Thereafter, changes in industrial output remained within the range of -5% and +1% of the same monthly averages of previous years. These changes reflect the changes in mobility constraints and policy stringency, as given in Panel B of Fig. 1. Global industrial output is negatively correlated with policy stringency ($r = -.61$, $p < .0001$, $n = 358$) and positively correlated with mobility measures; the lower the retail and workforce mobility, the lower the economic output (retail mobility: $r = .70$, $p < .0001$, $n = 337$; work mobility: $r = .66$, $p < .0001$, $n = 337$).

Along with the reduction in global industrial output, global food prices also decreased (Fig. 2; Elleby et al. 2020), albeit this reduction in prices was less than that of industrial commodity prices, mainly due to lower income elasticities (World Bank 2020). Food prices reacted differently at the commodity level because of differences in demand and supply responses, which reflect differences in policies and expectations related to individual commodities, types of products (such as perishability and storability), income elasticities, etc. For example, the prices of agricultural products that have stronger linkages with the demand for industrial goods, such as rubber, cotton, vegetable oils, and sugar cane dropped more significantly than the prices of products with weak linkages to industrial demand such as meat and dairy products (FAO 2021a). These heterogeneous price responses at the commodity level led to differential price impacts across countries, because countries trade different bundles of commodities.³

The pandemic and related policy measures were also associated with changes in other macroeconomic factors including exchange rates (Gen-Fu et al. 2021). As countries export and import different bundles of products and changes in trade across products were not uniform, the ratio of export and import value changes resulted in shifts in the relative demand for and supply of currencies.

The changes in economic output, price and exchange rate, in turn, affected trade. The simultaneous changes of these macroeconomic variables and trade are the result of the interaction of a multitude of supply and demand side factors. Given the purpose of this analysis, that is, to describe changes in agri-food trade and draw parallels between trade and COVID-19 related measures, the quantification of the causal relationships is beyond the scope of this paper.

2.4 Empirics of COVID-19 and agri-food trade

Given the simultaneity and multitude of the impacts, the empirical literature generally does not distinguish between changes in these factors individually and their association with changes in agri-food trade but, rather, focuses on the assessment of the collective impact of

COVID-19. An exception is a study by [Arita et al. \(2022\)](#), who econometrically show that an increase in COVID-19 incidence rates, governmental policy restrictions and declining human mobility led to reductions in agricultural trade in a range of 5 to 10%. Overall, few studies analyse the relevance of the pandemic for agri-food trade. Most of these studies rely on descriptive statistical methods and find only short-lived impacts, which are consistent with the peak of the policy measures and the short-term application of countries' trade restrictions.

The studies find that the decline in trade in non-agricultural sectors was generally more significant than the reduction in agri-food trade ([WTO 2020, 2021](#); [Arita et al. 2022](#)). [Arita et al. \(2022\)](#) show that trade in both agricultural and non-agricultural products decreased in the second quarter of 2020 by approximately 2 and 18%, respectively.⁴ The recovery of trade in subsequent quarters resulted in annual percentage changes of +3.5% for agricultural and -6% for non-agricultural products compared with the year before.⁵ Thus, agri-food trade seems to have been more resilient compared with trade in non-agricultural sectors, whereas staple food product trade was more resilient than trade in non-staples against the shock.⁶ In addition, the authors show that trade for least developed and low-income countries was most vulnerable to the shocks.

[Beckman and Countryman \(2021\)](#) find a total increase in global agricultural trade value of 2.3% in 2020 compared with 2019 but heterogeneous impacts across commodity groups. They show that the trade values of major food products (e.g. coarse grains, sugar, and oilseeds) increased, whereas trade of other products, such as beverages, tobacco, and plant-fibres, experienced reductions of more than 10%.

Similarly, [Schmidhuber and Qiao \(2020\)](#) show changes in biannual agri-food trade from 2019 to 2020 (0.8% increase in the first six months) and conclude that global food markets are resilient to COVID-19 shocks. In particular, the authors find a limited impact on staple foodstuffs (changes up to +11.2% for oilseeds and oleaginous fruits) and some food products important for a healthy diet, such as fruits and vegetables (2.5%).

[Vickers et al. \(2020\)](#) examine the impacts of COVID-19 on the food trade of Commonwealth countries and argue that national lockdowns affected domestic economic activities and trade logistics. These lockdowns also reduced the Commonwealth's exports between February and May 2020 relative to the same monthly averages for 2018 and 2019. However, exports from African Commonwealth countries decreased only in May 2020 following a subsequent introduction of lockdown measures in these countries.

[Barichello \(2021\)](#) shows that the pandemic's impact on Canadian agricultural trade in 2020 (year-on-year increase of 11%) differed substantially from the expected impact at the beginning of the pandemic (decline of 12% to 20%). Consistent with this finding, [Hailu \(2021\)](#) also shows that the pandemic hit Canadian food exports in April and May 2020; however, thereafter, exports were higher than in the same months in 2019.

Based on combined CGE and household model simulations, [Laborde et al. \(2021\)](#) project a decline in global trade from both demand and supply-side effects. [Elleby et al. \(2020\)](#) employ a recursive dynamic partial equilibrium model (Aglink-Cosimo) and project that the rather inelastic nature of food consumption toward prices would prevent a sharp decline in agri-food trade.

2.5 Specific research questions

Based on the discussion of individual impact channels and the evidence found in the literature, we derive several specific research questions (RQs). The first question (RQ1) is whether increased morbidity and mortality rates induced policy responses, and macroeconomic impacts are significantly related to changes in trade values. Subsequent questions simultaneously consider the channels. The following questions are asked: (RQ2) What are the direction and the magnitude of the changes in global trade values during COVID-19?

(RQ3) How does the impact on trade values differ across regions and commodities? (RQ4) What are the changes in the extensive and intensive margin of trade at global and regional levels during the pandemic? (RQ5) Are there changes in the net trade position of the different regions? (RQ6) Are there differences in the changes in the inter- and intra-regional trade values? Moreover, we consider several questions regarding the diversification of the agri-food trade and question (RQ7) the relationship between individual impact channels with trade diversification. (RQ8) What are the changes in the diversification of the trade system globally, regionally, and across commodities? (RQ9) Are there differences in the diversification along the extensive and intensive margins of trade? Finally, we ask (RQ10) whether changes in trade diversification occur more along market or product diversification.

3. Empirical approach and data

To answer the questions, we examine a set of export and import trade indicators and diversification measures at the global, regional, and commodity levels. We calculate the indicators and measures for the first half of 2020 on a monthly basis and compare them to the same monthly averages of 2018 and 2019.⁷ Moreover, we run a correlation analysis to examine the relations of the individual indicators of COVID-19 with the changes in agri-food import values and import diversification measures.

We consider three trade indicators, namely percentage change in trade values, percentage change in the number of active trade links, and absolute values of the regional agri-food net trade positions. The percentage changes in monthly import and export trade values reflect the overall changes in trade during the pandemic compared to the pre-pandemic period. The percentage changes in the number of active trade links (i.e. the number of exporting and importing country pairs per HS six-digit product level for each month) denote the changes in the extensive margin of trade. We use information on the changes in total trade value and the extensive trade margin to deduce changes in the intensive margin of trade. The total trade value Q as the product of the number of trade links N (i.e. the extensive margin of trade) times the average of the trade values per trade link q (i.e. intensive margin of trade) results in $Q = Nq$. Therefore, we can infer the intensive margin of trade q from the changes in total trade values Q and the changes in the extensive margin of trade N .⁸

We also compare the net agri-food trade position at a regional level before and during the pandemic. This indicator is defined as the regional trade balance (export minus import value) over the trade value (sum of export and import values) and varies between -1 and 1 . A positive number indicates net exporting regions, and a negative number indicates net importing regions. The higher the index, the stronger the position of the region towards having a positive trade balance.

We further use three diversification/concentration measures (hereafter called diversification measures) before and after the pandemic. These diversification measures include the Theil index, the Gini index, and the Herfindahl index and are applied to measure both import and export diversification. We present the calculation of the import diversification measures but skip the presentation of the export diversification measures because they are analogous to the import side diversification measures.

The Theil index measures the inequality of trade values across trade links based on the maximum possible entropy of the data (i.e. complete equality in the distribution) and the observed entropy and ranges from zero to an infinite number. A higher Theil index shows greater inequality. We follow the reasoning of Cadot et al. (2011) and calculate the Theil entropy index to measure the diversification of trade values across trade links. We then attribute the total Theil index to the within-group components that show diversification along the intensive margin of trade and the between-group components that show diversification along the extensive margin of trade. The change in the diversification along the extensive margin of trade refers to the change in the number of active trade links by each commodity

and each source of imports. The change in diversification along the intensive margin of trade refers to the change in the equality of the import values across the existing trade links. The Theil index $T_{i,m,t}$ as an overall diversification measure for product i in importing country m in year t is calculated as⁹

$$T_{i,m,t} = \frac{1}{N_{i,m,t}} \sum_{x=1}^{N_{i,m,t}} \frac{V_{i,m,t,x}}{\mu_{i,m,t}} \ln \left(\frac{V_{i,m,t,x}}{\mu_{i,m,t}} \right), \quad (1)$$

where $\mu_{i,m,t} = \frac{1}{N_{i,m,t}} \sum_{x=1}^{N_{i,m,t}} V_{i,m,t,x}$. Considering that each trade link refers to the trade value of commodity i imported by country m from country x in year t , the trade value occurring at each trade link is defined as $V_{i,m,t,x}$. Additionally, $N_{i,m,t}$ refers to the number of trade links available for an importing country.

The decomposition of the total Theil index ($T_{i,m,t}$) into the within-group ($T_{i,m,t}^W$) and between-group ($T_{i,m,t}^B$) components ensures that:

$$T_{i,m,t} = T_{i,m,t}^W + T_{i,m,t}^B. \quad (2)$$

The between-group Theil index is defined as follows:

$$T_{i,m,t}^B = \sum_{g=0}^1 \frac{N_{i,m,t}^g}{N_{i,m,t}} \frac{\mu_{i,m,t}^g}{\mu_{i,m,t}} \ln \left(\frac{\mu_{i,m,t}^g}{\mu_{i,m,t}} \right). \quad (3)$$

The superscript g refers to each group of observations zero and non-zero. $N_{i,m,t}^g$ is the number of import links in group g and $\mu_{i,m,t}^g$ is the average trade value.

The within-group Theil index is defined as:

$$T_{i,m,t}^W = \sum_{g=0}^1 \frac{N_{i,m,t}^g}{N_{i,m,t}} \frac{\mu_{i,m,t}^g}{\mu_{i,m,t}} \left[\frac{1}{N_{i,m,t}^g} \sum_{x \in g} \frac{V_{i,m,t,x}^g}{\mu_{i,m,t}^g} \ln \left(\frac{V_{i,m,t,x}^g}{\mu_{i,m,t}^g} \right) \right]. \quad (4)$$

The Gini index as an alternative measure to the Theil index shows the extent of inequality in trade values across different import links, that is, the diversification of import values across different trade links. It ranges between zero, which indicates complete equality, and one, which indicates complete inequality in import shares across different import links. Following Jaimovich (2012), we calculate the Gini index using

$$Gini_{i,m,t} = 2 \frac{\sum_{x=1}^{N_{i,t}} X V_{i,m,t,x}}{N_{i,t} \sum_{x=1}^{N_{i,t}} V_{i,m,t,x}} - \frac{1 + N_{i,t}}{N_{i,t}}. \quad (5)$$

$Gini_{i,m,t}$ is the value of the Gini index for imports of commodity i by importer m for year t . Each exporter x is numerically ordered according to its value of exports of i to m during t , from smallest to highest, including zero trade flows. The variable X refers to the numerical order.

Lastly, the Herfindahl index also shows the concentration of import shares across the spectrum of agricultural and food imports. It is defined as the sum of the squares of the import shares across import links and is normalized by subtracting $\frac{1}{N}$ and dividing by $(1 - \frac{1}{N})$, where N refers to the number of active import links. The normalization ensures that the index ranges from zero to one. A larger index value is associated with greater concentration. An index value of zero indicates high diversification across numerous trade links, and the index value of one indicates the complete concentration in one import link. We follow Jaimovich (2012) and define the value of the normalized Herfindahl index of import shares

of commodity i by importer m in year t as:

$$H_{i,m,t} = \frac{\sum_{x=1}^{N_{i,t}} (S_{i,m,t,x})^2 - \frac{1}{N_{i,t}}}{1 - \frac{1}{N_{i,t}}}, \text{ where } S_{i,m,t,x} = \frac{V_{i,m,t,x}}{\sum_{x=1}^{N_{i,t}} V_{i,m,t,x}}. \quad (6)$$

$N_{i,t}$ is the total number of active exporters of i during t . An active exporter of i during t is a country that has exported a strictly positive amount of goods i at least to one importer during year t . This index shows the overall concentration along both markets and products. A modification also allows for separately calculating the diversification for both dimensions. Removing subscript m from the previous formula results in a product diversification measure. Removing subscript i results in a market diversification measure. Market diversification refers to the diversification of import shares across trading partners regardless of the diversity of the product groups from each trading partner and to how a country's imports across all import sources differ from a uniform distribution; that is, it shows how import shares from different sources vary. In contrast, the product diversification measure refers to the diversification of import shares across the commodities regardless of the source country.

We calculate the aforementioned indicators and measures using monthly trade values from Trade Data Monitor (TDM) at the HS6 level for ninety-six countries up to June 2020. TDM gathers monthly export and import statistics from statistics institutes, customs agencies, and other sources. Trade values are given in USD. In our analysis, we include all HS6 level commodities belonging to agri-food commodity groups following Annex 1 of the WTO Agreement on Agriculture (AoA) plus fishery products (see Table A.1 for detailed information on the commodities considered). The analysis covers twenty-two countries in Asia, forty countries in Europe, seventeen countries in Latin America and the Caribbean, two countries in Northern Africa, two countries in Northern America, two countries in Oceania and, eleven countries in sub-Saharan Africa (see Table A.2 for the country coverage).

At the global level, we analyse changes in both the imports and exports of the ninety-six sample countries to/from all countries. For the correlation analyses, we use country level data on incidence and mortality numbers provided by John Hopkins University, the Oxford Stringency Index, Google's Community Mobility Reports, and the UNIDO Index of Industrial Production (Blavatnik School of Government, University of Oxford 2021; Google 2021; JHU 2021; UNIDO 2021).

4. Results and discussion

4.1 Trade values

The changes in the trade values at the global level suggest short-term disruptions during the pandemic. As shown in Fig. 3, in January 2020, global import values declined by 2.0%, followed by an increase in February (4.5%).¹⁰ In March, global import values increased by 2.2% compared with previous years. In general, no trade reduction was observed in the first quarter of 2020. Nonetheless, our analysis does not exclude the possibility that trade on a global level could have been higher in the absence of COVID-19. Widespread virus containment policies adopted by most countries mainly started during the second half of March 2020 when mortality and morbidity rates increased more strongly (FAO 2021a; see also Fig. 1). Global movement restrictions to contain the spread of the virus peaked in the following two months (Panel B of Fig. 1), when we observe a downturn in economic activity (Fig. 2) and a decline in import values in April (−5.5%) and even more significantly in May (−10.0%). Thereafter, in June 2020 and in parallel with a relaxation of global movement restrictions and the recovery of the global economy, global import values rebounded and increased by 4.8% compared with the average import value of June 2018/2019. The changes in export values display a similar pattern as import values (Fig. 3).¹¹

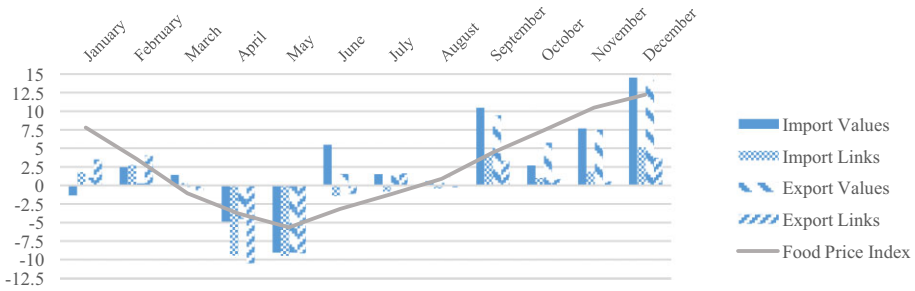


Figure 3. Global changes in trade indicators (percentage change compared with 2018/19). Source: Own calculations based on data from TDM and the Food Price Index (FAO 2021b).

Both containment measures and global economic activity are significantly correlated with import values. When policy stringency reaches its highest level, workplace as well as retail mobility are at their lowest levels, and industrial output and agri-food trade values decline. Fig. 4 shows the correlations of the COVID-19 related factors with changes in import values. Policy stringency and changes in trade values are significantly, albeit weakly, negatively correlated ($r = -.22$). Both workplace and retail mobility are weakly positively correlated with changes in import values (with correlation coefficients of 0.24 and 0.23, respectively). A stronger association ($r = .38$) is found between the change in import value and the level of industrial production output. No significant correlation exists between changes in import value and the numbers of COVID-19 cases and related deaths. Similar correlations (not reported here) are found for the export value changes with the measures of global economic activity and policy restrictions. Thus, considering RQ1, we conclude that morbidity and mortality rates are not significantly related to changes in import value, whereas induced policy responses to the pandemic and macroeconomic impacts show associations with changes in trade values.

With respect to RQ2, we find that global trade values declined at the beginning of the COVID-19 pandemic relative to pre-pandemic levels, particularly in April and May 2020. Changes in trade values are associated with changes in both trade volume and price. A significant drop in food prices was observed between March and May 2020 (Fig. 3), which suggests that part of the reduction in trade values may reflect declining prices. However, percentage decreases in prices are generally lower than that of import values in April and May, suggesting decreases in trade volumes.

Comparing changes by product groups, non-food commodities were relatively more affected than foods (Fig. A.2). Import values of cotton declined by almost 30 and 50% in April and May, respectively. The main reason for this strong decline appears to have been reduced demand for downstream products that use cotton as an intermediate input (Muhammad et al. 2021; Voora et al. 2021). Significant declines are also evident on import values of products such as live animals (-18% in April, -14% in May), live plants and cut flowers (-28% , -14%), and tobacco (-12% , -21%), which were induced by logistical bottlenecks, reduced demand and, partly, policy restrictions (Morton 2020; Saha and Bhattacharya 2020).

Among food products, trade values of staples and other essential foods were least affected. They only decreased in May, with reductions ranging from -1% (fruits and nuts) to -4% (vegetables). In contrast, fish (-21% , -22%) and beverage (-16% , -25%) import values declined considerably, probably related to virus containment measures such as the closure of restaurants and restrictions on social events (Eftimov et al. 2020; FAO 2020a). Import values of most product groups recovered in June but still remained lower than the average level of 2018/19 for beverages (-11%), fish (-7%), live animals (-5%) and, noticeably, cotton (-39%).

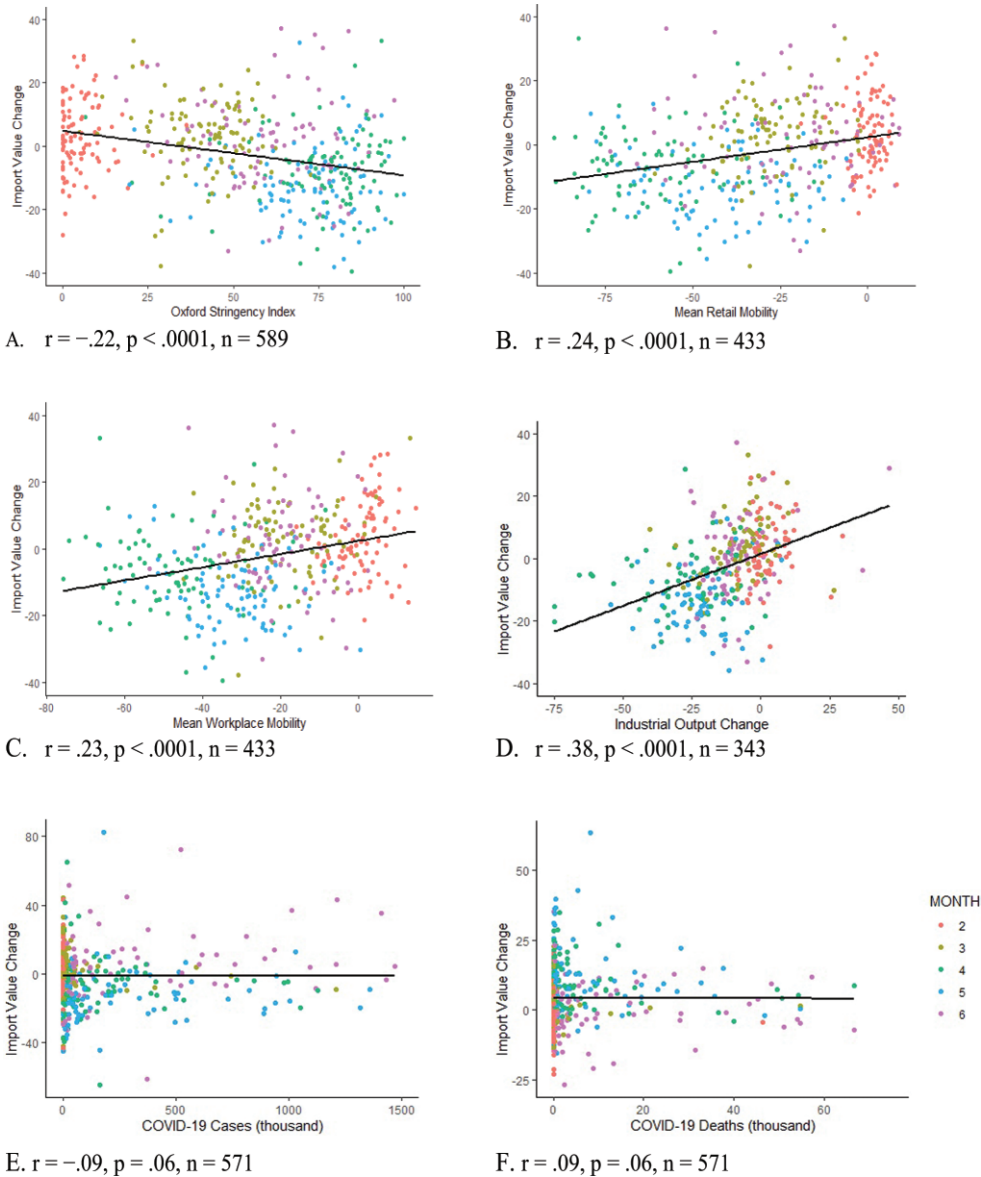


Figure 4. Correlations of import value (percentage change) with containment measure indicators (indices) and industrial production output (percentage change). Source: Own calculations based on data from TDM, John Hopkins University (Dong et al. 2020; JHU 2021), Oxford Stringency Index (Blavatnik School of Government, University of Oxford 2021), Google Mobility indices (Google 2021), and the Monthly Index of Industrial Production (UNIDO 2021).

At the regional level, mixed developments of import values are observed during the first quarter of 2020; however, similar to the global level, most regions show reduced imports in April and May (Fig. 5). In June, import values generally rebounded.

Only the import values in sub-Saharan Africa and Latin America and the Caribbean remained lower than the monthly averages of previous years by 13 and 4%. One reason for the

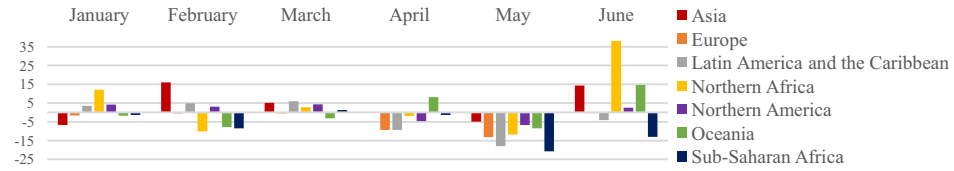


Figure 5. Import value changes at regional level (per cent).

Source: Own calculations based on data from TDM.

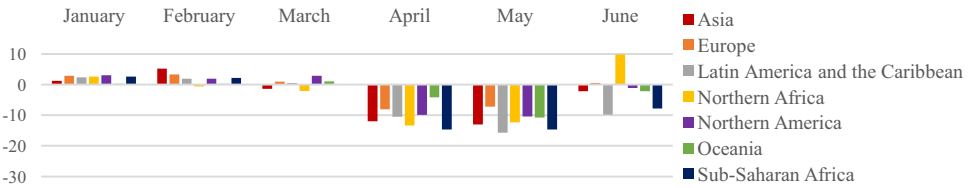


Figure 6. Changes in the number of active import links on a regional level (per cent).

Source: Own calculations based on data from TDM.

delayed impact in the sub-Saharan region could be that, given delayed soaring of COVID-19 infections, virus containment and trade-restricting measures in this region took place slightly after other regions (UN 2021). In Latin America—a major net exporting region—the reduction in import values in absolute terms was relatively low.

On the export side, all regions except for Latin America and the Caribbean experienced a reduction in their exports between March and May 2020 (Fig. A.1). Some of the major agricultural exporters are located in Latin America and the Caribbean and might have acted as a buffer to mitigate the negative impact on the imports of their partner countries. One driver of this development is China's increased import demand for oilseeds and grains from Brazil and Argentina (Schmidhuber and Qiao 2020). In June, mixed results are observed for export recovery.

Based on these findings and in accordance with RQ3, we state that non-food commodities experienced significant reductions compared with foods, whereby many staples were least affected. Changes in the trade values across regions were mixed, but most regions experienced a decrease in their imports and exports.

4.2 Extensive and intensive margins of trade

Percentage changes in the number of active trade links—denoting the extensive margin of trade—reveal sharp reductions in April and May 2020 (Fig. 6). During these months, the decrease in the extensive import (export) margin at the global level was 9.3 and 9.4% (11.1 and 10.1%), respectively.

The change in the extensive margin of trade in April and May 2020 (Fig. 6) was more pronounced than the change in the overall trade values (Fig. 5). This finding indicates that changes in trade values are mainly derived by a reduction in trade links and less by changes in the intensive margin of trade. The data also suggest that the reduction in trade links was, in part, even counteracted by increasing intensity of trade in the remaining trade links. In June, the number of trade links still remains slightly lower than the 2018/19 average, whereas overall trade values rebounded, suggesting increases in the intensive margin of trade (i.e. the average trade values per link).

Across regions, we notice similar patterns of change in the extensive margin of imports at the global level that reflect changes in the number of varieties available to consumers in terms of products and origins. In April and May in all regions, reductions range from -4.2% in Oceania (in April) to -15.7% in Latin America and the Caribbean (in May).

In June, the extensive margin of imports increased again in Europe and Northern Africa, whereas the other regions continued to record subdued numbers of trade links. Additionally, at the regional level, the decline in the extensive margin of imports is more pronounced than the decline in import values, implying that the reduction in import values in April and May mainly stem from reduced numbers of trade links. In Asia, the percentage change in the total import value in April is negligible, whereas a reduction of 13.0% in the extensive margin of imports is observed (Fig. 6). This finding implies that an increase in the intensive margin of trade outweighed the decline in the extensive margin of trade. A similar pattern is found in June when total import values of most regions increased, but the extensive margin of imports was still depressed.

Moreover, we observe a decline in the extensive margin of exports in all regions from March to June, with the exception of Latin America and the Caribbean, for which the number of export links increased (Fig. A.3). In June, the number of export links is still lower than in 2018/19 but on an upwards trend compared with the previous months. Export values increased already in June, indicating that disruptions in the export links were compensated through higher trade intensity in the remaining links at the global level.

Linking these findings to RQ4, we summarize that agri-food trade declined mainly in the extensive margin at the global level and in most regions in April and May. Only in Latin America and the Caribbean did the number of export links increase throughout all months relative to previous years.

4.3 Net trade positions

The changes in import and export values led to changes in the net (agri-food) trade positions at the regional level, as shown in Fig. A.4. Asia and Northern Africa are, on aggregate, net importing regions of agri-food products throughout the period under investigation and deepened their position as net importers at the beginning of the pandemic. Latin America and the Caribbean and Oceania remained, on aggregate, net exporting regions during the pandemic. The former region had a more pronounced export position compared with the pre-pandemic period, suggesting this region's important role in alleviating severe reductions in the imports of some other regions, whereas net exports of the latter region weakened but remained positive. Considering the limited country coverage in sub-Saharan Africa in this study, this region also shows a positive and deepening net export position.¹² In May 2020, Europe changed its position from a net exporter to a net importer. Northern America shows a tendency to turn from a net exporting to a net importing region during the observed months in 2020 relative to 2018/19. However, when considering only the monthly net trade positions of 2019, Northern America is observed to already have been a net importer in April and May 2019.

In view of RQ5, changes in the net trade positions are generally small. The effects can also be mixed because regional net trade positions are often driven by a few major importers or exporters. Moreover, the limited country coverage of some regions must be considered when evaluating the regional net trade positions.

4.4 Intra- and inter-regional trade values

Next, we investigate the changes in inter- and intra-regional trade during the first months of the pandemic. Generally, intra-regional import links declined more intensely than inter-regional import links (see Figs. 7 and 8), but the pattern differs across regions. In sub-Saharan Africa, a region with many developing countries that mainly export a limited range of agricultural raw materials to global markets and import foods from global markets, inter-regional trade links experienced less disruptions than trade links with countries within the region. Europe and Northern America, with a majority of high-income countries and strong market integration, show higher resilience of intra-regional trade (FAO 2020b,

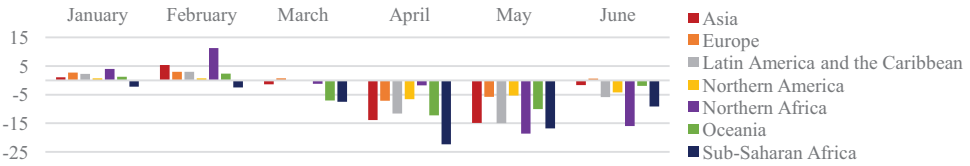


Figure 7. Changes in the number of active links of intra-regional imports (per cent).
Source: Own calculations based on data from TDM.

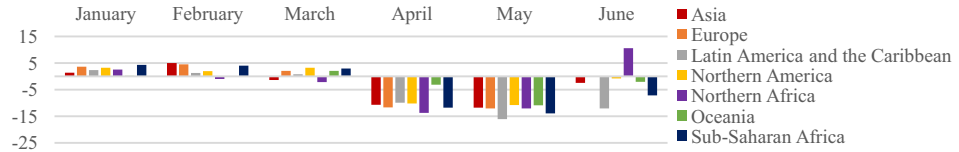


Figure 8. Changes in the number of active links of inter-regional imports (per cent).
Source: Own calculations based on data from TDM.

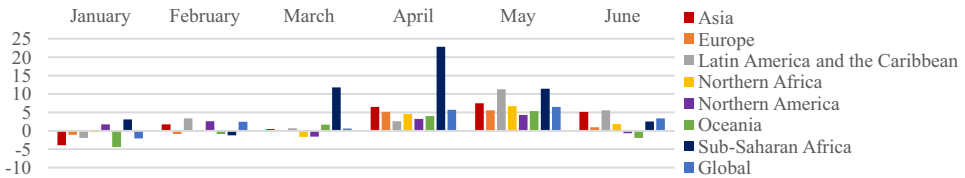


Figure 9. Changes in the Theil index of imports on global and regional levels (per cent).
Source: Own calculations based on data from TDM.

2021a). Intra-Asian trade also decreased more intensely than Asian countries' inter-regional trade. Figs. A.5 and A.6 show the changes in intra- and inter-regional import values.

Given RQ6, the data suggest an association between the role of inter- and intra-regional trade of available food varieties in terms of the number of products and product origins and regions' stages of development and level of integration in global and regional markets. Given a higher level of development and regional integration, intra-regional trade proved more resilient than trade with other regions. The reverse holds for regions with a majority of countries at lower development stages.

4.5 Diversification of trade system

Import diversification as measured by the percentage changes in the Theil index is presented in Fig. 9. Compared with the pre-pandemic period, the import diversification at a global level decreased (i.e. the Theil index increased) by approximately 6% in April and May and by 3.3% in June.¹³

Policy stringency ($r = .41$), retail ($r = -.46$) and workplace mobility ($r = -.41$) and industrial output changes ($r = -.49$) are significantly correlated with the percentage changes in the level of import diversification (Fig. 10). These correlations are somewhat stronger than the association of these variables with trade values.

With respect to RQ7, we conclude that stringer policy restrictions, lower industrial output, workplace, and retail mobility are correlated with higher concentrations of countries' imports. However, we observe no significant correlations of case and death rates with import diversifications.

We find significant declines in import diversification (increases in the Theil index) for almost all commodity groups during April and May 2020, except for some staple foods, such as oilseeds (increase in April) and cereals (increase in all considered periods). Generally,

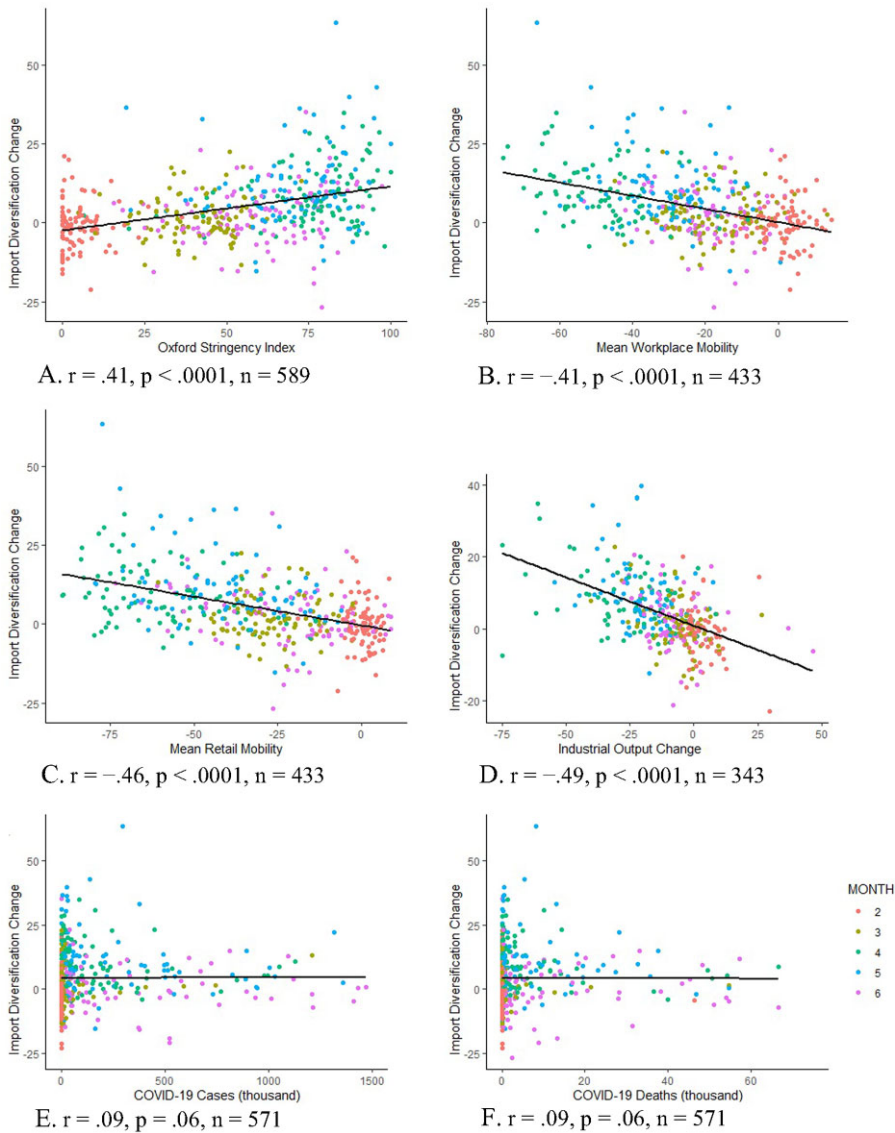


Figure 10. Correlations of import diversification (percentage change) with containment measures indicators (indices) and the global economic activity (percentage change).
Source: Own calculations based on data from TDM, John Hopkins University (Dong et al. 2020; JHU 2021), Oxford Stringency Index (Blavatnik School of Government, University of Oxford 2021), Google Mobility indices (Google 2021), and Monthly Index of Industrial Production (UNIDO 2021).

the diversification of staple foods has shown weaker deterioration than for non-staple foods. The meat sector experienced the most noticeable concentration of import shares across trade links during the considered periods (range from 6 to 18%; see Fig. A.7 for more detail at product level).

The results at the regional level (Fig. 9) reveal similar patterns of change towards less diversification as at the global level. The most significant decline in import diversification is observed in sub-Saharan Africa, where trade diversification as measured by the Theil index diminished by 12, 23, and 12% in April, May, and June, respectively. Import

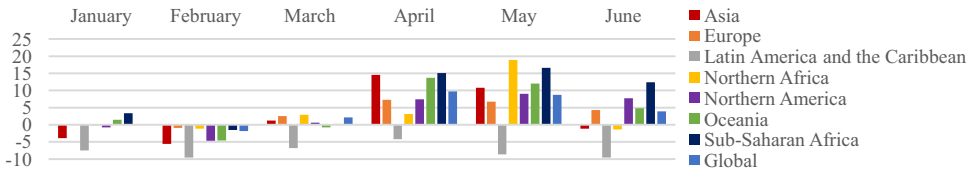


Figure 11. Changes in the Theil index of exports on global and regional levels (per cent).

Source: Own calculations based on data from TDM.

diversification remained lower than in previous years from April to June also in Asia, Europe, Latin America, and the Caribbean and Northern Africa. Northern America and Oceania experienced declining diversification rates in only April and May but not June 2020.

We apply the Theil index to exports and find that the diversification of export values across trade links also decreased significantly at both global and regional levels in April and May (Fig. 11). At the global level, diversification decreased by 9.7% and 8.7% during these months but less significantly in June (3.7%).

Similar patterns are observed at the regional level. In fact, exports were less diversified in all regions during April and May (in the range of 3.2 to 18.9% across regions and months). In line with increasing export values, Latin American and Caribbean exports were also more diversified throughout the considered period. While the concentration declined slightly again in June in Asia, Northern Africa and—quite significantly—in Latin America and the Caribbean, we observe further export concentration in all other regions.

We also provide information from two alternative measures—the Herfindahl and Gini indices—which reveal similar changes (see Figs. A.8 and A.9). Although the Theil and Gini indices are the two most popular diversification measures, the Herfindahl index is a widely employed trade concentration measure. The latter gives no weight (or very small weight) to zero (close to zero) values; thus, its results divert in some cases from the Theil and Gini indices.

With respect to RQ8, we conclude that the diversity of global agri-food trade decreased since February 2020 but mainly in April and May 2020. Non-staple foods and non-food commodities show the strongest tendency towards concentration. Considering each region separately, all regions, except for Latin America and the Caribbean's exports, show development towards more trade concentration—at least in April and May.

Next, we decompose the Theil index to identify changes in the diversification resulting from the extensive and intensive margins of trade. Changes in the between-group component of the Theil index indicate the diversification of trade flows along the extensive margin of imports (Fig. A.10). At the global level, we observe a reduction in diversification along the extensive margin of trade in April and May by 16.2 and 15.6%, respectively. Therefore, imports occur in fewer trade links relative to the pre-pandemic period. These figures are in line with the changes in the number of active import links in Fig. 6. Similarly, we observe a decrease in import diversification in all regions, noticeably in sub-Saharan countries (more than 40% increase in the between-group Theil index in April and May).

Moreover, Fig. A.11 shows changes in the within-group component of the Theil index—the diversification along the intensive margin of trade given the distribution of import shares in value terms across existing trade links. Diversification along the intensive margin of trade declines at the global level, but the results at the regional level are mixed. Overall, the changes in the diversification along the intensive margin are minor compared with the changes in the diversification along the extensive margin of imports. A comparison of the results of the overall Theil index (Fig. 9) and its components (Figs. A.10 and A.11) suggests that import trade diversification declines mostly through changes in the diversification along the extensive margin of imports.

Similar to the changes in import diversification, the changes in export diversification, as reported by Fig. 11, are mainly driven by changes in the diversification along the extensive margin of trade (Fig. A.12). In this respect, the Latin America and Caribbean region again stands out with strongly increasing diversification along the extensive margin of trade. The within-group Theil index of exports shows that all regions except for Latin America and the Caribbean increased their diversification along the intensive margin in April and May (Fig. A.13).

Concluding on RQ9, on both the import and the export side, changes in the extensive margin of trade towards more concentration dominate the changes in the intensive margin of trade.

4.6 Product and market diversification

Lastly, we use the modified Herfindahl index to show the results of import diversification in terms of trading partner and product differentiation. At the global level, market diversification—the range of countries from which imports are sourced—decreased throughout April, May, and June by 4.1, 11.9, and 18.3%, respectively (Fig. A.14). Therefore, on average, countries imported from fewer trading partners than during the pre-pandemic period. At the regional level, the impact on market diversification is mixed.

Considering the diversification across product groups (Fig. A.15), at the global level, import diversification increased significantly in February (40.8%), mostly driven by changes in the Asian region (33.3%),¹⁴ followed by no significant changes in March. Subsequently, product diversification decreased from April to June. Interestingly, in May and June, the changes in the Herfindahl index of product diversification at the global level is greater than those at the regional levels, suggesting a greater increase in the concentration of imports across products between the different regions relative to the changes in concentration within each region.

A comparison of Figs. A.14 and A.15 reveals that the overall decline in import diversification was mainly driven by a decline in the range of products imported, whereas changes in the number of trade partners played a smaller role. In some regions in which the trade of countries concentrated through market interruptions in March and April, the diversification across products increased, thus mitigating the overall reduction in the diversity of the trade values across trade links. Considering these changes along with RQ10, we state that reductions in trade diversification mainly occurred through a decline in the range of products traded.

5. Summary and conclusions

The pandemic and related containment measures have raised questions over the resilience of the global food system and its ability to ensure importers' access to sufficient import quantity and variety and whether exporters can realize their export earnings. To answer these questions, we provide a short-term analysis of the changes in agricultural and food trade in light of the COVID-19 pandemic and related containment measures. We use monthly data from the first half of 2020 to compare trade indicators, such as trade values, trade links, and various diversification indices, with their pre-pandemic averages. We explicitly consider changes in the intensive and extensive margins of trade and the differences across regions and product groups. At the country level, different pandemic-related factors, including direct health impacts (morbidity and mortality rates), induced policy restrictions (policy stringency and mobility changes), and macroeconomic impacts (industrial output), appear to be related to changes in the trade value and diversification of agri-food trade.

Our results indicate that the changes of agri-food trade values and the extensive margin of trade remained limited to short-term disruptions primarily in April and May 2020. We find that morbidity and mortality rates are not significantly related to import values and

trade diversification. However, policy responses implemented to combat the pandemic and the induced macroeconomic changes show parallels with the changes in trade value and diversification measures. Overall, in this regard, non-food commodities experienced relatively more changes than foods, whereby some staple foods were most resilient.

The extensive margin of trade decreased significantly at both the global and regional levels; however, trade intensity increased in some regions. The sharp reduction in the extensive margin of trade dominated the increase in the intensive margin, if any, during the period of heightened policy restrictions, thus leading to a decline in overall trade values in April and May. In June, increasing trade intensity compensated for the reduction in the extensive margin of trade and led to a rebound in trade values. Latin American and Caribbean exports were an exception as trade values and trade links increased during all months. Major exporters in this region increased their export values mostly in the extensive margin of trade, thus alleviating further global reductions in imports during the peak of the first wave of the pandemic.

Considering the changes in exports and imports, net trade position indicators reveal that most regions deepened their net import positions. Northern America and Europe changed their positions from net exporting to net importing regions of food and agricultural products in respective months. Mixed effects were found for changes in inter- and intra-regional trade across regions. For example, the intra-regional trade of sub-Saharan Africa, particularly in the extensive margin, was more prone to reductions than its inter-regional trade. However, the opposite held true for Europe and Northern America.

The diversity of global agri-food trade decreased primarily in April and May 2020. Overall, the deterioration in export diversification was greater than that for imports. More pronounced policy restrictions, reduced workplace and retail mobility, and lower industrial output during COVID-19 are associated with a higher concentration of trade value across a lower number of products and countries.

Changes in the extensive margin were found to play a stronger role than changes in the intensive margin of trade in reducing overall trade diversification. Non-staple foods and non-food items showed stronger concentration tendencies than basic foods. In addition, our results indicate that reductions in the number of products traded were more pronounced than those in the number of trade partners.

The simultaneity of the implementation of strict virus containment measures and the sharp changes in international trade suggest a clear association between COVID-19-related effects and short-term trade disruptions. However, results should be interpreted cautiously as other factors besides the pandemic might have influenced the observed trade patterns during the study period. In addition, while the analysis considers the extensive and intensive margins of trade and provides insights into changes in aggregated agri-food trade quantities based on overall food prices and values, we do not decompose price and quantity components of trade values for each country and at commodity level because of data limitations. Given the observed variations in prices across commodities and countries, the results in this respect should be taken with caution. Lastly, the use of more advanced quantitative methods in future research could provide further insights with respect to quantifying the role that various factors (including macroeconomic variables such as exchange rate fluctuations) play in determining trade impacts.

Data availability

The trade data were obtained from Trade Data Monitor (TDM). The links to all other data sources used in this article are provided in the reference list. The R script used for the analysis is provided as online appendix.

Supplementary material

Supplementary data are available at [Q Open](#) online.

End Notes

- 1 [Arita et al. \(2022\)](#) are the first who econometrically examine the factors affecting agricultural trade values and the extensive margin of trade of different products and regions.
- 2 See [Melitz \(2003\)](#) and subsequent literature on firm heterogeneity showing the negative impact of productivity reductions on trade. Lower productivity increases the cost of production and trade, thereby leading to less profitable firms, which can discourage them from operating in foreign markets.
- 3 Data limitations mean that we do not consider heterogeneous price impacts across countries and commodities in our study.
- 4 All agricultural products are HS codes considered under the USDA's BICO definition of Agricultural and Agricultural-related goods, and non-agricultural products cover all other HS codes. They also find that reductions are mainly driven by reductions in the extensive margin of trade (8–10%).
- 5 The authors associate the recovery with the less stringent restrictions in subsequent months and the learning effects from the preceding quarter that resulted in supply chain adjustments.
- 6 These differences can be explained by the necessity of food and, accordingly, lower income-elasticity of food products ([WTO 2020](#)).
- 7 An overview of global changes in agri-food trade through December 2020 is provided in [Fig. 3](#).
- 8 Taking the natural logarithm of both sides ($\ln(Q) = \ln(N) + \ln(q)$) leads to $\frac{dQ}{Q} = \frac{dN}{N} + \frac{dq}{q}$ after total differentiation. Based on this formula, we infer the change in the intensive margin of trade.
- 9 The export diversification measures can be simply obtained by changing the notation m to exporter x and vice versa.
- 10 One reason behind these figures is a change in the trade data reporting of China, which combined data for January and February in 2020 to account for volatility during the Chinese New Year period ([Leng 2020](#)). As China is a major exporter and importer of agri-food products, this change in reporting affects not only Asian trade values but might also be reflected in global patterns in January and February 2020 compared with previous years.
- 11 The deviation of global exports from imports is caused by several reasons. First, we consider the imports and exports reported by ninety-six countries, whereby relatively more countries with higher imports than countries with higher exports are missing. Furthermore, the time lag of the reporting of imports and exports can lead to differences in trade statistics, and imports are often more accurately reported at customs. Another important source of discrepancies is the fact that export values are reported on the basis of Free on Board (FOB) prices, whereas import values are based on Cost, Insurance, and Freight (CIF). Therefore, import values are generally expected to be higher than export values.
- 12 Although many countries in sub-Saharan Africa are, in fact, net food importers, the sample includes mainly net exporters and also considers trade of a broader range of non-food agricultural commodities. Moreover, a large portion of intra-African trade is not formally reported which might bias results ([Malabo Montpellier Panel 2020](#)).
- 13 Note that the patterns of change of the diversification measures remain the same regardless of whether these measures are applied to trade values or trade volumes.
- 14 The significant increase in import diversification in Asia might reflect the change in trade data reporting in China in January and February 2020, as previously mentioned.

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Appendix

Table A.1. Correspondence between commodity groups and HS2/4/6-digit levels

Commodity groups	HS 2-digits 01-24/HS 4/6-digits
Live animals	01
Meat	02
Fish	03
Dairy products	04
Others	05, 13, 14, 23, 290543, 290544, 3301, 3501–3505, 380910, 382360, 4101–4103, 4301, 5001–5003, 5101–5103, 5201–5203, 5301, 5302
Live plants and cut flowers	06
Vegetables	07
Fruits and nuts	08
Coffee, tea, and spices	09
Cereals	10
Flours, starches, and malts	11
Oilseeds	12
Fats and oils	15
Food preparations	16, 19, 20, 21
Sugar and confectionery	17
Cocoa and chocolate	18
Beverages	22
Tobacco	24
Cotton	5201–5203

Source: WTO (1995), AoA Annex 1 plus fishery products.

Table A.2. Correspondence between regions and countries

Regions	Countries
Asia	Armenia, Bahrain, Brunei Darussalam, China, Cyprus, India, Indonesia, Israel, Japan, Jordan, Kazakhstan, Malaysia, Myanmar, Pakistan, Philippines, Qatar, Republic of Korea, Saudi Arabia, Singapore, Sri Lanka, Thailand, Turkey
Europe	Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kosovo*, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom
Latin America and the Caribbean	Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Paraguay, Peru, Uruguay
Northern Africa	Egypt, Morocco
Northern America	Canada, United States
Oceania	Australia, New Zealand
Sub-Saharan Africa	Botswana, Egypt, Ethiopia, Ivory Coast, Kenya, Madagascar, Mauritius, Mozambique, Namibia, Senegal, South Africa, Zambia

Note: Countries for which monthly agri-food trade data (from TDM) were available at the time of extraction. The regional aggregation follows the M49 standard of the United Nations Statistics Division (UNSD); *inclusion of Kosovo follows from our data availability.

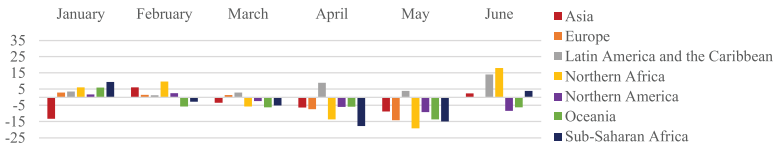


Figure A.1. Export value changes at the regional level (per cent). Source: Own calculations based on data from TDM.

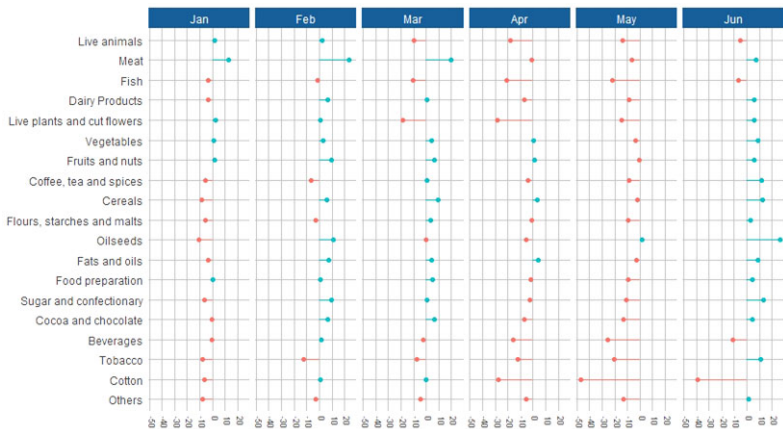


Figure A.2. Global changes in import values at the commodity level (per cent). Source: Own calculations based on data from TDM. Note: Changes are calculated as percentage changes in the import values for each commodity group (aggregated as shown in Table A.1) in a specific month in 2020 compared with the average values in the same month in 2018 and 2019.

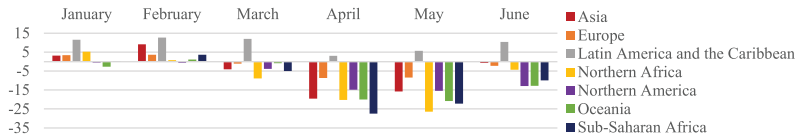


Figure A.3. Changes in the number of active export links at the regional level (per cent).
Source: Own calculations based on data from TDM.



Figure A.4. Net trade positions at the regional level.
Source: Own calculations based on data from TDM.
Note: The net trade position (exports minus imports over exports plus imports) ranges between minus one and one.

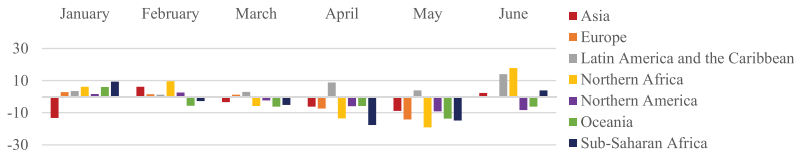


Figure A.5. Import value changes in intra-regional trade (per cent).
Source: Own calculations based on data from TDM.

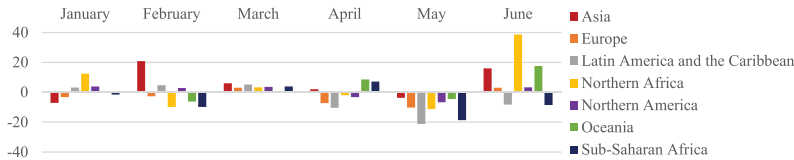


Figure A.6. Import value changes in inter-regional trade (per cent).
Source: Own calculations based on data from TDM.

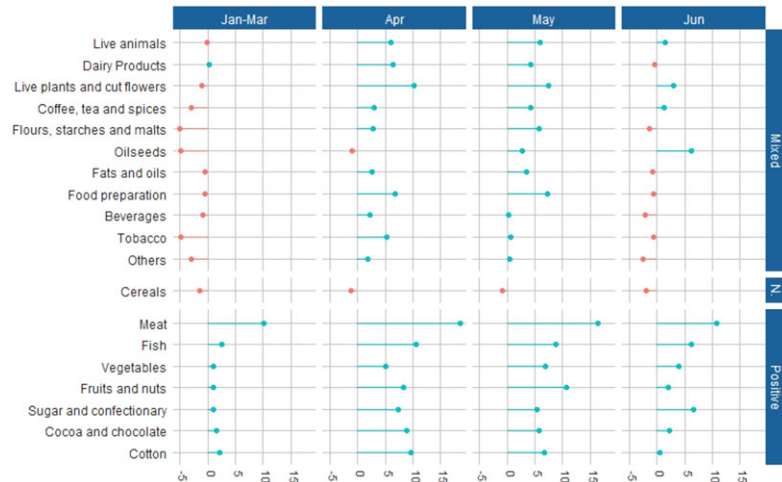


Figure A.7. Global changes in the Theil index of imports at the commodity level (per cent).
Source: Own calculations based on data from TDM.
Note: Figure A.4 shows the changes in import diversification at the commodity level based on the Theil index.

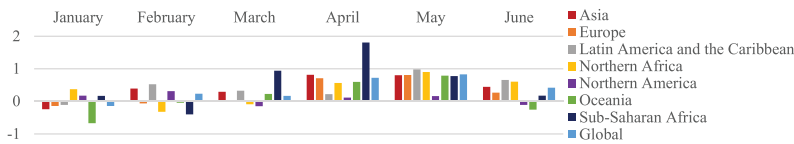


Figure A.8. Changes in the Gini index of imports at the global and regional levels (per cent).
Source: Own calculations based on data from TDM.

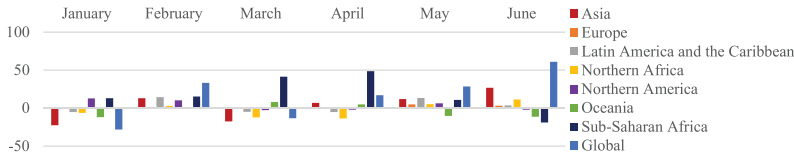


Figure A.9. Changes in the Herfindahl index of imports at the global and regional levels (per cent).
Source: Own calculations based on data from TDM.

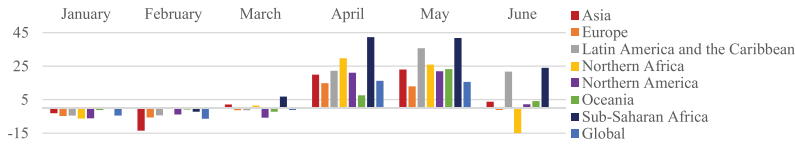


Figure A.10. Changes in the between-group Theil index of imports at the global and regional levels (per cent). Source: Own calculations based on data from TDM.

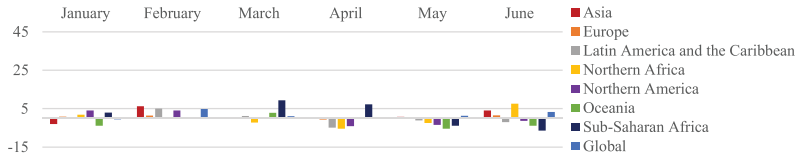


Figure A.11. Changes in the within-group Theil index of imports at the global and regional levels (per cent). Source: Own calculations based on data from TDM.

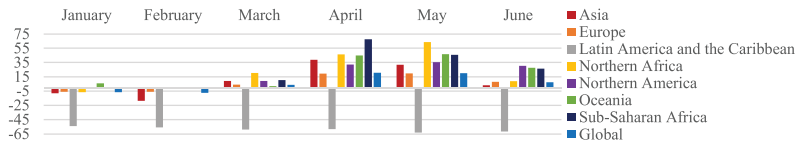


Figure A.12. Changes in the between-group Theil index of exports at the global and regional levels (per cent). Source: Own calculations based on data from TDM.

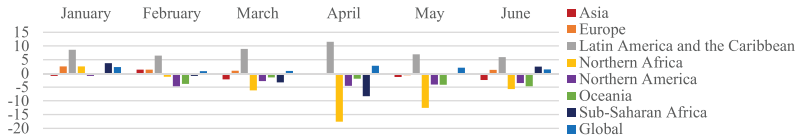


Figure A.13. Changes in the within-group Theil index of exports at the global and regional levels (per cent). Source: Own calculations based on data from TDM.

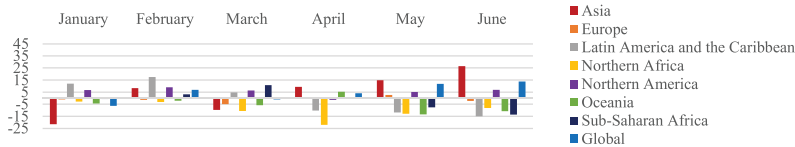


Figure A.14. Changes in market diversification according to the Herfindahl index of imports at the regional level (per cent). Source: Own calculations based on data from TDM.

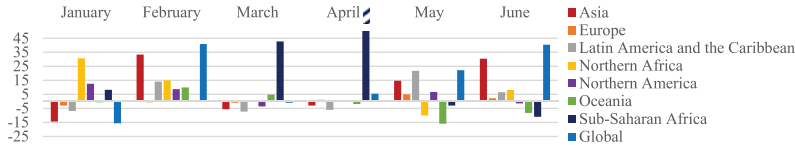


Figure A.15. Changes in product diversification according to the Herfindahl index of imports at the regional level (per cent). Source: Own calculations based on data from TDM.
Note: In April, the change in the Herfindahl's product diversification index in sub-Saharan Africa is 123.38%.



Properly capturing tariff rate quotas for trade policy analysis in computable general equilibrium models

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ABSTRACT

Computable general equilibrium (CGE) models are generally used to conduct trade policy analysis; however, given the complexity in data collection and modeling, tariff rate quotas (TRQs) are often simplified in these models. However, TRQs are crucial for trade negotiations because they are rarely completely liberalized and often the obstacles to negotiations. We propose an approach to model TRQs explicitly and at the product level within CGE models and compare with previous approaches that considered an explicit (or implicit) representation at the tariff line or sector level. Using the Canada–EU trade agreement as an example, we find significant aggregation bias if TRQ shocks are implemented at the aggregate sectoral level. This bias is only partially eliminated if TRQs are implicitly represented by *ad-valorem* equivalents at the tariff line. Our findings suggest the need to represent TRQs explicitly at the relevant commodity detail in trade impact assessments.

1. Introduction

To estimate the trade and welfare impacts associated with the implementation of free trade agreements (FTAs), computable general equilibrium (CGE) models are generally used because of their ability to capture intersectoral and global bilateral linkages. However, CGE models are often based on simplifications and special assumptions necessary to be tractable, thereby creating a context considered as rather artificial because of the oversimplified representation of policy changes, including insufficient product detail (Junior and Galvão, 2008). In terms of trade policy and FTAs, one aspect typically simplified is the representation of trade policies through *ad-valorem* equivalents (AVEs), which is an attempt to express import instruments through a single percentage of the value of the commodity.¹ As such, important information, particularly with respect to tariff rate quotas (TRQs) under liberalization, could be

overlooked.² Another aspect relates to the implementation of TRQs at an aggregate sectoral level. Here, detailed products might be subject to an aggregate TRQ where the initial TRQ regimes differ across products or some products are even not traded under a TRQ regime. Furthermore, substitution possibilities in trade between detailed products are ignored. Therefore, TRQ liberalization experiments often result in an ill-posed implementation of policy shocks.

Countries often use TRQs in FTAs to protect domestic producers against foreign competition, typically where applied most favored nation (MFN) tariffs remain high (Beckman et al., 2017).³ TRQs are primarily used in agri-food sectors (a few exceptions, such as textiles, exist), thereby mirroring that agriculture remains the most protected sector worldwide. Various attempts have been made to properly account for TRQs' specificity in CGE modeling; however, problems relating to both modeling and data deficiencies remain.

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¹ More thoroughly, AVEs express the combined impacts of all considered trade policy instruments on a commodity as a percentage tariff levied using the Cost Insurance Freight (c.i.f) price, typically first calculated at the level of individual tariff lines, and afterward aggregated to the sectoral detail in the CGE model.

² The conversion of the TRQ to an AVE eases and facilitates their implementation in global CGE models by summarizing information on In-Quota-Tariff Rates (IQTRs), Out-Quota-Tariff Rates (OQTRs), and fill rates (i.e., the import quantity over predetermined quota (Narayanan et al., 2012)). Determining the AVE of a TRQ after liberalization requires, however, an assumption about the future fill rate, which is endogenously modeled under the explicit approach.

³ TRQs are granted to either a single country in a bilateral trade agreement (Bilateral-TRQs), a group of countries (FTA-TRQs), or to all countries (Erga Omnes-TRQs).

This study introduces a methodological approach, an endogenous TRQ aggregator within the CGE model, where TRQs can be implemented explicitly at any level of product or tariff line details. This methodological approach allows for endogenous switches in the tariff regime, for implementing shocks to relevant products, and to consider substitution across detailed products, thereby preventing bias from both aggregation (commodity and shock aggregation) and neglecting the TRQ mechanism. To address the possibility of these biases, this study first compares the results of two standard approaches to modeling TRQs at the aggregate sector level: their implicit treatment based on AVEs by using the so-called MACMap approach and their explicit modeling that endogenously captures the regime shift from a low to high tariff when imports exceed the authorized quantity by using a mixed complementarity programming (MCP) approach (e.g., Beckman and Arita, 2017). Second, this study compares the results of representing TRQs at some aggregated sector with their implementation at detailed product (i.e., tariff line) levels.

An explicit TRQ regime in the CGE model requires either the aggregation of TRQs from the detailed product level to CGE sectors or a disaggregation to product detail in CGE modeling. The aggregation approach is more common (e.g., Elbehri and Pearson, 2000; Berrettoni and Cicowiez, 2002; van der Mensbrugghe et al., 2003; van der Mensbrugghe, 2005) and depicts a TRQ switching regime at the sector level, even if not all related products fall under TRQs or TRQ structures differ across these products (Grant et al., 2009). However, marginal impacts at the aggregate level can vary dramatically, depending on the TRQ regime that is active at the detailed product level (Chepeliev et al., 2019; Golub et al., 2020). A few studies (e.g. Decreux and Ramos, 2007; Chepeliev et al., 2019; Golub et al., 2020; Jafari et al., 2021) have developed approaches that allow the treatment of TRQs at a desired level of bilateral trade resolution given the data availability.⁴ Golub et al. (2020) have provided the most recent application, thereby presenting a framework (GTAP-HS-TRQ) that disaggregated larger parts of the CGE model to Harmonized System (HS) 6 detail, including all bilateral trade flows and domestic sales. By contrast, to reduce the data needed for such detail, Jafari et al. (2021) split variables related to selected bilateral trade flows to tariff line detail, which are subject to liberalization. This framework removes the aggregation bias and allows for substitution between narrowly defined products at the level of bilateral trade flows. Following their approach, we explicitly allow for TRQ regime shifts for each detailed product, which allows the provision of evidence on the potentially associated biases related to the previous approaches.⁵

To illustrate our approach, we consider the Canada–EU trade agreement (CETA) focusing on two politically sensitive sectors where TRQs are found in the agreement: dairy for Canada and some meat sectors for the EU. These two sectors are among the most protected ones worldwide⁶ and provide typical examples of sensitive sectors in trade agreements protected by (newly) introduced TRQs.

The remainder of the study is presented as follows. Section 2 discusses the importance of modeling TRQs in FTAs, possible TRQ regimes, the different approaches to depict TRQ policies in the CGE models and their consequences on the analysis of trade impact, and the relevance of TRQs

in the CETA agreement. Section 3 presents the proposed methodology that allows the implementation of TRQs explicitly and at different bilateral trade resolution. Section 4 details the software and baseline data. Section 5 specifies the scenarios, followed by Section 6 discussing the results. The final section concludes.

2. Literature

2.1. Importance of TRQs in FTAs

One of the achievements of the Uruguay Round Agreement on Agriculture (URAA) was the tariffication of several types of existing tariffs and nontariff barriers (NTBs) into one binding MFN tariff (Skully, 2001). In some cases, this process led to prohibitively high tariffs, and TRQs were implemented to provide some market access in such cases (Beckman and Arita, 2017). TRQs are a two-tier tariff scheme: a tariff charged on imports under a defined quota and an additional higher tariff charged such that the applied tariff becomes a step function of the import quantity. The higher tariff is generally equal to the MFN tariff for the World Trade Organization (WTO) members.

After the URAA, more than 1400 individual TRQs for agri-food commodities alone have been introduced through the WTO, thereby reflecting high levels of protection (Beckman et al., 2021). As shown in Table A1, Norway (232 TRQs) imposes the most quotas in agri-food sectors, followed by the EU (117), Iceland (90), Columbia (67), and South Korea (67) (WTO, 2018). China trades more than 14 million metric tons (MMTs) under TRQs annually, followed by the EU (9 MMTs) and Japan (8 MMTs), jointly accounting for approximately half of the agri-food trade under TRQs (Beckman et al., 2021).

2.2. Economics of TRQs

The structure of the TRQ system, together with the import demand and supply conditions, determines the tariff applied to the imported product and its price. Panels *a* to *c* in Fig. 1 illustrate different possible TRQ regimes. Across the panels, ES_0 and ID denote the initial import supply and demand functions for a given country that define its average cost–insurance–freight (c.i.f) price.⁷ The presence of the TRQ shifts the import supply curve depending on the quota volume and two tariffs, namely, the In-Quota-Tariff Rates (IQTR) and the Out-Quota-Tariff Rates (OQTRs). The IQTR is frequently zero, and the OQTR is often equal to the MFN rate (Ingco, 1996; Diakosavvas, 2001; De Gorter and Kliauga, 2006). Assuming that the IQTR is zero, such that imports below the quota level are duty-free, the TRQ shifts ES_0 to ES_1 .⁸ Accordingly, the interaction of ID and ES_1 determines the tariff applied under the TRQ system (and therefore the related import price), which leads to the following regimes:

1. Underfill: Import demand does not meet the quota level, that is, the fill rate is less than 100%, as shown in panel *a*. The IQTR applies and import price is equal to the c.i.f. price times $(1 + IQTR)$.
2. Binding quota: Import demand exactly meets the quota level as in panel *b*. In this case, the IQTR applies and the price for imported quantity is determined by the location of the ID curve and where it crosses the vertical part of ES_1 .⁹ The price paid by the importer is equal to the c.i.f. price if the rent is collected by the importer or equal to the c.i.f. price plus the per unit rent if the rents accrue to exporters.

⁴ These approaches are based on nested constant elasticity of substitution (CES) and constant elasticity of transformation (CET) import demand and export supply equations. Chepeliev et al. (2019) and Jafari et al. (2021) have not directly introduced TRQs in their approach but both models suggest the related frameworks for explicit TRQ modeling. Decreux and Ramos (2007) implemented TRQs at HS6 level in the Mirage model.

⁵ It is important to realize the circumstances under which the projected trade impacts, and consequently domestic consumption/production and welfare are over- or underestimated. For example, depending on the share of imports in domestic consumption, significant impacts will be observed on domestic sectoral output, household consumption, and welfare.

⁶ In 2016, the average tariff, in chapter HS2 “02” (Meat) was 32.9% and 35.9% in HS2 “04” (Dairy), while the average agri-food sectors (chapters 01 to 24) was 16.2% and 4.1% when considering all products (source: MACMap-HS6).

⁷ Assuming that the c.i.f. price is not affected by import quantities does not change the analysis.

⁸ The TRQ structure holds as long as the IQTR is smaller than the OQTR. We assume a zero IQTR for the sake of simplicity, as is often done in FTAs.

⁹ See discussion in Skully (2001) and Decreux and Ramos (2007) for the implication of different methods of TRQ administration on the distribution of TRQs rent.

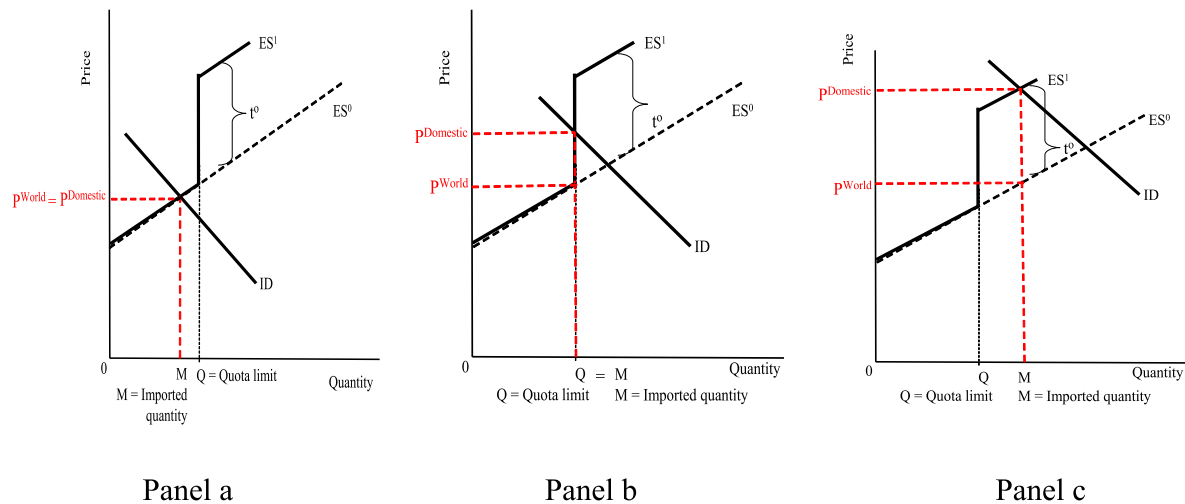


Fig. 1. TRQ system under different import demand and supply conditions.

In both cases, the price for the imported region by demanders is equal to the c.i.f. price plus the per unit rent.

3. Overfill: Import demand exceeds the quota limit, as shown in panel c. In this case, the OQTR applies, and the price for the imported origin is equal to the c.i.f. price plus the OQTR. The rent revenue is maximal and equal to the quota quantity times the difference between OQTR and IQTR.

Although the baseline imports and the IQTR and OQTR are known from the observed trade data, we cannot know ex-ante where import demand and the tariff rate under counterfactuals. In the case of a binding, but not overfilled quota, the per unit rent cannot be observed or easily derived, particularly if the imported and domestic products are not perfect substitutes. Only if one assumes that rents fully accrue to exporters, the usually observed c.i.f. price would comprise the rent, and the price for the imported origin would be known. In this case, however, it would be challenging to predict the c.i.f. price under future underfill because the observed free-on-board (f.o.b.) price is not equal to the marginal cost but comprises the rent. These problems led to a larger body of literature proposing different ways to handle TRQs and the related difficulty. The primary modeling issue is the nonequalities associated with the kinked structure of the shifted import supply curve. Common approaches that implicitly convert TRQs to AVEs calculate some weighted average of IQTR and OQTR or measure the AVEs of TRQs based on the marginal rate of protection, as discussed next.

2.3. Explicit versus implicit modeling TRQs in CGE

Converting TRQs into AVEs has become standard in the trade modeling literature, which Cipollina and Salvatici (2008) term the “natural” solution in CGE analysis. Perhaps the most widely used approach for converting TRQs into AVEs is the MacMap-HS6 data set (Bouët et al., 2008; Guimbard et al., 2012), which computes the marginal protection (AVE) of a TRQ based on the IQTR, OQTR, the quota volume, and the observed imported quantities. The ratio on quantities (imported over authorized) provides the fill rate of a given TRQ. If this rate is smaller than 90%, underfill is assumed and the AVE is set equal to the IQTR.¹⁰ For import quantities exceeding 98% of the quota volume, quota overfill is assumed and, accordingly, the AVE is set equal to the OQTR. For the intermediate case (90%–98% fill rate), a binding quota is

assumed and MacMap estimates the per unit rent as a simple average of the IQTR and OQTR.¹¹ Although these AVEs are useful for comparing protection levels and are straightforward to implement, they might create an endogeneity bias related to trade and tariffs (Anderson and Neary, 2005).

Given the different pieces of information that a TRQ entails, explicitly accounting for them in the CGE models has been a challenge for researchers (Horridge, 1993; Bach and Pearson, 1996; Harrison and Pearson, 1996; Elbehri and Pearson, 2000; Berrettoni and Cicowiez, 2002). van der Mensbrugghe (2005) extended this work using an MCP approach (Rutherford, 2001) to implement TRQs, which provide information on the tariff rate, import level, and quota rent to explicitly represent regime switching. This approach has become a standard in CGE modeling when TRQs are explicitly modeled (Beckman et al., 2017).¹²

2.4. Consequences of modeling of TRQs in CGE using MCP and MacMap

The explicit representation of TRQs in the CGE models by using MCP reflects the detailed TRQ structure as shown in Fig. 1. In this approach, the initial tariffs in panels a and c are calibrated exactly using the IQTR and OQTR, respectively, while in panel b the per unit rent as the initial tariff is typically taken—similar to MacMap—as the arithmetic mean of the two tariffs. This approach can be interpreted as the assumption that the quota rent is equally distributed between the exporter and importer partners. When a policy shock is implemented, the location of the ID curve and, therefore, the TRQ regime can change from one panel to the other. The MCP approach tracks the new location of the ID curve, the new quota regime, and the final tariff rate.

The traditional AVE approach might project different percentage changes in tariffs compared with the MCP solution for several reasons. First, the initial tariffs in the model are calibrated differently in MacMap than under an MCP solution if the initial fill rate is within [90–100]%. Considering Fig. 1 (panel a), the initial tariff is zero if the fill rate is less

¹⁰ The IQTR and OQTR is often a specific or compound rate and thus itself might require a conversion in an AVE based on trade unit values.

¹¹ The intermediate case refers to the situation where there is uncertainty on whether quota is binding or not. Due to administrative or technical obstacles, quotas might be binding even if the imports are slightly lower than the quota.

¹² Another approach is that introduced by Liapis and Britz (2001), based on a sigmoid function and equivalent to the MCP solution, but requires higher coding efforts. It allows using general-purpose non-linear solvers and makes the approximations of the nonlinearities transparent. In an MCP solution, such approximations are performed by the solver in the background and more flexibly handled compared to Liapis and Britz (2001).

than 90%, which is consistent with MCP. The initial tariff rate is $0.5t^0$ if the initial fill rate is between 90% and 98%, and t^0 if the initial fill rate is higher than 98%. If the fill rate is 100% (panel b) or higher (panel c), MACMap still takes t^0 as an initial tariff rate. Second, under an AVE approach, the postshock location of the ID curve and thus the final fill rate must be determined before the actual model simulation, and this fill rate could be different from the one simulated under an MCP approach. The assumed final fill rates under the MACMap approach are calculated as the observed trade quantity in the baseline over the new quota. In other words, fill rates are calculated based on the assumption of no change in the actual traded quantities. This assumption is likely to differ from the actual simulation results of the CGE model, thereby leading to potential inconsistencies with premodel assumptions and in differences between the results obtained using the AVE and explicit TRQ approach. Third, even if the assumed final fill rate is correctly identified, in cases where the final fill rate is within [90–100]%, the AVE rate under the MACMap is different from that under the MCP approach; as for any fill rate less than 100%, the MCP approach will always use the IQTR as the relevant tariff; and for fill rates of 100%, it uses a tariff between the IQTR and OQTR.

As mentioned previously, MACMap considers different initial and final tariff rates within the fill rate of [90–100]% primarily to reduce biases that might arise from projecting the wrong TRQ regime after a policy shock. Nonetheless, this approach does not remove the bias under many circumstances. In particular, quota expansions that allow ex-post fill rates higher than 90% decline to less than 90% assume the application of the IQTR (= underfill) ex-ante, and the CGE model might respond to the related tariff drop by expanding trade beyond the allowed quota, where a different marginal tariff would be applied. Therefore, the MACMap approach tends to overestimate impacts. Moreover, MACMap can easily lead to biased results if a policy leaves the TRQ-related instruments (i.e., quota level, IQTR, and OQTR) unchanged but changes the location of the import demand curve, such as by changing nontariff measures (NTMs), for example, an initial situation as in panel a (underfill) and a policy-induced upward shift in import demand, which leads to a TRQ shift from panel a to panel b (binding quota) or c (overfill). The MACMap approach will lead to an overestimation of trade impacts because it will continue to use the IQTR. Similarly, results are overestimated if panel b (binding quota) is the initial situation and import demand because of non-TRQ policy shifts to a regime as in panel c. There are also circumstances leading to the underestimation of the results. This is the case when the import demand curve, moves downward reflecting a shift from higher to lower tariff regimes because of a non-TRQ policy; for example, when policies increase competitiveness of importers.

2.5. Sectoral-versus product-level representation of TRQs

Another aspect related to the implementation of TRQs is the product detail considered in the analysis. TRQs often include some product levels ranging from HS4 to HS6 or even narrower definitions for which international trade statistics are not generally easily available. Databases dedicated to global CGE analysis offer fewer details such that either the model structure is expanded to reflect the variables related to bilateral trade (and potentially further transactions, e.g., domestic sales) at higher detail, such as at tariff line level (see, [Chepeliev et al., 2019](#); [Golub et al., 2020](#); [Jafari et al., 2021](#)), or TRQs defined at the product level are aggregated to the sectoral level of the CGE.

[Lips and Rieder \(2002\)](#) suggested two approaches to implement TRQs for individual tariff lines at a more aggregate level. The first and more common approach estimates AVEs from each TRQ, which are later aggregated to an average AVE (e.g., [Agbahey et al., 2017](#)). In this approach, the CGE model cannot consider regime switches or changes of the quota rent endogenously. In the second approach, a TRQ switching regime at the aggregate product level is introduced in the CGE model, with its quota volume equal to the sum of the individual TRQs and its IQTR and OQTR derived as trade-weighted averages. [Cipollina and](#)

[Salvatici \(2008\)](#) considered this approach as an “atheoretic” approximation to an equivalence index. In particular, if the initial regimes of the individual TRQs differ, simulated changes in the aggregated TRQ regime are ambiguous ([Bouët et al., 2004](#)). Furthermore, the product aggregates may comprise tariff lines not subject to TRQs that will become subject to the aggregated TRQ regime. Both approaches face potential aggregation bias. [Jafari et al. \(2021\)](#) found in their CETA analysis that the premodel aggregation of AVEs across tariff lines results in higher trade and welfare impact.

2.6. CETA agreement and status of trade between the EU and Canada

To further clarify the complex analysis of TRQ policies, we present the status of trade and changes in TRQs due to CETA, which is chosen as the example for numerical illustration. CETA is a free trade agreement between Canada and the EU, which is provisionally applied since autumn 2017.¹³ When fully phased in, it will remove tariffs for 98% of all tariff lines between the two regions. For agricultural products, 94% of the EU tariff lines and 91% for Canada will be duty-free, whereas for tariff lines with existing TRQs, the IQTR or OQTR might change and/or quotas might be expanded.

[Table 1](#) shows the bilateral import values of Canada and EU, along with shares in total imports. Reflecting the size of the economies, 0.8% of EU imports stem from Canada, as opposed to 15.5% of Canadian imports from the EU. Bilateral import shares of agri-food products are slightly lower, with 0.7% and 12.1%, respectively. However, the share of EU imports from Canada is substantially higher in some cases, such as for wheat (10.6%), oilseeds (3.0%), and other cereals (2.8%). For beverages and tobacco (43.1%), other animal products (35.9%), dairy products (29.6%), and wool products (28.3%), the EU's share in Canadian imports is quite important.

[Table 1](#) also shows the initial AVEs of tariffs between the EU and Canada and their percentage reductions because of CETA (calculated with MACMap) at the agri-food sectoral level of GTAP database for agri-food. Manufacturing and extraction sectors are summarized because they are fully liberalized, whereas no trade in services and related protection is currently covered by the data.

As shown in [Table 1](#), the dairy sector with an AVE of 38.7% and meat with an AVE of 18.9% are the most protected EU sectors before the implementation of CETA, as shown by the low import shares from Canada. The AVEs for Canada are substantially lower with 1.7% in case of dairy and 0.8% in case of meat, although they are partially protected by TRQs, which again underlines the challenges of converting TRQ regimes into AVEs. The negotiations for meat and dairy sectors are often challenging in FTAs. For example, in the Trans-Pacific Partnership, the dairy sector was a primary sticking point in negotiations for Canada ([Schott, 2016](#)), similar to the meat sector for the EU when negotiating the Transatlantic Trade and Investment Partnership ([Jafari et al., 2019](#)).

Next, we summarize the status of the EU–Canada bilateral protection of cheese and meat before and after CETA based on the legal text of the agreement ([European Union, 2017](#)). Under CETA, EU cheese exports will remain subject to a TRQ with a prohibitive OQTR; however, its quota will be increased from 13,500 tons to 31,972 tons. The EU protects its beef sector with TRQs featuring prohibitive MFN rates, with two quotas relevant for Canada before CETA: the High-Quality-Beef (HQB)-TRQ¹⁴

¹³ Canada, all EU Member countries, and the European parliament have approved the agreement, but the ratification of some EU Member states is pending along with a positive opinion by the European Court of Justice.

¹⁴ The High-Quality Beef Quota (HQB), otherwise known as “Hilton,” beef refers to the special type of beef cuts obtained from exclusively pasture-grazed animals of certain age, weight, etc.

Table 1
The EU–Canada trade and tariffs.

	EU import				Canada Import			
	Import value (Mil USD)	Share from total import (%)	initial import tax (%)	Reduction in import tariff due to CETA (%)	Import value (Mil USD)	Share from total import (%)	initial import tax (%)	Reduction in import tariff due to CETA (%)
All sectors	54.98	0.80	0.9		86.61	15.51	1.0	
Agri-food	3.20	0.65	6.4		4.46	12.14	1.7	
MEAT*	0.05	0.08	18.9	36.5	0.11	3.22	0.8	22.5
Wheat (WHT)	0.81	10.59	5.0	100	0.01	25.64	0.5	100
Cereal grains nec (GRO)	0.28	2.79	0.1	100	0.02	3.93	0.0	100
Vegetables, fruit, nuts (V_F)	0.29	0.46	0.5	100	0.15	2.29	1.6	100
Oil seeds (OSD)	0.41	2.98	0.0	100	0.01	1.11	0.0	100
Plant-based fibers (PBF)	0.00	0.00	1.0	100	0.00	–	0.0	100
Crops nec (OCR)	0.04	0.12	2.2	100	0.09	5.64	2.0	100
Cattle, sheep, goats, horses (CTL)	0.03	0.56	0.2	100	0.02	20.72	0.0	100
Animal products nec (OAP)	0.16	1.09	0.6	99.9	0.37	35.86	0.0	95
Vegetable oils and fats (VOL)	0.04	0.10	2.8	100	0.18	12.23	1.0	99.9
Dairy products (MIL)	0.02	0.05	38.7	100	0.18	29.57	1.7	6
Sugar (SGR)	0.06	0.70	4.2	100	0.01	1.15	2.8	100
Food products nec (OFD)	0.93	0.61	16.1	99	1.26	8.97	4.4	74
Beverages and tobacco products (B_T)	0.08	0.14	2.2	100	2.03	43.05	0.5	99.9
Extraction	5.02	0.90	0.1	100	0.22	1.00	0.1	100
Manufacturing	25.43	0.60	1.0	100	45.56	11.32	1.6	100
Services	21.33	1.35	–	–	36.37	40.65	0.0	–

Note: * Meat refers to the aggregate of Meat: cattle, sheep, goats, horse (CMT) and Meat products nec (OMT).

Source: GTAP database (GTAP 10, 2014 reference year) for initial trade volume and import tax rates; Jafari et al. (2021) for percentage change in import tax rate based on MacMap-HS6 reference group method that considers sensitive products for which tariffs are not reduced or reduced only partially.

with 4162 tons and the Fresh-beef-TRQ with 1150 tons.¹⁵ For the HQB-TRQ, the IQTR is lowered from 20% to 0% at unchanged quantities, whereas the Fresh-beef-TRQ is expanded by nearly a factor of 30, to 31, 164 tons. Additionally, the FTA introduces two new TRQs: the Frozen-beef-TRQ with 15,000 tons and the Bison-TRQ¹⁶ with 3000 tons. All TRQs face a 0% IQTR. Accordingly, the total quota related to beef imports from Canada to the EU has increased around 10-fold in CETA, approximately from 5300 tons to 54,000 tons, whereas out-of-quota and over-quota trade will likely remain of minor relevance given the high OQTRs and out-of-quota MFN rates.

The literature review of papers on CETA in Jafari et al. (2021) has shown that older papers estimate substantially higher impacts because they did not yet consider exceptions for sensitive products and tended to have lower sectoral and regional detail. This underlines the need for more detail in CGE studies, particularly to consider exemptions for sensitive products. Jafari et al. (2021) have concluded that models should be “extended to trade policy instruments with variable *ad-valorem* tariff rates (e.g. TRQ, specific tariffs, composite tariffs), modeling changes in AVEs endogenously.”

3. Methodology

This study uses the modular platform for CGE modeling “CGEBox”

¹⁵ 11,500 tons of the EU bovine meat quota is shared between the United States and Canada. We assume that 10% of this amount is allocated to Canada because it represents 10% of the total export of beef from Canada and United States to the EU.

¹⁶ As part of the EU commitment to the WTO, the EU also grants a 45,000-tons grain-fed beef quota that can be accessed by Australia, the United States, Canada, New Zealand, Uruguay, and Argentina. The quota is not affected by CETA.

(Britz and van der Mensbrugghe, 2018). It takes the standard GTAP model (Corong et al., 2017; van der Mensbrugghe, 2018) as its core, expanding it optionally by variants dealing with factor supply; production; demand; and a range of options to depict trade (Jafari and Britz, 2018), including a disaggregation of bilateral trade to a more fine-grained resolution, as in Jafari et al. (2021). CGEBox, accompanied by an aggregation and disaggregation facility (Britz, 2021), is used to transform the GTAP Data Base into the desired dataset for simulation purposes. It comprises an algorithm to filter out small data entries from the global CGE database and later rebalance it to improve numerical stability when solving the CGE model (see Britz and van der Mensbrugghe, 2016).

Next, we discuss the extension of this framework to explicitly capture TRQs.

3.1. Representation of TRQs in the tariff line module based on MCP

Jafari et al. (2021) have further categorized commodities relating to selected bilateral trade, see extensions in Figs. 2 and 3 [for further detail see Jafari et al. (2021)], thereby leaving domestic supply and demand at the sectoral detail of the CGE database. We extend this module for an explicit MCP representation of bilateral TRQs, thereby yielding a fully consistent aggregation from the tariff line to the product level and to the sectoral level.

The bilateral import tax defined at the tariff line level becomes endogenous under TRQs. Therefore, we use the MCP approach to allow for tariff regime shifts based on complementary slackness conditions similar to that found in the LINKAGE model (van der Mensbrugghe, 2005), the GLOBE model (Burrell et al., 2011), Himics and Britz (2013), and Himics et al. (2020).

$$Quota - I^{iq} \geq 0 \perp t^s \geq 0, \quad (1)$$

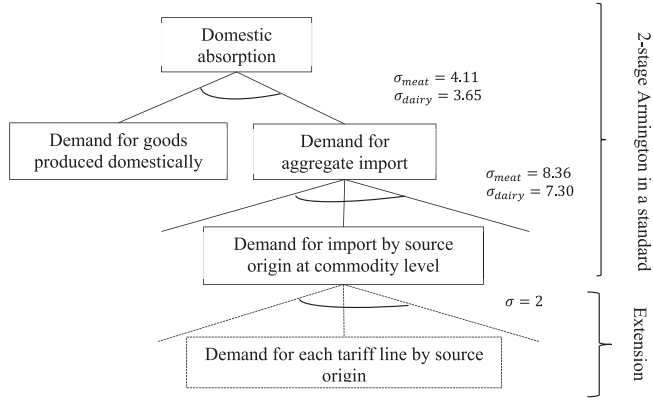


Fig. 2. Nested Armington demand. **Note:** σ refers to substitution elasticities in the CES functions. The substitution elasticities for the two higher nests are from the GTAP Data Base as used in the standard GTAP model (van der Mensbrugghe, 2018) and for the lower nest from Jafari et al. (2021).

Source: Jafari et al. (2021).

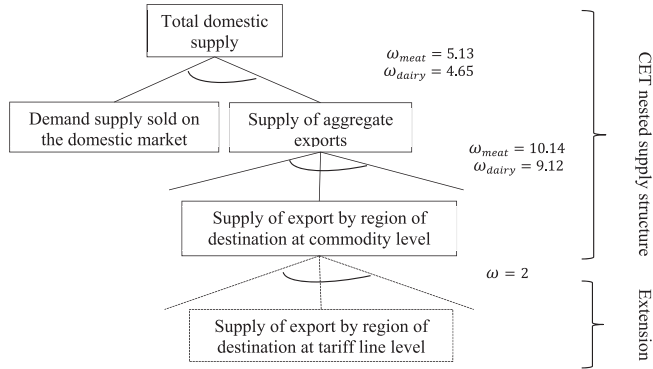


Fig. 3. Nested CET supply. **Note:** ω refers to transformation elasticities in the CET functions. The transformation elasticities for the two higher nests are derived based on the substitution from the GTAP Data Base, where CET elasticities are higher than CES elasticities by factor 1.25 (Britz and van der Mensbrugghe, 2018) and for the lower from Jafari et al. (2021).

Source: Jafari et al. (2021).

$$t^{oq} - t^{iq} \geq t^s \perp I^{oq} \geq 0 \quad (2)$$

$$\tau^m = t^{iq} + t^s \quad (3)$$

$$I = I^{oq} + t^{iq} \quad (4)$$

Equation (1) represents the regime switch between IQTR to OQTR regimes under TRQs. If in-quota imports, I^{iq} , reach or exceed the quota level, *Quota*, then the unit quota rent, t^s (the shadow tariff that defines the quota rent per unit of imports), becomes nonzero, thereby representing an OQTR regime. Equation (2) defines bounds for the shadow tariff that should be equal to the difference of IQTRs and OQTRs (t^{iq} and t^{oq} , respectively) if out-of-quota imports I^{oq} occur. Equation (3) defines the endogenously determined applied tariff rates τ^m based on the in-quota and shadow rates, and finally equation (4) is the import balance defining total imports I . This system of equations is defined for all tariff lines that are subject to bilateral TRQs.¹⁷

¹⁷ If the tariff lines are subjected to non-bilateral TRQs, one could follow the common approach in the literature to exogenously distribute a given tariff line quota to different countries based on a certain exogenous share. Alternatively, the quota allocation shares across countries can be endogenously determined depending on the mechanism of quota allocation between countries.

4. Data

We use the latest GTAP Data Base (GTAP 10, with 2014 as reference year) as the benchmark, and keep its full 65 sector resolution, except for the two meat sectors, that is, ruminant meat (CMT) and other meat (OMT), which are aggregated into a single MEAT sector as different meat TRQs in CETA relate jointly to CMT and OMT. This aggregated MEAT sector and the dairy sector (MIL) are disaggregated to high detail on the EU–Canada trade link. The model considers three regions: the EU, Canada, and rest of the world.

4.1. Trade, tariffs, and TRQs data

To break down bilateral trade data at different resolutions, a part of bilateral trade data relating to MEAT and MIL (products that are subjected to TRQs) are disaggregated to the 8-digit-level tariff-line level detail¹⁸ based on information from COMTRADE for Canada and from COMEXT for the EU. We do not disaggregate the parts of MEAT and MIL that are not subjected to TRQs. The information for the product and tariff lines affected by TRQs are obtained from the official WTO MFN tariffs for the benchmark and from the CETA agreement text (European Union, 2017) for the counterfactual, including changes in IQTRs, OQTRs, and TRQ volumes. The AVEs of tariffs for products not affected by TRQs are obtained from the MACMap-HS6 dataset (2014).

The definition in the CETA text for trade that falls under each TRQ exceeds the HS8 detail for which trade data are available. For example, for the MEAT sector, no trade information is readily accessible to distinguish the trade of fresh and frozen beef, bison, and HQB beef. At the 8-digit tariff line, the Fresh-beef-TRQ and Frozen-beef-TRQs are mutually exclusive across tariff lines; however, trade under some tariff lines could be placed under each of three TRQs: Bison-TRQ, HQB-TRQ, and Fresh/Frozen-TRQ (see Table A5, for the complexity of TRQs in the meat sector). The fresh and frozen meat TRQs are mutually exclusive because the HS8 tariff line definitions distinguish this clearly. However, whether beef meat stems from bison cannot be determined from the HS8 classification, such that trade under any of the tariff line could be allocated to the Bison-TRQ. Similarly, some frozen or fresh meat tariff lines might be imported under the HQB-TRQ depending on further product properties not reported in the HS8 classification but checked by custom authorities. Consequently, there are multiple tariff lines that could be mapped to three TRQs. To implement the TRQs in the CGE, we distribute the quantity of TRQs to the relevant tariff lines based on the observed import value and/or aggregate TRQs into a single MEAT_AggTRQ. The latter seems defensible (see Table 2) because the Bison and HQB TRQs account for a small share of the summed up quota; their OQTR are always MFN rates, and only the IQTR of HQB-TRQ is different from other TRQs. Accordingly, we do not expect significant bias, if any, associated with this aggregation approach.

5. Scenario specifications

We consider four scenarios differentiated along two dimensions for our comparative static analysis. The first dimension is the level of the product detail considered, thereby keeping the original GTAP sectors or disaggregating to HS8. The second dimension is whether TRQs are modeled explicitly or presented implicitly as AVEs based on the MACMap approach (see Table 3).

Tables 4 and 5 show the details on the TRQs in the dairy and MEAT sectors, respectively. The initial and post-CETA quotas for each TRQ are distributed across the tariff lines based on the observed trade share of

¹⁸ HS8 codes are not harmonized globally such that, for instance, MACMap and similar global data sets are available at the HS6 level, only. To consider more detail, we use here statistics provided by the EU and Canada as importers using their specific HS8 definitions (for detail, see Table A2).

Table 2

TRQs of EU cheese imports into Canada and Canadian meat imports into the EU (tons).

	Baseline	Expansion in CETA agreement	Post- CETA
Cheese TRQ	13472	18500	31972
Meat			
Fresh-TRQ	4162	35002	39164
Frozen-TRQ	0	15000	15000
HQB-TRQ	1150	0	1150
Bison-TRQ	0	3000	3000
MEAT-AggTRQs	5312	53002	58314

Source: Authors' compilation based on CETA text.

Table 3

Scenario layout.

Scenarios	Level of bilateral Trade Resolution		TRQ Modeling	
	Sector	Tariff Line	Explicit	Implicit
TRQ_Sec	✓		✓	
TRQ_TL		✓	✓	
AVE_Sec	✓			✓
AVE_TL		✓		✓

*Tariff line resolution is considered only for products affected by TRQ, that is, Cheese and Beef. In the TRQ_TL scenario, the parts of meat and beef sector unaffected by TRQs are modeled as that in AVE_TL. The implementation of TRQs for all other commodity sectors other than Cheese and Beef is consistent with AVE_Sec.

each tariff line on the total import value of each aggregated sector defined in scenario 3.¹⁹ The post-CETA column shows, in addition to the potential changes in the IQTR and quota, the AVE at unchanged trade quantities, as calculated by MacMap, assuming the same fill rate for all HS8 lines mapped to a TRQ. For the scenarios defined at the aggregated level, the lines at the bottom report the relevant information.

6. Simulation results

6.1. Impacts of TRQ_TL and its comparison with AVE_TL

We first discuss the results from the most refined scenario combining tariff line detail with the explicit TRQ presentation. Using this approach, trade between Canada and the EU is simulated to increase by approximately 3% (see Fig. 4). The primary drivers of increased Canadian exports to the EU are increased agri-food (20%) and manufacturing (4%) trade, whereas changes in the EU exports to Canada are primarily because of higher manufacturing (6%) and agri-food (3%) trade. This is consistent with welfare gains by 10.6 USD per capita for Canada and by 1 USD per capita for the EU. Higher gains for Canada per capita reflect improved access to a considerably larger market, whereas in absolute terms, the welfare gains of both partners are more comparable. The rest of the world is basically unaffected by a change of −0.01 USD per capita.

Table 6 presents the changes for agri-food sectors. Results indicate that Canada will increase its imports from the EU in all sectors, the largest increase being in dairy products (+8.2%), thereby reflecting the increase in the cheese TRQ, crops nec (+7.4%), vegetables and fruits (+7.2%), and sugar (+6.1%), in the latter cases primarily because their initial tariffs are relatively higher than that of other sectors and reduced by 100% (see Table 1). The EU imports of MEAT from Canada are projected to increase by 130%, thereby reflecting the TRQ expansions, followed by

other food processing (38.7%) and wheat (24.8%) primarily because their initial tariffs are relatively higher than that of other sectors but reduced by almost 100% (see Table 1).

Further, we describe the changes in the two sectors subject to TRQs: Canadian meat exports to the EU and EU dairy exports to Canada. As presented in Fig. 5, significant impacts are seen in the MEAT sector, with EU beef imports from Canada increasing by 168.2% and other meat by 113.6%. Canadian imports from the EU increase by 8% compared to the baseline. For the dairy sector, the EU exports of cheese to Canada increase by 8.2% and of the non-cheese sector by 6.4%.²⁰ Where imports are subjected to TRQs; that is, for Canadian cheese and EU beef imports, the initial import tariffs across tariff lines are all equal (reflecting the pre-CETA IQTR in the beef sector and the pre-CETA OQTR in the cheese sector) and are all reduced to zero. Therefore, no significant differences in bilateral import impact are seen across tariff lines.

How do these results change when the level of details changes or TRQs are only considered implicitly? When considering product detail in the model, the MacMap approach and the explicit TRQ representation yield the same result (Fig. 6) because the tariff lines in the Cheese and Beef sectors have the same initial tariffs, which are subject to 100% reduction. In the meat sector, the quota is underfilled ex-post and in the simulation, and the IQTRs is reduced to zero. In the cheese sector, the quota is overfilled ex-post but underfilled in the simulation. Accordingly, the MCP mechanism will choose a zero IQTR as the relevant tariff for both sectors in the simulation that is equal to the AVE chosen by MacMap because of significant underfill ex-post (fill rate <90%).

What happens if shocks are implemented following the mainstream approach, that is, maintaining the original sector resolution? This implies implementing shocks (TRQ_Sec and AVE_Sec) on an aggregate sector where some parts are subjected to TRQs and others not, thereby running the risk of answering policy questions that are wrongly implemented or are ill posed. (Flores, 2008). Moreover, implementing the shock at the aggregate sector ignores the substitution possibilities between detailed products.

As shown in Fig. 6, both the implicit and explicit implementation of TRQs in the aggregated case result in lower projected import changes of 119% and 124% compared with the detailed analysis, where 130% were found both in the TRQ_TL and AVE_TL scenarios. This aggregation bias might result from applying shocks to an aggregate where some tariff lines are not subject to TRQs and from ignoring substitution across detailed commodities. For the former effect, aggregating TRQs and normal tariffs dampens the shock and, therefore, underestimates the trade impacts. On the latter effect, the aggregation bias increases if higher substitution possibilities across the detailed products are assumed. Fig. 7 compares different parameterizations of the detailed model against the aggregate solutions TRQ_Sec and the AVE_Sec. First, the bars labeled with _TL_2 and _TL_5 show that higher substitution elasticities increase simulated trade impacts compared with the standard pre-model aggregation case which implicitly assumes a substitution elasticity of zero.²¹ If transformation and substitution elasticities across detailed products are set to zero (_TL_0), results under the detailed representation tend to be closer to working at the aggregate product level. Differences in these cases to aggregate scenarios (TRQ_Sec and AVE_Sec) stem from aggregating the

²⁰ The aggregate Canadian tariff on cheese imported from the EU as reported in the GTAP 10 database is 1.7% (Table 1), far below the tariffs obtained from the MacMap database. In our database, this aggregated 1.7% tariff is split across different tariff lines, based on the tariff rates reported in Table 4. Therefore, small trade impacts are observed. The large differences between the tariffs found in the GTAP and MacMap databases mostly reflect that different fill rates are assumed at the benchmark. The GTAP database assumes an underfill such that the resulting tariff is an average of IQTRs, whereas the MacMap approach data assumes filled quotas and, thus, reports the QQTRs as initial tariffs.

²¹ A zero elasticity (lower bound for our sensitivity analysis) corresponds to the standard (fix) trade weighted tariff aggregator, which is implicitly used when the aggregation is performed pre-model.

¹⁹ We also introduce a framework (see Appendix B) that endogenously allocates quotas across tariff lines, where a virtual export distributor allocates quotas endogenously to different tariff lines to maximize its profit. This approach, however, requires the marginal willingness to pay at the tariff line level by the export partner that is unfortunately not easily obtainable. Future studies might use the introduced approach depending on data availability.

Table 4
Trade and TRQs of Canada import from the EU of dairy products.

Product level	HS8	Import			Pre-CETA				Post-CETA			
		Value	Quantity	IQTR (%)	OQTR (%)	Quota (ton)	Fill rate	AVEs (%)	IQTR (%)	OQTR (%)	Quota (ton)	AVEs (%)
Cheese	04061020	524751	67.7	0.71	245.5	66.50	1.01	245.5	0	245.5	157.8	0
	04062012	1728	0.25	0.48	245.5	0.25	1.01	245.5	0	245.5	0.6	0
	04062092	597493	44.9	0.56	245.5	44.10	1.01	245.5	0	245.5	104.7	0
	04063020	4085390	449.0	0.58	245.5	441.02	1.01	245.5	0	245.5	1046.6	0
	04064020	12598051	1020.0	0.36	245.5	1001.86	1.01	245.5	0	245.5	2377.6	0
	04069012	9918714	881.3	0.46	245.5	865.63	1.01	245.5	0	245.5	2054.3	0
	04069022	2815856	279.7	0.54	245.5	274.73	1.01	245.5	0	245.5	652.0	0
	04069032	11855967	1009.7	0.54	245.5	991.74	1.01	245.5	0	245.5	2353.6	0
	04069042	35850920	3150.0	0.54	245.5	3093.98	1.01	245.5	0	245.5	7342.7	0
	04069052	1327994	140.9	0.54	245.5	138.39	1.01	245.5	0	245.5	328.4	0
	04069062	1935844	191.46	0.54	245.5	188.06	1.01	245.5	0	245.5	446.3	0
	04069072	2536108	292.8	0.54	245.5	287.59	1.01	245.5	0	245.5	682.5	0
	04069082	72749	5.4	0.54	245.5	5.30	1.01	245.5	0	245.5	12.6	0
	04069092	1485025	154.4	0.54	245.5	151.65	1.01	245.5	0	245.5	359.9	0
	04069094	39980733	3053	0.54	245.5	2998.71	1.01	245.5	0	245.5	7116.6	0
	04069096	4501486	407.9	0.54	245.5	400.65	1.01	245.5	0	245.5	950.8	0
	04069099	27423520	2567.5	0.54	245.5	2521.84	1.01	245.5	0	245.5	5984.9	0
Aggregate cheese		157512329	13716	0.52	245.5	13472	1.01	245.5	0	245.5	31972	0
Non-cheese		5533851	1550					16.94				8.86
MIL		163046180	15198	1.08	237.7	13472	1.12	237.7	0.3	237.5	31972	0.3

Note: See Table A3 for a description of the 8-digit-level commodities.

Table 5
Trade and TRQs of the EU import from Canada of meat products.

Product level	HS8	Import		Pre-CETA					Post-CETA			
		Value	Quantity	IQTR (%)	OQTR (%)	Quota (ton)	Fill rate	AVE (%)	IQTR (%)	OQTR (%)	Quota (ton)	AVE (%)
Beef	02011000	0	0	20	60	0		20	0	60	0	0
	02012020	0	0	20	57	0		20	0	57	0	0
	02012030	0	0	20	48	0		20	0	48	0	0
	02012050	0	0	20	66	0		20	0	66	0	0
	02012090	136199	5.9	20	79	57.26	0.10	20	0	79	489	0
	02013000	6692130	486.7	20	67	4723.74	0.10	20	0	67	40333	0
	02021000	0	0	20	67	0		20	0	67	0	0
	02022010	0	0	20	51	0		20	0	51	0	0
	02022030	0	0	20	43	0		20	0	43	0	0
	02022050	0	0	20	61	0		20	0	61	0	0
	02022090	0	0	20	70	0		20	0	70	0	0
	02023010	168909	11.6	20	71	59.46	0.16	20	0	71	1957	0
	02023050	0	0	20	71	0		20	0	71	0	0
	02023090	1099552	92	20	92	471.54	0.20	20	0	92	15523	0
	02061095	0	0	20	63	0		20	0	63	0	0
	02062991	0	0	20	144	0		20	0	144	0	0
	02102010	0	0	30	30	0		30	0	30	0	0
	02102090	0	0	33	33	0		33	0	33	0	0
	02109951	0	0	114	114	0		114	0	114	0	0
	02109959	0	0	13	13	0		13	0	13	0	0
Aggregate Beef		8,096,790	597	20	70.6	5312	0.11	20	0	70.6	58314	0
Non-Beef		22,058,730	4422					5.76				0.61
MEAT		30,155,520	5019	9.80	23.17	5312	0.94	16.5	0.45	19.4	58314	0.45

Note: See Table A3 for the definition of 8-digit level commodities. Furthermore, note that the European Union's import of pork from Canada is subject to an import TRQ. The existing WTO quota is 4625 tons and CETA adds 75,000 tons to the initial amount. In this study, we only consider the AVEs of the TRQs for pork in the "Non-beef" sector for two primary reasons. First, as of 2019, the EU import of pork was only 1000 tons, which is far away from the quota limits, and its modeling through implicit or explicit TRQ modeling does not make any difference. This is similar to the observed information for the beef, and we have chosen only one sector to illustrate the consequences of different ways of modeling TRQs.

trade subject to protection and the trade not subject to protection.

Moreover, the implicit and explicit treatments of TRQs at the aggregate sector estimate different trade impacts primarily because the two approaches project different percentage reductions in tariffs. For Canadian exports of MEAT to the EU (Table 5), beef products are subjected to TRQs and account for 26% of the import value; the remaining 74% of non-beef products use ordinary tariffs. Tariffs on beef products decrease

from 20% (the initial IQTR) to 0% (the final IQTR), whereas non-beef tariffs decrease from 5.76% to 0.61%. If an aggregate TRQ is used in the model, its initial fill rate amounts to 94% (Table 5, the final row), such that under explicit and implicit representations of TRQs, the model is benchmarked against different initial tariffs, which is the opposite of the true disaggregated situation where the model is always calibrated against the IQTR. When using an aggregated meat sector, the related

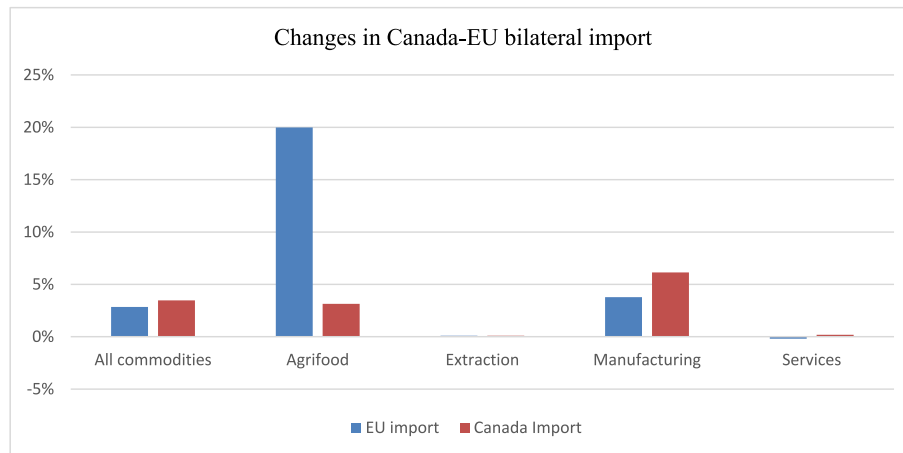


Fig. 4. Trade impact of CETA under TRQ_TL.

Table 6

The impacts of TRQ_TL on agri-food products.

	EU's imports from Canada		Canada's imports from the EU	
	Baseline (Mil USD)	% change	Baseline (Mil USD)	% change
Agri-food	3.20	19.98	4.46	3.14
MEAT*	0.05	130.15	0.11	0.37
Wheat (WHT)	0.81	24.77	0.01	3.85
Cereal grains nec (GRO)	0.28	-0.05	0.02	0.47
Vegetables, fruit, nuts (V_F)	0.29	0.56	0.15	3.68
Oil seeds (OSD)	0.41	-0.45	0.01	0.17
Crops nec (OCR)	0.04	7.67	0.09	7.36
Cattle, sheep, goats, horses (CTL)	0.03	0.14	0.02	0.32
Animal products nec (OAP)	0.16	0.77	0.37	0.40
Vegetable oils and fats (VOL)	0.04	10.66	0.18	3.75
Dairy products (MIL)	0.02	-0.32	0.18	8.17
Sugar (SGR)	0.06	12.89	0.01	6.15
Food products nec (OFD)	0.93	38.68	1.26	7.23
Beverages and tobacco products (B_T)	0.08	2.68	2.03	0.61

* Meat refers to the aggregate of meat: cattle, sheep, goats, horse (CMT) and Meat products nec (OMT).

Source. Simulation results.

aggregated tariff reduces from 9.8% to 0.45% with an explicit TRQ mechanism, instead from 16.5% to 0.45% under the implicit treatment with AVEs (Table 5, the last row). Accordingly, higher trade impacts are found for the implicit approach. For example, in the MEAT sector, the trade impacts under the implicit and explicit treatments are 124% and 119%, respectively (Fig. 6).

The estimated changes in the MIL sector (Fig. 6) are only slightly lower when aggregated sectors are considered (TRQ_Sec and AVE_Sec) compared with outcomes by using product-level detail in the model (TRQ_TL and AVE_TL). One reason is that in the MIL sector, 98.7% of the import value from the EU into Canada stems from cheese products subject to TRQs (Table 4); only a small remainder faces ordinary tariffs so that the aggregation bias becomes almost zero. Another reason is that because the tariff on all trade subjected to TRQs are reduced by 100%, considering substitution across commodities can be disregarded. In the MacMap approach, the tariff on cheese decreases from 245.5% (i.e., initial OQTR) to 0% (final IQTR), whereas non-cheese tariffs decrease from 16.94% to 8.86%. When an aggregate TRQ is constructed, the resulting fill rate is 112%, such that the model is calibrated against the OQTR. Accordingly, both the explicit or implicit TRQs reduce the tariff from 237.7% to 0.3%.

Overall, the trade impact in TRQ_Sec and AVE_Sec are lower than that in other TRQ_TL and AVE_TL scenarios (as evident in the MEAT sector); the potential bias associated with TRQ_ and AVE_ is found only if the original sector resolution of GTAP is maintained. In this case, the model is calibrated to different tariff rates compared with the detailed

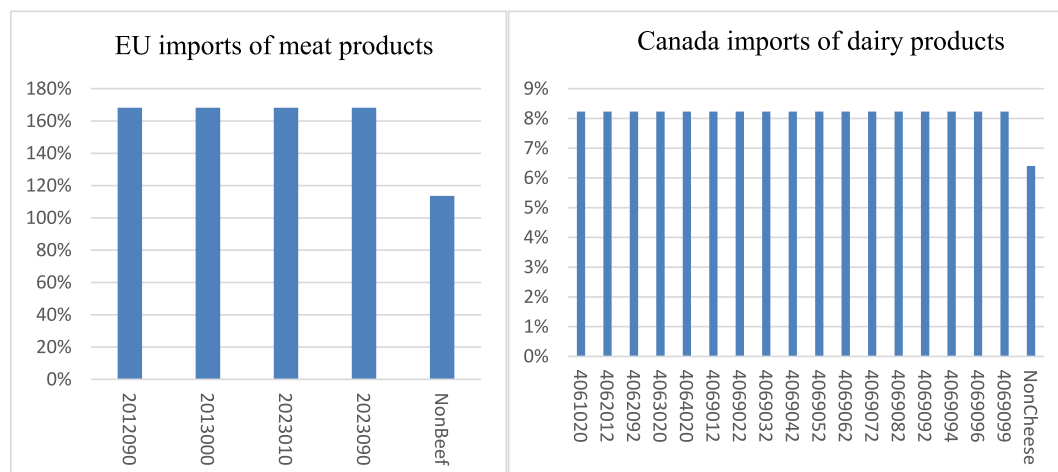


Fig. 5. Changes in EU-Canada bilateral imports at the tariff line level, TRQ_TL.

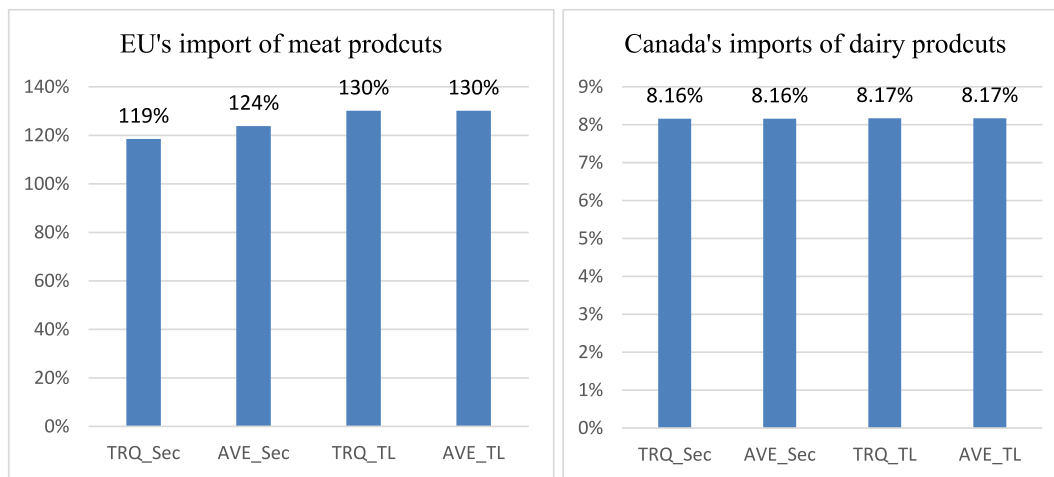


Fig. 6. Changes in EU–Canada bilateral import across different scenarios. Impacts of TRQ_Sec and AVE_Sec and its comparison with _TL scenarios.

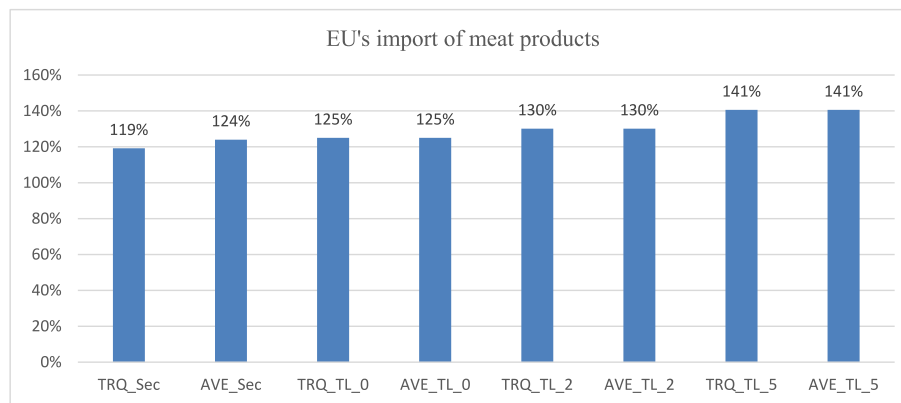


Fig. 7. Sensitivity analysis on the CES and CET substitution elasticities.

presentation, and substitution possibilities between detailed products are not considered.

6.2. Importance of properly capturing TRQs under different assumptions ex-post and ex-ante

Thus far, we have shown the importance of explicit and implicit treatments of AVEs by comparing TRQ_Sec and AVE_Sec. The two approaches have shown no differences at the tariff line level for the specific data and policy shock considered. We show now the conditions under which these results could differ. We assume in a first counterfactual that the EU quota for Canadian beef imports is binding (100%) at the benchmark (different from the actual) and that the final IQTR is only halved and not set to zero. The MacMap approach would consider the OQTR as the initial AVE because any fill rate of equal or higher than 98% is considered overfill. The MCP approach depicts a regime where the rent is endogenously determined and benchmarking of the model requires choosing this rent, which is taken as the average of the IQTR and OQTR (similar to what MacMap assumes under a filled quota). The reduction to the IQTR of 10% is now double as large under the AVE approach (from OQTR to IQTR) compared with the explicit TRQ representation (from $[OQTR + IQTR]/2$ to IQTR). Now, the substitution effects between disaggregated products in the overall MEAT sector are likely because the original IQTRs are different such that disaggregated products experience different tariff reductions. Fig. 8 shows the expected differences between the approaches: the AVE representation now generates stronger impacts than an explicit TRQ regime, particularly for the meat aggregate. Now, the projected trade impact also differs across meat products (Fig. 9),

thereby reflecting a different percentage reduction in tariffs, which is in contrast to the projected results in Fig. 5.

Significant differences in results can emerge if the observed TRQ regime used by MacMap to calculate the AVE differs from the simulated regime under an explicit TRQs implementation. To demonstrate this point, we assume in a second counterfactual that the quota is expanded by only 20%. With an observed fill rate at 100%, MacMap assumes a new fill rate of 100/120, which is below the 90%–98% range, where a binding quota is assumed. Accordingly, the IQTR will be used as the new AVE. The simulation with the explicit TRQ representation yields a rent within the range between the new IQTR and OQTR rates because a binding quota is simulated. This results in a smaller simulated trade impact under an explicit TRQ treatment (Fig. 10).

Finally, we provide another counterfactual where both the dairy and meat sectors show an initial fill rate of 80% to ensure that both the MCP and MacMap consider IQTR as the same initial tariff rate for benchmarking. The scenario now considers changes in another policy impacting trade, here assumed as reduced NTMs captured by changes in the Armington share parameter reflecting a demand shift (see e.g., Jafari and Britz, 2018; Jafari et al., 2019). Figs. 11 and 12 indicate the impacts on meat and dairy imports, assuming an increase in the share parameter between 1% and 11%. Here, the MCP and MacMap approaches project the same trade changes, provided that the NTM reduction leads to a shift of less than 5% and 7% for the meat and dairy demand, respectively. Beyond this point, the AVE approach estimates quota overfill and thus higher impacts. However, the simulated over quota imports are inconsistent with the assumed AVE based on the IQTR.

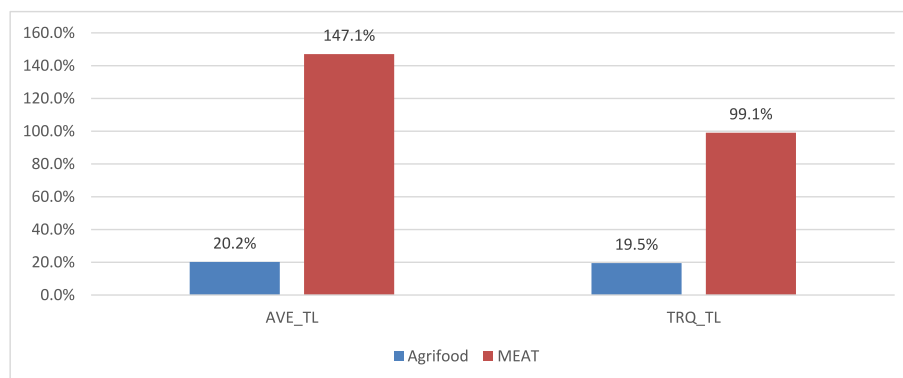


Fig. 8. Explicit vs. Implicit treatment of TRQs under the first counterfactual scenario (TRQ fill ex-post, IQTR reduced to 10%).



Fig. 9. Changes across tariff lines under the first counterfactual scenario (TRQ fill ex-post, IQTR reduced to 10%).

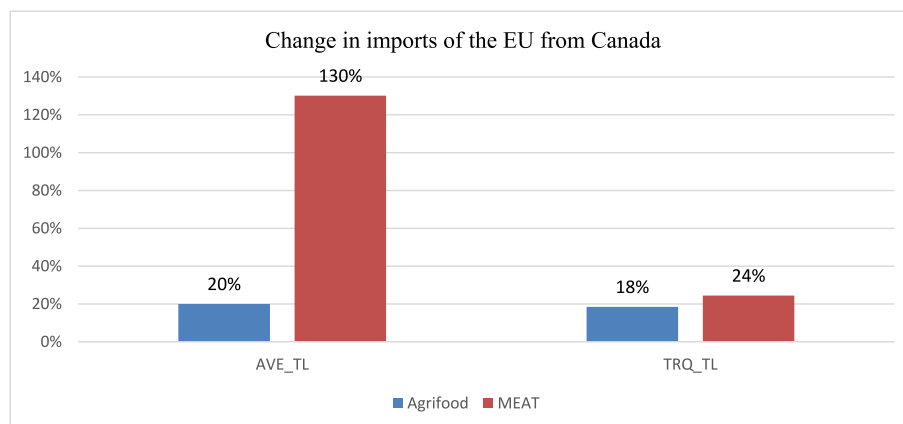


Fig. 10. Explicit vs. implicit treatment of TRQs under the second counterfactual scenario (100% fill rate ex-post, 20% TRQ expansion).

7. Conclusion and remarks

CGE models are quantitative models widely used to analyze the economy-wide impacts of trade policies; however, they are often criticized for simplifying real-world behavior. One reason for this is that the implementation of trade policy instruments is challenging. TRQs provide an example that is discussed here in detail. Another reason is that trade policy is typically defined at some detail, which exceeds the usual product resolution of CGE models. This study addresses these issues by drawing on an approach for bilateral trade modeling at the tariff line based on Jafari et al. (2021), which is now expanded to explicitly capture TRQ regimes based on MCP.

The study results indicate that the proposed approach can remove inconsistencies in two more standard approaches that either convert TRQs to an *ad-valorem* equivalent tariff by using the widely used MAC-Map approach or implement TRQs at more aggregate sector level. The MCP approach endogenously depicts the TRQ regime, that is, the simulated marginal tariff depends on the endogenously simulated quota fill rate. Considering the tariff line detail prevents the construction of aggregated TRQs comprising actual TRQs in different initial regimes (i.e., underfill, binding, and overfill), thereby allowing the consideration of differences in IQTR and OQTR rates and quota rents. This avoids cases where trade not under a TRQ becomes subject to an aggregate TRQ regime. Furthermore, the tariff line detail allows for the consideration of

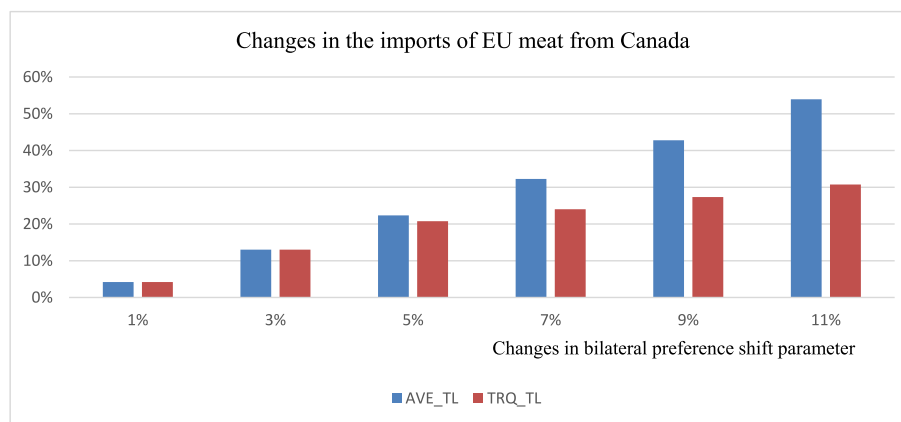


Fig. 11. Sensitivity analysis on the impact of NTMs reduction on meat import.

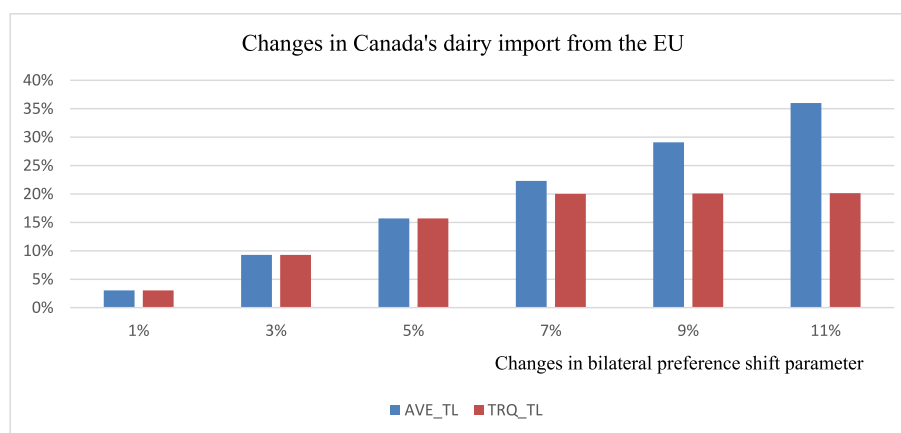


Fig. 12. Sensitivity analysis on the impact of NTMs reduction on dairy import.

substitution in trade between products falling under the same aggregate sector in the CGE model. The MacMap approach determines the marginal protection rate pre-model based on the observed trade; the resulting AVE is exogenous to the CGE model itself, which can lead to inconsistencies if the simulated trade quantities do not match the TRQ regime used to calculate the AVE. In particular, a TRQ expansion at unchanged trade quantities often implies that a zero IQTR is used as the AVE. If the original TRQ regime was overfill or a binding quota, the CGE model likely responds to the drop in the AVE with a trade expansion beyond the quota, where the typically prohibitive OQTR would be applied instead.

We use the CETA agreement as an example to demonstrate the potential bias associated with the more common approaches. First, when TRQs are explicitly modeled at an aggregated sector level, we find lower trade impacts compared with the AVE approach, which predicts a larger reduction in marginal tariff rates. Second, we find that modeling at the aggregate level, with explicit TRQs or AVEs, leads to lower trade impacts than when considering the product detail in the model itself. The primary reason is that because some trade is subjected to TRQs and others to normal tariffs, aggregating TRQs and normal tariffs dampen the shock, and thus underestimate the trade impacts. Third, we compare the trade impacts under both TRQ modeling approaches at a disaggregated level but use different substitution elasticities across products falling under the aggregated sector. Our results show that the simulated impacts increased with higher possibilities of substitution among detailed products on the same trade link.

We also performed three counterfactuals. In the first, we show that when the quota is initially filled, but not overfilled and the IQTR is lowered, the AVE approach shows larger changes. This reflects that the MacMap approach assumes the maximal per unit quota rent (the

difference between OQTR and IQTR) once the fill rate exceeds 98%. The MCP approach chooses the initial per unit rent instead; in general, the selected marginal tariff rate is lower, such as in the usual assumption to use the average of initial IQTR and OQTR. In a second counterfactual, we show a case where the AVE approach predicts a different TRQ regime ex-ante than when simulated with the model. In this example, the quota expansion lets the MacMap approach assume that the IQTR will be the new marginal tariff rate. The model responds with an expansion of trade beyond the quota, where the OQTR would apply instead. Similarly, we show that if the quota and related tariffs remain unchanged but another trade policy changes (here a reduction in NTM is used, which shifts import demand), similar inconsistencies can be found; here, trade exceeded the quota in some experiments, whereas the exogenous marginal tariff rate was lower than the OQTR.

Despite the combination of explicit TRQ representation and bilateral tariff line detail, potential for improvements remain. First, because a single TRQ often relates to multiple products at the HS6 or even deeper classifications, depicting TRQs at the tariff line can require an ex-ante allocation of the overall quota to these tariff lines. We propose, but do not implement in our empirical application, a framework to do so endogenously, where a virtual export agent allocates quotas to different tariff lines to maximize revenues. However, this requires the marginal willingness to pay at the tariff line level by the export partner, which is unfortunately not easily obtainable. Future studies might expand on this, for instance, with econometric work. Second, the endogenous TRQ allocation approach could be extended to erga-omnes TRQs, which require import demand and export supply equation systems for all trading partners delivering into such a TRQ. Third, as found in our empirical example, even products at a fine-grain tariff line level may fall

under different TRQs. With our 8-digit-level detail trade data, we were not always able to associate each TRQ to a single tariff line. Here, further data might help. Fourth, although our approach captures bilateral trade changes at the detailed commodity level, production changes are not simulated at this detail as, for example, in the GTAP-HS-TRQ model. Finally, for benchmarking under a binding quota when TRQs are implemented explicitly, an assumption on the per unit quota rent must be made. In this study, we took the average of the IQTR and the OQTR, following the MACMap approach.

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The paper has not been published previously and it is not under

consideration for publication elsewhere. All authors approve this publication and if the paper accepted, it will not be published elsewhere in the same form.

Declarations of competing interest

Authors have no competing interests to declare.

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Appendix A. Supplementary Tables

Table A1
TRQs by market

Country	Number of TRQs	Quota Size(tons)	TRQ Imports (tons)	TRQ imports (\$1000, estimated)
Australia	2	22,684	12,324	109,632
Barbados	36			
Brazil	2	760,000	6,108,073	2,130,699
Canada	22	885,825	431,738	693,984
Chile	1	60,000		
China	10	25,282,000	14,315,597	4,639,051
Columbia	67	1,495,041	7,682,462	2,767,557
Costa Rica	27	3378	795	37
Dominican Republic	8	1,208,560	123,628	
European Union	117	19,434,470	9,176,406	
Ecuador	14	55,035		
El Salvador	11	785	156	487
Guatemala	22	107,275	347,943	
Iceland	90	87,172	139,728	185,568
India	4	510,000	19,972	30,293
Indonesia	2			
Israel	12	492,208	1,836,389	511,622
Japan	20	8,602,702	8,213,786	6,885,841
Macedonia	1	80,000	49,863	18,247
Malaysia	19	75,443	68,477	113,340
Mexico	11	20,000	244,040	758,012
Moldova	3	8340	7406	5234
Morocco	19	2,326,390	2,304,357	1,535,764
New Zealand	3	3331	4572	6503
Nicaragua	9	24,776	18,987	4631
Norway	232	42,746	38,373	118,730
Panama	19	26,196	18,756	51,152
Philippines	14	732,459	587,217	329,693
Russia	9	1,379,000	1,184,887	3,579,436
South Africa	53	1,130,106	716,348	752,909
South Korea	67	9,028,552	8,238,916	3,596,579
Switzerland	28	1,499,975	1,600,106	5,092,451
Taiwan	22	260,884	176,182	
Thailand	23	60,559	98,310	241,346
Tunisia	13	1,239,691	127,029	468,888
Ukraine	1	267,800		
United States	54	2,452,547	1,736,524	4,425,351
Venezuela	61	4,854,614	4,133,289	3,453,380
Vietnam	3	347,526	278,500	291,300

Source. Beckman et al., (2021).

Notes. Quota sizes and TRQ imports (value and volume) reflect information from the Member country's most recent WTO TRQ notification.

Table A2
Description of tariff line commodities

Tariff line	Description
04061020	Cheese and curd. - Fresh (unripened or uncured) cheese, including whey cheese, and curd - Over access commitment
04062012	Cheese and curd. - Grated or powdered cheese, of all kinds - Cheddar and Cheddar types: Over access commitment
04062092	Cheese and curd. - Grated or powdered cheese, of all kinds - Other: Over access commitment
04063020	Cheese and curd. - Processed cheese, not grated or powdered - Over access commitment
04064020	Cheese and curd. - Blue-veined cheese and other cheese containing veins produced by <i>Penicillium roqueforti</i> - Over access commitment
04069012	Cheese and curd. - Other cheese - Cheddar and Cheddar types: Over access commitment
04069022	Cheese and curd. - Other cheese - Camembert and Camembert types: Over access commitment
04069032	Cheese and curd. - Other cheese - Brie and Brie types: Over access commitment
04069042	Cheese and curd. - Other cheese - Gouda and Gouda types: Over access commitment
04069052	Cheese and curd. - Other cheese - Provolone and Provolone types: Over access commitment
04069062	Cheese and curd. - Other cheese - Mozzarella and Mozzarella types: Over access commitment
04069072	Cheese and curd. - Other cheese - Swiss/Emmental and Swiss/Emmental types: Over access commitment
04069082	Cheese and curd. - Other cheese - Gruyere and Gruyere types: Over access commitment
04069092	Cheese and curd. - Other cheese - Other: Havarti and Havarti types, Over access commitment
04069094	Cheese and curd. - Other cheese - Other: Parmesan and Parmesan types, Over access commitment
04069096	Cheese and curd. - Other cheese - Other: Romano and Romano types, Over access commitment
04069099	Cheese and curd. - Other cheese - Other: Other, Over access commitment
02011000	Meat of bovine animals, fresh or chilled: Carcasses and half carcasses
02012020	Meat of bovine animals, fresh or chilled: Other cuts with bone in - Compensated quarters
02012030	Meat of bovine animals, fresh or chilled: Other cuts with bone in - Unseparated or separated forequarters
02012050	Meat of bovine animals, fresh or chilled: Other cuts with bone in - Unseparated or separated hindquarters
02012090	Meat of bovine animals, fresh or chilled: Other cuts with bone in - Other
02013000	Meat of bovine animals, fresh or chilled: Boneless - high quality
02021000	Meat of bovine animals, frozen: Carcasses and half carcasses
02022010	Meat of bovine animals, frozen: Other cuts with bone in - Compensated quarters
02022030	Meat of bovine animals, frozen: Other cuts with bone in - Unseparated or separated forequarters
02022050	Meat of bovine animals, frozen: Other cuts with bone in - Unseparated or separated hindquarters
02022090	Meat of bovine animals, frozen: Other cuts with bone in - Other
02023010	Meat of bovine animals, frozen: Boneless - Forequarters, 'compensated' quarters, and hindquarter
02023050	Meat of bovine animals, frozen: Boneless - Crop, chuck-and-blade and brisket cuts
02023090	Meat of bovine animals, frozen: Boneless - Other
02061095	Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies, fresh, chilled or frozen: Of bovine animals, fresh or chilled - Other, Thick skirt and thin Skirt
02062991	Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies, fresh, chilled or frozen: Other - Thick skirt and thin Skirt
02102010	Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat or meat offal: Meat of bovine anima - ith bone in
02102090	Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat or meat offal: Meat of bovine anima - Boneless
02109951	Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat or meat offal: Other offal - Thick skirt and thin Skirt
02109959	Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat or meat offal: Other offal - Other

Source. The definition of tariff lines by the EU available from TARIC (the integrated Tariff of the European Union) database,^a and by Canada available from Canada border Services Agency^b.

^a https://ec.europa.eu/taxation_customs/dds2/taric/taric_consultation.jsp?Lang=en.

^b <https://www.cbsa-asfc.gc.ca/trade-commerce/tariff-tarif/2015/html/tblmod-2-eng.html>.

Table A3

Correspondence between tariff lines at 8-digit-level in Canada and the EU

MIL		MEAT	
Canada (Importer)	EU (Exporter)	EU (Importer)	Canada (Exporter)
04061020	04061030	02011000	02011020
	04061050	02012020	
	04061080	02012030	
04062012	04062000	02012050	
04062092	04062000	02012090	
04063020	04063010	02013000	02013020
	04063031	02021000	02021020
	04063039	02022010	02022020
	04063090	02022030	
	04064010	02022050	
	04064050	02022090	
	04064090	02023010	02023020
04069012	04069021	02023050	
	04069023	02023090	
04069022	04069082	02061095	02061000
04069032	04069084	02062991	02062100
04069042	04069025		02062200
	04069029		02062900
	04069074	02102010	02102000
	04069078	02102090	
04069052	04069073	02109951	02109990
04069062	04069050	02109959	
04069072			

(continued on next column)

Table A3 (continued)

MIL		MEAT	
Canada (Importer)	EU (Exporter)	EU (Importer)	Canada (Exporter)
	04069013		
	04069017		
	04069018		
04069082	04069015		
	04069035		
04069092	04069075		
	04069076		
04069096	04069061		
	04069063		
04069099	04069001		
	04069032		
	04069037		
	04069039		
	04069069		
	04069079		
	04069081		
	04069085		
	04069086		
	04069089		
	04069092		
	04069093		
	04069099		

Source. Authors compilation based on the definition of tariff lines by the EU available from database, and by Canada available from Canada border Services Agency.

Table A4

Trade value and AVEs across tariff lines

Product Code	Canada import of Meat from EU			Product Code	EU import of Mil from Canada		
	Pre-CETA AVEs(%_	Post-CETA AVEs (%)	Trade Value (USD)		Pre-CETA AVEs(%_	Post-CETA AVEs (%)	Trade Value (USD)
02011000	26.50	0	0	04061020	4.66	0	0
02012020	26.50	0	0	04062012	3.49	0	0
02012030	26.50	0	0	04062092	3.49	0	0
02012050	26.50	0	0	04063020	3.13	0	0
02012090	26.50	0	0	04064020	1.70	0	42
02013000	26.50	0	0	04069072	3.08	0	902
02021000	26.50	0	0	04069012	2.85	0	5672052
02022010	26.50	0	0	04069082	2.90	0	0
02022030	26.50	0	0	04069062	2.71	0	0
02022050	26.50	0	0	04069094	3.38	0	0
02022090	26.50	0	0	04069096	3.38	0	0
02023010	26.50	0	0	04069052	2.71	0	0
02023050	26.50	0	0	04069092	2.71	0	0
02023090	26.50	0	0	04069042	2.71	0	26978
02061095	0	0	0	04069022	2.71	0	0
02062991	0	0	0	04069032	2.71	0	0
02102010	0	0	0	04069099	2.89	0	148566
02102090	0	0	0				
02109951	0	0	0				
02109959	0	0	0				
TRQMeat_Can	0	0	0	TRQMil_EU	2.85	0.00	5848541
NonTRQMeat_Can	0.58	0	84645858	NonTRQMil_EU	2.51	0.00	576327

Source. Authors' compilation based on the definition of tariff lines by the EU available from TARIC database, and by Canada available from Canada border Services Agency.

Table A5

Possible allocation of tariff lines to TRQs

HS8 code	Fresh meat TRQ	Frozen Meat TRQ	High Quality Meat TRQ	Bison TRQ
02011000	x		x	x
02012020	x		x	x
02012030	x		x	x
02012050	x		x	x
02012090	x		x	x
02013000	x		x	x
02021000		x	x	x
02022010		x	x	x
02022030		x	x	x
02022050		x	x	x

(continued on next column)

Table A5 (continued)

HS8 code	Fresh meat TRQ	Frozen Meat TRQ	High Quality Meat TRQ	Bison TRQ
02022090		x	x	x
02023010		x		x
02023050		x		x
02023090		x		x
02061095	x		x	x
02062991		x	x	x
02102010		x		x
02102090		x		x
02109951		x		x
02109959		x		x

Source. Authors' compilation based on the definition of tariff lines by the EU available from TARIC database, and by Canada available from Canada border Services Agency.

Appendix B. Endogenous allocation of quota

Trade negotiations often determine a 'collective' quota for each of the product categories that have some similarities. For example, CETA determines three types of quota for different classifications of meats: bison, fresh, frozen, and HQB meat and a single quota for the Cheese. Each of the categories comprises some products at finer details and their share in the collective quota is not predetermined. The shares depend on endogenous variables (e.g. prices) and exogenous parameters (e.g. substitution elasticities at the tariff line) that affect the profit of exporters. Given this background, modeling TRQs for ex-ante policy analysis is challenging as one has to allocate the collective quota to each tariff line either exogenously or endogenously. While one could simply allocate the quota equally or proportionally based on observed trade data to the detailed tariff line levels, we present an approach that allows for the endogenous allocation of the shares.

Let q denote a given tariff rate quota accessible to a representative exporting firm that can be filled by tl different tariff lines. The firm has shipped amounts $\bar{x}$ of these different products tl to the export destination at given CIF cost $PMTL_{s,tl,r}^{cif}$ and receives related prices $PMTL_{s,tl,r}$ by selling at the export destination, and has to pay the yet to determine tariffs. The OQTR, t^{oq} differ across the tariff lines while IQTR is zero. The problem is to determine which amounts of the different x are formally declared to fall under the quota and if the firm shall sell the rest or not. The problem is hence,

$$\max \pi = \sum_{tl} x_{tl,oq} \left[\overline{PMTL}_{s,tl,r} - t_{tl}^{oq} \overline{PMTL}_{s,tl,r}^{CIF} \right] + x_{tl,iq} \overline{PMTL}_{tl} - \bar{x}_{tl} \overline{PMTL}_{s,tl,r}^{CIF} \quad s.t. \quad x_{tl,oq} + x_{tl,iq} \leq \bar{x}_{tl} \quad [\lambda_{tl}] \quad \sum_{tl} x_{tl,iq} \leq \bar{q} \quad [\lambda_q]. \quad (C.1)$$

where the profit π , to be maximized, depicts the difference between the revenues received by selling the product at the export destination and the cost that includes the tariff. The first set of constraints state for each of the different product that the purchased quantity must be declared as in-quota iq or out-of-quota oq , potentially in shares. The second set of constraints ensures that the quota is filled. This is a simple linear problem that we can solve via Lagrange multipliers,

$$\frac{\partial L}{\partial x_{tl,oq}} = \overline{PMTL}_{s,tl,r} - t_{tl}^{oq} \overline{PMTL}_{s,tl,r}^{CIF} - \lambda_{tl} \perp x_{tl,oq} \quad \frac{\partial L}{\partial x_{tl,iq}} = \overline{PMTL}_{tl} - \lambda_{tl} - \lambda_q \perp x_{tl,iq}. \quad (C.2)$$

We have two expressions for the λ_{tl} which can be combined to get,

$$\lambda_{tl} = \overline{PMTL}_{s,tl,r} - t_{tl}^{oq} \overline{PMTL}_{s,tl,r}^{CIF} = \overline{PMTL}_{tl} - \lambda_q \quad (C.3)$$

Rearrange Equation (C.3) to find the optimal quota rent gives

$$\lambda_q = \overline{PMTL}_{s,tl,r}^{CIF} \perp x_{tl,oq} \quad (C.4)$$

This implies that the uniform quota rent is defined by the per unit tariff costs which must be equalized across the different products falling under the same quota.

Let us assume that we have only two products. We would only export over-quota quantities of a product if the difference between the price received $\overline{PMTL}_{tl}$ and the cost $(1 + t_{tl}^{oq}) \overline{PMTL}_{tl}^{CIF}$ is positive. The product with the smallest positive difference defines the quota rent λ_q , and its λ_{tl} is exactly zero. Products with higher positive differences have an extra value of λ_{tl} which can be interpreted as additional economic rent. The firm would rather export these products over quota, either because they have a lower *ad-valorem* tariff or lower production cost. Note that in the above maximization problem we assumed that the representative firm has already shipped the products to the destination and then realizes the quota to be filled, such in case of a first-come-first-serve quota, this includes the case to dispose of quantities instead of selling them. That is the case if the $t_{tl}^{oq} \overline{PMTL}_{tl}^{CIF} > \overline{PMTL}_{tl} - \overline{PMTL}_{tl}^{CIF}$, i.e. if the difference between the per unit revenues from selling minus the sunk c.i.f. costs are smaller from the tariff to pay to be allowed to sell.

To use the results in the context to define appropriate AVE rates, this suggests using the highest AVE rate which at given CIF price would still be able to be sold in the export market. This requires information in the marginal willingness to pay at the tariff line level by the export partner that is unfortunately not easily obtainable.

Appendix C. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.econmod.2021.105620>.

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ARTICLE

It is all in the details: A bilateral approach for modelling trade agreements at the tariff line

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Abstract

Policymakers are increasingly relying on computable general equilibrium (CGE) models to provide economy-wide impacts of trade agreements; however, these assessments often make the simplifying assumption of complete bilateral tariff elimination. But agreements typically involve partial tariff elimination for sensitive sectors—which are often differentiated at the tariff line. As such, applying a uniform tariff reduction in a CGE sector that encompasses many products could introduce bias. We propose a tariff line approach for modelling exemptions for sensitive goods in CGE models with the aim of reducing this bias. This approach is tested for the Canada–EU trade agreement, and systematically compared to standard approaches to bilateral trade liberalisation in CGE analysis. We find that more common approaches might systematically overestimate trade and welfare impacts by neglecting partial liberalisation in selected sectors and/or not considering substitution across tariff lines.

KEYWORDS

aggregation bias, CETA, computable general equilibrium, free trade agreements, sensitive products, tariff line analysis, trade policy

Résumé

Les décideurs s'appuient de plus en plus sur des modèles d'équilibre général calculable (EGC) pour estimer les effets des accords commerciaux sur l'ensemble de l'économie. Cependant, ces évaluations considèrent souvent l'hypothèse simplificatrice d'une élimination complète des droits de douane entre les pays signataires. En pratique, ces accords incluent généralement des produits dits sensibles : le taux de protection final des lignes tarifaires concernées ne sera que partiellement (ou pas) supprimé. Dans les modèles EGC, la méthodologie classique consiste à traiter ces lignes tarifaires à l'extérieur du modèle et à agréger ensuite les tarifs finaux en secteurs compatibles avec la résolution du modèle. Pour réduire les biais potentiels de cette méthode, nous proposons une modélisation fine, au niveau des lignes tarifaires pour prendre en compte les

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exemptions des produits sensibles dans les modèles EGC. Nous testons notre approche en simulant l'accord commercial Canada-UE et nous comparons systématiquement nos résultats aux approches standards des accords commerciaux dans la littérature EGC. Nous concluons que les approches plus utilisées pourraient systématiquement surestimer les effets sur le commerce et le bien-être en négligeant la libéralisation partielle dans certains secteurs et/ou en ne considérant pas les substitutions possibles au niveau des lignes tarifaires.

1 | BACKGROUND AND LITERATURE REVIEW

Policymakers are increasingly relying on computable general equilibrium (CGE) models to provide assessments of potential free trade agreements (FTAs), given their ability to provide a global, economy-wide perspective, with interindustry linkages and bilateral trade relations. For example, the United States Trade Representative requires a CGE-based analysis for any trade agreement under discussion in the United States; similarly, CGE models have provided *ex ante* impact analyses of changes in European Union (EU) trade policy (e.g., Jean et al. (2014) for Chile; Fontagne et al. (2013) with the United States; European Commission (2017) with Canada; Antimiani and Salvatici (2015); and Boulanger et al. (2016) on the combined effects of several EU agreements). Most CGE analyses rely on the Global Trade Analysis Project (GTAP) database (Aguiar et al., 2019), given that it provides global data on bilateral trade, production and consumption. This database distinguishes most countries individually; however, its product differentiation at 65 sectors is much more aggregated than where trade negotiations are focused (at the tariff line). But considering all individual tariff lines in a CGE model is practically impossible, given that there are more than 5,300 products at the HS 6 level.

The current practice aggregates bilateral trade data from the tariff line to the GTAP sector level before they enter the CGE model. Such pre-model aggregation of trade and tariff data remains challenging for at least two reasons. First, FTAs tend to fully liberalise the majority of tariff lines, with some exemptions for sensitive products (often specified at the HS6 or HS8 level). As research is often conducted before the (final) legally binding text detailing all exemptions is available, CGE models often either assume full tariff liberalisation¹ or underrepresent exemptions for sensitive products. As such, tariffs might be reduced according to the percentage of tariff lines in a sector exempted from full trade liberalisation (see Jafari and Britz (2018) for a review). Second, even if exemptions are considered, tariff aggregators can provoke systematic bias since high tariff rates tend to decrease traded volumes more than lower tariffs, resulting in underestimated average border protection (Anderson, 2009; Bach & Martin, 2001; Himics & Britz, 2016). The related bias generally increases with greater initial tariff dispersion and with larger tariff cuts. To illustrate how the lack of commodity details might lead to aggregation bias, consider two exporters who do not face direct competition at the HS6 level in weak substitutes such as butter and cheese. At the aggregate GTAP level these exporters would appear as competitors since the data combines the two into one 'dairy product' sector.

Two approaches have been developed to address the tariff aggregation bias: the full or partial extension of the model to the tariff line or improved pre-model aggregation. First, CGE models can be extended to the tariff line to avoid aggregation bias. One approach iteratively links the CGE model to a detailed partial equilibrium (PE) model operating at the tariff line (Grant et al., 2007). Another adds model equations to the model itself and splits up selected elements in the production and demand structure to the tariff line (Narayanan et al. (2010) and Beckman and Arita (2016) for pork and poultry; Chepeliev et al. (2019) for vegetables and fruits). In both cases, demand and bilateral trade information must be available and rendered consistent to the overall data base (Hertel, 2012), which is often challenging. Ultimately, neither the partial disaggregation nor the iterative PE-CGE link scale up well as it is numerically difficult to extend them to many or all commodities (Himics & Britz, 2016). Regarding the second approach, the so-called reference group method (Guimbard et al., 2012) is frequently applied for pre-model aggregation. This approach decreases endogeneity bias by calculating aggregation weights based on the observed trade patterns of a (reference) group of countries, rather than using country specific bilateral trade flows, which would miss prohibitive tariffs without bilateral trade flows.

¹ For example, most CGE studies examining the Transatlantic Trade and Investment Partnership (TTIP) assume complete tariff removal. This is despite a large number of sensitive products traded between the EU and United States (see Jafari et al., 2019 for a review). Moreover, frequent examples can be found on the website of European commission and CEPII. The European Commission considers at least one scenario of full liberalizing tariffs for all goods in EU agreements with New Zealand (2017), Australia (2017), Indonesia (2019), Mercosur (2020) and Canada (2011).

Given the discussion above, pre-model aggregation remains the dominant approach in CGE-based analysis of FTAs with many using the “Tariff Analytical and Simulation Tool for Economists” (TASTE) tariff aggregation tool (Horridge & Laborde, 2008), developed as an add-on for the GTAP database.² However, simulation results with the TASTE-GTAP combined approach face an aggregation bias, because the pre-model aggregator does not consider substitution effects between commodities at the tariff line. An unchanged CGE model cannot help here as it considers substitution at the limited number of (highly aggregated) sectors.

We propose extending the CGE model structure directly to the tariff line. Our approach requires less data (i.e., no need for detailed data on production and consumption), requires less additional equations and it still reduces the tariff aggregation bias. We test this approach using the EU–Canada Comprehensive Economic and Trade Agreement (CETA), which fully removes tariffs on many traded goods between the EU and Canada, but exempts several tariff lines in the agri-food sector from full liberalisation. As discussed before, neglecting these exceptions could lead to significant aggregation bias, especially as they represent a substantial share of trade. Given that CETA might significantly alter global agri-food markets due to trade diversion effects (since the EU and Canada are both among the top four exporters of agri-food products worldwide), it is an inviting case for testing our approach. We extend a CGE model to the HS6 tariff line level, relying on policy data directly extracted from the legal text of the CETA agreement, and taking into account sensitive products. In order to evaluate the advantages of the proposed approach, we compare our simulation results to two traditional approaches: (i) a full liberalisation scenario, where sensitive goods are neglected and (ii) a scenario with weighted average tariff cuts (including sensitive tariff lines) calculated with the pre-model aggregation tool TASTE.

2 | A REVIEW OF THE IMPACT ASSESSMENTS OF THE CETA

Several studies have analysed the potential economic impacts of CETA, comprising of work dating back to when discussions were informal up to assessments using the text of the ratified agreement. Our review (Table 1) focuses on studies that used CGE models, with most applying some variant of the GTAP model or database. The comparison of the three official impact assessments of the negotiating parties shows an increasing level of detail over time, both in terms of sensitive products considered and with respect to regional and sectoral aggregation: Hejazi and Francois (2008)³ assumed full tariff liberalisation; Kirkpatrick et al. (2011) exempted some GTAP sectors from tariff cuts (but did not account for sensitive tariff lines); finally, European Commission (2017) calculated the impact of tariff line-exceptions on the sector-level tariff cuts with a pre-model aggregation approach, from 6-digit level to GTAP sectors. Note that Table 1 indicates that the impact on bilateral trade and welfare tends to decrease in more recent studies with more sectoral and regional detail, and by adding more exceptions for sensitive products. Philippidis and Kitou (2012) consider three scenarios, full tariff elimination as opposed to two different offers, with differences in the lists of sensitive products. Results indicate that even small changes in the list of sensitive products can alter results significantly. Boulanger et al. (2016) vary the size of the partial tariff cuts for sensitive products (25% or 50% cut) and find that variances in bilateral import changes. These systematic differences highlight the need for more disaggregation in CGE studies and show that taking into account even a small number of sensitive products can alter significantly the simulated impacts.⁴

3 | EXTENSIONS TO TARIFF LINE DETAILS

3.1 | Conceptual framework

Similar to most Armington based equilibrium models, the standard GTAP model uses a three-tier representation of demand. The top-level demand for individual (aggregated) commodities is broken down to a two-stage nested Armington demand structure (Figure 1). The first Armington stage decomposes total demand for each agent⁵ and commodity i (XA_i)

² Similar to the reference group method, the aggregation weights in TASTE are based on trade flows between countries of similar economic profiles.

³ Hejazi and Francois (2008) is often referred to as the ‘joint study’, as it was commissioned jointly by the negotiating parties. Kirkpatrick et al. (2011) is part of the sustainability impact assessment (SIA) of the EU. European Commission (2017) is part of the final economic impact assessment of the European Commission.

⁴ The need for more disaggregated databases is also illustrated by comparing country specific studies with the EU aggregate studies. For example, Francois and Pindyuk (2013) calculate a potential increase of +131% in Austrian exports to Canada in the processed food sector, which is larger than any

TABLE 1 Ex-ante impact assessments of the CETA

Study	Modelling approach	Database	Sectoral and regional aggregation	Tariff aggregation approach	CETA scenarios	Trade impacts	Welfare impacts
Cameron and Loukine (2001)	Static CGE; GTAP	GTAP v4 (reference year 1995)	10 sectors; six regions, including Canada, EU and countries in accession negotiations at the time of the study	Pre-model	Full tariff liberalisation with and without exception for agricultural sectors (no tariff cuts)	Canada bilateral exports: from +0.78% to +0.86% EU bilateral exports: from +1.1% to +1.2%	Welfare as a percent of GDP: from +0.03% to +0.04% for Canada, around four times smaller gains for the EU (+770 million USD)
Hejazi and Francois (2008)	Static CGE; Copenhagen Economics model	GTAP v7 (reference year 2004, projected to 2007 and 2014)	Not reported	Pre-model aggregation (TASTE)	Full liberalisation; no exceptions for sensitive products	Bilateral export increases: +36.6% for the EU, +24.3% for Canada bilateral processed food exports: +326% for EU, +142% for Canada bilateral Primary agriculture exports: +6% to the EU, +42% for Canada	Impact measured as equivalent variation: +10.5 billion EUR for the EU, +8.4 billion EUR for Canada GDP gains: +0.08% for EU, +0.77% for Canada
Kirkpatrick et al. (2011)	Static CGE; GTAP	GTAP v7 (reference year 2004)	Sectors not reported; 10 regions, including Canada and the EU	Pre-model aggregation (TASTE)	Partial liberalisation; full tariff cuts for most GTAP sectors no tariff cuts for sensitive GTAP sectors ('dairy products' and 'other foods nec' for Canada, 'meats' and 'meat products nec' for the EU)	EU exports +0.05% to +0.07% Canada exports +0.54% to +1.56%	Real GDP increase: the EU: 0.02% to 0.03% Canada: 0.18% to 0.36%

(Continues)

TABLE 1 (Continued)

Study	Modelling approach	Database	Sectoral and regional aggregation	Tariff aggregation approach	CETA scenarios	Trade impacts	Welfare impacts
Philippidis and Kitou (2012)	Static CGE; Defra-Tap (agricultural variant of GTAP)	GTAP v7 (reference year 2004)	32 sectors; 18 regions, including Canada, UK, EU- 4 (Austria, Germany, Netherlands, Sweden), rest of the EU	Pre-model aggregation (TASTE)	Partial liberalisation; partial tariff cuts for sensitive products calculated by TASTE, aggregating from HS6 to sectoral level pre-model	Trade balance changes in agriculture and fisheries: Canada: +19 to +386 million EUR, the EU: –46 to –455 million EUR Trade balance changes in Food processing: Canada: –434 to +3 million EUR; the EU: –205 to 1307 million EUR	Welfare gains measured as equivalent variation: from +2.5 billion EUR to +3.3 billion EUR (+0.46% of per capita real income) for Canada, at constant 2004 prices from +3.1 billion EUR to +4.1 billion EUR (+0.04% of per capita real income) for EU, at constant 2004 prices
Francois and Pindyuk (2013)	Static CGE; Copenhagen Economics model	GTAP v8 (reference year 2007)	Sectors not reported; nine regions, including Canada, Austria and rest of the EU	Pre-model aggregation (TASTE)	Partial liberalisation, tariff reduction and NTM reduction aggregated to sector level	Only Austrian results are provided: ‘agriculture, forestry and fisheries’ sector: –1.8% exports to Canada, +124.8% imports from Canada ‘processed food’ +131% exports to Canada, +112.8% imports from Canada	Only Austrian results are provided: +0.215% in national income

(Continues)

TABLE 1 (Continued)

Study	Modelling approach	Database	Sectoral and regional aggregation	Tariff aggregation approach	CETA scenarios	Trade impacts	Welfare impacts
Boulanger et al. (2016)	Recursive dynamic CGE; MAGNET	GTAP v9 (reference year 2011)	57 sectors; 19 regions, including Canada and the EU	Pre-model aggregation (TASTE)	Partial liberalisation; partial tariff cuts for sensitive products (25% or 50% cut), aggregated to GTAP sectors	Bilateral exports increase: the EU +4.8% Canada +10.6% to +11.1%	Not comparable, as other EU FTAs are included in the scenarios
European Commission (2017)	Dynamic CGE; GDyn (dynamic version of GTAP)	GTAP v9 (reference year 2011)	57 sectors; 13 regions, including Canada and EU-28	Pre-model aggregation (TASTE)	Partial liberalisation; tariff schedule mapped/aggregated (pre-model) from tariff line to GTAP sectoral level; combined with assumptions on reduction of non-tariff barriers	Canada bilateral exports: +8.13% in value EU bilateral exports: +8.04% in value	EU: annual GDP gains between 1.7-2.1 billion EUR Canada: annual GDP gains between 2.4-3.0 billion EUR
Tamminen et al. (2017)	Static CGE; Copenhagen Economics model	GTAP v9, (reference year 2011)	57 sectors; four regions (Canada, Finland, the UK and rest of the EU)	Pre-model aggregation (TASTE)	Partial liberalisation: full cuts except dairy sector (25% cut) and other food products (50%) explicit cut on non-tariff barriers	Only Finnish exports reported: 'Primary products' to Canada +0.1 million EUR 'Food and beverages' to Canada +1.2 million EUR	Real GDP changes: Canada +0.34%, the EU +0.026%, Finland: +0.039%
Devadoss and Luckstead (2018)	Heterogeneous firms (Melitz type) model, partial equilibrium	GTAP v9 (reference year 2011)	Focus on food processing sector; four regions (Canada, the EU, the United States and rest of world)	Pre-model aggregation (TASTE)	Tariff removal combined with firm level cost changes (incl. fixed trade costs)	Results of tariff removal scenario: +83.9% EU exports to Canada +107.5% Canada exports to the EU	Comparable results not reported

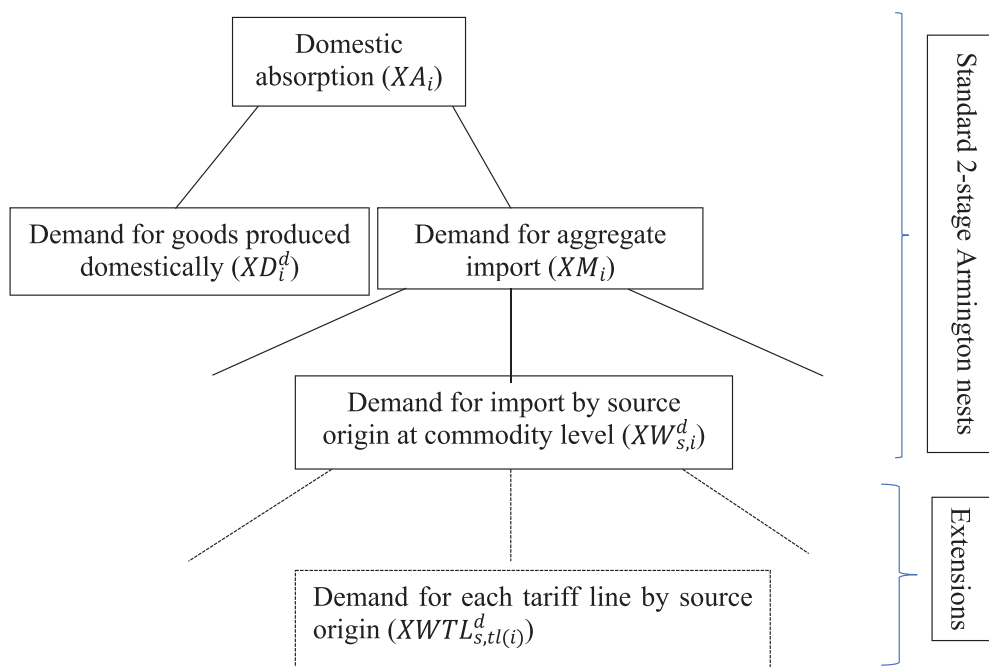


FIGURE 1 Nested Armington demand

into domestically produced (XD_i^d) and imported (XM_i) goods, which represent a constant elasticity of substitution (CES) preference structure in final consumption goods or a CES technology in intermediate demand. The second Armington stage decomposes aggregate import demand by source of origin, ($XW_{s,i}^d$), where s denotes the partner country. Due to data availability and to reduce model size, there is only one aggregate agent that allocates aggregate import demand across regions of origin, again based on a CES functional form.

Analogously to the above nested import demand structure, domestic supply is allocated in our model to the domestic market and to export destinations using a nested constant elasticity of transformation (CET) structure (Figure 2). The first nest breaks down total domestic supply of commodity (XS_i), to domestic sales (XD_i^s) and aggregate exports (XET_i). The second allocates aggregate exports across all export destinations d to determine bilateral export supply ($XW_{d,i}^s$).

Our approach extends the above two-stage Armington approach and splits *selected* bilateral trade flows from commodity to the tariff line level. In the FTA policy analysis context, this allows us to identify the tariff lines treated as sensitive goods and to simulate endogenous substitution between tariff lines within the total bilateral imports and exports of the corresponding aggregate commodities. As we keep the existing supply and demand structure at the top level (aggregated commodities) unchanged, our approach does not require tariff line level (disaggregated) details on domestic sales and consumption. The additional CES nest decomposes bilateral import demand from country s to the tariff lines, tl ($XWTL_{s,tl(i)}^d$). The subscript $tl(i)$ denotes tariff lines, tl , under the aggregate commodity level, i . Consequently, an additional CET nest allocates bilateral export supply to country d across the various tariff lines tl ($XWTL_{d,tl(i)}^s$). For increased readability we drop i from the notation of the tariff lines $tl(i)$, as tariffs lines are assumed to belong to one aggregated commodity only (no overlaps).

3.2 | Mathematical framework

The proposed CGE extension requires the following additional equations:

- CES share equations for bilateral import demand at the tariff line level.
- CET share equations for bilateral export supply at the tariff line level.

simulated impacts at the EU aggregate level. Although we keep the EU as one region in our study, we break down the sectors to the tariff line level in the EU–Canada bilateral trade direction to better depict product heterogeneity within the sectors.

⁵ We do not show the subscript for each agent here.

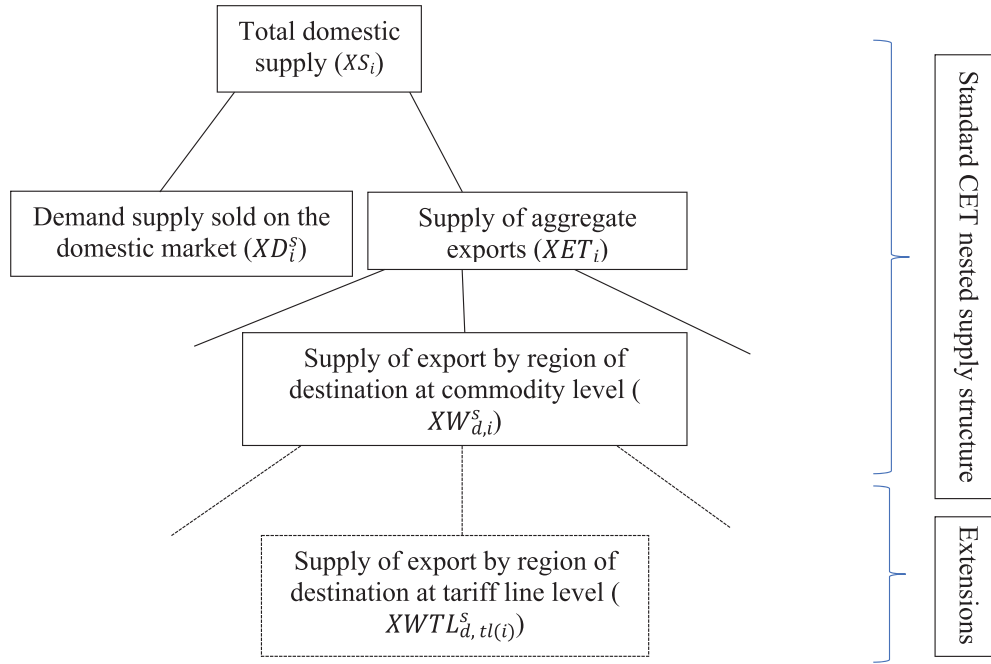


FIGURE 2 Nested CET supply

- Dual price aggregators (price index equations) for bilateral export supply and import demand prices, from the tariff line to the aggregated commodity level.
- A market clearing condition equalizing bilateral export supply and import demand at tariff line level, replacing market clearing at the aggregated commodity level.
- Price transmission equations linking domestic prices to bilateral import and export prices at the tariff line. The price transmission equations take into account trade costs, including import tariffs, export subsidies and transport margins. The tariff line level price transmission mechanism replaces the one at the commodity level.

The following section presents the above equations in detail. In the standard GTAP model, the allocation of aggregate imports across all source regions, indexed by s , is represented by Equation (1). The variable $XW_{s,i,r}^d$ represents the demand for exports from region s to region r for commodity i . The variable PM is the purchasers' price of bilateral imports that is tariff inclusive, later to be modified in our implementation. The formulation allows for changes in trade preferences based on the preference shifter λ^m . Parameter α^w is the CES share parameter and σ^w represents the substitution elasticity for each commodity across importing regions. The price of aggregate imports, PMT , is defined in Equation (2) using the CES dual price expression.

$$XW_{s,i,r}^d = \alpha_{s,i,r}^w XMT_{r,i} \lambda_{s,i,r}^m \sigma_{r,i}^{w-1} \left(\frac{PMT_{r,i}}{PM_{s,i,r}} \right)^{\sigma_{r,i}^w}. \quad (1)$$

$$PMT_{r,i} = \left[\sum_s \alpha_{s,i,r}^w \left(\frac{PM_{s,i,r}}{\lambda_{s,i,r}^m} \right)^{1-\sigma_{r,i}^w} \right]^{1/(1-\sigma_{r,i}^w)}. \quad (2)$$

Building on Equations (1) and (2), we introduce the following two additional equations that represent the new demand nest at the tariff line level. The variable $XWTL_{s,tl,r}^d$ represents the demand for exports from region s to region r for each tariff line tl that maps to commodity i . Here α^t is the share parameter for each tariff line and σ^t represents the substitution elasticity across tariff lines. Note that the latter is not the elasticity of substitution between importers for the same tariff line, but across tariff lines aggregated to the same product. The variable $PMTL$ is the purchasers' price of bilateral imports that includes tariffs. The price of bilateral imports at commodity level, PM , is defined in Equation (4) as an aggregation

over the tariff-line prices using the CES dual price expression.

$$XWTL_{s,tl,r}^d = \alpha_{s,tl,r}^t XW_{s,i,r}^d \left(\frac{PM_{s,i,r}}{PMTL_{s,tl,r}} \right)^{t_{r,tl}}, \quad (3)$$

$$PM_{s,i,r} = \left[\sum_{tl \in i} \alpha_{s,tl,r}^t PMTL_{s,tl,r}^{1-\sigma_{r,tl}^t} \right]^{1/(1-\sigma_{r,tl}^t)}. \quad (4)$$

The formulation of the nested export supply system reflects the special treatment of an infinite elasticity of transformation parameter across export markets. Equation (5) represents the second-level CET supply functions for imperfect transformation across export markets, XWs, that represents the exports from region r to region d for commodity i . The price PE represents the export price; γ^w and ω^w are the share parameter and the transformation elasticity for each commodity across exporting regions, respectively. PET represents the price of aggregate exports at commodity level i . Equation (6) represents the market clearing condition for bilateral export supply at the commodity level, represented by the CET dual price expression.

$$\begin{cases} XW_{r,i,d}^s = \gamma_{r,i,d}^w XET_{r,i} \left(\frac{PE_{r,i,d}}{PET_{r,i}} \right)^{\omega_{r,i}^w} & \text{if } \omega_{r,i}^w \neq \infty, \\ PE_{r,i,d} = PET_{r,i} & \text{if } \omega_{r,i}^w = \infty \end{cases}, \quad (5)$$

$$\begin{cases} PET_{r,i} = \left[\sum_d \gamma_{r,i,d}^w PE_{r,i,d}^{1+\omega_{r,i}^w} \right]^{1/(1+\omega_{r,i}^w)} & \text{if } \omega_{r,i}^w \neq \infty, \\ XET_{r,i} = \sum_d XW_{r,i,d}^s & \text{if } \omega_{r,i}^w = \infty \end{cases}. \quad (6)$$

Equations (7) and (8) introduce the additional nest in the CET structure at the tariff line level, and link it to the upper nests (Equations (5) and (6)). The variable $XWTL_{r,tl,d}^s$ denotes bilateral export supply at tariff line level, tl , from the origin r to destination region d . The variable PETL depicts the price of bilateral exports at the tariff line level gross of export and import taxes. Here γ^t is the share parameter for each tariff line and ω^t represents the substitution elasticity across tariff lines. The price of bilateral exports at commodity level, PE, is defined in Equation (8) as an aggregation over the related tariff-line prices, using the CET structure.

$$\begin{cases} XWTL_{r,tl,d}^s = \gamma_{r,tl,d}^t XW_{r,i,d}^s \left(\frac{PETL_{r,tl,d}}{PE_{r,i,d}} \right)^{\omega_{r,tl}^t} & \text{if } \omega_{r,tl}^t \neq \infty, \\ PETL_{r,tl,d} = PE_{r,i,d} & \text{if } \omega_{r,tl}^t = \infty \end{cases}, \quad (7)$$

$$\begin{cases} PE_{r,i,d} = \left[\sum_{tl \in i} \gamma_{r,tl,d}^t PETL_{r,tl,d}^{1+\omega_{r,tl}^t} \right]^{1/(1+\omega_{r,tl}^t)} & \text{if } \omega_{r,tl}^t \neq \infty, \\ XW_{r,i,d}^s = \sum_{tl} XWTL_{r,tl,d}^s & \text{if } \omega_{r,tl}^t = \infty \end{cases}. \quad (8)$$

The standard GTAP model includes two market equilibrium conditions for goods and services. The first condition guarantees equality of supply and demand for domestically produced goods sold on the domestic market. The second, as reflected in Equation (9), guarantees equality of supply and demand for each bilateral trade node at the commodity level.

$$XW_{r,i,d}^s = XW_{s,i,r}^d. \quad (9)$$

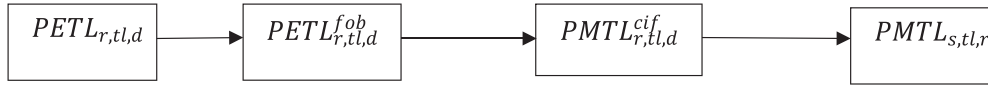


FIGURE 3 Trade price linkages

This equation is replaced with Equation (10) which ensures the equality of bilateral supply and demand at the tariff line level. The related shadow price determines the price of export supply at the tariff line level (PETL).

$$XWTL_{r,tl,d}^s = XWTI_{s,tl,r}^d. \quad (10)$$

In addition, export supply and import demand prices on the same trade link are directly related. Three price wedges translate export supply prices at the origin to the corresponding import price at the destination (Figure 3), taking into account bilateral export taxes or subsidies, as well as transport cost margins.

Producers in region r receive the price $PETL$ for delivering goods at tariff line tl to region d . A bilateral export tax or subsidy at tariff line (τ^e) is applied to the producer price, $PETL$, and determines the export border price (or the free on board – FOB price), $PETL^{fob}$ as represented in Equation (11).⁶ The price for international trade and transport services for each trade node ζ^{mg} is added to the FOB price to determine the cost-insurance-freight (CIF) price, $PMTL^{cif}$ as in Equation (12). In order to obtain the transport margin at the tariff line for each mode of transport, we split the transport margin for each mode and for each individual commodity into their related tariff lines using benchmark trade values as weights. Equation (13) determines the purchaser's import price at tariff line where the import tax or subsidy at tariff line (τ^m) is applied to the CIF price.

$$PETL_{r,tl,d}^{fob} = PETL_{r,tl,d} * \left(1 + \tau_{r,tl,d}^e + \tau_{r,tl}^e \right), \quad (11)$$

$$PMTL_{s,tl,r}^{cif} = PETL_{r,tl,d}^{fob} + \zeta_{s,tl,r}^{mg} PWMG_{s,tl,r}, \quad (12)$$

$$PMTL_{s,tl,r} = PMTL_{s,tl,r}^{cif} \left(1 + \tau_{s,tl,r}^m + \tau_{s,tl}^m \right). \quad (13)$$

Equations (11)–(13) present the bilateral price relationships in the extended framework, replacing those at the commodity level. Accordingly, the purchaser's price of bilateral imports at commodity level, PM , in Equation (1) and (2) directly corresponds to a CES weighted price of import prices at tariff line level.

In this study, we set the elasticity to 10 between total exports and domestic sales, and to 15 across export flows, following Britz and Van Der Mensbrugghe (2018). The substitution elasticity in the benchmark scenario equals 2 across tariff lines, both in the CES and the CET nests and for all commodities.

The additional (third) level of the extended Armington system can be interpreted as a nonlinear (CES) tariff aggregator, with endogenously determined aggregation weights. This third level is not directly related to the Armington assumption, because it does not aggregate over regions, but over tariff lines of a given product and trade link. One advantage of our approach is that it allows for substitution between tariff lines, such that aggregation weights can change during simulation. A further advantage of integrating tariff aggregation in the model structure (as above) arises if trade policies allow tariffs rates to change, for instance, to let tariff rates under a tariff-rate quota (TRQ) depend on whether the imported quantities exceed quota thresholds.⁷

In our approach, the substitution between tariff lines is at the level of the individual bilateral trade flow of an aggregated product, versus substitution between importers depicted at the level of individual tariff lines in Chepeliev et al. (2019), since we only split commodities to the HS6 level. With this approach, substitution between importers remains at the aggregated product level of the Armington nest, as in standard CGE-models. Note that the work of Chepeliev et al. (2019) requires a

⁶ Although our formulation allows for export taxes and subsidies, in our application export taxes/subsidies are not differentiated at the tariff line level. In addition, trade margins are assumed to be identical for all tariff lines belonging to the same commodity.

⁷ In this study we do not consider the possibility of endogenous ad-valorem tariffs at the tariff line. But the proposed approach is straightforward to extend with an equation system for modelling TRQs, with only a modest increase in the computational complexity.

new set of Armington elasticities, because traded goods at the tariff line level are more homogenous than the aggregate products, which consumers tend to substitute in their consumption bundle differently. In our partial (bilateral) extension, there is no need to update the second level Armington elasticities, when the third level is added to the system.

4 | DATA AND SOFTWARE

We introduce the model-endogenous bilateral tariff line aggregator in the modular platform for CGE modelling 'CGEBox' (Britz & Van Der Mensbrugghe, 2018). CGEBox offers flexible nesting options for modelling production and factor supply, supports different functional forms for demand and includes optional trade models (e.g., the heterogeneous firm model).⁸ We combine the GTAP Data Base (GTAP 10, 2014 reference year) with detailed bilateral trade data and protection levels at the tariff line, and simulate the impact of changes in import protection between the EU and Canada according to the CETA agreement.

Average bilateral Canada–EU trade data for 2015–2017 are taken from the UN-Comtrade Database at the six-digit HS level. Data on border protection in the form of Ad Valorem Equivalents (AVEs) of import tariffs and quotas are taken from the Market Access Map (MACMap) database, for the year 2017, covering both applied and bound rates. Post-agreement bound rates are derived from the legal text of the agreement (European Union, 2017). In order to take into account the possible gaps between applied and bound rates (binding overhang), the post-agreement applied rates are estimated as the minimum of the post-agreement bound rate and the current applied rate. Given that our data on bilateral trade flows are more recent than the trade data underlying the GTAP version 10 database (2015–2017 vs. 2014), we opt for the more recent trade statistics in the tariff line model extension to harmonise trade and tariff statistics at the six-digit level. This requires the calibration of data on trade flows at the tariff line level to the given ones for standard GTAP commodities, based on uniform scaling factors.

We keep the full resolution of the GTAP database (GTAP 10, 2014 reference year) at 65 sectors, and keep important EU and Canada trading partners. The regional coverage includes Australia and New Zealand, East Asia, Southeast Asia, Canada, the United States and Mexico, Latin America, Middle East and North Africa, Sub-Saharan Africa and other regions.⁹ For reporting purposes only, we aggregate the simulation results post-model for the extraction, manufacturing and services sectors. Similarly, simulated results for the regions other than the EU and Canada are aggregated post-model, and reported as 'Rest of the World' (ROW).

4.1 | State of trade between the EU and Canada

Table 2 presents base total and bilateral imports of the EU and Canada. Canada imports a large share (15.5%) from the EU, particularly in comparison with the relatively small share of EU imports from Canada (0.80%). Shares in agri-food trade are similar: 12.1% of Canadian agri-food imports are sourced from the EU, while only 0.65% of EU agri-food imports are from Canada. Larger shares of EU imports to Canada in agri-food sectors are found for 'beverages and tobacco products' (43%), 'animal products nec' (36%) and 'dairy products' (30%). Further agri-food products sourced with a relatively high share from the EU are 'vegetable oils and fats' (12%) and 'food products nec' (9%).¹⁰ Regarding EU imports from Canada, 'wheat' (11%) and 'oil seeds' (3%) have significant import shares in total EU agri-food imports.

Table 3 breaks down bilateral import shares and tariffs. Agri-food trade represents 6.6% and 5.4% of bilateral imports of the EU and Canada, respectively at the benchmark. Other food (OFD), and wheat (WHT), each have a 26–30% share of EU agri-food imports from Canada while OFD and beverage and tobacco (B_T) constitute 29–45% of Canadian agri-food imports from the EU. The average tariff for agri-food products is 6.5% for the EU and 1.7% for Canada, respectively. These protection levels are considerably higher than the average trade-weighted average of all goods (0.86% for the EU and 0.96% for Canada). Furthermore, they also vary substantially among food products, peaking at 39% for the GTAP sector 'dairy products' for EU imports and 4.4% for Canadian imports of 'food products nec'.

⁸ See Jafari and Britz (2018).

⁹ GTAP data base comprises many small entries, which can affect the numerical stability during the solution procedure of a CGE. We, therefore, filter out small transactions in relative terms in a systematic way after aggregation to our ten regions while maintaining a balanced global SAM (Britz & Van der Mensbrugghe, 2016).

¹⁰ Products with very small import value such as WHT, and WOL are ignored in ranking Canada's import share of agri-food products from the EU.

TABLE 2 Importance of trade between the EU and Canada compared with the ROW

	EU import			Canada import		
	Total [Million USD]	From Canada [Million USD]	Share from CanadaEU (%)	Total[Million USD]	From EU [Million USD]	Share from the EU (%)
All sectors	7100.92	56.617	0.80	575.505	89.242	15.51
Agri-food	574.854	3.735	0.65	39.417	4.786	12.14
Paddy rice (PDR)	0.075	0.00	0.00	0.000	0.000	–
Wheat (WHT)	9.096	0.963	10.59	0.039	0.01	25.64
Cereal grains nec (GRO)	11.168	0.312	2.79	0.535	0.021	3.93
Vegetables, fruit, nuts (V_F)	67.524	0.312	0.46	7.721	0.177	2.29
Oil seeds (OSD)	16.994	0.507	2.98	0.63	0.007	1.11
Sugar cane, sugar beet (C_B)	0.525	0.000	0.00	0.007	0.000	–
Plant-based fibers (PBF)	0.862	0.000	0.00	0.023	0.000	–
Crops nec (OCR)	32.992	0.041	0.12	1.719	0.097	5.64
Cattle, sheep, goats, horses (CTL)	5.185	0.029	0.56	0.111	0.023	20.72
Animal products nec (OAP)	15.286	0.166	1.09	1.054	0.378	35.86
Raw milk (RMK)	0.147	0.001	0.68	0.000	0.000	–
Wool, silk-worm cocoons WOL)	5.195	0.000	0.00	0.06	0.017	28.33
Meat: cattle, sheep, goats, horse (CMT)	21.573	0.046	0.21	1.37	0.012	0.88
Meat products nec (OMT)	43.979	0.01	0.02	2.175	0.104	4.78
Vegetable oils and fats (VOL)	43.91	0.045	0.10	1.554	0.19	12.23
Dairy products (MIL)	43.438	0.021	0.05	0.629	0.186	29.57
Processed rice (PCR)	3.464	0.002	0.06	0.393	0.004	1.02
Sugar (SGR)	10.116	0.071	0.70	0.783	0.009	1.15
Food products nec (OFD)	183.611	1.128	0.61	15.615	1.4	8.97
Beverages and tobacco products (B_T)	59.715	0.082	0.14	5.001	2.153	43.05
Extraction	589.365	5.324	0.90	24.206	0.241	1.00
Manufacturing	4358.93	26.228	0.60	422.394	47.834	11.32
Services	1577.76	21.33	1.35	89.488	36.381	40.65

Source: GTAP database (GTAP 10, 2014 reference year).

5 | EMPIRICAL ANALYSIS AND RESULTS

5.1 | Scenario specifications

We simulate the impacts of CETA using two different model layouts and related scenarios (Table 4), with comparisons made based on trade and welfare. In the first scenario (partial liberalisation at the tariff line, PL_TL), we remove bilateral trade barriers at the tariff line level for all non-services sectors, while explicitly taking into account sensitive products exempted from liberalisation. This requires the tariff line extension module to implement shocks as negotiated in CETA. The second scenario, full liberalisation at the tariff line (FL_TL), uses the tariff line module as well but removes all bilateral tariffs. The third scenario, partial liberalisation at the sectoral level (PL_SL), uses the standard two-stage Armington structure. Bilateral changes in tariffs at the sector level are calculated based on the reference group method using the same information at the tariff line as in PL_TL; this scenario is currently the main method used in trade analysis. The fourth scenario, full tariff line scenario sectoral level (FL_SL), uses the structure of the standard GTAP model but assumes full tariff liberalisation.¹¹

The difference between the results of PL_TL and FL_TL provides information on the sensitivity of results with regard to exclusion/inclusion of sensitive products from trade liberalisation. Tables 5 and 6, respectively, show the status of tariffs

¹¹ The GTAP data base does not report tariffs for services – but these are not subject to liberalisation in any of the scenarios. Accordingly, we do not break-down service sectors at the tariff line in the _TL variants.

TABLE 3 Composition of EU-Canada state of trade and related tariffs

	EU bilateral import (%)		Canada bilateral import (%)	
	Sectoral share	Tariff rate	Sectoral share	Tariff rate
All sectors	100	0.86	100	0.96
Agri-food	6.60	6.45	5.36	1.71
Paddy rice (PDR)	0.00	0.00	0.00	0.00
Wheat (WHT)	25.78	5.00	0.21	0.48
Cereal grains nec (GRO)	8.35	0.07	0.44	0.04
Vegetables, fruit, nuts (V_F)	8.35	0.46	3.70	1.63
Oil seeds (OSD)	13.57	0.00	0.15	0.00
Sugar cane, sugar beet (C_B)	0.00	0.00	0.00	0.00
Plant-based fibers (PBF)	0.00	0.00	0.00	0.00
Crops nec (OCR)	1.10	2.19	2.03	1.98
Cattle, sheep, goats, horses (CTL)	0.78	0.16	0.48	0.00
Animal products nec (OAP)	4.44	0.57	7.90	0.01
Raw milk (RMK)	0.03	0.00	0.00	0.00
Wool, silk-worm cocoons WOL)	0.00	0.00	0.36	0.00
Meat: cattle, sheep, goats, horse (CMT)	1.23	19.28	0.25	0.11
Meat products nec (OMT)	0.27	16.99	2.17	0.90
Vegetable oils and fats (VOL)	1.20	2.85	3.97	0.96
Dairy products (MIL)	0.56	38.69	3.89	1.69
Processed rice (PCR)	0.05	8.55	0.08	0.00
Sugar (SGR)	1.90	4.21	0.19	2.81
Food products nec (OFD)	30.20	16.08	29.25	4.41
Beverages and tobacco products (B_T)	2.20	2.17	44.99	0.49
Extraction	9.04	0.14	0.27	0.07
Manufacturing	46.33	0.95	53.60	1.64
Services	37.67	–	40.77	–

Source: GTAP database (GTAP 10, 2014 reference year).

TABLE 4 Scenario specifications

	PL_TL	FL_TL	PL_SL	FL_SL
Model layout	Tariff line for all sectors except services Standard structure for services sectors		Standard ArmingtonTariffs aggregated according to Taste	
Shock	Changes in tariffs at tariff line according to FTA agreement	Full bilateral liberalisation (difference only relevant for Agri-food)	Changes in tariffs at tariff line according to FTA agreement	Full bilateral liberalisation (difference only relevant for Agri-food)

after CETA¹² for sensitive products where tariffs are only partially removed, or they stay unchanged (note that agri-food accounts for all tariff lines exempted). The difference between PL_TL and PL_SL provides information on the importance of aggregation bias that arises from assuming full bilateral liberalisation (hereafter, ‘Bias from an oversimplified shock definition’) and/or from the tariff aggregation bias. Tariffs levels on different tariff lines within some aggregated GTAP sectors can be quite dispersed. Considering a weighted average, only, flattens this dispersion and implicitly assumes that all tariff lines within a sector are subject to an identical reduction in tariff.

Tables 5 and 6 shows the percentage reduction of tariffs for some sectors that are not fully liberalised in CETA. The tariffs for all other tariff lines, and sectors that are not shown in Table 5 and 6 are reduced to zero across all liberalisation

¹² Note that like any other trade agreement, CETA negotiated changes in current bound rates, which might exceed currently applied ones. Wherever post-agreement-AVEs of bound rates are higher than applied tariff rates, we report the level of applied tariffs. If post-agreement-AVEs of bound rates are lower than applied tariff rates, we use the new bounds rates.

TABLE 5 EU tariff on sensitive products

HS*	Corresponding GTAP sector	Initial tax rate (%)	Final tax rate (%)	Tariff reduction at sector level (%)**	Reference group trade share in GTAP sector (%)	Actual bilateral trade share in GTAP sector (%)
020130	Ruminant meat (CMT)	54	54	28	67.48	1.90
020230		64	64		3.16	0.49
020120		41	41		1.24	0.39
020629		275	275		0.06	0.00
020610		112	112		0.04	0.00
020220		81	81		0.04	0.00
020110		136	136		0.01	0.00
020210		13	13		0.00	0.39
010599	Other animal (OAP)	57	57	99.9	0.00	0.00
200580	Other food (OFD)	18	18	99	0.06	0.00
040811		15	15		0.03	0.00
040899		170	170		0.00	0.00
040819		24	24		0.00	0.00
021099	Other meat (OMT)	42	15	49	25.03	0.00
020329		36	36		7.51	0.00
020714		9	9		6.91	0.00
020727		570	570		4.54	0.00
021020		15	15		2.88	0.00
020319		46	46		2.63	0.00
020312		284	284		0.76	0.00
020322		34	34		0.62	0.00
020713		103	103		0.30	0.00
021011		12	12		0.10	0.00
020712		75	75		0.06	0.00
020711		147	147		0.02	0.00
020726		378	378		0.01	0.00
020724		210	210		0.00	0.00
020725		296	296		0.00	0.00

Note: Initial tax rates are based on MACMap database for the year 2017, final rates are based on the text of agreement, and the share are based on UN–Comtrade Database for the average of years 2015–2017.

*See Table A1. for the HS descriptions.

**Calculated based on MACMap reference group method.

scenarios in _TL and _SL variants. As shown in Table 5, the two sectors with the lowest tariffs cuts for the EU, ruminant meat (CMT) and other meat (OMT) are liberalised by about 28% and 49%.

In Canada (Table 6), more sectors are exempted from full liberalisation. Here the Dairy (MIL), OMT and OFD show the lowest tariff reductions with 6%,¹³ 55% and 75%, respectively. In comparing PT_TL and PT_SL, we do not separate the two sources of aggregation bias as these are linked together. To do so, we compare the result of FL_TL and FL_SL to filter out the bias from the tariff aggregation, and provide information on the importance of the bias from an oversimplified shock definition. Jointly, the four scenarios shed light on the differences (based on trade and welfare impacts) resulting from different implementations of trade in the model structure and from different shock definitions.

¹³ High protection in Canada's dairy program is one reason why partners seek better access (Cardwell et al., 2015).

TABLE 6 Canada tariff on sensitive products

HS*	Corresponding GTAP sector	Initial tax rate (%)	Final tax rate (%)	Tariff reduction at sector level (%)**	Reference group share in GTAP sector (%)	Bilateral share in GTAP sector (%)
220290	Beverages and tobacco (B_T)	256	256	99.9	7.27	0.00
020990	Ruminant meat (CMT)	207	207	99.9	0.00	0.37
040690	Dairy (MIL)	123	123	6	53.96	78.15
040510		299	299		9.13	6.19
040410		110	104		6.49	0.19
040640		123	123		5.16	6.29
210500		277	277		4.40	0.06
040630		123	123		2.76	2.42
040620		123	123		2.34	0.91
040490		270	270		1.88	0.08
040310		238	238		1.47	0.02
040210		202	202		1.22	0.21
040610		123	123		1.16	0.56
040120		241	241		1.16	0.09
040221		269	269		0.99	0.00
040390		212	212		0.92	0.00
040590		314	314		0.57	0.00
040299		255	255		0.15	0.00
040291		259	259		0.14	0.04
040110		241	241		0.04	0.00
040229		269	269		0.00	0.00
040140		293	293		0.00	0.00
040150		293	293		0.00	1.23
040520		275	275		0.00	0.00
010511	Other animal (OAP)	238	238	95	4.89	1.22
010594		238	238		0.00	0.00
010599		155	155		0.00	0.00
040711		201	201		0.00	0.00
040721		164	164		0.00	0.00
040790		164	164		0.00	0.00
210690	Other food (OFD)	135	135	74	9.48	6.97
180690		265	265		9.01	10.71
230990		206	206		2.91	2.54
190120		245	245		1.63	1.03
190190		259	259		1.36	0.37
180620		265	265		1.31	2.02
040899		94	94		0.04	0.00
350211		68	68		0.01	0.00
020713	Other meat (OMT)	249	249	55	25.43	0.00
160100		196	196		12.73	8.41
160232		251	251		2.05	3.99
160231		167	167		1.47	0.00
020714		245	245		0.83	5.09

(Continues)

TABLE 6 (Continued)

HS*	Corresponding GTAP sector	Initial tax rate (%)	Final tax rate (%)	Tariff reduction at sector level (%)**	Reference group share in GTAP sector (%)	Bilateral share in GTAP sector (%)
020726		165	165		0.60	0.04
020711		238	238		0.56	0.00
160220		196	196		0.43	0.40
020727		162	162		0.28	0.00
020724		155	155		0.21	0.00
021099		207	207		0.13	0.00
020712		238	238		0.03	0.00
020725		155	155		0.00	0.00
151790	Vegetable oil and fats (VOL)	218	218	99.9	12.06	0.00
151710		103	103		1.36	0.00

Note: Initial tax rate are based on MACMap for the year 2017, Final rates are based on the text of agreement, and the share are based on UN–Comtrade Database for the average of years 2015–2017.

*See Table A1 for the HS descriptions.

**Calculated based on MACMap reference group method.

5.2 | Simulation results

5.2.1 | Trade and welfare impacts of PL_TL

Bilateral trade impacts for an aggregate of all commodities, an aggregate agri-food sector and for individual agri-food sectors for the EU and Canada are presented in Tables 7 and 8. Following the reduction of tariffs on imports by the EU and Canada at the tariff line level, their total bilateral imports increase by 2.3% and 3.4%, while agri-food imports increase by 15.5% and 1.2%. Despite its less than 7% share in bilateral trade at the benchmark, agri-food products account for 44.9% of the increase in bilateral imports of the EU from Canada. Therefore, the agri-food sector is a key driver of the expansion of imports, particularly for the EU.

Hejazi and Francois (2008) simulated a significantly larger expansion in bilateral trade (+24.3% for EU imports and 36.6% Canadian imports), but they assumed larger tariff cuts (full tariff elimination) combined with additional reductions in trade costs due to lowered non-tariff measures. The trade impacts in their study are largely driven by the processed food sector, increasing by +326% for Canadian imports and +142% for EU imports. The simulated trade impacts in European Commission (2017) also exceed our PL_TL scenario results (+8.0% for Canadian imports and +8.1% for EU imports), but they are close to the impacts in the PL_SL scenario. This suggests that the PL_SL approach corresponds to the state-of-the-art CGE modelling approach (followed in European Commission, 2017); and the smaller impacts in PL_TL suggests that the tariff aggregation bias might overestimate impacts in most CGE-based CETA studies.

The largest contributor to the bilateral import increase of agri-food trade in the EU is the OFD sector, which accounts for 30% of agri-food imports from Canada and was subjected to a 16% bilateral import tax at the benchmark (Table 3). The contribution of other sectors to the overall increase is negligible. Still, in terms of relative changes, larger impacts can be observed for the MIL (270%), reflecting a high initial average tariff of 39%. Note that this large relative increase relates to a quite small initial import share which leaves the total expanded traded volumes still relatively small.

Other sectors are not affected as much (in terms of absolute values), because either their initial trade volume or average tariff was small. Impacts partly reflect the intra-industry relations as well, when, for instance, increased export demand drives up prices which in turn lets domestic firms substitute away from domestic supply. Similarly, increased imports of processed products crowd out domestic production, reducing intermediate import demand from sectors where output drops. For example, in our analysis, EU's OFD imports from Canada increase. Related inter-sectoral linkages reduce the EU's import demand for the WHT sector. The importance of such a sectoral-linkage effect also suggests that reducing the sectoral resolution of the database by aggregating can bias results by removing information on sectoral relationships. Keeping the resolution of the data base and instead aggregating the results post model is therefore recommended by Britz and Van der Mensbrugghe (2016).

TABLE 7 Impacts on the imports of the EU from Canada

	Baseline(Million USD)	PL_TL (%)	FL_TL (%)	PL_SL (%)	FL_SL (%)
All sectors	56.617	2.3	2.4	4.8	5.5
Agri-food	3.735	15.5	17.6	31.1	44.9
Paddy rice (PDR)	0.00	−0.4	−0.5	−3.0	−3.6
Wheat (WHT)	0.963	−0.3	−0.3	43.3	42.9
Cereal grains nec (GRO)	0.312	0.1	0.1	−0.3	−0.4
Vegetables, fruit, nuts (V_F)	0.312	0.8	0.8	0.9	0.7
Oil seeds (OSD)	0.507	−0.2	−0.2	−0.9	−1.1
Crops nec (OCR)	0.041	8.1	8.1	13.6	13.2
Cattle, sheep, goats, horses (CTL)	0.029	0.3	0.3	−0.3	−0.4
Animal products nec (OAP)	0.166	0.7	0.9	0.9	0.8
Raw milk (RMK)	0.001	−0.1	−0.1	−1.6	−2.3
Meat: cattle, sheep, goats, horse (CMT)	0.046	0.02	155.3	282.1	281.0
Meat products nec (OMT)	0.01	35.0	129.1	105.5	290.2
Vegetable oils and fats (VOL)	0.045	11.2	11.2	16.3	19.0
Dairy products (MIL)	0.021	269.8	269.6	11.9	968.1
Processed rice (PCR)	0.002	25.5	25.5	51.7	51.4
Sugar (SGR)	0.071	13.1	13.0	24.1	23.9
Food products nec (OFD)	1.128	45.3	45.6	53.3	79.8
Beverages and tobacco products (B_T)	0.082	2.8	2.7	4.4	4.7
Extraction	5.324	0.1	0.1	0.2	0.2
Manufacturing	26.228	3.2	3.2	3.9	3.8
Services	21.33	−0.2	−0.2	−0.2	−0.2

Source: Simulation results.

The change in Canadian bilateral imports is mostly due to the increase in OFD imports, which has a 29% share of the total bilateral agri-food imports and an average bilateral import tariff of 4.4% at the benchmark. As opposed to the EU case, MIL Canadian imports increase only marginally (+0.23%). This is due to the combination of small tariff reductions, a low share of bilateral agri-food imports (4%) and a low initial tariff (1.7%). This contrast to the results of Philippidis and Kitou (2012), who identify dairy as the driver of the expansion in Canadian agri-food imports (at 40 percent) under a full liberalisation scenario (i.e., they assume the removal of the prohibitive Canadian dairy TRQs). Regarding other sectors, they are subject to relatively low tariffs and/or have small bilateral trade weights, which implies limited impacts overall.

We report welfare impacts based on the equivalent variation (EV) criterion, that is, the amount of income to be added to the regional household's benchmark income at benchmark prices to reach the same utility as under simulated income and prices. At the global level, an increase in welfare of 0.03 USD per capita (Figure 4) is not much different from the EU's gain of 0.7 USD per capita. Canada shows a larger gain of 6.6 USD per capita. The significantly larger per capita welfare gains in Canada are in line with previous studies (e.g., Philippidis and Kitou (2012) report a 10 times larger impacts for Canada).

5.2.2 | Exclusion of sensitive products

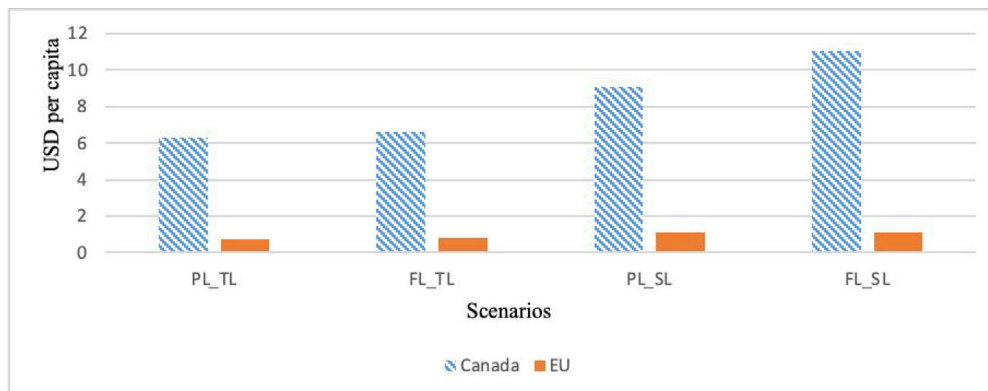
We now shed light on the importance of exemptions for sensitive products by using the same model layout, but liberalizing tariffs fully at the tariff line level. We compare the results generated from PL_TL with FL_TL and focus on the sectors that comprise the sensitive products. The FL_TL scenarios projects an increase of agri-food bilateral imports of 17.6% for the EU and 4.65% for Canada (compared to 15.5% and 1.2% under the PL_TL scenario).

As indicated in Table 5, sensitive products in the EU are found in the CMT, OMT, OFD and other animal product (OAP) sectors. There are eight HS6 categories noted as sensitive in the CMT sector (accounting for 2.5% of bilateral trade), but

TABLE 8 Impacts on the imports of Canada from the EU

	Baseline(Million USD)	PL_TL (%)	FL_TL (%)	PL_SL (%)	FL_SL (%)
All sectors	89.242	3.38	3.57	6.5	6.5
Agri-food	4.786	1.20	4.65	6.9	7.2
Wheat (WHT)	0.01	0.85	0.93	7.5	7.9
Cereal grains nec (GRO)	0.021	0.61	0.66	0.6	1.0
Vegetables, fruit, nuts (V_F)	0.177	3.90	3.92	6.2	6.3
Oil seeds (OSD)	0.007	0.25	0.27	0.2	0.4
Sugar cane, sugar beet (C_B)	0.000	0.29	0.29	0.3	0.4
OCR (Crops nec)	0.097	7.98	8.00	13.1	13.2
Cattle, sheep, goats, horses (CTL)	0.023	0.16	0.43	0.8	0.9
Animal products nec (OAP)	0.378	0.44	0.49	0.6	0.9
Wool, silk-worm cocoons (WOL)	0.017	0.58	0.62	0.5	0.9
Meat: cattle, sheep, goats, horse (CMT)	0.012	0.69	0.71	0.8	1.7
Meat products nec (OMT)	0.104	1.80	4.97	4.4	8.8
Vegetable oils and fats (VOL)	0.19	4.18	4.38	6.3	6.6
Dairy products (MIL)	0.186	0.23	8.10	11.5	12.0
Processed rice (PCR)	0.004	0.20	0.22	0.4	0.5
Sugar (SGR)	0.009	9.51	9.55	16.5	16.7
Food products nec (OFD)	1.4	1.70	11.55	17.8	18.1
Beverages and tobacco products (B_T)	2.153	0.31	0.89	1.0	1.0
Extraction	0.241	0.07	0.07	0.0	0.0
Manufacturing	47.834	6.22	6.22	6.5	6.5
Services	36.381	0.13	0.14	6.9	7.2

Source: Simulation results.

**FIGURE 4** Welfare impacts [USD per capita]

Source: Simulation results

liberalisation of these products increases the bilateral import of the sector to 155% in FT_TL (PL_TL simulated an increase of 0.02%). Similarly, for OMT there are 15 HS6 lines considered sensitive. Their share is almost zero, but they feature tariffs ranging from 9 to 570%, thus full liberalisation more than triples the trade effect from 35% to 129%. There is a total of four HS6 categories for OFD and one for OAP that are sensitive; their weight in the bilateral trade of respected GTAP sectors is almost zero. The bilateral tariff removal results in an increase in their bilateral trade 45.3 % and 0.07% in PL_TL to 45.6 % and 0.9% and in FL_TL.

The OFD sector in Canada, which accounts for 9% of total imports from EU, has high protection (68–265%) across HS6 lines. FT_TL considers tariff removal for all HS6 lines, while PT_TL keeps tariffs on sensitive tariff lines unchanged

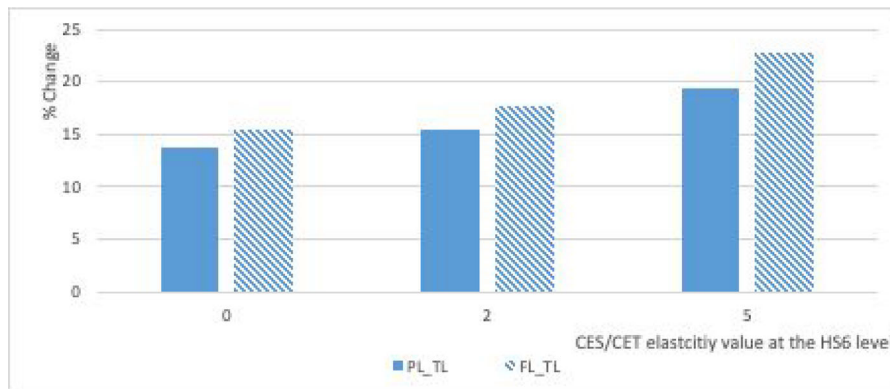


FIGURE 5 Impacts on the agricultural import of the EU from Canada

Source: Simulation results

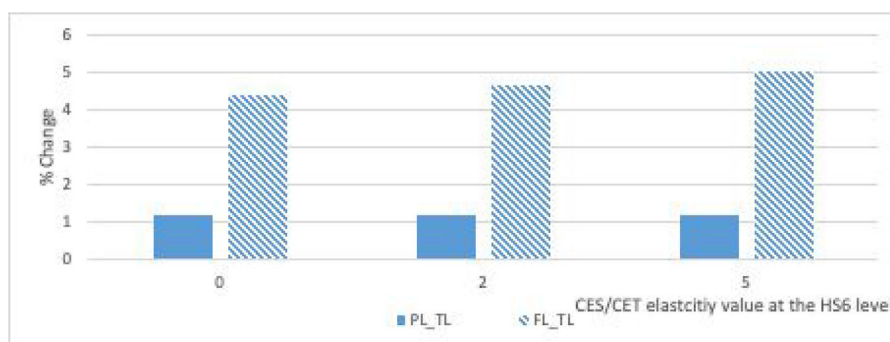


FIGURE 6 Impacts on the agricultural import of Canada from the EU

Source: Simulation results

(Table 6). Due to the higher tariff cuts, FL_TL projects an increase of bilateral imports by 11.55% compared to a 1.7% increase from PT_TL. Similar to the EU case, MIL Canadian imports increase significantly by 8.1% in FL_TL, compared to a 0.23% increase in PT_TL. The other sector that experiences significant bilateral import growth is OMT with an increase ranging from 1.8% in PT_TL to 4.97% in FL_TL. The same occurs for the B_T sector, where simulated impacts are tripled between the two scenarios: from 0.31% to 0.89%. Also, other sensitive sectors, experience increases in imports, namely OAP, CMT and VOL (Vegetable oils). The systematically higher simulated impacts under the full liberalisation scenario are in line with the findings of the literature review in Section 2, with authors often noting that follow-up analysis could consider exemptions for sensitive products (e.g., Cameron & Loukine, 2001).

To assess the robustness of the simulated impact on trade, we also perform a sensitivity analysis on the size of transformation and substitution elasticities in the CET and CES functions at the tariff line. We randomly draw a sample for the transformation and substitution elasticities from a truncated normal distribution within the interval of 0 and 5 and perform 100 model runs. Simulated impacts are found to change only marginally (not reported here) for different elasticities. Significant, but still small, changes are observed when the substitution elasticities are from the tails of the distribution. We report the simulated results for the upper and the lower bound of the distribution interval, comparing those to the results with the benchmark elasticity of 2. The detailed results are presented in Appendix A Tables A2 and A3, and confirm the pattern described above. Increasing the substitution and transformation elasticities tends to increase the simulated impacts on bilateral trade (Figure 5 and 6). A zero elasticity (lower bound for our sensitivity analysis) corresponds to the standard (fix) trade weighted tariff aggregator. The simulated impacts under different elasticity values suggest that trade liberalisation impacts strongly depend on the dispersion of tariff changes, and on the attached trade weights.

Overall, our result shows that neglecting exemptions for sensitive products can lead to sizeable overestimation of trade generated effects. Welfare gains also tend to be overestimated when sensitive products are neglected, but to a smaller degree (compare results for Figure 4 under the same model layout). The sensitivity analysis identifies a positive correlation between simulated bilateral trade impacts and the size of the substitution elasticities in the modelling framework.

5.2.3 | Aggregation bias

This section compares the results of PL_TL and PL_SL, that is, the same shock considering exemptions for sensitive products implemented in the different model structures. PL_SL, using the GTAP standard trade representation, requires pre-aggregating tariff changes; while PL_TL tries to reduce the aggregation bias by moving the tariff aggregator into the model itself such that aggregation weights adjust endogenously. Differences in outcomes relate to the workings of a CES/CET nesting over multiple bilateral tariff lines compared to one using (implicitly) fixed shares. From the demand side, the CES will adjust the shares according to changes in CIF price relations. Tariff lines that experience a (CIF) price drop above the average will increase their value share. This can, however, decrease quantity if their benchmark (CIF) price is well above the average, implying higher per unit utility. Size and direction of these effects also reflect the assumed substitution and transformation elasticities.

In the EU, the bilateral imports of all products except the MIL are projected to be higher under the current GTAP standard plus TASTE (PL_SL) method. On average, bilateral imports of agri-food products increase from 15.5% to 31.1%, stemming mostly from OFD which increases from 45.3% to 53.3%. The drop in the simulated increase of dairy products from 269% to 11.9% reflects the unchanged trade shares which adjust quite strongly in PL_TL. Similarly, the Canadian bilateral import of agri-food products increases from 1.2% to 6.9%. This increase is largely associated with the increase of OFD from 1.70% to 17.8%. The highest relative change in bilateral imports is found for the MIL sector which expands 11.5% compared to 0.23% in the PL_TL setup. As a response to higher simulated trade, the welfare gain in the EU increases from 6.6 to 9.1 USD per capita and in Canada from 0.7 to 1 USD per capita (Figure 4). The results are also in line with the literature reviewed in Section 2, suggesting that adding more sectoral details (and ultimately moving to the tariff line level) tends to decrease simulated trade impacts.¹⁴

To shed further light on the differences between model structures, we compare results of FL_TL and FL_SL where identical shocks are imposed and the final average protection rate of each sector at bilateral level is zero, independent from the tariff aggregator. As can be seen from Tables 7 and 8, the trade impact tends to decrease with the tariff line extension for all sectors.

Overall, we find that the bias from neglecting tariff cut exemptions (full liberalisation assumptions) is likely bigger than the bias from neglecting the substitution effect between tariff lines in the tariff aggregation (pre-model aggregators). Interestingly, the pre-model aggregation provoked stronger trade generation effects and welfare gains than the tariff line aggregator. The different simulated impacts highlight the need for considering the substitution between tariff lines, in particular, if tariff dispersion and the variability in trade weights are large. Furthermore, the impacts with the pre-model aggregation are systematically higher, even if the substitution and transformation elasticities are reduced to zero. This suggests that the endogenous aggregation keeps the average protection rate higher than the pre-model approach, even if we reduce the flexibility for substituting away from exempted tariff lines by decreasing elasticities.

6 | IMPORT RESPONSE OF THE MODEL

To verify our model extension, we calculate import demand elasticities based on the results of the sensitivity analysis and compare them to those derived with the standard GTAP model. We do not consider the third level of the Armington nesting in the analysis below, since it simply acts as a tariff aggregator in this context, that is, it does not impact demand. We run a stylised policy shock with a 10% import tariff reduction at the aggregated commodity level, and for bilateral trade between the EU and Canada. The shock of the sensitivity analysis is run with two different model configurations: with a CET formulation, which is required for the tariff line module and without CET, as in the standard GTAP. The transformation elasticity of the CET is set to 15 across export flows and set to 10 between total exports and domestic sales. Consequently, the 10% shock we introduce decreases the CIF price on the bilateral trade links between EU and Canada by 10%.¹⁵

Bilateral trade flows react quite elastically to a 10% drop in the CIF price (Table 9), as we would expect, reflecting the lower level Armington elasticities in GTAP that are quite elastic. These observations are also in line with Hertel et al.

¹⁴ To show that the results are mainly driven by the dispersion of tariffs across tariff lines within each aggregated sector and their attached weights, we again compare the results of PL_TL with zero substitution and transformation elasticities across tariff lines (Table A1 and A2), and show that the impacts are significantly higher in PL_SL.

¹⁵ Actual simulated (FOB) price changes will slightly deviate from the shock on CIF prices due to endogeneity of the trade margins.

TABLE 9 Import quantity changes for a 10% reduction in CIF price between Canada and the EU, with and without a CET transformation approach

		% Change in bilateral imports (from the EU/Canada to its CETA partner)		% Change in total imports (to all trade partners)	
		CET	Standard GTAP	CET	Standard GTAP
Canada	wht	80.83	162.01	2.65	6.01
	gro	28.19	33.64	0.07	0.14
	v_f	50.49	62.80	0.12	0.21
	osd	57.16	80.27	0.43	0.89
	pfb			0.02	0.03
	ocr	62.83	96.09	0.88	1.12
	ctl	39.74	51.68	2.14	2.51
	oap	24.32	28.67	1.92	2.10
	wol			0.00	
	frs	53.55	75.24	0.47	0.60
	fsh	34.36	39.75	0.51	0.59
	vol	58.58	91.22	3.40	4.92
	meat	71.56	129.42	0.57	0.92
	mil	12.77	18.18	3.23	3.97
	pcr	61.65	86.80	0.05	0.05
	sgr	44.67	64.24	0.72	1.23
	ofd	32.44	41.65	1.51	1.78
	b_t	19.69	22.40	4.06	4.35
EU	wht	71.94	120.18	2.21	2.92
	gro	27.72	32.85	0.20	0.22
	v_f	37.86	48.29	0.04	0.05
	osd	46.46	63.21	0.66	0.78
	pfb	47.82	69.17	0.01	0.01
	ocr	60.87	97.25	0.02	0.04
	ctl	39.20	52.01	0.11	0.13
	oap	25.58	30.65	0.10	0.11
	wol			0.00	
	frs	49.95	71.02	0.06	0.07
	fsh	22.49	26.56	0.06	0.06
	vol	61.91	98.66	0.12	0.16
	meat	66.12	120.09	0.04	0.06
	mil	33.16	53.47	0.01	0.02
	pcr	43.66	63.30	0.00	0.00
	sgr	48.95	72.77	0.10	0.01
	ofd	33.60	44.38	0.07	0.09
	b_t	23.34	27.52	0.01	0.02

Source: Simulation results.

(2007), Kee et al. (2008), and Fontagne et al. (2019) who show the import price elasticity is above one. Relative differences in simulated impacts among products reflect differences in the respective Armington elasticities (taken from GTAP database). Simulated impacts on bilateral trade with and without the CET can differ up to a factor of two. These differences are somewhat surprising, given the large transformation elasticities applied in the CET function. Still, the bilateral trade response remains quite elastic with the CET specification. The smallest simulated demand elasticity is around 1.2 in the case of Canadian EU imports, for MIL, and around 2.3 for EU imports from Canada, for (B_T). The largest demand elasticities are found for wheat trade, with around 16 for Canada and 12 for the EU imports.

Total import changes are clearly more muted and reflect additionally the original import share of the partner country, as well as smaller elasticities at the top Armington level (again taking the elasticities from the GTAP database). The relative differences in total import changes with and without the CET structure are quite similar to the ones we found on the bilateral trade link. The median total import change in Canada is around 1%, far bigger than the 0.07% we find for the EU, which reflects the different market sizes and the strong integration¹⁶ between EU countries (EU single market).

7 | SUMMARY AND CONCLUSION

Sensitive products, those with high rates of protection, are often exempted from trade liberalisation, but many CGE analyses ignore these exemptions. Doing so likely overestimates trade impacts. In addition, some CGE analyses perform pre-model tariff aggregation, but this is prone to bias due to neglecting how importers substitute tariff line-level goods. Recent developments (e.g., GTAP-HS) attempt to mitigate these problems by extending the GTAP structure to HS lines by disaggregating trade, consumption and production data for one (or a few) sectors. However, this approach requires a substantial amount of data from different sources, causing data harmonisation problems (subsectors classifications might differ from one dataset to the other). Moreover, this approach increases overall model size considerably, which renders it computationally challenging to disaggregate sectors comprising many tariff lines, while at the same time considering regional detail.

The approach proposed in this paper, instead, solely extends the two-stage CES/CET trade structures, found in many global CGE models, to the tariff line for selected trade links. This module acts as an endogenous tariff aggregator across tariff lines, allowing for substitution of commodities across tariff lines, reducing data needs and the computational burden. To test the framework, we generate four scenarios to quantify CETA impacts, which jointly allow for a systematic comparison of the aggregation bias in state-of-the-art approaches for modelling trade liberalisation in the CGE framework. Our simulation results confirm that neglecting sensitive products in CGE-based FTA analysis overestimates trade generation and welfare gains. In cases where sensitive products are included in the analysis, the proposed approach resulted in significantly lower simulated trade and welfare impacts compared to standard pre-model tariff aggregation approaches. Consequently, we find that the state-of-the-art reference group method for tariff aggregation implies potentially overestimated trade dynamics.

We conclude that our approach, based on open-source and open-access code, provides a relatively easy to employ alternative to pre-model tariff aggregation and can be valuable for policy makers who conduct trade policy discussions at the HS level. Our CETA analysis demonstrates that it is computationally feasible to even disaggregate all GTAP sectors to over 5,000 HS6 tariff lines for one specific bilateral link, based on the proposed extension of the CES/CET nests depicting bilateral trade. Such an approach is especially suitable to analyse FTAs between two (or few) trading partners where typically detailed data on bilateral policy instruments and their changes are readily available.

Nevertheless, reduced computational burden and easy implementation comes at a price. Some limitations are as follows: the proposed model extension does not capture changes in production and domestic supply as well as consumption and demand for domestically produced good at the tariff line level. Substitution and transformation elasticities across tariff lines should be backed up by empirical estimates (commodity and country specific), which are currently not available in the literature, in contrast to the approach of the explicit representation of the tariff line commodities where trade elasticity estimates are available (e.g., Fontagné et al., 2019). Our approach does not reduce the data needed by much for such multilateral trade policies, compared to other existing approaches in the literature. Commodity aggregation is extended to the tariff line only for the FTA partners, but not for third country trade relations. This makes sense when considering the extension as an endogenous non-linear tariff aggregator. As long as tariffs on a trade link do not change, either exogenously due to the shock, or endogenously due to, for instance, TRQs, there is no need to integrate a tariff aggregator in the model itself. However, keeping commodities highly aggregated for non-FTA partners might distort simulated trade diversion effects. The high level of details on sensitive products potentially limits trade creation between FTA partners, compared to standard (more aggregated) CGE modelling exercises. In theory, small (or no) trade creation for sensitive tariff lines also limits trade diversion, including the impact on trade of these sensitive products with third countries. Our approach is

¹⁶ Note here that the EU in our model is one aggregate region over the 28 individual EU Member States (pre-Brexit status). Imports between the Member States are aggregated to an EU–EU bilateral trade flow in the data base used for benchmarking. Accordingly, domestic sales for the EU model region are an aggregate of the domestic sales of the individual EU member countries.

biased in terms of this indirect effect on third countries, because tariff lines that are declared sensitive for intra-FTA trade are aggregated to broader commodity definitions in extra-FTA trade relations.

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APPENDIX A

TABLE A1 HS descriptions

HS	Descriptions
010511	Poultry: live, fowls of the species <i>Gallus domesticus</i> , weighing not more than 185 g
010594	Poultry: live, fowls of the species <i>Gallus domesticus</i> , weighing more than 185 g
010599	Poultry: live, ducks, geese, turkeys and guinea fowls, weighing more than 185 g
010599	Poultry: live, ducks, geese, turkeys and guinea fowls, weighing more than 185 g
020110	Meat: of bovine animals, carcasses and half-carcasses, fresh or chilled
020120	Meat: of bovine animals, cuts with bone in (excluding carcasses and half-carcasses), fresh or chilled
020130	Meat: of bovine animals, boneless cuts, fresh or chilled
020210	Meat: of bovine animals, carcasses and half-carcasses, frozen
020220	Meat: of bovine animals, cuts with bone in (excluding carcasses and half-carcasses), frozen

(Continues)

TABLE A1 (Continued)

HS	Descriptions
020230	Meat: of bovine animals, boneless cuts, frozen
020312	Meat: of swine, hams, shoulders and cuts thereof, with bone in, fresh or chilled
020319	Meat: of swine, nes. in item no. 0203.1, fresh or chilled
020322	Meat: of swine, hams, shoulders and cuts thereof, with bone in, frozen
020329	Meat: of swine, hams, shoulders and cuts thereof, with bone in, frozen
020610	Offal, edible: of bovine animals, fresh or chilled
020629	Offal, edible: of bovine animals, (other than tongues and livers), frozen
020711	Meat and edible offal: of the poultry of heading no. 0105, of fowls of the species <i>Gallus domesticus</i> (not cut in pieces), fresh or chilled
020711	Meat and edible offal: of fowls of the species <i>Gallus domesticus</i> , not cut in pieces, fresh or chilled
020712	Meat and edible offal: of the poultry of heading no. 0105, of fowls of the species <i>Gallus domesticus</i> , (not cut in pieces), frozen
020712	Meat and edible offal: of fowls of the species <i>Gallus domesticus</i> , not cut in pieces, frozen
020713	Meat and edible offal: of the poultry of heading no. 0105, of fowls of the species <i>Gallus domesticus</i> , cuts and offal, fresh or chilled
020713	Meat and edible offal: of fowls of the species <i>Gallus domesticus</i> , cuts and offal, fresh or chilled
020714	Meat and edible offal: of the poultry of heading no. 0105, of fowls of the species <i>Gallus domesticus</i> , cuts and offal, frozen
020714	Meat and edible offal: of fowls of the species <i>Gallus domesticus</i> , cuts and offal, frozen
020724	Meat and edible offal: of the poultry of heading no. 0105, of turkeys, (not cut in pieces), fresh or chilled
020724	Meat and edible offal: of turkeys, not cut in pieces, fresh or chilled
020725	Meat and edible offal: of the poultry of heading no. 0105, of turkeys, (not cut in pieces), frozen
020725	Meat and edible offal: of turkeys, not cut in pieces, frozen
020726	Meat and edible offal: of the poultry of heading no. 0105, of turkeys, cuts and offal, fresh or chilled
020726	Meat and edible offal: of turkeys, cuts and offal, fresh or chilled
020727	Meat and edible offal: of the poultry of heading no. 0105, of turkeys, cuts and offal, frozen
020727	Meat and edible offal: of turkeys, cuts and offal, frozen
020990	Fat: poultry fat, not rendered or otherwise extracted, fresh, chilled, frozen, salted, in brine, dried or smoked
021011	Meat, preserved: of swine, hams, shoulders and cuts thereof, with bone in, salted, in brine, dried or smoked
021020	Meat, preserved: of bovine animals, salted, in brine, dried or smoked
021099	Meat and edible meat offal: salted, in brine, dried or smoked and edible flours and meals of meat or meat offal, other than of primates, whales, dolphins, porpoises, manatees, dugongs, seals, sea lions, walruses, reptiles (including snakes and turtles)
021099	Meat and edible meat offal: salted, in brine, dried or smoked and edible flours and meals of meat or meat offal, other than of primates, whales, dolphins, porpoises, manatees, dugongs, seals, sea lions, walruses, reptiles (including snakes and turtles)
040110	Dairy produce: milk and cream, not concentrated, not containing added sugar or other sweetening matter, of a fat content not exceeding 1% (by weight)
040120	Dairy produce: milk and cream, not concentrated, not containing added sugar or other sweetening matter, of a fat content exceeding 1% but not exceeding 6% (by weight)
040140	Dairy produce: milk and cream, not concentrated, not containing added sugar or other sweetening matter, of a fat content, by weight, exceeding 6% but not exceeding 10%
040150	Dairy produce: milk and cream, not concentrated, not containing added sugar or other sweetening matter, of a fat content, by weight, exceeding 10%
040210	Dairy produce: milk and cream, concentrated or containing added sugar or other sweetening matter, in powder, granules or other solid forms, of a fat content not exceeding 1.5% (by weight)
040221	Dairy produce: milk and cream, concentrated, not containing added sugar or other sweetening matter, in powder, granules or other solid forms, of a fat content exceeding 1.5% (by weight)

(Continues)

TABLE A1 (Continued)

HS	Descriptions
040229	Dairy produce: milk and cream, containing added sugar or other sweetening matter, in powder, granules or other solid forms, of a fat content exceeding 1.5% (by weight)
040291	Dairy produce: milk and cream, concentrated, not containing added sugar or other sweetening matter, other than in powder, granules or other solid forms
040299	Dairy produce: milk and cream, containing added sugar or other sweetening matter, other than in powder, granules or other solid forms
040310	Dairy produce: yoghurt, whether or not concentrated or containing added sugar or other sweetening matter or flavoured or containing added fruit or cocoa
040390	Dairy produce: buttermilk, curdled milk or cream, kephir, fermented or acidified milk or cream, whether or not concentrated or containing added sweetening, flavouring, fruit or cocoa (excluding yoghurt)
040410	Dairy produce: whey, whether or not concentrated or containing added sugar or other sweetening matter
040490	Dairy produce: natural milk constituents (excluding whey), whether or not containing added sugar or other sweetening matter, nec. in chapter 04
040510	Dairy produce: derived from milk, butter
040520	Dairy produce: dairy spreads
040590	Dairy produce: fats and oils derived from milk (other than butter or dairy spreads)
040610	Dairy produce: fresh cheese (including whey cheese), not fermented, and curd
040620	Dairy produce: cheese of all kinds, grated or powdered
040630	Dairy produce: cheese, processed (not grated or powdered)
040640	Dairy produce: cheese, blue-veined and other cheese containing veins produced by <i>Penicillium roqueforti</i> (not grated, powdered or processed)
040690	Dairy produce: cheese (not grated, powdered or processed), nec. in heading no. 0406
040711	Birds' eggs, in shell: fresh, fertilised eggs for incubation, of fowls of the species <i>Gallus domesticus</i> (domestic hens)
040721	Birds' eggs, in shell: fresh, not for incubation, of fowls of the species <i>Gallus domesticus</i> (domestic hens)
040790	Birds' eggs, in shell: preserved or cooked
040811	Eggs: birds' eggs, yolks, dried, whether or not containing added sugar or other sweetening matter
040819	Eggs: birds' eggs, yolks, fresh, cooked by steaming or by boiling in water, moulded, frozen or otherwise preserved, whether or not containing added sugar or other sweetening matter
040899	Eggs: birds' eggs (not in shell, excluding yolks only), fresh, cooked by steaming or boiling in water, moulded, frozen, otherwise preserved, whether or not containing added sugar or other sweetening matter
040899	Eggs: birds' eggs (not in shell, excluding yolks only), fresh, cooked by steaming or boiling in water, moulded, frozen, otherwise preserved, whether or not containing added sugar or other sweetening matter
151710	Margarine: excluding liquid margarine
151790	Edible mixtures or preparations of animal or vegetable fats or oils or of fractions of different fats or oils of this chapter, other than edible fats or oils of heading no. 1516
160100	Meat preparations: sausages and similar products, of meat, meat offal or blood, and food preparations based on these products
160220	Meat preparations: of the prepared or preserved liver of any animal (excluding homogenised preparations)
160231	Meat preparations: of turkeys, prepared or preserved meat or meat offal (excluding livers and homogenised preparations)
160232	Meat preparations: of the poultry of heading no. 0105, (i.e., of fowls of the species <i>Gallus domesticus</i>)
180620	Chocolate & other food preparations containing cocoa; in blocks, slabs or bars weighing more than 2 kg or in liquid, paste, powder, granular or other bulk form in containers or immediate packings, content exceeding 2 kg
180690	Chocolate and other food preparations containing cocoa; nec. in chapter 18
190120	Food preparations; mixes and doughs for the preparation of bread, pastry, cakes, biscuits and other bakers' wares
190190	Food preparations; of flour, meal, starch, malt extract or milk products, for uses nec. in heading no. 1901
200580	Vegetable preparations; sweetcorn (<i>Zea mays</i> L. var. <i>saccharata</i>), prepared or preserved otherwise than by vinegar or acetic acid, not frozen

(Continues)

TABLE A1 (Continued)

HS	Descriptions
210500	Ice cream and other edible ice; whether or not containing cocoa
210690	Food preparations; nec. in item no. 2106.10
220290	Non-alcoholic beverages: nes. in item no. 2202.10, not including fruit or vegetable juices of heading no. 2009
230990	Dog or cat food: (not put up for retail sale), used in animal feeding
350211	Albumins: egg albumin, dried

TABLE A2 Impacts on the import of the EU from Canada (Sensitivity analysis)

	PL_TL (%)		FL_L (%)	
CES/CET substitution elasticities at the tariff line	0.0	5	0.0	5
All sectors	2.2	2.5	2.3	2.7
Agri-food	13.8	19.3	15.4	22.7
Paddy rice (PDR)	−0.4	−0.5	−0.5	−0.6
Wheat (WHT)	−0.3	−0.3	−0.3	−0.4
Cereal grains nec (GRO)	0.1	0.1	0.1	0.1
Vegetables, fruit, nuts (V_F)	0.8	0.8	0.8	0.8
Oil seeds (OSD)	−0.2	−0.2	−0.2	−0.2
Crops nec (OCR)	8.1	8.1	8.0	8.0
Cattle, sheep, goats, horses (CTL)	0.3	0.2	0.3	0.4
Animal products nec (OAP)	0.6	0.8	0.8	1.1
Raw milk (RMK)	−0.1	−0.1	−0.1	−0.1
Meat: cattle, sheep, goats, horse (CMT)	0.0	0.0	114.9	256.1
Meat products nec (OMT)	32.5	40.1	116.5	169.5
Vegetable oils and fats (VOL)	10.9	11.8	10.9	11.8
Dairy products (MIL)	264.4	277.2	264.2	277.0
Processed rice (PCR)	25.5	25.5	25.5	25.4
Sugar (SGR)	13.1	13.0	13.0	13.0
Food products nec (OFD)	39.5	58.3	39.8	58.6
Beverages and tobacco products (B_T)	2.7	2.8	2.7	2.8
Extraction	0.1	0.1	0.1	0.1
Manufacturing	0.1	0.1	0.1	0.1
Services	3.2	3.2	3.2	3.1

Source: Simulation results.

TABLE A3 . Impacts on the import of Canada from the EU (sensitivity analysis)

	PL_TL (%)		FL_TL (%)	
CES/CET substitution elasticities at the tariff line	0.0	5	0.0	5
All sectors	3.4	3.4	3.5	3.6
Agri-food	1.2	1.2	4.4	5.0
Wheat (WHT)	0.8	1.0	0.9	1.1
Cereal grains nec (GRO)	0.6	0.7	0.6	0.8
Vegetables, fruit, nuts (V_F)	3.8	4.1	3.8	4.1

(Continues)

TABLE A3 (Continued)

	PL_TL (%)		FL_TL (%)	
Oil seeds (OSD)	0.2	0.3	0.2	0.3
Sugar cane, sugar beet (C_B)	0.3	0.3	0.3	0.3
OCR (Crops nec)	7.9	8.1	7.9	8.1
Cattle, sheep, goats, horses (CTL)	0.1	0.2	0.4	0.6
Animal products nec (OAP)	0.4	0.5	0.5	0.6
Wool, silk-worm cocoons (WOL)	0.5	0.7	0.6	0.7
Meat: cattle, sheep, goats, horse (CMT)	0.7	0.7	0.7	0.7
Meat products nec (OMT)	1.8	1.8	4.9	5.1
Vegetable oils and fats (VOL)	4.1	4.3	4.3	4.5
Dairy products (MIL)	0.2	0.3	8.1	8.2
Processed rice (PCR)	0.2	0.2	0.2	0.3
Sugar (SGR)	9.3	9.9	9.3	10.0
Food products nec (OFD)	1.7	1.7	10.9	12.7
Beverages and tobacco products (B_T)	0.3	0.3	0.8	1.0
Extraction	0.1	0.1	0.1	0.1
Manufacturing	6.2	6.2	6.2	6.2
Services	0.1	0.1	0.1	0.2

Source: Simulation results.



Brexit: an economy-wide impact assessment on trade, immigration, and foreign direct investment

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Abstract

We assess the impacts of Brexit on the UK economy along three dimensions: EU market access based on consideration of tariffs and non-tariff barriers, reduced numbers of EU citizens working in the UK, and reductions in FDI. Using a Computable General Equilibrium model with an integrated Melitz (Econometrica 71(6): 1695–1725, 2003) framework, we consider capital accumulation and population size feedback on tax income and demand for public services. In the worst-case scenario where all dimensions are considered simultaneously, welfare losses of approximately 1100 USD per UK citizen are predicted, exceeding the results of many other studies, which we attribute to our relatively comprehensive scenario design and application of the Melitz framework for manufacturing sectors. We find that a reduced labor force as a consequence of expected reduced immigration to the UK has the greatest welfare impact. Therefore, policy measures that increase labor participation and/or allow for continued immigration of workers could mitigate negative impacts of Brexit.

Keywords Brexit · Computable general equilibrium modeling · Modern trade theory

JEL Classification F14 · F17 · F21 · C63 · J61

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1 Background

After decades of enlarging the EU and deepening market integration among EU members, the Brexit vote marked a potential turning point with a majority of those voting in the referendum in the UK opting to leave the EU. Potential explanations for this result are manifold: skepticism about the benefits of globalization (which have been a central argument for EU integration among member countries); perceptions of over-regulation by, or the loss of autonomy to, a bureaucracy based in Brussels; and discontent regarding how first the financial and lately the migration crises have been handled by EU countries and institutions. Potentially, domestic UK policy issues played a role as well, such as concerns about income distribution among regions and household groups in a largely de-industrialized UK economy, with growing disparity between urban and rural areas.

Brexit will most likely affect trade between the UK and EU, as EU membership has significantly reduced trading costs among members, but not only by eliminating tariffs. Removal of border controls and rules of origin checks, as well as minimizing cross-country regulation differences such as non-tariff measures (NTMs) were at least equally important. Today the EU is the UK's dominant export market with 45% and 38% shares of the merchandise and services sectors respectively (Busch and Matthes 2016). The European Single Market has also significantly reduced barriers against foreign suppliers of services as part of FDI. Currently EU members can establish greenfield investments, acquire local companies or expand existing businesses in the UK. After the USA and China, the UK is the third major recipient of FDI worldwide, with half of its FDI stemming from other EU members. Although the UK attracts FDI due to good governance, flexible labor markets, and a highly educated workforce, Brexit could significantly reduce FDI for at least two reasons (Centre for Economic Performance 2016). First, the UK currently provides an attractive point-of-access to the European Single Market for multinationals with low trade costs, a benefit that might be lost depending on future trade arrangements between the EU and UK. Second, Brexit will likely increase costs for multinationals that also operate in other EU countries, for example, relocation costs of staff between the UK and other member countries.

Additionally, EU membership allows free movement of natural persons, which the 'leave' (anti-EU membership) campaign in the UK perceived as a major point of contention. Currently 35% of all immigrants living in the UK arrive from other EU countries. The number of immigrant residents in the UK increased from 0.9 to 3.3 million between 1995 and 2015 (Centre for Economic Performance 2016), with a significant share attributed to the EU accession of eight eastern European countries in 2004. Of the 3.3 million EU immigrants currently living in the UK, 2.2 million of the approximately 2.5 million immigrants of working age (16–64) are actively working (Centre for Economic Performance 2016). The UK currently offers only a restricted number of working visas to non-EU nationals, an instrument which could be expanded to all or some EU countries after Brexit. However, work visa expansion would require a future EU–UK trade agreement with less

concessions than current agreements with Norway or Switzerland, both of which allow unrestricted immigration with the EU.

Quantitative assessments of the consequences of Brexit employing either Computable General Equilibrium (CGE) or gravity-based econometric models were made before the actual vote (Busch and Matthes 2016). Booth et al. (2015), Ottaviano et al. (2017), and Aichele and Felbermayr (2015), among others, focused their analyses on the impacts of the restoration of tariff and NTMs between the UK and EU. Other studies analyze the impacts of changes in immigration and FDI, but without sectoral details of trade relationships (Busch and Matthes 2016), either using aggregated CGEs (PricewaterhouseCoopers 2016) or other models (Oxford Economics 2016). Unlike some gravity-based models, only few CGE studies have considered fixed costs in trade and ‘love of variety’ effects that underly modern trade theory and result in heterogeneous firm models à la Melitz (2003) that well explain recent patterns of global trade. Consequently, Hosoe (2017) criticized existing studies because they might underestimate Brexit impacts on trade and found 60% greater GDP losses based on the Melitz specification relative to a standard Armington layout. The only other study we found that incorporates imperfect competition is PricewaterhouseCoopers (2016), however it uses the more restrictive Dixit and Stiglitz approach (1977) in a single-country dynamic CGE model.

Because of the uncertainties of what Brexit will actually mean to the UK economy, these assessments make quite different assumptions with regard to issues such as immigration, capital movements, tariff and NTMs, but not considering these aspects simultaneously and consistently. Furthermore welfare impacts of alternative options to Brexit are hardly discussed in literature, a very interesting issue from an economic perspective as existing literature focuses on changes in GDP that do not reflect impact on purchasing power. Our assessment focuses on the gaps we perceive in existing analyses. First, looking at EU market access we consider changes in tariffs and non-tariff barriers (NTBs) in goods and services using the Melitz (2003) framework for manufacturing sectors (i.e., allowing for imperfect competition with product differentiation between heterogeneous firms). Second, we link labor immigration, population size and demand for public services with the question of how to finance the UK government. And finally, we analyze the role of FDI considering feedback of changes in investments on capital stock. The impacts of these aspects are analyzed both independently and jointly in a CGE model that provides a stringent and coherent framework for economy-wide assessments focusing on welfare impacts.

2 Existing quantitative analyses of Brexit

Several studies have already appraised ex-ante impacts of Brexit, differing in terms of both methods and scenario design. Applications of CGE and New Quantitative Trade Models (NQTMs) based on gravity theory are the more frequently applied approaches. Given the uncertainty of the implications of Brexit, these studies evaluate a broad diversity of assumptions regarding changes to one or more of the “four freedoms” (e.g., free movement of goods, services, persons, and capital) of the

internal European market (Booth et al. 2015; Busch and Matthes 2016; House of Commons Foreign Affairs Committee 2013). The scenarios considered range from a comprehensive free trade agreement (FTA) with the EU covering all four freedoms (Norwegian option) to a fall back to most favored nation (MFN) rates under default WTO rules (WTO option) without further concessions. A wide range of alternative possibilities is assessed between these two extremes on the scenario spectrum, including: the “Switzerland option,” where UK’s relationship with the EU is regulated by a wide ranging FTA with restricted movement of labor and capital; and the “Turkey option,” where the UK and EU form a joint customs union.

Possible scenarios not only consider EU–UK trade, but also UK trade relationships with third countries, both with and without existing FTAs with the EU. Currently the EU has FTAs with 55 other countries that the UK might need to renegotiate post-Brexit (Booth et al. 2015). Potential UK trade deals with the USA and Canada have also been reviewed (HM Treasury 2016a). Studies have also evaluated the impacts of large-scale deregulation that the UK might implement domestically (Booth et al. 2015), or the potential outcome of UK national policies replacing current EU policies, such as the Common Agricultural Policy (CAP) (Harvey and Hubbard 2016), or considered the potential impacts of Brexit with a focus on the importance of financial stability in banking sectors of the UK and EU, especially in the longer term (Samitas et al. 2017).

The majority of Brexit impact assessments suggest that the negative consequences might not be great; and some suggest that there could even be a modest benefit to the UK economy over the long term under certain assumptions (Busch and Matthes 2016; Harvey and Hubbard 2016). For example, Booth et al. (2015) analysed a scenario similar to the WTO option using a dynamic version of the Global Trade Analysis Project (GTAP) model, however, with all other FTAs remaining in place and assuming that the UK will save 0.5% of its GDP by no longer contributing to the EU administrative budget. Against that background, bi-lateral imposition of MFN tariffs and NTBs led to a predicted decrease (−2.2%) in the UK GDP by 2030. Under a very optimistic scenario in which the UK manages to enter comprehensive FTAs with the EU and the rest of the world while simultaneously implementing large-scale domestic deregulation and saving its entire annual contribution to the EU, the GDP could even increase by 1.6%. Boulanger and Philippidis (2015) applied a world trade CGE model to simulate impacts of an FTA between the EU and UK under the assumption of saving UK’s payments to the EU and suggest that Brexit could contribute to a moderate (+0.6%) increase in per capita GDP. However, assuming additionally a 2% increase in iceberg cost associated with UK’s loss of access to the EU single market almost cancels out the savings benefit, while a simulation with a 5% increase in iceberg cost is predicted to reduce GDP by 0.7%. Using an NQTM (Ottaviano et al. 2017) predicted a reduction in GDP (−1.1%) if the UK and EU agree on the continued elimination of all tariffs and a modest decrease in NTBs. That analysis predicted further GDP losses of up to 3.1% under a combined shock scenario, including (values in parentheses represent the respective contributions of each of the following): re-introduction of MFN tariffs (−0.14%), restoration of two-thirds of existing NTMs (−0.93%), saving the entire annual contribution to the EU budget (+0.53%), and the EU succeeding to implement further

NTB reductions of 40% internally over the next ten years (-2.55%). Similarly, Aichele and Felbermayr (2015) employed an NQTM and found that under a “soft exit” scenario where UK-EU trade is subject to some NTBs but not tariffs, GDP would decrease by 0.6% in 2030. However, under a hard exit scenario with tariffs and increased NTBs on bilateral UK-EU trade, the UK’s GDP was predicted to drop by between 1.5% and 2.8% in that study. Finally, under a scenario featuring isolation of the UK, where the UK also loses privileges from all FTAs that the EU currently has with third countries, GDP was predicted to decline between 1.6 and 3%. Using a CGE model, CEPR (2013) also found small changes in GDP based on simulations of the WTO and Trans-Atlantic Investment Partnership (TTIP) options.

The studies mentioned so far focus solely on tariff and NTMs, as well as partly considering savings from ending contributions to the EU budget. Only a few studies extended their coverage to immigration and FDI issues. Using a macroeconomic single-country dynamic CGE model, PricewaterhouseCoopers (2016) predicted a long term GDP loss (-1.2%) in a scenario that leaves the UK largely integrated with the EU, and a slightly greater GDP loss (-3.5%) in a scenario where MFN rates are applied, NTMs are restored, net immigration is reduced, and uncertainty in capital markets is introduced. In the later scenarios, GDP decline mainly stems from the imposition of tariffs and NTMs (-2.1%) and restrictions on immigration that reduce labor supply (-1.6%). Only limited changes were attributed to factors such as increased uncertainty (-0.1%), while domestic deregulation in the UK was predicted to have a slight positive impact (0.3%).

Oxford Economics (2016) employed the “Oxford Economics’ Global Economic Model” and predicted that real GDP would only decrease by 0.1% by 2030 in the best-case scenario, which closely resembles EU membership. In the worst-case scenario assuming no FTA with the EU, no domestic deregulation, and the adoption of immigration control measures, GDP exhibited a -3.9% change by 2030.

The HM Treasury (2016a) used a gravity model that considered Brexit impacts on trade and FDI flows, and draw from there impacts on productivity. Subsequently, the changes in trade, FDI and productivity were introduced into a global macroeconomic model to predict the impact on GDP. That analysis suggests that Brexit would lead to GDP reductions of 7.5% under the WTO option, 6.2% under the Canada option, and 3.8% under the Norway option. These values represent differences predicted in the 15th year post-Brexit. In a similar study also conducted by the HM Treasury (2016b) using econometric estimates combined with a macroeconomic model, the impacts of uncertainty, financial market volatility, and reduced trade and investment openness are predicted under two scenarios (“shock” and “severe shock”). In the shock scenario the UK negotiates bilateral trade agreements while uncertainty reaches a level just below that of the 1990s recession and financial volatility increases by the same magnitude reflecting increased uncertainty. In this case the predicted UK GDP decreases by 3.6% in the short term. In the severe shock scenario the rise in both uncertainty and financial market volatility is around 50% greater than in the shock scenario, while trade is depicted with the WTO option, which leads to a short term GDP decrease of 6%. Ebell et al. (2016) mainly attributes these higher percentage change reductions to the inclusion of productivity shock in HM Treasury (2016b).

Portes and Forte (2017) utilized findings from other studies to forecast a “middle range” Brexit outcome, where net EU immigration to the UK falls by as much as 91,000 annually, would cut GDP growth by 0.6% in 2020 and 2.7% in 2030. In a more extreme hard Brexit scenario where EU immigration drops by 150,000 annually, the GDP is expected to decrease by 0.8% in 2020 and 4.4% in 2030. Recently, Dhingra et al. (2017) estimated total GDP losses ranging from 1.3 to -2.7% attributed to losses from imposition of the UK’s MFN tariff (-0.1%), the UK-EU27 NTBs (-0.5 to -1.3%), and intra-EU27 integration (-0.9 to -1.6%). Kierzenkowski et al. (2016) predicted similar GDP losses.

Overall the different studies predicted GDP changes in the UK ranging from slightly positive (1.6%) in Boulanger and Philippidis (2015) to -7.5% in HM Treasury (2016a). Differences in the results can be attributed to the type of model used and scenario design. Generally, a more comprehensive scenario design accounting for more aspects of Brexit leads to greater GDP losses.

Furthermore, the majority of the studies considers rather overall aggregate export and import relationships and related trade barriers (Busch and Matthes 2016), not sectoral specific trade as in trade focused CGE models. Using aggregate export and imports might result in aggregation bias, which could dampen simulated impacts (Britz and Van der Mensbrugghe 2016). Hosoe (2017) provides another explanation of why studies might potentially underestimate Brexit impacts. That paper compares the results of different Brexit scenarios in a CGE structure that follows either Melitz 2003 or the more standard Armington assumption for manufacturing sectors. Its most comprehensive scenario considers the imposition of WTO MFN tariff rates, a 25% increase in NTBs on bi-lateral trade between the EU and UK, a reduction of immigrants to the UK of 50%, and EU budget savings of 3% of the UK’s GDP. Here the Melitz configuration, which also considers firm exits and love-of-variety results in a GDP loss of 1.5%. That change is 60% greater than under the constant return to scale model’s prediction, where the UK would benefit or only be marginally harmed due to the assumed budget savings of 3% offsetting negative trade impacts. However, the analysis does not consider changes in FDI and treats capital stock as fixed.

Overall, we identify three gaps in existing literature on Brexit impact assessment. First, there is not a simultaneous and consistent analysis considering all four freedoms linked to EU market access. Second, most studies neglect modern trade theory and thus might underestimate impacts. Finally, these studies measure impact using GDP changes rather than by consistent welfare measures.

3 Modeling framework overview

We use the flexible and modular CGE model CGEBox developed by Britz and Van der Mensbrugghe (2016). A full documentation of all equations for that open-source CGE modeling platform can be found in Britz (2017).¹ An online appendix to our

¹ http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_e.htm includes full documentation, including information how to download the code and additional material (i.e., training videos).

paper adds the files needed to replicate the database used in here and rerun the shocks. The model is encoded in General Algebraic Modelling Language (GAMS) and is based on the GTAP database, both of which require a license. CGEBox can accommodate different assumptions with regard to model structure. We will discuss below in detail the changes we introduced relative to the Standard GTAP Model by Hertel (1997), a comparative static global CGE model based on Walrasian general equilibrium structure. It assumes cost minimizing behavior under constant returns to scale (CRS) production technologies along with utility maximizing consumers in competitive markets.

3.1 Melitz module structure

For our analysis, we expand CGEBox by a module based on Melitz (2003) that considers firm heterogeneity, firm entry and exits in the industry as a whole and on specific trade linkages, and love-of-variety effects by different agents, resulting in monopolistic competition. The module allows for each sector the choice between imperfect competition based on Melitz (2003) and the default assumption of perfect competition based on the Armington assumption [plus an optional Constant Elasticity of Transformation (CET) function to distribute supply]. The Melitz module is detailed in Technical Appendix 1. Full documentation of all equations from our model framework with details on calibration and parameterization as well as codes is available online.² In our application the Melitz module is applied for all manufacturing sectors, while other sectors are treated as perfectly competitive (see Table 8 in Appendix 2). That choice was motivated by literature highlighting the importance of considering firm heterogeneity in manufacturing sectors, (i.e., Akgul et al. 2016; Balistreri et al. 2011; Luckstead and Devadoss 2016; Jafari and Britz 2018). Further, according to recent estimates, the highest productivity dispersions are observed across firms in manufacturing sectors (Spearot 2016).

3.2 Vintage capital structure and endogenous capital stock

The standard case in comparative-static CGE models is that savings determine investment demand, but capital stock is fixed. Recursive-dynamic models update capital stock instead, considering depreciation of existing capital stock and adding gross investments from the previous solution period. We introduce that mechanism here in a comparative-static framework, additionally differentiating between existing (vintage) and new capital following ENVISAGE (Van der Mensbrugghe 2008). Specifically, we define old immobile capital stock derived from initial stock, yearly depreciation and the assumed time horizon of the comparative-static simulation. As physical depreciation is around 4% annually and we assume 5 years, the old stock considered immobile amounts to about 80% of the initial one. Endogenous gross investments form new mobile capital. This transparent and relative simple

² http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

mechanism thus makes the capital stock endogenous and thereby allows accounting for capital accumulation in a comparative static setting. This is important for our analyses, especially with regard to the immigration and FDI aspects of Brexit, which are discussed below.

3.3 Other adjustments to the standard GTAP model

In a standard GTAP model a regional household allocates regional income among private consumption, government consumption, and savings. Instead, we consider separate accounts to distinguish between a private household and the government. The single virtual representative private household in each region owns the production factors and receives factor returns of net factor taxes paid by firms on which the household pays additional direct taxes. That net income is distributed to savings and final demand based on fixed-value shares (i.e., a CD utility function). The government collects all tax income, which together with government savings finance government consumption. Government consumption is fixed in real terms to a scenario specific level. We also exogenize government deficits (as savings) in real terms while endogenizing direct taxes to close the account. Considering income generation and distribution for these accounts separately allows more detail in the scenario design and result analysis. The sum of regional savings (i.e., private household savings and government budget surplus or deficit) and foreign savings determine gross investments, and, as detailed above, capital stock.

As in the standard GTAP model, production is defined as the Leontief aggregate of value added and intermediate inputs bundles; the value added composition is based on a constant elasticity of substitution (CES) aggregate of primary factors, while the composition of intermediate demand is based on fixed physical input coefficients. However, for Livestock³ and food-processing sectors⁴ we consider substitution between feed inputs⁵ and agricultural inputs⁶ respectively based on GTAP-AGR (Keeney and Hertel 2005). Substitution elasticities between inputs in the livestock and food processing sectors are 2.0 and 0.5, respectively.

The standard GTAP model does not differentiate across destination markets (including the domestic market) from the suppliers' perspectives. The distribution of output to the domestic market and exports for competitive sectors is depicted in our configuration as sluggish based on CET functions with two nests, complementing the Armington specification.

Primary factors can either be assumed to be perfectly mobile across sectors or else can be treated as sluggish based on CET in the standard GTAP model, but

³ Livestock sectors are ctl, oap, rmk, and wol sectors (i.e., full details are found in the GTAP 9 database).

⁴ Food-processing sectors are cmt, omt, vol, mil, pcr, sgr, ofd, and b_t (i.e., full details are found in the GTAP 9 database).

⁵ Feed inputs comprise all crops (pdr, wht, gro, v_f, osd, c_b, pfb, ocr), as well as meats and food processing outputs (cmt, omt, vol, mil, pcr, sgr, ofd).

⁶ Agricultural inputs include all crops (pdr, wht, gro, v_f, osd, c_b, pfb, ocr) and livestock products (ctl, oap, rmk, wol).

without sector differentiation. Instead we configure CGEBox such that it depicts sluggish mobility of factors between agricultural and non-agricultural sectors following Keeney and Hertel (2005), including parameterization. Land is specific to agriculture in the GTAP database and natural resources are sector specific. The use of land and natural resource inputs are treated the same as in the standard GTAP model. We also consider new capital to be fully mobile within agricultural and non-agricultural sectors, but sluggish between them. Vintage capital is considered completely immobile (i.e., sector specific). In addition to new capital, which is investment driven, other primary factors are depicted by fixed stocks.

As in the GTAP standard model, private household demand for commodities is derived from a non-homothetic constant difference elasticity (CDE) implicit expenditure function, while government and saving demands for commodities are driven by a constant elasticity of substitution function. Demands for the different commodities and agents—the private household, government, investments and competitive sectors—are defined as a CES composite of domestic and import demand following the Armington assumption. The import demand composition from bi-lateral trade flows is depicted by a second CES nest, which is not agent specific. For the monopolistic sectors and related commodities, we consider love-of-varieties depicted by an agent specific single nest as in the Melitz (2003) model (Table 1).

3.4 Welfare measure

In the standard GTAP model the regional household's utility is specified by consumption of the private household, government spending, and saving (all per capita). The welfare effect measured in this framework is based on a money metric, equivalent variation (EV), of the regional household's utility change, expressed in constant dollar values (USD million). This welfare measure recognizes that the regional household benefits from private consumption and the government's provision of public goods, and expects benefits from net savings to increase future consumption. In our modified framework the private household and government are modelled separately, where the household's aggregate utility is governed by the Cobb–Douglas (CD) utility function over per capita private consumption and savings, while aggregate government utility is defined as the CD utility function over public spending and government saving. Accordingly, the welfare measure is specified as the sum of the money metric (EV) of private household and government utility change. Thus, any distortion resulting in changes in private consumption, government spending, or private and public saving affects the welfare measure.

3.5 Sectoral and regional aggregation

We maintain the full sectoral detail of the latest GTAP database (i.e., version 9). Table 8 reports if the Melitz or competitive market assumption is applied to these sectors. We aggregated that global database into 12 regions (EU post-Brexit, UK, USA, Australia and New Zealand, East Asia, Southeast Asia, South Asia, North America, Latin America, Middle East and North Africa, Sub-Saharan Africa, and

Table 1 Model setup compared to the standard GTAP model structure

Aspect	Standard GTAP model	CGEBox configuration in this study
International trade	Competitive sectors a la Armington	Melitz for industry sectors, Armington plus CET otherwise
Capital structure	No differentiation between old and new capital	Vintage capital specification
Capital stock	Fixed	Non-depreciated capital stock fixed, the rest is driven by investment
Income distribution	Regional household concept	Separate accounts for private household and government
Production function	Leontief aggregate of value added and intermediate inputs bundles; Leontief for intermediate inputs	Substitution between feed inputs in the livestock sector; substitution between agricultural inputs in food-processing sectors as separate CES nests
Output supply	Perfect transformation across destinations	Imperfect transformation across destination markets using two-level nested CET structure for sectors where Melitz module is not applied
Factor markets	Factors are either mobile or sluggish between all sectors	Factors are either mobile or sluggish within agricultural sector and non-agricultural sector nests, but sluggish between agricultural and non-agricultural sectors
Final demand and sectoral intermediate input demand	Two-level Armington demands for perfectly competitive sectors	Two-level Armington demands for perfectly competitive sectors, single nest for imperfect competition sectors with love-of-variety

other regions) to allow for interactions among major geographic regions. For the post-model analysis we aggregate results for all regions except EU 27, UK, and the USA into a rest-of-the-world (ROW) aggregate, and define sector aggregates as depicted in Table 8.

3.6 Model parameterization and calibration

In order to apply the framework described, the different parameters must be chosen, such as to recover an observed benchmark. That benchmark consists of the global social accounting matrix (SAM) provided by the GTAP database (version 9) with a reference year of 2011. That global SAM comprises many small entries, both in relative and absolute terms, which can affect numerical stability during solution of a CGE. Therefore we filter out small transactions in relative terms in a systematic way while maintaining a balanced global SAM, reflecting the fact that our aggregated database still comprises all sectors and a larger set of regions (Britz and Van der Mensbrugghe 2016).

For the parameters that characterize the Melitz structure, we use an estimate of 3.8 following Bernard et al. (2003) for elasticity of substitution, and an estimate of 4.6 for the Pareto shape parameter following Balistreri et al. (2011). The same parameter values are applied to all Melitz sectors, as sector specific parameters are not yet described in related literature. All other parameter values are from the GTAP database.

4 Modeling different aspects of Brexit and scenario specifications

4.1 Modeling impacts on trade

In our default scenario we assume that the UK will not enter into an FTA with the EU (i.e., both the UK and EU member countries impose bi-lateral MFN tariffs and (re)introduce NTMs against each other). However, EU trade agreements with third countries will remain in place for the UK. In practice, there is no obvious reason why third countries should not apply FTAs that cover all current EU member countries, including the UK, with the UK post-Brexit if tariff rates and other benefits from the agreement remain untouched (Booth et al. 2015).

While all of the studies discussed above somewhat suggest that tariff barriers have no significant aggregate impacts post-Brexit, regulatory divergences could emerge over time between the EU and UK. Different proxies for restoration of NTBs for goods are used in the literature. While some studies use some share of tariff equivalent estimates of current US-EU NTBs as a proxy (e.g., Ottaviano et al. 2017), other studies increase bilateral trade costs by some assumed percentage (e.g., Boulanger and Philippidis 2015) to reflect costs associated with reintroducing custom procedures and rules of origin post-Brexit. Egger et al. (2015) provides interesting insights based on calculated ad valorem cost saving equivalents (AVE) of being part of the EU for different economic sectors based on a gravity model (Table 2).

Table 2 AVEs (%) of NTBs in goods and services sectors. Source: Egger et al. (2015), Jafari and Tarr (2015)

Goods	Intra-EU AVEs saving	Services	AVEs of current poli- cies
Mean	12.9	Mean	12.8
Primary agriculture	25.2	Air transport	25.0
Primary energy	0.0	Maritime transport	1.7
Processed foods	48.4	Other transport	29.7
Beverages and tobacco	41.8	Banking	1.5
Petrochemicals	7.9	Insurance	6.6
Chemicals and pharmaceuticals	20.6	Communication	1.1
Metals and fabricated metals	38.5	Distribution	1.4
Motor vehicles	19.5	Other business services	35.4
Electrical machinery	1.4	Public services	–
Other machinery	1.6	Construction	–
Other manufactures	5.7	Personal and recreational services	–

Additionally, it is expected that increases in NTBs post-Brexit could be even more relevant for cross-border supply of services, as WTO rules for merchandise trade are more liberal than the General Agreement on Trade in Services (GATS) rules for services. Gravity estimates from Egger et al. (2015) are not available, but compiled data (Table 2) from estimates of trade restrictions in services from the World Bank (Borchert et al. 2014), AVEs for trade barriers in services based on World Bank data (Jafari and Tarr 2015), and assessments of GATS bindings, and how these compare to preferential trade agreement (PTA) services commitments from the WTO (Roy 2014). The figures shown in Table 3 are AVEs on cross-border trade in services. Note that intra-EU market access for services is much more liberal than the multilateral service trade regime relevant to third countries (Busch and Matthes 2016). Thus, a Brexit could reintroduce NTBs in service sectors with considerable impact on trade relative to almost free access under EU membership. Table 8 shows the concordance of sectors for which we have AVE estimates with the GTAP and thus our model sectors. In this study we assumed that half of the AVE of NTMs in goods and services currently estimated between the EU and non-EU member countries will be reintroduced in the worst-case scenario.

4.2 Accounting for changes in FDI

In the standard GTAP model a “global bank mechanism” determines foreign savings by equilibrating expected returns to investment across regions. The foreign savings for each region, together with regional savings and depreciation,

Table 3 Scenario specifications

Scenarios	Tariff rate change	Restoration of AVE of NTMS (%)	Reduced savings (%)	Net reduction in labor force (millions)
Scenario 1: tariff dimension	MFN rate			
Scenario 2: tariffs and NTMs dimension	MFN rate	50		
Scenario 3: FDI dimension			25	
Scenario 4: immigration dimension				1.0
Scenario 5: comprehensive worst-case scenario	MFN rate	50	25	1.0
Scenario 6: comprehensive intermediate scenario	50% of MFN rate	25	12.5	0.5
Scenario 7: scenarios 3 + 4			25	1.0
Scenario 8: scenarios 2 + 4	MFN rate	50		1.0
Scenario 9: scenarios 2 + 3	MFN rate	50	25	
Scenario 10: comprehensive conservative intermediate scenario	50% of MFN rate	25	12.5	0.25
Scenario 11: comprehensive conservative intermediate scenario (without Melitz sectors)	50% of MFN rate	25	12.5	0.25

determine total investment demands. Changes in foreign savings also ensure that the balance of payments is equal to the trade balance.

Currently, about one-half of the FDI stock of the UK comes from other EU members. After Brexit, higher trade costs would be likely to shrink this source of FDI. Dhingra et al. (2016) estimated that EU membership has raised foreign investment by about 25%. In our worst-case scenario, we exogenously decrease foreign savings for the UK to a level 25% lower as the benchmark following these findings, thus discontinuing the global bank approach.

4.3 Labor force and population

A key concern during the Brexit vote in the UK was the impact of labor immigration into the UK, particularly the fear that immigration crowds out domestic labor and strains public services (Centre for Economic Performance 2016; Harvey and Hubbard 2016). The UK government, in contrast to Germany, immediately granted unlimited access to immigrants of new member states when admitted to the EU in 2005. In addition to an already strong influx of well-educated EU citizens before the EU's east enlargement, especially into the service sectors, that led to a total of around 2.2 million EU citizens working in the UK. Clearly, we cannot model in detail the more immediate concerns of UK citizens such as longer waiting time to access public services or job displacement. The statement of the exchequer (Dustmann and Frattini 2014) was, however, quite clear in showing that EU migrants provide a net contribution to the government budget.

The main interrelated impacts of reduced migration in our CGE framework are threefold: (1) the production possibility of the economy as a whole is reduced as the labor stock is reduced, (2) domestic demand shrinks as less consumers live in the UK, and (3) tax income is reduced as well. What we cannot model is the claim of the exchequer that migrant households lead to a net contribution to government coffers, as we do not consider different household types. If that claim is true it would most likely reinforce the negative consequences discussed below, as UK households would contribute less (on average) to the government.

We assume that a reduced workforce from immigration also means a smaller population and therefore less demand for services. However, any reduction in government demand is certainly not fully proportional to population change. A striking example are the costs for national defense, which are unlikely to be affected at all by population change. The same relationship might hold, more or less, for the costs of central and local government services, and many areas of national administration. We therefore reduce total government demand compared to the benchmark by only 25% of the change in population size and fix the resulting value in real terms. Assuming that it will not be easier for the UK to finance a potential public budget deficit post-Brexit, we also fix government savings. Thus, in order to close the budget gap, direct taxes are endogenously adjusted, which is the least distortive way of introducing new taxes.

Currently there are estimated to be around 2.2 million EU migrants working in the UK out of a total working population of around 31 million. Furthermore,

approximately 1.2 million UK citizens live in other EU countries. Assuming that each worker has 0.2 dependents suggests that about one million UK citizens work in other EU countries. Hence, one would expect that after repatriating UK workers from the other EU countries and further assuming that at least a certain number of immigrant workers (0.2 million) will stay in the UK post-Brexit, we assumed net reductions of one million in the UK workforce and of one million multiplied by 1.2 for the general population in our worst-case scenario, comparable with the worst-case scenario of Kierzenkowski et al. (2016). Such higher estimates reflect the points addressed by Alfano et al. (2016) among others who show that immigration overall did not affect the employment rate of the UK-born population, and that EU might have even positively contributed to it. Furthermore, according to projections of the UK's Office for National Statistics, long-term non-EU net migration to the UK is decreasing. Thus, along with the obvious wish of voters to curb migration, offsetting decreasing EU by non-EU immigration would be certainly challenging for UK policy makers. However, the UK might undertake policy measures that increase labor participation and/or allow for continued immigration of workers. Hence, we perform a range of scenarios regarding the reduction in UK's labor force. It should be noted that our study ignores the impact of repatriating EU migrants on the EU due to its relatively small share of the total EU population and workforce.

At this point, the importance of a dynamic framework as discussed earlier is more evident, especially with regard to the immigration and FDI aspects of Brexit. First, when both labor force and population shrink, and lost access to the EU market lowers GDP, regional savings in the UK will drop, implying less investment and reduced capital stock compared to the benchmark. Second, reduced foreign savings would imply less FDI and again lead to reduced capital stock in the UK. As a consequence of lower labor and capital stocks, the production potential of the economy and hence output will be reduced.

4.4 Scenario specifications

Since the details of a post-Brexit deal between the UK and EU are uncertain, we consider a range of counterfactual scenarios to further explore the likely impacts of the UK leaving the EU. For each dimension (market access for good and services, immigration, FDI), we consider a no change, an intermediate, and a worse-case scenario. For market access we further differentiate between tariffs and NTBs. These potential changes are then applied in different combinations, leading to the first nine scenarios shown in Table 3. Note that assumptions in the intermediate scenario are always defined as 50% of the worst-case scenario. We further show results for a variant of the intermediate scenario based on a more conservative immigration policy shock (Scenario 10: Comprehensive conservative intermediate scenario). Finally, we performed structural sensitivity analysis on that conservative intermediate scenario, considering all sectors perfectly competitive sectors (Scenario 11).

Some of the scenarios can be interpreted in terms of the options discussed above. Scenario 7 represents a situation where the UK exits the EU and only maintains the

first freedom (i.e., the UK forms a custom union with the EU and harmonizes all NTBs). However, the UK's labor stock and FDI are expected to be reduced, suggesting less flexibility in capital movement and labor between the EU and UK. Scenario 8 assumes a hard Brexit without impacts on FDI, while scenario 9 captures the complete loss of preferential market access to the EU for goods and services, but no change in labor force (e.g., achievable by setting up a new immigration program).

Losing EU market access in combination with a reduced population implies less demand both for exports and in the domestic market, such that output adjusts by contracting. The resulting impacts are quite different between the competitive (Armington) and monopolistic (Melitz) settings. In the former, where only variable costs exist under constant returns-to-scale, lower production liberates resources. This effect drives down prices for primary factors and consequently for intermediate factors, which implies that UK sectors may become more competitive in both the domestic market and abroad, such that stronger trade diversion effects can be expected. In the monopolistic setting following Melitz, fixed costs might overshadow these consequences. These fixed production and trade costs will have to be distributed among lower output quantity, driving up per unit costs. There will, however, be some cost savings, as the least competitive firms will exit industries first. Generally the negative consequences from a less freer trade environment or shrinking domestic demand will be larger in the Melitz model. The existence of fixed costs also implies that the first order positive effect of reduced primary factor and intermediate demand on prices and thus competitiveness will be reduced. The impact of the Melitz setup on simulated GDP and welfare changes is shown by comparison against a competitive one based on the Armington assumption in the next section.

5 Results

First we examine the insulated impact of any of three analyzed dimensions (trade, labor and population, FDI). As shown in Table 4, returning to MFN rates for bilateral trade would have the smallest impact with approximate change of -138 USD per capita. However, when market access for goods is further restricted in combination with a 50% increase in NTMs on the top of MFN tariff rates, welfare loss amounts to almost -375 USD per capita. Assuming that Brexit also implies less FDI, considered here by the UK being forced to reduce its trade balance deficit by one-quarter (associated with a 25% reduction in net foreign savings), yields an equally considerable welfare impact (-217 USD per capita). Unexpectedly, the highest welfare losses are predicted when solely considering the impact of labor force and population reductions at around -402 USD per capita. Here, real GDP shrinks (-2.49%) by double the percentage reduction in population (-1.24%), which mostly reflects feedback from reduced savings on capital stock. The drop in savings stems primarily from shrinking income if both labor force and domestic demand are reduced. Furthermore however, with indirect tax income dropping by 0.65% , direct taxes need to be increased by about 7.56% to offset the loss to the tax base (less consumption relative to tax revenues due to a smaller population, less labor, and reduced capital) under the assumption that the budget deficit will not

Table 4 Key results

	MFN Tariffs		MFN Tariffs and NTM restoration		Reduced Foreign Savings		Reduced Immigration		Comprehensive worst-case scenario		Comprehensive intermediate scenario	
	EU27	UK	EU27	UK	EU27	UK	EU27	UK	EU27	UK	EU27	UK
Welfare change (USD per capita)	−4	−138	−49	−375	−2	−217	−3	−402	−25	−1123	−51	−575
Real GDP (%)	0.01	−0.38	−0.23	−1.17	−0.01	−0.59	−0.01	−2.49	−0.17	−4.45	−0.09	−2.28
Price index (%)	0.05	−0.36	−0.01	−0.30	−0.06	−0.64	0.01	0.20	−0.04	−1.24	−0.01	−0.71
Direct taxes (%)	−0.29	−1.66	−1.06	−7.83	−0.05	−0.54	0.03	7.56	−1.07	−0.96	−0.72	−1.7
Tax income (%)	0.12	−0.25	0.16	1.54	−0.07	−1.13	0.01	−0.65	0.13	−0.5	0.14	0.11
Population size (million/%)								−1.2 (−1.24)		−1.2 (−1.24)		−0.6 (−0.62)

Population size is based on scenario specific exogenous assumptions

increase further. Higher direct taxes along with other effects, such as price increases for imports, reduce the purchasing power of private households.

The worst-case scenario predicts yearly welfare losses of 1123 USD per capita. The impact on real GDP is quite strong at -4.45% , however, considering that the UK population would shrink by about 2.16% compared to the baseline dampens the impact on a per capita basis. Additionally, the consumer price index increase ($+2.46\%$) relative to the factor price index defined as the regional numeraire, underlining the importance of considering welfare impacts. The intermediate scenario results shown in the last column of Table 4 also suggest significant welfare and GDP loss.

In the comprehensive mid-range and worst-case scenarios, total output of the UK economy decreases by about 2.00% and 3.68% respectively. Table 5 shows the impact details for different economic sectors.

Business services (-3.32%), and construction (-8.17%) sectors are the greatest contributors to the reduction in total output under the worst-case scenario (Table 5). Our sensitivity analysis (not shown) reveals that the strongest contraction in relative terms for business services is due to high AVEs (see Table 2) and the labor intensity of this sector. The strong contraction in the construction sector reflects its relatively high capital and labor intensity. The other major contributors to the reduction in total output are ranked in the first column (3–8). The cumulative reduction of output quantity in absolute value of the top eight sectors contributes to 85% of total output reduction (not shown). The greatest sector changes in percentage change terms relative to their baseline values are also among the top contributors. The output of the motor vehicles (-17.89%), metals and fabricated metals (-15.88%), chemicals and pharmaceuticals (-11.43%), and construction (-8.17%) sectors are expected to decrease significantly. The strong contraction in manufacturing sectors reflects changes in existing strong trade linkages between the UK and EU, as well as a relatively high capital and labor intensity. The results for the mid-range Brexit scenario show a similar order with lesser magnitude as expected.

Imports to the UK (from EU and non-EU members) drop by around 14% and 8% in the worst-case and mid-range scenarios respectively, reflecting reductions in population and per capita purchasing power, as well as tension on trade balance from reduced foreign savings. As expected, imports from the EU are affected most with a reduction of around 26% (worst-case) and 15% (intermediate). Exports from the UK decrease by 13% and 8% respectively, while exports to the EU exhibit more severe drops in the worst-case (-25%) and intermediate (-15%) scenarios as expected.

While global welfare shrinks, the welfare impact on the regions other than the UK and EU is positive. The USA is predicted to gain approximately 19 USD and 10 USD per capita in the worst-case and intermediate scenarios from the changes in re-allocation of global foreign savings, driven by our scenario assumptions. The simulation results for welfare and GDP from scenarios 7–9 are shown in Table 9. The results from the comprehensive intermediate scenario with less reduced labor force (Table 6) underline the importance of immigration in our results: the welfare loss decreases by 158 ($=575-417$) USD per capita, and the UK faces 0.61 ($=2.28-1.67$)% less reduction in the GDP, if labor force reduces by only 0.25 million instead of 0.5 millions, under otherwise unchanged assumptions. In addition,

Table 5 Sectoral output changes

No.		Baseline output ^a	Intermediate scenario		Worst-case scenario	
			Absolute change ^a	% Change	Absolute change ^a	% Change
	Total output	4318	− 88.18	− 2.00	− 162.34	− 3.68
1	Business services	878	− 14.65	− 1.64	− 29.63	− 3.32
2	Construction	272	− 11.4	− 4.02	− 23.17	− 8.17
3	Distribution	450	− 8.75	− 1.91	− 17.96	− 3.91
4	Public services	1040	− 9.01	− 0.86	− 17.9	− 1.71
5	Chemicals and pharmaceuticals	139	− 10.21	− 6.83	− 17.09	− 11.43
6	Metals and fabricated metals	94	− 12.11	− 11.39	− 16.88	− 15.88
8	Motor vehicles	77	− 11.37	− 12.93	− 15.74	− 17.89
9	Other transport	188	− 3.45	− 1.81	− 6.59	− 3.45
10	Petroleum and coal products	111	− 2.79	− 2.46	− 5.24	− 4.62
11	Other machinery	203	− 1.8	− 0.88	− 4.39	− 2.14
12	Personal and recreational services	138	− 1.78	− 1.28	− 3.87	− 2.77
13	Communication	110	− 1.23	− 1.11	− 2.6	− 2.34
14	Other manufacturing	223	− 0.4	− 0.18	− 2.34	− 1.05
15	Air transport	45	− 1.17	− 2.52	− 2.26	− 4.89
16	Beverages and tobacco	42	− 0.18	− 0.42	− 0.32	− 0.76
17	Primary energy	61	− 0.08	− 0.13	− 0.13	− 0.22
18	Electrical machinery	38	0.18	0.47	− 0.09	− 0.25
19	Primary agriculture	37	0.07	0.18	0.29	0.78
20	Maritime transport	44	0.24	0.55	0.36	0.83
21	Processed food	129	1.73	1.36	3.22	2.53

^aValues are in million USD

Table 6 Welfare and GDP impact for Melitz compared to competitive setup for comprehensive conservative intermediate scenario

Scenario	Welfare (USD per capita)		Real GDP (%)	
	EU27	UK	EU27	UK
Melitz (10)	– 49	– 417	– 0.08	– 1.67
Competitive (11)	– 13	– 328	– 0.05	– 1.50

Details of the scenario definition can be found in Table 3

replacing the Melitz by a competitive set-up leads to significantly lower impacts on welfare and GDP (Table 6), supporting the points discussed earlier in Sect. 4.4 above.

Felbermayr et al. (2017) and Oberhofer and Pfaffermayr (2017) calculate within-scenario confidence intervals for findings associated with alternative Brexit scenario specifications in statistically estimated extended NQTM approach. Such an approach which requires sampling from distributions of all behavioral and others parameters in the model cannot be implemented for CGE analysis. It is computationally hardly feasible and, furthermore, distributions for most parameters are not known. We refrain here from the often repeated exercise or more less arbitrarily drawing around key parameters such as the Armington elasticities as the sensitivity of results to these have been sufficiently often demonstrated.

6 Discussion

The predicted change in GDP (–4.45%) from the worst-case scenario is at the upper range of the results of previous studies. Greater changes were only reported by HM Treasury (2016a, b), which evaluated change in GDP due to Brexit compared to maintaining EU membership after 15 years. The greater predicted reduction in GDP in that study might reflect the future benchmark basis, a scenario design featuring greater isolation of the UK from the EU, or their gravity based approach. These approaches often predict greater ex-post impacts on trade from changes in border protection relative to CGE based analyses. The predicted GDP change from our model (–0.38%) attributable to MFN tariff impositions is slightly higher than the range of results from other studies, for example –0.1% (Dhingra et al. 2017; Hosoe 2017) and –0.14% (Ottaviano et al. 2016). These studies, however, reported nominal rather than real GDP changes and typically consider less detailed sectoral information.

The restoration of tariff and NTMs (Scenario 2) leads to a reduction in the UK's GDP of 1.17%, which is comparable with the results (–1.1%) of Hosoe (2017) using a Melitz framework, however that study did not take into account saving and investment dynamics. Our results are also comparable to the –1.1% reduction by Ottaviano et al. (2017) based on an NQTM approach. Dhingra et al. (2017) predicts a somewhat greater impact (–1.5%), however under a scenario with more severe shocks with respect to NTBs (75%) compared to 50% in our analysis.

The predicted GDP change from a reduction in net immigration (-2.49%) is comparable with (-2.7%) from Portes and Forte (2017) in a scenario where net immigration is decreased by 91,000 annually over 12 years. PricewaterhouseCoopers (2016) estimates GDP reduction of 1.6% with a net reduction of 600,000 immigrants, which is consistent with our predicted change with net immigration reduction under minus one million. That study also asserts that reductions in net immigration is the major contributor to GDP reduction, which supports our findings. The scenario (8) with GDP reduction (-3.8%) resulting from both restoring tariffs and NTMs as well as reduced immigration exceeds -2.7% reported by Dhingra et al. (2017). We attribute this difference to the fact that we consider the impact of reduced savings on capital stock.

The worst-case scenario result of -4.45% change in GDP exceeds -3.5% reported by PricewaterhouseCoopers (2016) under a scenario that also considers restoration of tariff and NTMs as well as reductions in labor force and capital. We attribute the greater value from our model to the use of the Melitz framework and of a global instead of single country CGE. This also explains the difference between our predicted change in GDP and the result of -3.9% of Oxford Economics (2016).

In summary, four factors explain why the impacts predicted by our model, especially under the worst-case scenario, are greater than the results of most similar studies. First, we use a database with details for 57 economic sectors of GTAP9, which might avoid aggregation bias as it considers tariff peaks found for instance in agricultural and food processing sectors. Second, we consider all four freedoms simultaneously and more conservative budget savings from the discontinuation of contributions to the EU. These assumptions can be challenged, but the net UK contribution to the budget is not significant when measured in relative GDP terms and central services of EU administration such as managing international trade negotiations will need to be assumed by the UK. Third, our model considers important feedback channels such the linkage between savings and capital stock, and how reduced immigration impacts production. These feedback channels are only considered in some of the other studies. Finally, applying the Melitz model, in accordance with Hosoe (2017), considers empirical evidence from modern trade theory suggesting greater welfare losses from trade barriers.

The greater welfare changes from our model are not only consistent with other empirical analyses (e.g., Balistreri et al. 2011), but are also consistent with results of Melitz and Redding (2015) showing that endogenous firm entry and exit in conjunction with love-of-variety can lead to additional welfare gains depending on the structure and parameterization of the model. This is also consistent with the point raised by Arkolakis et al. (2012:95) that overall welfare gains from trade are independent of the application of an Armington or Melitz approach under one of the following assumptions applied to a single sector: (1) Dixit–Stiglitz preferences; (2) single factor of production; (3) linear cost functions; and (4) perfect or monopolistic competition; as well as three macro-level restrictions: (1) trade is balanced; (2) aggregate profits are a constant share of aggregate revenues; and (3) the import demand system is CES. Obviously, these assumptions do not fit our CGE model with several production factors and non-linear cost functions. Furthermore, Arkolakis et al. (2012: 114) find that when expanding analyses to multiple sectors “we see that the welfare

consequences of foreign shocks, in general, and the gains from trade, in particular, may no longer be the same under perfect and monopolistic competition with free entry.” The same holds when trade in intermediates are considered. Arkolakis et al. (2012: 116) also explains that in the case of multiple sectors: “This is because sector-level trade flows cannot tell us what is fundamentally an economy-wide impact of trade on factor prices. Under monopolistic competition, this issue is complicated by the implications of trade for the measure of goods that can be produced in different sectors.” The multiple sector analysis used in that study assumes CD-preferences for final consumers, which is not the case in our model. We conclude from the findings of Arkolakis et al. (2012) and Melitz and Redding (2015) that welfare changes using CGE with multiple sectors, multiple factors, and a non-linear costs function under the Melitz and Armington approaches will be different.

7 Summary and conclusions

We quantified impacts of Brexit along three dimensions: access to EU markets, reduced EU labor immigration (and associated changes to population size) and FDI. Our CGE analysis is based on the monopolistic competition model of Melitz (2003) for manufacturing sectors and drives capital stock by investment. We find very strong annual welfare losses and reduction in real GDP under a worst-case scenario in which the UK would face: (1) EU MFN tariffs and some restoration of NTBs, (2) reduced net labor immigration from the EU of one million with related consequences on the labor force and population size, and (3) the need to reduce trade balance in the midterm by a quarter with reduced FDI. About two-thirds of the impacts predicted by our model are due to the consequences of a reduced labor force and associated changes in population size. This reflects a shrinking tax base, less domestic consumption, a smaller labor force, and reduced capital stock along with decreased regional savings such that, despite a limited reduction in overall government demand, taxes will need to be increased. While our findings for sub-scenarios fit well with the results of existing quantitative analyses, the combined GDP loss under our comprehensive combined scenario mostly exceeds impacts from previous studies. We attribute the greater impacts predicted by our model to a more comprehensive scenario design that considers capital accumulation and feedback from changes in population size on tax income and demand for public services, and to the assumptions of the Melitz model. Under this monopolistic competition model, a smaller domestic market and reduced exports to the EU imply that fixed industry costs are distributed among lower overall outputs such that per unit production costs increase.

Our results suggest that labor force development will be a key issue in determining impacts post-Brexit. Reducing immigration without meaningful efforts to increase labor participation rates within the population is expected to reduce output and demand, and to diminish the tax base. Such efforts should especially target low-wage sectors that have relied heavily on immigrated labor. A potential policy instrument is increasing minimum wage, however, this option could raise production costs and thus reduce competitiveness. Other potential instruments such as

promoting higher graduation rates would require additional government spending and be a long-term strategy. If free movement of EU citizens to the UK labor market will be discontinued, the UK will need to implement some form of active immigration policy.

Our analysis also highlights the challenge for the UK to remain an attractive recipient of FDI after leaving the EU. In particular, losing passporting rights for financial services could lead to a re-allocation of FDI towards the continent. Given the importance of the financial sector for the UK, we can only conclude that negotiators should do their best to avoid disruption in this area of the economy. There are similar concerns with respect to the damage that could result from losing EU market access for goods and services, highlighting that the severity of impacts might be less a question of tariffs than of NTBs, which would likely aggravate long-term effects. In this respect the UK might end up in the same unpleasant position as other European Free Trade Association members outside of the EU: accepting future EU regulations on trade in order to not increase NTBs to the detriment of their own industries and consumers. If such an option would be feasible in the current political environment in the UK favoring Brexit remains to be seen.

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Appendix 1: Technical appendix

Implementation of Melitz model into the standard GTAP model

We incorporate a module based on Melitz (2003) into the flexible and modular CGE model CGEBox (Britz 2017). The actual implementation of the Melitz model into CGEBox draws largely on the empirical method by Balistreri et al. (2011), Balistreri and Rutherford (2013) and Akgul et al. (2016) to introduce the Melitz (2003) model into an applied equilibrium model.

The Melitz framework focuses on intra-industry differentiation where each firm produces a single unique variety. However, data at the firm level are limited and applied equilibrium models work at aggregate levels. Fortunately, Melitz offers a numerical framework build around (marginal changes in) the average firm operating within a trade linkage. That average firm's productivity comprises all necessary information on the distribution of productivity levels of firms active in that link. That vastly eases the model's implementation by effectively eliminating any data needs at individual firm level as detailed below. Against a background of that definition of an average firm within each trade linkage, we now focus on the formulation of an empirically computable version of Melitz model and its linkages with the GTAP model.

Assume that a representative agent ' a ' (private households, government, investors, intermediate inputs by the different firms) in region ' r ' obtains utility U_{air} from consumption of the range of differentiated varieties of product ' i ' and considering the CES utility function as proposed by Dixit and Stiglitz (1977), the aggregate

demand by each agent a for commodity i in region r (Q_{air}) which is equivalent to utility ($Q_{air} \equiv U_{iar}$) can be represented as:

$$Q_{air} = \left(\sum_s \int_{\omega \in \Omega_{isr}} \lambda_{aisr}^{\frac{1}{\sigma_{ir}}} Q_{aisr}(\omega)^{\frac{\sigma_{ir}-1}{\sigma_{ir}}} d\omega \right)^{\frac{\sigma_{ir}}{\sigma_{ir}-1}} \quad (1)$$

where Ω_{isr} represents the set of products i sourced from region s to r and $\omega \in \Omega_{isr}$ index the varieties in the set Ω_{isr} . In this context, $Q_{aisr}(\omega)$ represents the demand quantity of commodity i for variety ω in region r by agent a which is sourced from region s , σ_i represents the constant elasticity of substitution for each commodity, and λ_{aisr} are preference weights (share parameters)⁷ that reflect differences between origins not linked to diversity in varieties. Note that substitution elasticities might be differentiated by destination region r , but are uniform across agents in each region in our implementation.

The resulting CES unit expenditure function which is the dual price index on Dixit–Stiglitz composite demand in region r (P_{air}) is given by:

$$P_{air} = \left(\sum_s \int_{\omega \in \Omega_{isr}} \lambda_{aisr} P_{aisr}(\omega)^{1-\sigma_{ir}} d\omega \right)^{\frac{1}{1-\sigma_{ir}}} \quad (2)$$

where $P_{aisr}(\omega)$ is agent's a (purchase) price of product i for variety ω in region r sourced from region s . Using the aggregate price index in Melitz (2003) based on the definition of the average firm and considering that varieties do not differ in their marginal utility for the first unit, one can define the price index as equivalent to the dual price defined in Eq. (2)

$$P_{air} = \left(\sum_s \lambda_{aisr} N_{isr} \widetilde{P}_{aisr}^{1-\sigma_{ir}} \right)^{\frac{1}{1-\sigma_{ir}}} \quad (3)$$

where $\widetilde{P}_{aisr}$ denotes the agent price inclusive of export, import and consumption taxes for the average firm, and N_{isr} refers to the number of firms operating on the trade link s - r . Equation 3 generates the top level Armington price for each agent, replacing the Armington price aggregator in GTAP from the agents' domestic and import prices. Consistent with Melitz (2003), there is a one-to-one mapping among firms and varieties such that the number of firms is equal to the number of varieties on each trade linkage. In comparison to Eq. (2), which is based on the individual

⁷ The reader should note that the share parameters are absent in the original Melitz paper. We hence allow here a differentiation between products from different origins as in the Armington model in addition to the love of variety effect.

varieties, Eq. (3) summarizes the compositional change (i.e., change in the number of varieties), which goes along with an update of the average price. Again we assume the same substitution elasticities across agents.

The total (Q_{air}) and average per firm ($\tilde{Q}_{air}$) demand for the average variety by an agent to be shipped from s to r ($\tilde{Q}_{air}$) can be obtained by applying *Shephard's Lemma* on the expenditure function:

$$Q_{air} = \tilde{Q}_{air} N_{isr} = \lambda_{air} N_{isr} Q_{air} \left(\frac{P_{air}}{\overline{PA}_{air}} \right)^{\sigma_{ir}} \quad (4)$$

This equation replaces the equations determining the agent specific Armington demands for the domestic and imported good as well as the equations for bi-lateral import demand which are not agent specific in the GTAP standard model.

This reveals the main differences to a standard Armington composite: the share parameters vary with the number of operating firms (i.e., the number of varieties comprised in the bilateral trade bundles). As the agent demand for the average firm's output in region s in each industry i in region r (Q_{air}) depends on the aggregate regional demand for that industry Q_{air} , we need to determine this in equilibrium for each agent. In other word, we need to determine the demand for use of i as an intermediate input in each sector separately, and as final demand for household consumption, government consumption, investment, and for international transport margins. In the standard GTAP model, each agent has a specific preference function which determines the demand for each Armington commodity; the government and saving sector based CES preferences, while households use a CDE indirect demand function. The Armington demand for each agent and commodity is then decomposed into a domestic and import component in the first Armington nest. The second nest decomposes import demand by each region by origin, independent of the agent.

The implementation of the Melitz model thus simplifies the demand structure present in the standard GTAP model by aggregating the two Armington nests into a single one, however, note that the GTAP database does not yet differentiate in the SAM bi-lateral flows by agent. Therefore we use the same shares by origin to separate import demand for the different agents.

Assume that a small profit maximizing firm facing the constant elasticity of demand according to Eq. (4) for its variety and based on the assumption of the large group monopolistic competition, a firm will not consider its impact on the average price index and therefore follow the usual markup rule to translate their marginal cost of production (c_{is}) to the optimal price.

Firms in Melitz (2003) face different types of cost: sunk fixed cost of entry f^{ie} , fixed cost of operating on a trade linkage f_{isr} and marginal cost c_{is} . Let φ_{isr} indicate the firm's specific productivity, which measures the amount of "variable composite unit" needed per unit of output Q_{isr} . Accordingly, the marginal cost per unit is the amount of "composite input" required per unit ($\frac{1}{\varphi_{isr}}$) times the unit cost of the "vari-

able composite input" (c_{is}) in industry i of region s . Therefore, a firm wishing to supply Q_{isr} units from region s to r employs ($f_{isr} + \frac{Q_{isr}}{\varphi_{isr}}$) units of "variable composite

input.” The structure of fixed costs and variable composite input demand is discussed in detail below. Let, τ_{isr} denote the iceberg cost of trade, which represent domestic production costs and not the international trade margins present in GTAP. Focusing on the average firm with a productivity $\tilde{\varphi}_{isr}$ operating within a trade linkage and solving the firm’s profit maximization problem, the price charged by the average firm in region s to supply region r $\widetilde{PF}_{isr}$ (inclusive of domestic transport margin) is:

$$\widetilde{PF}_{isr} = \frac{\sigma_{ir}}{\sigma_{ir} - 1} \frac{\tau_{isr} c_{is}}{\tilde{\varphi}_{isr}} \quad (5)$$

where $\frac{\sigma_{ir}}{\sigma_{ir}-1}$ represents the constant markup ratio in industry i , which reflects market power due to product differentiation into varieties. This newly introduced equation translates the variable per unit cost function for each sector and region into offer prices by the firms on each trade link including domestic sales. In the standard GTAP model, offer prices are not differentiated by destination and are equal to per unit cost corrected for output taxes.

The average price in Eq. (5) therefore depends on the price of variable composite input c_{is} , which is a function of the price of intermediates and primary factors. Given the assumption of constant return to scale and the way technology is presented in the standard GTAP model, the unit cost function for sector i in region s c_{is} in GTAP is given by the Leontief composite of the value added bundle (CES aggregate of factors of production) and the aggregate of intermediate demand (Leontief aggregate of intermediate demands). In the CGEBox, m_px ⁸ is a macro defined as producer price, which constitute per unit costs corrected for production taxes. To be consistent with our Melitz formulation, the unit cost inclusive of production tax is directly introduced in the markup Eq. (5). It should be emphasized that the presence of fixed cost in the Melitz model is the source of increasing returns to scale in a monopolistically competitive industry: if firms expand production, the fixed cost can be distributed over a greater quantity of outputs such that per unit cost decreases.

While observed data on quantities traded and related prices allow identifying the necessary attributes of an average firm, additional information is needed to gain information about the marginal firm (i.e., the firm that earns zero profit). Obviously, the distance in productivity between the average and marginal firm reflects properties of the underlying distribution. We rely here on a Pareto Productivity distribution, which has analytical tractability.

Let M_s indicate the number of firms choosing to incur the fixed entry cost (i.e., total industry size), each individual firm receives its productivity φ draws from a Pareto distribution with Probability Density Function (PDF):

$$g(\varphi) = \frac{a}{\varphi} \left(\frac{b}{\varphi} \right)^a \quad (6)$$

⁸ http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

and Cumulative Distribution Function (CDF):

$$G(\varphi) = 1 - \left(\frac{b}{\varphi} \right)^a \quad (7)$$

where b is the minimum productivity and a is a shape parameter. Lower values of the shape parameter imply higher productivity dispersion among firms. As discussed in Melitz (2003), $a > \sigma_{ir} - 1$ should be applied in order to ensure a finite average productivity level in the industry.

On each bilateral trade linkage, the given fixed bilateral trade cost, variable costs and demand define jointly a certain cut off productivity level (φ_{sr}^*) at which firms will receive zero profit. A firm with the productivity equal to that threshold level ($\varphi_{sr} = \varphi_{sr}^*$) will therefore face zero profits and act as the marginal firm from region s supplying r . Those firm whose productivity is above the threshold level ($\varphi_{sr} > \varphi_{sr}^*$) will receive a positive profit and will operate on the $s - r$ link and those firm with productivity that is below the threshold level ($\varphi_{sr} < \varphi_{sr}^*$) will not operate on the $s - r$ linkage. Focusing on the fixed operating cost f_{isr} in composite input units, the marginal firm on s - r linkage receives zero profit at:

$$c_{isr} f_{isr} = \frac{r(\varphi_{isr}^*)}{\sigma_{ir}} \quad (8)$$

where $r(\varphi_{isr}^*) = p(\varphi_{isr}^*)q(\varphi_{isr}^*)$ denotes the revenue of marginal firm at the productivity equal to the cut off level ($\varphi_{isr} = \varphi_{isr}^*$).

The zero cut off productivity level in each bilateral market φ_{isr}^* can be obtained by solving Eq. (8). However, it is numerically easier to define this condition in terms of the average rather than the marginal firm. To do this, we define the productivity and revenue of the average firm relative to that of the marginal firm. Following Melitz (2003), average productivity is defined as the CES aggregation of productivities of all firms operating on a given trade link:

$$\tilde{\varphi}_{isr} = \left[\frac{1}{1 - G(\varphi_{isr}^*)} \int_{\varphi_{isr}^*}^{\infty} \varphi_{isr}^{\sigma_{ir}-1} g(\varphi) d\varphi \right]^{\frac{1}{1-\sigma_{ir}}} \quad (9)$$

If these productivities are Pareto distributed, we can write⁹:

$$\tilde{\varphi}_{isr} = \left[\frac{a}{(a + 1 - \sigma_{ir})} \right]^{\frac{1}{1-\sigma_{ir}}} * \varphi_{isr}^* \quad (10)$$

⁹ One could use industry specific shape parameter (a_i) given the availability of data at sectoral level. In this study we assume that all firms entering in different industries draw their productivity from the Pareto distribution function with same characteristics (i.e., same scale and shape parameter).

Equation (10) provides the relationship between the productivities of the average and marginal firm

Using optimal firm pricing according to Eq. (5) and given the input technology, the ratio of revenues of the firms with marginal productivity $r_{isr}(\varphi^*)$ in relation to the revenue of the firm with the average productivity $r_{isr}(\tilde{\varphi})$ is defined as:

$$\frac{r_{isr}(\varphi^*)}{r_{isr}(\tilde{\varphi})} = \left(\frac{\varphi^*}{\tilde{\varphi}} \right)^{\sigma_{ir}} \quad (11)$$

Solving Eq. (10) for $\frac{\varphi^*}{\tilde{\varphi}}$, substituting it into (11), and then solving the resulting equation for $r_{isr}(\varphi^*)$ and replacing its value in Eq. (8), defines a relation between the bilateral fixed cost at current composite input price [the LHS of (12) below], the average firms revenue ($\widetilde{PF}_{isr}\tilde{Q}_{isr}$), the shape parameter of the Pareto distribution of the productivities and the substitution elasticity of demand:

$$c_{isr}f_{isr} = \frac{(a + 1 - \sigma_{ir})}{a\sigma_{ir}} \widetilde{PF}_{isr}\tilde{Q}_{isr} \quad (12)$$

Note that average firm's sale in region s in each industry i to region r ($\tilde{Q}_{isr}$) at the equilibrium is composed of the demand for use of i by different agents.¹⁰

The optimal pricing in the markup Eq. (5) requires information on the average productivity on each bilateral trade link. In Melitz (2003), the probability that a firm will operate is $1 - G(\varphi_{isr}^*)$, which is equal to the fraction of operating firms over total number of firms choosing to draw their productivity $\left(\frac{N_{is}}{M_{is}}\right)$. Using the Pareto

cumulative distribution function from Eq. (7) and inverting it we have:

$$\varphi_{isr}^* = \frac{b}{\left(\frac{N_{isr}}{M_{is}}\right)^{\frac{1}{a}}} \quad (13)$$

Substituting Eqs. (13) into (10) results in Eq. (14) introduced into the model:

$$\tilde{\varphi}_{isr} = b \left[\frac{a}{(a + 1 - \sigma_{ir})} \right]^{\frac{1}{1 - \sigma_{ir}}} * \left(\frac{M_{is}}{N_{isr}} \right)^{-\frac{1}{a}} \quad (14)$$

Next, the number of firms selecting to enter the market M_{is} is determined. Based on the free entry condition, the last firm that enters has expected profits over its life

¹⁰ $\tilde{Q}_{isr} = \sum_a \tilde{Q}_{aisr}$

Table 7 Equilibrium conditions

Equations	Equilibrium condition	Paired variable
(3)	Sectoral aggregation	P_{air} : sectoral price index
(4)	Firm-level demand	$\tilde{P}_{isr}$ average firm price
(5)	Firm-level pricing	$\tilde{Q}_{isr}$: average firm quantity
(12)	Zero cut off condition	M_{is} number of operating firms
(14)	CES weighted average productivity	N_{is} : average firm productivity
(16)	Free entry condition	N_{isr} : number of entered firm
(17)	Factor market clearing condition	c_{is} : sectoral composite input price

time, which just offset the sunk cost of entry. Industry entry of a firm requires a one-time payment of f^{ie} . A firm that enters a market faces a probability of δ to suffer a shock, which forces its exit in each future period. Therefore δM_{is} firms are lost in each period. Based on Melitz (2003), in a stationary equilibrium, the number of aggregate variables must remain constant over time, including industry size. This requires that the number of new entrants in every period is equal to the number of firms lost δM_{is} . Therefore, total entry cost is equal to $c_{is} \delta M_{is} f^{ie}$. Each firm faces the same expected share on that cost (i.e., $c_{is} \delta f^{ie}$ if risk neutral behavior and no time discounting is assumed). The firm's expected share of entry costs must be equal to the flow of expected profit on the condition that firm will operate:

$$\tilde{\pi}_{isr} = \frac{\tilde{P}F_{isr} \tilde{Q}_{isr}}{\sigma_{ir}} - c_{is} f_{isr} \quad (15)$$

The probability that a firm will operate on the s-r trade linkage is given by the ratio of $\frac{M_{isr}}{N_{is}}$.¹¹ Thus, the free entry condition ensures that the expected industry prof-

its (i.e., the profits summed up over all potential bilateral trade links) is equal to the annualized flow of the fixed costs of entry

$$c_{is} \delta f^{ie} M_s = \sum_r N_{isr} \tilde{P}F_{isr} \tilde{Q}_{isr} \frac{\sigma_{ir} - 1}{a \sigma_{ir}} \quad (16)$$

where zero profit condition in Eq. (12) is used to replace the fixed operating cost $c_{is} f_{isr}$. With the number of entered firm established in Eq. (16), we now turn to total composite input demand of the industry Y ,¹² which consists of three components: sunk entry costs of all entrants ($\delta M_{is} f^{ie}$), operating fixed cost ($\sum_s N_{isr} f_{isr}$) on each

¹¹ The probability that the firm will operate is $1 - G(\varphi_{isr}^*) = \frac{N_{is}}{M_{is}}$.

¹² Y corresponds to XP in the CGEBox.

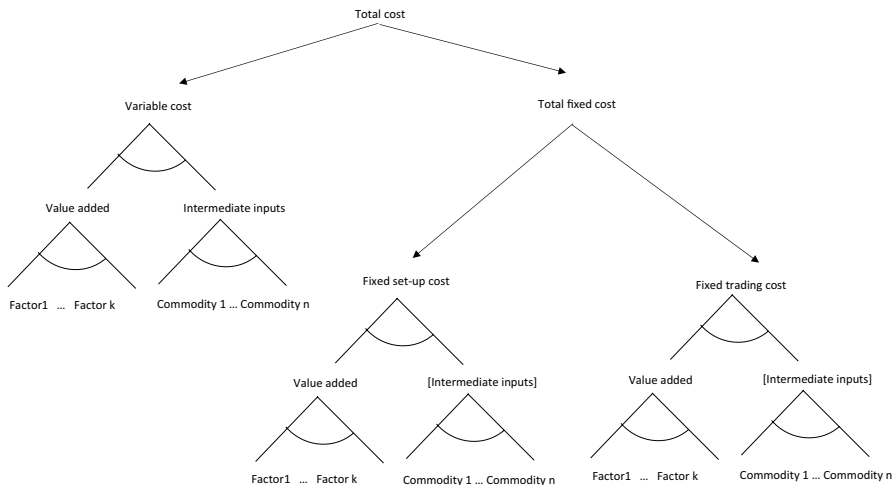


Fig. 1 Production structure in Melitz sectors

trade linkage, and variable costs ($\sum_r N_{isr} \frac{\tau_{isr} \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}}$). Therefore, composite input demand is defined as:

$$Y_{is} = \delta M_{is} f^{ie} + \sum_r N_{isr} \left(f_{isr} + \frac{\tau_{isr} \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}} \right) \quad (17)$$

This equation replaces the output balance equation in the standard GTAP model which ensures that exports and domestic sales for each sector are equal to input composite demand. Table 7 summarizes the full set of Melitz equations, and shows the variables through which Melitz model is linked into the structure of the GTAP standard model.

Production structure for sectors in the Melitz module

This section briefly introduces the production technology for the Melitz commodities which is based on Akgul et al. (2016). The main differences to the GTAP standard model are production function nestings specific to variable and fixed costs. The production nesting for variable and fixed cost is shown in Fig. 1 where the total cost is the sum of variable and fixed costs, the latter is added up from fixed cost per firm which entered the industry and fixed cost on each trade link per firm operating on that link.

The variable cost nest uses both a value-added and an intermediate composite based on constant returns to scale (CRS) technology, and in the default case, the fixed cost nest only uses value-added. However, if the overall total cost share of value-added in a sector is small, also the fixed nests comprise a share of intermediate composite. This alternative is identified with the intermediate composite in brackets. The value added and intermediate bundles are CES composite of primary factors of production and intermediate inputs, respectively. The total value added (not shown here) is the sum of value added used in both variable and fixed cost nestings. Similarly, the total use of intermediate commodities and primary factors (not shown here) are the sum of their use in fixed and variable cost nestings

In the variable cost nests for the Melitz sectors, primary factors or intermediate inputs used are proportional to output, i.e. average output per firm on each trade link times firm operating on the link, summed up over all trade links, corrected for average productivity. On the other hand, the fixed cost nests reflect solely the number of firms which entered the industry and the trade links, and not average output per firm.

Each intermediate commodity used by a Melitz sector could be either a Melitz or Armington commodity, and the intermediate input bundle is a CES composite of these commodities, in the default configuration based on fixed input coefficients. For the Armington goods, we retain the standard GTAP model assumption of domestic and import distinction where imports are sourced at the border (not shown). There is no separate domestic and imports distinction for Melitz commodities, but only one aggregator with love-variety effects which comprises domestic sales and all bilateral imports.

Appendix 2: Supplemental tables

Tables [8](#) and [9](#).

Table 8 Sectoral correspondence of GTAP sectors to new sectors

No.	Code	GTAP and model sectors	Concordance of GTAP sectors and the sectors with information on AVEs of NTMs	Post model aggregation	Industry structure
1	PDR	Paddy rice	Primary agriculture	Primary agriculture	PC
2	WHT	Wheat	Primary agriculture	Primary agriculture	PC
3	GRO	Cereal grains nec	Primary agriculture	Primary agriculture	PC
4	V_F	Vegetables, fruit, nuts	Primary agriculture	Primary agriculture	PC
5	OSD	Oil seeds	Primary agriculture	Primary agriculture	PC
6	C_B	Sugarcane, sugar beet	Primary agriculture	Primary agriculture	PC
7	PFB	Plant-based fibers	Primary agriculture	Primary agriculture	PC
8	OCR	Crops nec	Primary agriculture	Primary agriculture	PC
9	CTL	Bovine cattle, sheep and goats, horses	Primary agriculture	Primary agriculture	PC
10	OAP	Animal products nec	Primary agriculture	Primary agriculture	PC
11	RMK	Raw milk	Primary agriculture	Primary agriculture	PC
12	WOL	Wool, silk-worm cocoons	Primary agriculture	Primary agriculture	PC
13	FRS	Forestry	Primary agriculture	Primary agriculture	PC
14	FSH	Fishing	Primary agriculture	Primary agriculture	PC
15	COA	Coal	Primary energy	Primary energy	PC
16	OIL	Oil	Primary energy	Primary energy	PC
17	GAS	Gas	Primary energy	Primary energy	PC
18	OMN	Minerals nec	Primary energy	Primary energy	PC
19	CMT	Bovine meat products	Processed foods	Processed foods	FH
20	OMT	Meat products nec	Processed foods	Processed foods	FH
21	VOL	Vegetable oils and fats	Processed foods	Processed foods	FH
22	MIL	Dairy products	Processed foods	Processed foods	FH
23	PCR	Processed rice	Processed foods	Processed foods	PC
24	SGR	Sugar	Processed foods	Processed foods	PC

Table 8 (continued)

No.	Code	GTAP and model sectors	Concordance of GTAP sectors and the sectors with information on AVEs of NTMs	Post model aggregation	Industry structure
25	OFD	Food products nec	Processed foods	Processed foods	FH
26	B_T	Beverages and tobacco products	Beverages and tobacco	Beverages and tobacco	FH
27	TEX	Textiles	Other manufactures	Other manufactures	FH
28	WAP	Wearing apparel	Other manufactures	Other manufactures	FH
29	LEA	Leather products	Other manufactures	Other manufactures	FH
30	LUM	Wood products	Other manufactures	Other manufactures	FH
31	PPP	Paper products, publishing	Other manufactures	Other manufactures	FH
32	P_C	Petroleum, coal products	Petrochemicals	Petrochemicals	FH
33	CRP	Chemicals, rubber, plastic products	Chemical and pharmaceuticals	Chemical and pharmaceuticals	FH
34	NMM	Mineral products nec	Other manufactures	Other manufactures	FH
35	I_S	Ferrous metals	Metals and fabricated metals	Metals and fabricated metals	FH
36	NFM	Metals nec	Metals and fabricated metals	Metals and fabricated metals	FH
37	FMP	Metal products	Metals and fabricated metals	Metals and fabricated metals	FH
38	MVH	Motor vehicles and parts	Motor vehicles	Motor vehicles	FH
39	OTN	Transport equipment nec	Other machinery	Other machinery	FH
40	ELE	Electronic equipment	Electrical machinery	Electrical machinery	FH
41	OME	Machinery and equipment nec	Other machinery	Other machinery	FH
42	OMF	Manufactures nec	Other manufactures	Other manufactures	FH
43	ELY	Electricity	Public services	Public services	PC
44	GDT	Gas manufacture, distribution	Public services	Public services	PC
45	WTR	Water	Public services	Public services	PC
46	CNS	Construction	Construction	Construction	PC
47	TRD	Trade	Distribution	Distribution	PC

Table 8 (continued)

No.	Code	GTAP and model sectors	Concordance of GTAP sectors and the sectors with information on AVEs of NTMs	Post model aggregation	Industry structure
48	OTP	Transport nec	Other transport	Other transport	PC
49	WTP	Water transport	Maritime transport	Maritime transport	PC
50	ATP	Air transport	Air transport	Air transport	PC
51	CMN	Communication	Communications	Communications	PC
52	OFI	Financial services nec	Banking	Business services	PC
53	ISR	Insurance	Insurance	Business services	PC
54	OBS	Business services nec	Other business services	Business services	PC
55	ROS	Recreational and other services	Personal and recreational Services	Personal and recreational Services	PC
56	OSG	Public administration, defense, education, health	Public services	Public services	PC
57	DWE	Dwellings	Public services	Public services	PC

FH firm heterogeneity, *PC* perfect competition (Armington)

Table 9 Welfare and GDP impact of alternative scenarios

Scenario	Welfare (USD per capita)		Real GDP (%)	
	EU27	UK	EU27	UK
FDI and migration (7)	– 3.60	– 623	– 0.02	– 3.08
MFN, NTBs, migration (8)	– 51	– 880	– 0.17	– 3.80
MFN, NTBs, FDI (9)	– 49	– 713	– 0.17	– 1.99

Details of the scenario definition can be found in Table 3

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Can Food Waste Reduction in Europe Help to Increase Food Availability and Reduce Pressure on Natural Resources Globally?

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Abstract

In recent years, reducing food waste and loss has become a policy priority in the European Union, but little is known about impacts of related measures in the EU and beyond. This study informs the debate on food waste reduction through a quantitative analysis. It considers adjustment costs for reducing food waste in food processing industries and impacts on food availability, pressure on land and water and other environmental consequences. The results suggest that the leakage effects of global trade may offset almost all benefits of food waste reduction in the EU. We thus conclude that costly efforts to reduce food waste in the EU cannot be motivated by larger contributions to global food availability and environmental benefits. This highlights the need for global coordination of such policies and/or more targeted actions in the EU which focus on specific production chains, where losses can be reduced and environmental gains obtained at a relatively low cost.

Key Words

policy analysis; food loss and waste; food availability; environment; simulation

1 Introduction

Questions surrounding 'food waste'¹ have gained more attention recently where the connotation “waste” often carries an ethical imperative to increase food availa-

bility for the hungry through less waste from the rich. Reducing food waste is also motivated by increasing biomass availability for material and energy use, thus easing “green growth”. Less food waste shall also reduce pressure on resources such as land and water and thus, decrease negative environmental externalities linked to agricultural food production. These potential benefits have stimulated government action plans. The EU, for example, has placed reducing food waste among its top priorities. The Circular Economy Package with 'a zero waste programme for Europe' was launched in 2014 (EUROPEAN COMMISSION, 2014a) and the 2018 Revised EU Waste Legislation (THE EUROPEAN PARLIAMENT, 2018) has called on the EU countries to actively monitor and reduce food waste at each stage of the food supply chain (FSC). THE EUROPEAN PARLIAMENT (2018) also has set a non-binding 30% target for food waste reduction by 2025, rising to 50% by 2030. In the global context, these objectives are in line with the Sustainable Development Goal (SDG) 12, formalized by the United Nations (UNITED NATIONS, 2015) to foster “responsible consumption and production”. Under these SDGs, the target 12.3 explicitly refers to halving per capita global food waste at different stages of the FSC. Such targets and related actions however, contrast with the many uncertainties about the current degree of food waste (XUE et al., 2017)) and even more so about the impacts of its reduction (HOJGARD et al., 2013), a field with little scientific findings so far. Thus, the prime motivation of this paper is to investigate the impact of food waste reduction policies. The impacts will be evaluated on food availability, consumer welfare, use of resources such as land and water and Greenhouse Gas (GHG) emissions both at the EU level and globally.

¹ In this paper we do not distinguish between waste and loss and instead use the term 'food waste' throughout the text, that include losses as well.

As summarised in Appendix A, there are different definitions of food waste and data matching these definitions are at an infancy stage. Each implies differences on how to quantify total waste, which under the same relative reduction target also means different costs and other impacts. Furthermore, literature often translates food waste reduction into higher productivity, i.e., more output with the same resources or less resources for the same output (RUTTEN and KAVALLARI, 2016; RUTTEN et al., 2015; among others). This neglects potential (adjustment) costs related to lower food waste and related impacts, a point of focus in our analysis.

Some studies (RUTTEN, 2013, for example) treat food waste reduction efforts as "manna from heaven", i.e. they assume that more food can be produced (or used) at unchanged amounts of biomass and other inputs. This perspective violates standard economic assumptions as cost minimizing firms should technically produce efficiently, i.e. not use more inputs than necessary and utility maximizing consumers should not spend money (and efforts) on goods they do not plan to consume, at least in the aggregate. The issue is not a purely theoretical one: modeling food waste reduction as less food input per unit of output (a productivity gain) should simultaneously consider that this change in input-output relations entails some implementation costs. Otherwise, quantitative analysis runs the risk of incorrectly informing the public debate about food waste. In line with this argument, TEUBER and JENSEN (2016) stress that reducing food waste is not costless, but requires productive resources. They therefore introduce the concept of "optimal food waste". From an economic perspective "optimal food waste" refers to the situation where the marginal cost of preventing food waste is equal to its marginal benefit. Accordingly, policies aiming at the reduction of "optimal food waste" need to balance the expected changes both in marginal benefits and costs.² This study models food waste reduction by improvements in partial factor productivities associated with utilisation of agricultural goods in the food processing industry while increasing the usage of all other production factors in the sector, to ensure that mainstream economic assumptions about preferences and rationality at the benchmark are respected. Equally, it refrains from making any normative consideration

about individual or social preferences, meaning that we take choices as they are, not as they "should be", according to some ethical principle. This, however, contrasts with the implicit moral judgment associated with the word "waste", recalling not only inefficiency but also injustice and deprecated behaviour. In addition,, rationality, as assumed in the model used by us, implies that observed food waste is the outcome of voluntary choice considered optimal by the individual making that choice. In other words, observed food waste must be, economically speaking, efficient by construction. As a corollary: any departure from an optimal state must be costly, at least in the aggregate.

Here, distinguishing between fixed and variable implementation costs is important. All costs considered in this study are variable: it is assumed that the food processing sector employs more non-agricultural inputs when the food input is reduced. There may be cases, however, where efficiency improvements (in this case, in the utilization of agricultural inputs), are made possible by specific investments, for instance, into better food storage facilities. Considering investment-driven improvements adds a time dimension to the problem, whereby at least two phases should be kept distinct: one phase of investment and one phase of productivity benefits. An especially interesting case in this context is when investments in food waste reduction have the nature of a public good, i.e. if consumption by one agent does not exclude others such that public sector provision is favourable. For example, in the context of food waste reduction, we could envisage an investment in a public information campaign as a public good, capable of permanently reducing food waste by final consumers.

More generally, individual choices about food waste, even if rational, are not socially optimal when social values deviate from private ones. In this case, government intervention might help to correct externalities and market failures related to food waste, such as by informational campaigns. For instance, suppose that consumers only want perfectly rounded and red apples, so farmers dispose other ones. You may consider discarding "imperfect" yet fully eatable apples a "waste", but from a scientifically neutral perspective, we take such consumer preferences as given and rather pose the questions: are there socially valuable uses of "imperfect apples"? If such options exist, why are they not exploited by the apple supply chain? What kind of economic incentives can be offered to realign individual behaviour to social objectives?

We are not the first to take the adjustment cost into account. BRITZ et al. (2014), in their analysis of

² Note that when the amount of food waste is optimal from individual perspectives, it does not necessary means that it is optimal from social perspective [see TEUBER and JENSEN (2016) for more details].

food waste reduction at household level in the Netherlands, reflect food reduction costs by considering related efforts by households, like spending more time preparing food. Similarly, PHILIPPIDIS et al. (2019) analyse the impact of food waste reduction in the EU at household level by considering adjustment costs. Our study complements BRITZ et al. (2014) and PHILIPPIDIS et al. (2019) by focusing on the impact of food waste reduction in the food processing industry, explicitly accounting for the costs of reduced food waste. Specifically, considering an estimated 19% overall share in food waste by the processing sector in the FSC (STENMARCK et al., 2016; TONINI et al., 2017) and given the targeted 30% reduction in total food waste by the EU, we consider a 5% reduction in the volume of food waste as a target. As related costs in different branches of the food processing are vastly unknown, we perform a sensitivity analysis considering different levels of food waste reduction costs.

All the considerations above bring us to model food waste reduction policies in the food processing industry as a shift in its input demand structure: less demand for agricultural products, more demand for other goods and services. Our analysis therefore requires a multi-sectoral perspective, where market interdependences are fully taken into account and the welfare impacts can be identified. This objective is reached through the use of a rich data set, exploited by means of a Computable General Equilibrium (CGE) model, which allows for the consideration of all adjustment processes taking place in the economic system and highlights distributional consequences of food waste reduction policies.

Furthermore, in order to quantify some major impacts on the environment and natural resources, we employ a CGE model with special features such as substitution of intermediate inputs in agricultural and food processing sectors, modelling of water as an explicit factor of production, disaggregation of land in terms of agro-ecological zones and consideration of CO₂ and non-CO₂ emissions. Furthermore, we depict production and factor use for EU countries at the level of 280 sub-national regions, especially in order to gain insight into the impact on agriculture and related resource use at regional level.

2 Related Literature

Following a study by FAO (2013) on food waste, a vast variety of literature emerged which highlights

various negative impacts of food waste. The original study by FAO (2013) estimated that food waste accounts globally for 3.3 gigatonnes of CO₂ equivalents and implies inefficient usage of 250 km³ of water each year, according to KUMMU et al. (2012) equivalent to 23% of global water use, as well as requiring 30% of the global cropland. As a follow-up, FAO (2014b) estimates the global annual cost related to food waste at 2.6 trillion USD, equivalent to as much as 3.3% of global GDP. Of that total, one trillion USD is attributed to the production costs of the wasted food. “Social costs”, referring to hunger and conflict risks, are gauged at 882 billion USD. The remaining 700 billion USD is associated with environmental impacts, mainly GHG emissions (305 billion USD) and water use (165 billion USD). The importance of food waste is also highlighted by MONIER et al. (2010), who estimates that food waste accounts for 3% of total GHG emissions in the EU.

Food waste occurs at different stages of the FSC which consists of primary agriculture, food processing industries that transform agricultural outputs and other inputs to food and the wholesale and retail sector that distributes the output of the food processing industry to the final point of use (i.e., households, caterers, canteens, restaurants etc.). The majority of studies come to the conclusion that food waste mostly occurs during food processing and at the household level. For example, MONIER et al. (2010) report that 42% of food waste in Europe occurs at the household level and 39% in food processing, while the distribution and food service sectors account for 5% to 14% of food waste, respectively. That study, however, does not cover food waste at the production stage of primary agricultural products. Taking the latter into account, STENMARCK et al. (2016) find that 53% of food waste is taking place at the household level, 19% during intermediate processing, 10% during primary production, 12% in the food-service sector and 5% in the distribution sector. BERETTA et al. (2013) also find similar results for Switzerland, stating that 45% of the food waste is occurring at the household level, while food processing follows, with 31%. On the other hand, some studies report that food waste loss is less pronounced in the processing sector. TONINI et al. (2017) find that 19% of food waste in Denmark is at the processing phase, while van der WERF and GILLILAND (2017) report that the estimates of food waste in the food processing sector is generally lower than retail by comparing 55 studies in the literature. It should be noted that shares of food waste at different

stages of the FSC in developing countries might look rather different.

In recent years with increased political awareness of food waste, several global initiatives to tackle food waste emerged. Food waste reduction is one of the SDGs and many countries and regional organizations set targets accordingly to reduce food waste. International organizations such as FAO and UN Environmental Agency are cooperating with regional organizations to develop policy frameworks and to disseminate best practices. These efforts lead the way for important achievements, such as standards to measure food waste (THE FOOD LOSS & WASTE PROTOCOL, 2019) to address the ambiguity of the definition of food waste. However, effects of these efforts are yet to be observed in the amount of food waste reductions (HAMILTON and RICHARDS, 2019).

Different approaches and methodologies are used to analyse food waste in applied economic studies: single country CGE models (CAMPOY-MUNOZ et al., 2017; BRITZ et al., 2014), global multi-regional CGE models (RUTTEN et al., 2013; RUTTEN and VERMA, 2014; RUTTEN and KAVALLARI, 2016), Partial Equilibrium (PE) models (HOJGARD et al., 2013) as well as econometric methods (ELLISON and LUSK, 2018; BAHADUR et al., 2016; SOMKUN, 2017). Most studies find that reduced food waste brings about: (1) significant economic benefits and reduced environmental impacts from agricultural production, (2) improved food safety (RUTTEN and VERMA, 2014; RUTTEN and KAVALLARI, 2016), (3) a decline in agricultural production and (4) limited impacts on real GDP (RUTTEN et al. 2013; CAMPOY-MUNOZ et al., 2017). Marginal environmental and economic benefits are found by HOJGARD et al. (2013), the latter mainly due to lower food prices. However, impacts on real GDP especially depend on the assumptions of if and how costly food waste is.

In terms of distributional consequences, most studies show that global net effects of food waste reduction efforts in one region versus impacts in the rest-of-the-world (ROW) depend on many factors, such as the food trade balance and supply and demand factors. CAMPOY-MUNOZ et al. (2017) and HOJGARD et al. (2013) report different impacts across countries or regions of the same country, as well as between producers and consumers. The EUROPEAN COMMISSION (2014b) reports that food waste reduction would benefit food processors, while agricultural producers and retailers are likely to be worse off.

A major shortcoming of almost all studies cited above is that they do not take into account the costs involved in reducing food waste. Indeed, only a few of them consider what TEUBER and JENSEN (2016) have termed “optimal food waste”, where marginal cost of food waste reduction equals its marginal benefit. Currently observed levels of food waste may thus be privately optimal, reflecting consumer preferences and cost minimization; however, as in other fields, they could also partially be a consequence of irrational behaviour, asymmetric information, or organizational problems (FAO, 2014c). Not surprisingly, the few studies that take into account implementation costs of food waste (and rational economic decisions), qualitatively (KOESTER, 2014) or quantitatively (ELLISON and LUSK, 2018), suggest lower benefits of food waste reduction (KOESTER, 2014; ELLISON and LUSK, 2018).

If observed food waste is (to some degree) privately optimal, policies aimed at reducing food waste will generate some costs and thus require resources (CHABOUD and DAVIRON, 2017). Contrasted with the (implicit) “free lunch” hypothesis, accounting for costs of food waste lowers both the expected increase in food availability and environmental benefits. For example, cold storage facilities consume energy, donating excess food to food banks requires transportation of food and better packaging might require the use of more materials that are harmful to the environment. Furthermore, food waste efforts could face the Jevons paradox (see POLIMENI et al., 2008) where savings in energy and water as well reduced emissions of reduced food waste due to an efficiency increase will be partly offset due to higher demand at lower costs and thus prices. In the case of food waste, requiring producers (in the EU) to use less agricultural input to produce food makes agricultural commodities cheaper and thus induces demanders (in the EU and globally) to use more agricultural commodities. SALEMDEEB et al. (2017) report that 60% of the GHGs reductions due to food waste prevention may be offset due to rebound effects, i.e. GHGs emissions created by prevention measures themselves. RUTTEN (2013) confirms this based on a simple PE analysis where net GHG savings from food waste reduction are ambiguous.

Recent studies by BRITZ et al. (2014) and PHILIPPIDIS et al. (2019) focus on food waste at the household level, considering the efforts necessary for its reduction, such as spending more time for food

preparation. Food preparation is framed as an activity that uses both time – competing with leisure and work outside the household – and intermediate inputs to convert the food bought by the household to the food actually consumed. Our paper complements the literature by analysing food waste reduction at the food processing stage, while also depicting the trade interactions among regions and considering impacts on land use, water and GHG emissions. To the best of our knowledge, this is the first study with these specific characteristics.

3 Methods and Data

The provision of food in industrialized economies is based on complex value chains integrating firms from agricultural, food processing and distribution sectors. Efforts to reduce food waste at any stage will have market and thus, price mediated consequences along these chains. Technical measures to reduce food waste, such as improved cold chains, impact non-food intermediate and factor demand even more so and thus have consequences beyond food-related value chains, requiring a multi-sector perspective. Since markets affected by food waste reduction are inter-connected via national and international trade, modelling an increase in food availability requires a broad and systemic approach. We therefore opt for a global CGE analysis and depart from the well documented and tested Global Trade Analysis Project (GTAP) Standard model³, to which we add features especially important for the analysis at hand.

We use the flexible and modular CGE modelling platform CGEBox (BRITZ and VAN DER MENSBRUGGHE, 2018). It is encoded in the General Algebraic Modelling Language (GAMS) and uses the available GTAP database version 9 for which satellite data on emissions and land use are also available. CGEBox departs from Version 7 of standard GTAP model (VAN DER MENSBRUGGHE, 2018) as a core to which the modeller can flexibly add modules, change or add different nestings for the production structure and factor markets or change the structure of modelling international trade. A complete documentation of this platform can be found in BRITZ (2017).⁴

The appropriate (and efficient) combination of the available modules depends on the issue at hand. Due to our focus on food processing and agriculture, we add to the standard GTAP model the features of GTAP-AGR (KEENEY and HERTEL, 2005), i.e. segmented factor markets and specific nestings in agricultural production. Furthermore, to quantify impact on land and water use, as well as on GHGs, we add the modules GTAP-water (HAQIQI et al., 2016), to distinguish between irrigated and non-irrigated agriculture and GTAP-AEZ, where physical land use is disaggregated in terms of Agro-Ecological Zones (AEZs), based on HERTEL et al. (2009). The GTAP-AEZ module integrated with the Non-CO₂ emission database (GIBBS et al., 2014) together with the GTAP 9 CO₂ emission database allows analysing the changes in GHGs. Lastly, we are interested in looking into the land use and GHGs at sub-national regions across the EU for which we employ a module in CGEBox (BRITZ, 2017) which offers a breakdown of production and factor use for sub-regions.⁵ The introduction of these different modules into the GTAP model implies that the production structure differs across industries.

The next section provides an overview on the standard GTAP model and discusses in more detail the extensions we introduced. Full detail of the modelling framework and its GAMS implementation is provided in the Online Appendix.⁶

3.1 Structure of the Standard GTAP model

The standard GTAP model (HERTEL, 1997) is a comparative static, global CGE model based on the Walrasian general equilibrium structure. The equations, its parameters and structure of the data of the latest version 7 of the GTAP model are fully described in VAN DER MENSBRUGGHE (2018). The standard GTAP model assumes cost-minimizing behavior under constant returns to scale (CRS) production technologies along with utility maximizing consumers in competitive markets. There is a single virtual representative household in each region that owns the production factors and receives factor

³ As documented in Hertel, T.W. and M.E. Tsigas "Structure of GTAP", Chapter 2 in HERTEL (1997)

⁴ http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_e.htm covers full documentation, including information how

to download the code and additional material (i.e., training videos).

⁵ The module uses for the EU data at the level of administrative NUTS2 regions, equivalent to Regierungsbezirke for Germany.

⁶ The online Appendix can be found in http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

returns, net of taxes. That so-called, “regional household”, also collects income from taxation such as tariff revenues and rents accruing from export or import licenses that are depicted as exogenous ad-valorem price wedges. The regional income is then allocated to different agents (private household, government and saving) based on a modified Cobb-Douglas (CD) utility function.⁷ The private household’s demands for Armington commodities are derived from a non-homothetic Constant Difference Elasticity (CDE) implicit expenditure function, which allows for relatively flexible price responses, while government and saving demands for Armington commodities are driven by a constant elasticity of substitution function (CES). The Armington demand for each agent and commodity is defined as a CES composite of domestic and import demand. The import demand composition from bi-lateral trade flows is depicted by a second CES nest.⁸

On the supply side, production is defined as the Leontief aggregate of value added and intermediate inputs bundles; the value added composition is based on a CES aggregate of primary factors (unskilled labour, skilled labour, capital, natural resources, land) while the composition of intermediate demand is based on fixed physical input coefficients (Figure B1). As for the final demand agents, each sector features its own Armington nest to determine the composition of intermediate input demand for each commodity from domestic production and imports. However, the import composition is identical across sectors and final demand. The model assumes full mobility inside a region for capital, skilled and unskilled labor, sluggish mobility for land and sector-specific and thus immobile natural resources such as fish stocks, rare earths, or fossil oil reserves. Supply of primary production factors is modelled through fixed stocks and in the case of sluggish mobility across industries, governed by a CET⁹ allocation mechanism.

The standard GTAP model is accompanied with a global Social Accounting Matrix (SAM) database for different base years. We use the latest version of this

database, GTAP9, that comprises data on consumption, production, primary factor use, bilateral trade in goods and services, intermediate inputs among sectors, as well as taxes and subsidies imposed by governments and CO₂ emissions for 140 regions and 57 commodities for the year 2011, as well as data on land and irrigation water use.

3.2 GTAP-AGR Production Structure

In order to better capture some particular features of agricultural activities, KEENEY and HERTEL (2005) introduce some modifications to the standard GTAP structure. Among them, we apply the changes in the production structure. We follow GTAP-AGR in differentiating the supply of mobile factors (labour and capital) between agricultural and non-agricultural activities using a two-tier CET mechanism (Figure B2). Furthermore, contrary to the standard GTAP model, where intermediate factor demand is driven by fixed input-output coefficients, we introduce (as in GTAP-AGR) a sub-nest under the intermediate input composite for the livestock and food processing sectors to allow for the substitution of “feedstuffs” (Figure B3).

3.3 Irrigation Water as an Explicit Production Factor

We follow the GTAP-WATER framework (HAQIQI et al., 2016) to incorporate irrigation water as an explicit input and to account for substitution possibilities between water and other primary factors. The water data in HAQIQI et al. (2016) break down returns to land into “land rents” and “irrigation water rights rents” and distinguishes between irrigated and rainfed variants for the eight cropping activities from the GTAP database. The model allocates irrigation water across irrigated cropping activities using a CET mechanism. The production structure of irrigated crops is shown as in Figure B4; for rainfed crops, Figure B3 applies. HAQIQI et al. (2016) provide four different versions of the GTAP-WATER database that differ in the spatial and regional detail of irrigated and rainfed crop productions. We use the version GTAP-WATER-V9-A which fits best to our modelling structure and the regional aggregation. It is organised as a diagonal input-output make matrix, i.e. there are not only irrigated and non-irrigated production activities but also irrigated and non-irrigated products that are differentiated in demand, trade, etc. We therefore re-aggregate to derive a non-diagonal make matrix where irrigated and rainfed activities of the same crop produce an homogeneous output in each region.

⁷ Modified CD utility function updates the private consumption share in the regional household income distribution (see CGEBox documentation: http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf).

⁸ See page 2, Figure 2 in VAN DER MENSBRUGGHE (2018)

⁹ Constant Elasticity of Transformation, the supply side dual of the CES function.

3.4 Agro-ecological Zones

Following HERTEL et al. (2009), we spatially break down land into different AEZs (FAO/IIASA, 2000), characterized by climate and soil type. Sectoral demands for land are disaggregated to the different AEZs, using additional CES composites as shown in Figure B5. Likewise, as shown in Figure B6, each AEZ in a region is characterized by a given stock of land in economic use, which is allocated to different land use activities (forestry, pasture and cropping activities) through a CET. For calibration of the model parameters, we employ the GTAP-AEZ Land Use Data Base (LEVANO et al., 2015) which contains data in hectares by type of land cover (cropland, forests and pasture) and up to 18 AEZs for each region in the GTAP9 database.

Employing GTAP-AGR, GTAP-WATER and GTAP-AEZ implies that the production structure of different industries is not identical. Figure B3 displays the production structure of processed food sectors. The production structure of forestry, rainfed cropping and livestock activities is illustrated in Figure A5. The production structure of other GTAP sectors follows the standard GTAP model specification (Figure B1).

3.5 CO₂ and Non-CO₂ Emissions

CO₂ emissions in the GTAP9 database are based on the energy volume data for each industry and region. The GTAP Non-CO₂ Emissions Database (IRFANOGLU and MENSBRUGGHE, 2016) complements the GTAP9 database by providing information on three other major GHGs: Methane (CH₄), Nitrous Oxide (N₂O) and Fluorinated gases (FGAS). The non-CO₂ emissions are associated with four drivers: output, primary factors (land and capital), intermediate inputs and household consumption. Land carbon stock data (i.e. soil and biomass carbon stock) for different coverage of land (i.e. pasture, cropland and forest) for each AEZ in each region is available from Gibbs (2014). We use this information in the model to capture changes in the total carbon stock due to land cover change in different AEZs and regions.

3.6 Sub-national Detail for EU Countries

The European NUTS system classifies regions into different administrative levels. We use regional SAMs developed by FERRARI et al. (2010) at the NUTS2 level (281 regions for the EU-28 where 21 countries are disaggregated to sub regions and each of the other countries are considered as one single unit in NUTS2 classification) complemented by data from the CAPRI

data base (BRITZ and WITZKE, 2012) to disaggregate some macroeconomic variables in the model, using the methodology by BRITZ (2017). Based on the resulting database with sub-national detail, we consider irrigation water and land as regionally immobile, the latter at the level of AEZs, depict other factor supply as sluggish across sub-national units based on CET and specify a production function for each of the industries located in a NUTS2 region.

3.7 Sectoral and Regional Aggregation

In determining the industries and regions considered in our model, we tried to keep all the available information for agri-food sectors. “Forestry” and “Trade” which comprises the retail sector are equally kept as separate industries. The remaining sectors are mostly highly aggregated while retaining some details for providers to agriculture (see Table B1). With regard to regional aggregation, we keep 21 EU Member States as single regions (Finland, Sweden, Denmark, United Kingdom, Ireland, Germany, Netherlands, Belgium, France, Austria, Spain, Portugal, Italy, Greece, Poland, Bulgaria, Romania, Slovakia, Slovenia, Czech Republic, Hungary) with a break-down to NUTS2. Other EU countries in the dataset as single countries are: Estonia, Latvia, Lithuania, Croatia, while three smaller countries (Cyprus, Malta, Luxembourg) form an aggregate. We aggregate the non-EU regions into: North America, Latin America, the Middle East and North Africa, Sub-Saharan Africa, East Asia, Southeast Asia, South Asia, Oceania and ROW. Combined, that leads to a model with 16 crop sectors (8 irrigated and 8 rainfed crops), 37 non-crop activities, 281 NUTS2 regions (covering the EU28) and 9 remaining global regions.

4 Scenario Design

We focus here on food waste in the food processing industry and the related distribution network, leaving out food waste at farm and household level, partly to complement existing studies such as BRITZ et al. (2014) and PHILIPPIDIS et al. (2019) which focus on the household level and partly reflecting how policy measures are likely to address food production and distribution. The underlying database for the CGE analysis is the SAM where the value of food waste is part of intermediate input in the food processing sector. Current estimates indicate that the food processing sector contributes to 39% of the total food waste on the supply side and 19% of the total food

waste when both the supply and demand sides are considered. As mentioned above, considering the 19% overall contribution of the processing sector and given the target of 30% reduction in total food waste by the EU, we consider a 5% reduction as a realistic target. We cannot perform a detailed policy impact assessment as this would require legislative proposals which spell out policy measures such as changes in taxes or subsidies, command-and-control measures, etc. Instead, we analyse consequences of a 5% reduction of physical input use of primary agriculture and food products per unit of output in the EU food processing industry, under different assumptions on related costs.

The shocks are technically implemented as follows: Consider the following demand function for the intermediate inputs in line with the extension of the core model to GTAP-AGR (Figure B3) where the intermediate demand for primary agricultural output (the feed-stock component), XA , with the price PA is derived from a CES production function for the intermediate demand composite:¹⁰

$$XA_{r,i,a} = \alpha_{r,i,a}^{io} ND_{r,a} \left(\frac{PND_{r,a}}{PA_{r,i,a}^a} \right)^{\sigma_{r,a}^{nd}} (\lambda_{r,i,a}^{io})^{\sigma_{r,a}^{nd}-1} \quad (1)$$

Here the subscript r specifies the region, i the intermediate input and a the production activity using the intermediate input, respectively. The elasticity of substitution is given by σ^{nd} and zero in the standard GTAP model, but not in our model in case of the food industry. The coefficient λ^{io} denotes the efficiency level, equal to unity in the baseline. The coefficient α^{io} denotes the cost share parameter of the intermediate input in total intermediate demand at the benchmark and ND is aggregate intermediate input bundle. Its price PND is defined as:

$$PND_{r,a} = \left[\sum_i \alpha_{r,i,a}^{io} \left(\frac{PA_{r,i,a}^a}{PND_{r,a}} \right)^{1-\sigma_{r,a}^{nd}} \right]^{\frac{1}{1-\sigma_{r,a}^{nd}}} \quad (2)$$

We model reduced food waste by increasing the technology shifter λ^{io} related to agricultural inputs in food processing sectors by 5%. That implies changes in input-output relations. Quantities in the CGE are expressed in constant unit dollars and prices are set to unity in the benchmark. Without changing simulated relative changes in quantities and prices, one could

switch to physical units instead and redefine the prices accordingly. This underlines that the α^{io} which express cost shares in the benchmark denote also physical input-output relations, for instance, how much wheat or beef the food industry requires to produce one unit of output. Changing λ^{io} by 5% in (1) would hence allow the food industry to save 5% of physical inputs while still produce the same output quantity, i.e. food waste would be reduced. The first order effect of the shock is decreased intermediate demand for agricultural output such that agricultural product prices fall. As the production technology is not Leontief, agricultural input use per unit of output in the food processing sectors will increase again, leading to a “rebound effect”. Here, not only the substitution between different inputs matters but as well between the value-added and the intermediate composite. The “rebound” effect partly offsets the assumed change in technology.

Furthermore, as stated above, we don’t assume that the 5% input savings comes for free. We estimate the related costs as follows. First, we calculate the costs saved at prices of the benchmark. Next, we increase all other input demands by the same relative change such that a scenario specific share (or multiplier) of the saved costs would be added at benchmark prices. We consider two scenarios which should cover the relevant range of assumed costs:

1. *Cost-neutral scenario*: here, the EU food processing sector can achieve the target quite easily, i.e. we assume that one Euro saved by decreased food waste is offset by another Euro needed to achieve that reduction. That reflects “optimal private food waste” at the benchmark in combination with a rather flexible technology.
2. *Non-cost neutral scenario*: the second scenario is somewhat more pessimistic but possibly more realistic: each Euro saved from agricultural inputs leads to two Euros of additional costs for other inputs.

We also perform a third scenario without adjustment costs for comparison. Furthermore, as we do not aim at analysing in detail specific potential measures – that would require a much more detailed approach, hardly feasible with a global perspective as the one we adopt here – we equally implement the scenarios in all food processing sectors, without differentiation within the EU. The resulting changes in intermediate and factor demand lead to adjustments in the global economy and environmental impacts, which we track with our simulation.

¹⁰ Introduced equations are identical to Equations 6 and 7 in VAN DER MENSURGH (2018).

5 Results

We focus on the following three major impacts of reduced food waste which reflect the main issues in the societal debate: increased food availability, reduced pressure on land and water and other environmental benefits. We measure food availability through changes in two variables: (1) domestic production and (2) household consumption. The pressure on land and water resources will be analysed by looking into the pattern of land coverage change and reduced use of water resources. Among other environmental impacts, we consider the reduction in direct and indirect CO₂ equivalent emissions.

Expected impacts from reducing food waste in the European food industry are as follows. As intermediate demand for primary agricultural products drops, supply and prices for agricultural products would decrease and, consequently, returns to agricultural primary factors would reduce, leading to income losses for farmers. Reduced demand for land and irrigation water, as well as less intensive agricultural production practices, might improve environmental quality. Higher demand by the food industry for other inputs could lead to negative environmental impacts such that net effects, e.g. on GHG emissions, are uncertain.

One aim of reducing food waste is to increase food security. Food security is both a matter of regional food availability and of being able to afford food, which depends on income and prices. The impacts are in principle ambiguous. Dropping agricultural prices reduces the income and thus farmers' purchasing power but lead to cost savings in the ROW's

food industry, which should decrease the price of processed food. However, under the assumption that reducing food waste is not cost-neutral, European food processors will become less competitive, such that European net exports of processed food will decrease, countervailing the positive impact on global food security from reduced demand for agricultural products in Europe and cost savings in the ROW food industry. Equally, lower prices for agricultural products also imply a lower farming income which implies loss of purchasing power.

5.1 Impact on Food Availability

Table 1 presents the simulated changes of agricultural prices in both the EU and globally for both scenarios. As expected, the price of agricultural outputs decreases. In the cost neutral scenario, prices in the EU for primary agriculture products drop, by 0.9% for crop and by 1.1% for animal outputs, on average. As other input prices do not increase much due to higher input demand by the food industry, the production costs and the price of processed food products decreases by 1.2 % on average in the EU. The global reductions are smaller (around -0.2%, -0.3% and -0.4%) reflecting the share of the EU's food processing industry globally and its trade integration.

Variations among prices inside the aggregate groups (crops, animals, processed food) are relatively small (see, Table B2 in the Annex B for detail). Furthermore, there are also some differences in price changes for primary agriculture products across the EU Member States and across global regions (not shown in tables). Across the EU, agricultural price drops can be as large as 2%. There is no single expla-

Table 1. Changes in agri-food markets [% change]

Scenarios	Cost neutral		Non-cost neutral	
	EU	Global	EU	Global
Price of crops	-0.9	-0.2	-1.1	-0.2
Price of animals	-1.1	-0.3	-1.3	-0.3
Price of processed food products	-1.2	-0.4	-0.2	-0.1
Value added in processed food sectors	1.1	0.2	0.2	0.0
Value added in crop production	-0.8	-0.2	-0.8	-0.2
Value added in animal production	-1.5	-0.3	-2.6	-0.4
Land demand	-0.03	-0.07	-0.02	-0.0
Water demand	-0.17	-0.01	-0.19	-0.01
GHGs	-0.3	-0.01	-0.4	-0.02
Farmers income	-0.5	-0.1	-0.6	-0.0
Food consumption	0.16	0.04	0.02	0.00
Welfare (USD per capita)	-0.3	-0.2	-2.0	-1.0

Source: model results

nation for the differences in regional price changes which depend inter alia on the demand composition of the food industry and its sourcing from both domestic and import channels. Primary animal products such as live animals and milk have a tendency to show larger price drops. That reflects higher trade costs compared to crops such as cereals and that that EU meat exports face generally higher tariffs and non-tariff measures, compared to crops and products derived thereof.

As a consequence of lower agricultural prices, food production in the EU increases by 1.1%, compared to 0.2% in the ROW. The net effects of decreased per unit demand by the food processing industry and rebound effects, such as higher overall output by the food processing industry, results in the demand for primary agricultural products (i.e. crops and animals) to shrink by 0.8% and 1.5%, respectively. This finding is in line with other literature analysing food waste in quantitative economic frameworks (HÖJGARD et al., 2013; HAMILTON and RICHARDS, 2019), or qualitatively (RUTTEN, 2013; KOESTER, 2014). As a result, we observe a moderate decrease in the pressure on land and water. Impacts on GHG emissions are also not significant as output and input changes across the economy as a whole are small. Furthermore, less CO₂ emissions from lower agricultural output and less land use changes are partly offset by the increase in the use of other intermediate inputs which induce some CO₂ emissions, either directly or indirectly.

Impacts on income of the aggregate agricultural household, which mostly depend on factor income earned in the agricultural sector, are more pronounced with -0.5% in the EU average. A main reason is that return to lands, consistently in all EU Member countries, drop more than agricultural output prices. Sizeable positive changes across regions (not shown in the table) are not found; the maximum is an increase by 0.1% in the ROW; all EU Member countries with the exemption of Finland (+0.0%) show a drop in agricultural income. The impact on food consumption is also expected to be minor (see Table 1).

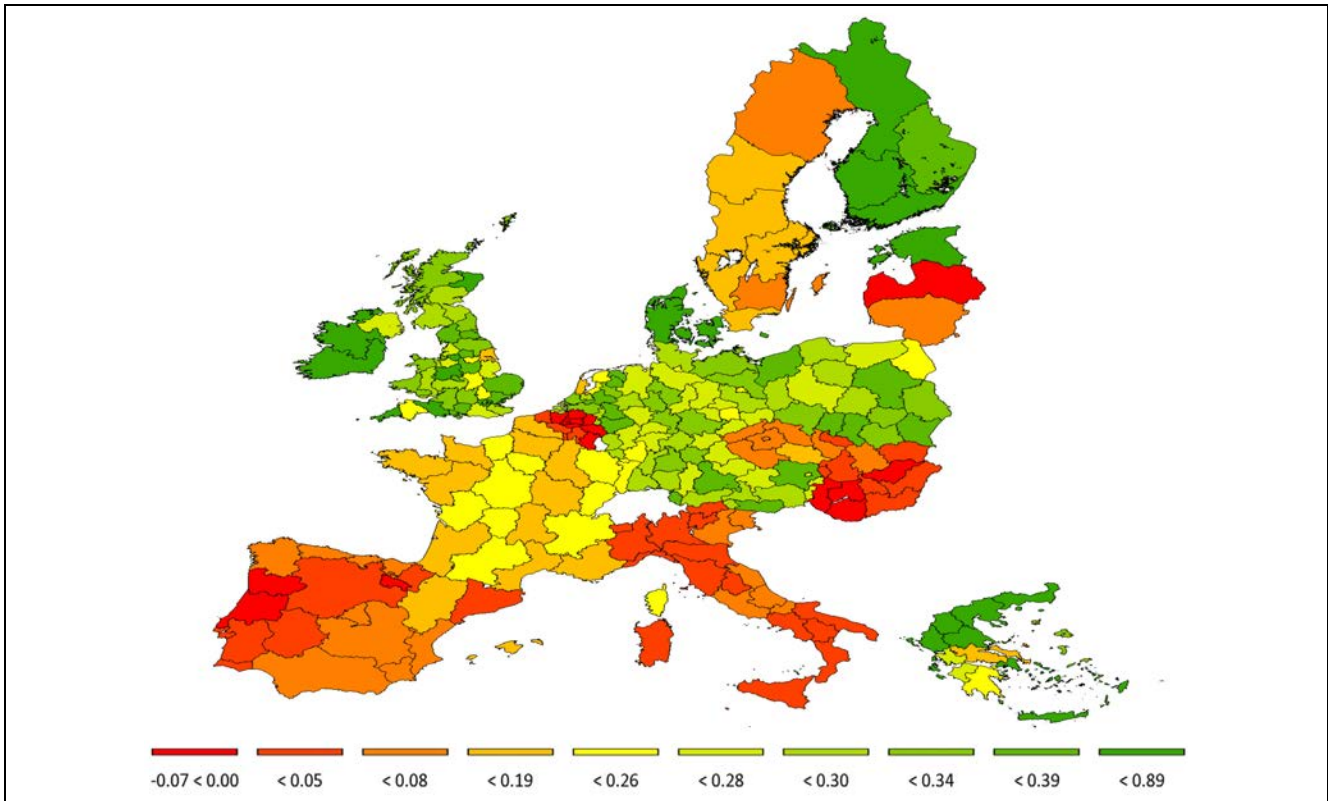
Once moving from the neutral-cost scenario to the second scenario where one dollar of saving from agricultural inputs requires two dollars more of the other intermediate inputs, price drops in processed food products are lower (-0.2%) and there are smaller increases in food products (0.2%), which in turn explain the larger decrease in production of primary agricultural outputs (mainly for animal products),

resulting in quite small and mixed impacts on the use of primary inputs. Considering the reduction in primary agricultural products there is no significant differences on the impact on value added for crops across the two scenarios but the reduction in value added for animal products is significantly larger. A possible explanation is that quantities of crop products no longer used domestically due to reduced food waste can be more easily exported than in case of animal ones as also reflected in the price changes discussed above.

We also check outcomes of cost saving scenario where the EU food industry can reduce its use of agricultural and food products by 5% for free, i.e. without producing less or requiring more of other inputs. This improves its production efficiency and competitiveness. Consequently, the demand for food products increases globally, which vastly offsets the reduced input demand for primary agricultural outputs. The resulting changes in demand for agricultural output are quite small, which in turn results in tiny impacts on land and water resources as well as GHGs, see Table B3. Equally, as expected, there are global welfare gains. As we consider such as “free lunch” as rather unlikely, we only discuss detailed outcomes for the two other scenarios in the following.

Considering the non-cost neutral scenario with adjustment cost, Figure 1 shows the impact on value added of the food processing industry. The map suggests some tiny losses (up to 0.07%) in the Southern Member States, France, Sweden, parts of the Baltics and Eastern Europe, while some regions would experience small positive changes (up to 0.9%). We have ascertained that most of the reductions in the value added are driven by export contraction. Figures B7 and B8 in the annex shows changes in agricultural value added. The largest decreases are in the animal production industries, with drops ranging from 1.7% up to 3.4%. These reductions mostly reflect lower intermediate demand by the food processing industries. As explained before, the reduction in demand for crop products is smaller, ranging from -1.6% to -0.5%.

Interestingly, there is a small rise in the global demand for processed food in both scenarios (Table 1). This is due to the increased competitiveness of the food industry, which reduces its production costs per unit of output. This has some implications in terms of food security, as even in many developing countries some staple foods, such as bread, stem from food processing.

Figure 1. Changes in value added of processed food sectors for NUTS2 regions

Source: model results (non-cost neutral scenario)

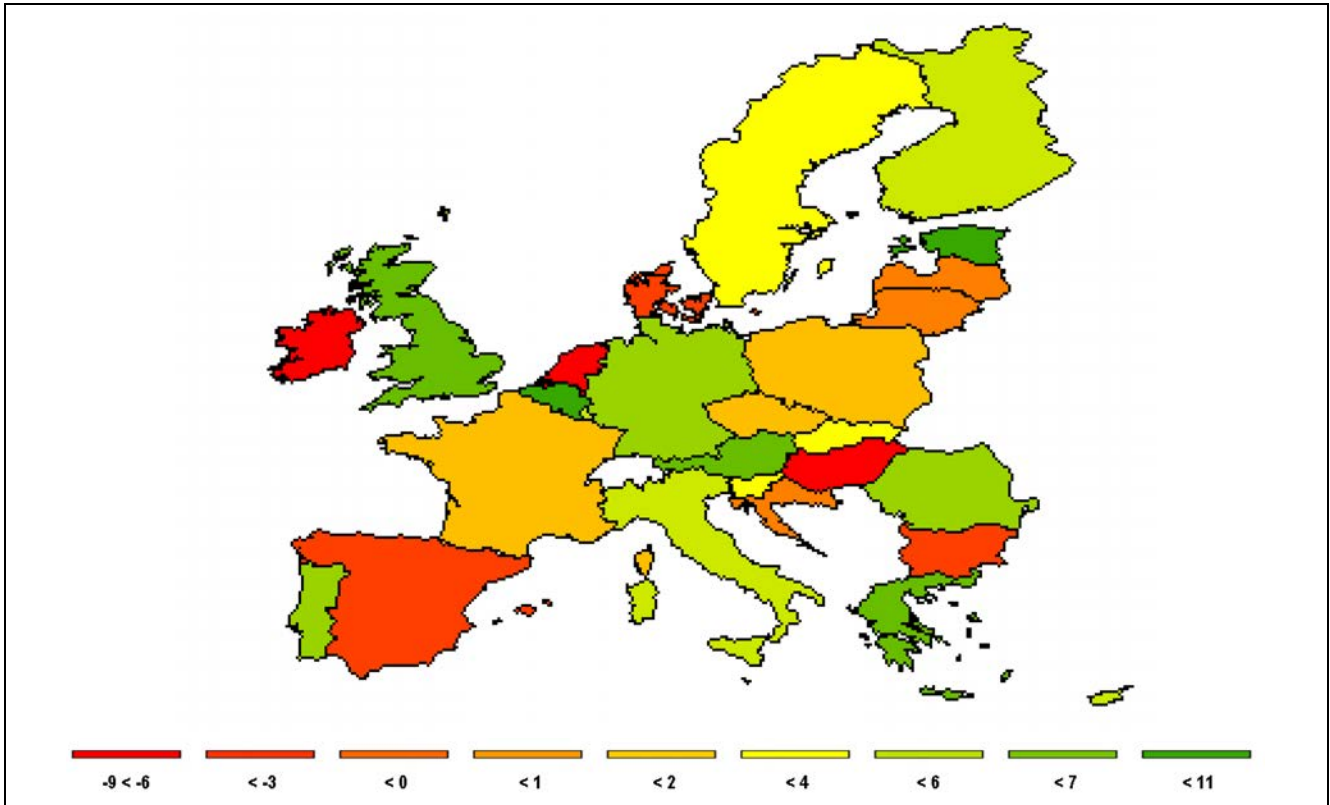
We also measure welfare impacts due to the changes in the market conditions. Our welfare measure is based on the Equivalent Variation (EV) criterion, i.e., the amount of income to be added to the regional household' benchmark income at benchmark prices to reach the same utility as under simulated income and prices. Global welfare drops very slightly, with a purchasing power loss of around \$0.1 per capita. The welfare losses for the EU are, of course, more pronounced but still small with around \$2 per capita which reflects the positive impacts of a higher value added of the food processing sectors at decreased prices and lower farm incomes (Table 1). Welfare decomposition (not shown here) suggests that the welfare loss mostly reflects reduced agricultural income, mainly resulting from lower returns to land.

These losses do not vary much across the EU member states (Figure 2). However, the direction of changes in general could be explained by the ratio of processed food output to primary agricultural output. The countries with the relatively higher ratio (4 and above) (the UK, Belgium, Italy, Portugal, Germany, Austria, Sweden and Estonia) tend to benefit, while

the countries with the relatively lower ratio (Netherlands, Denmark, Hungary, Spain, Bulgaria, Ireland and France) tend to lose. These results are consistent with our result presented earlier, where the welfare loss due to reduction in agricultural output outweighs the benefits generated from the processed food sector. Our analysis does not monetarize changes in environmental status and misses changes in environmental indicators, besides GHG emissions, where benefits from reduced and less intensive agricultural production could be expected from, for example, a reduction in nitrogen and phosphorous loads.

5.2 Impact on Land Use Change

As the demand for land decreases in both scenarios because of reduction in demand for primary agricultural outputs (see Table 1), land rents in the EU are negatively affected in both scenarios by -3.3% and -4.2%, respectively, while they exhibit very small but positive changes in other regions of the world. The relatively higher changes in land rent compared to the small changes in land demand are reflected by the inelastic nature of land supply and its low substitution

Figure 2. Equivalent variation (US\$ per capita)

Source: model results (non-cost neutral scenario)

elasticity. Nonetheless, significant differences in land rent changes are observed across the European regions. For example, in the non-cost-neutral scenario (Figure 3), land rent changes by -0.1% in some regions of Finland, Sweden, Italy and Southern France, but by -7% in some regions of Portugal, the UK, Germany, Ireland, Denmark, Estonia, Latvia and Lithuania. The magnitude of changes is largely explained by the magnitude of the reduction in animal and crop production illustrated in figures B7 and B8.

The most obvious impact on global land use is a change in pastureland (grazing), as can be seen from Figure 4. Indeed, as the EU's ruminant production and output of red meat drops (see Figure B8), the ROW expands pasturelands.

Croplands tend to expand (Figure 5), especially in the EU, where drops in animal production are larger compared to the reductions in food production (Figures B7 and B8). The expansion in cropland is driven by the decrease in pastureland that triggers substitu-

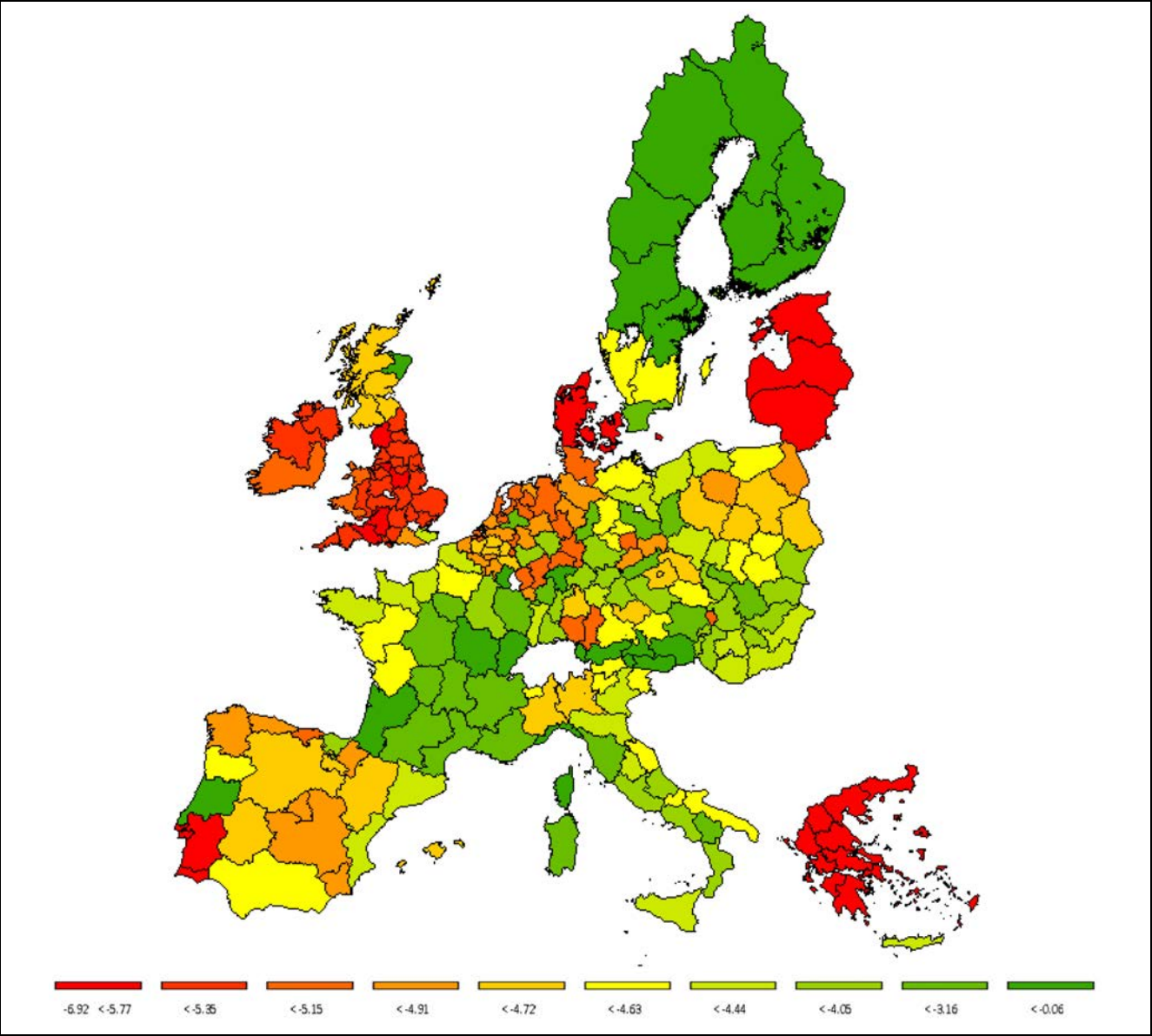
tion toward croplands (see Figure B6). In some regions such as Australia, South America and North America, the increase in pastureland may also reduce areas used for crop production.

Finally, the differentiated impact of a unilateral effort by the EU to reduce food waste can be seen from the change in managed forest areas (Figure 6). In the EU, reduced demand for agricultural products releases crop and pasture land, bringing about some afforestation in the long run. Of course, the opposite is true outside the EU, where pressure on the tropical rainforest would increase.

5.3 Impact on Water Resources

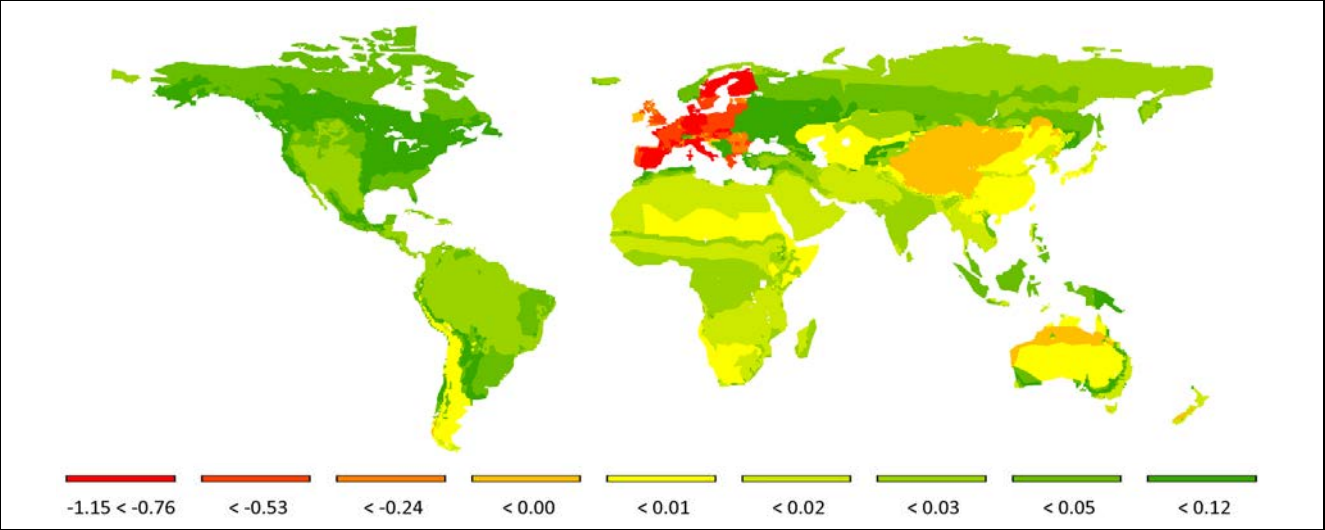
Usage of water resources in the EU decreases by 0.19 %. The largest reductions are observed in Sweden, Ireland, Poland, Slovakia and Romania. However, the use of water resources in other regions of the world increases, resulting in a negligible although positive change in a net global water use (Figure 7).

Figure 3. Percentage change in agricultural land rents



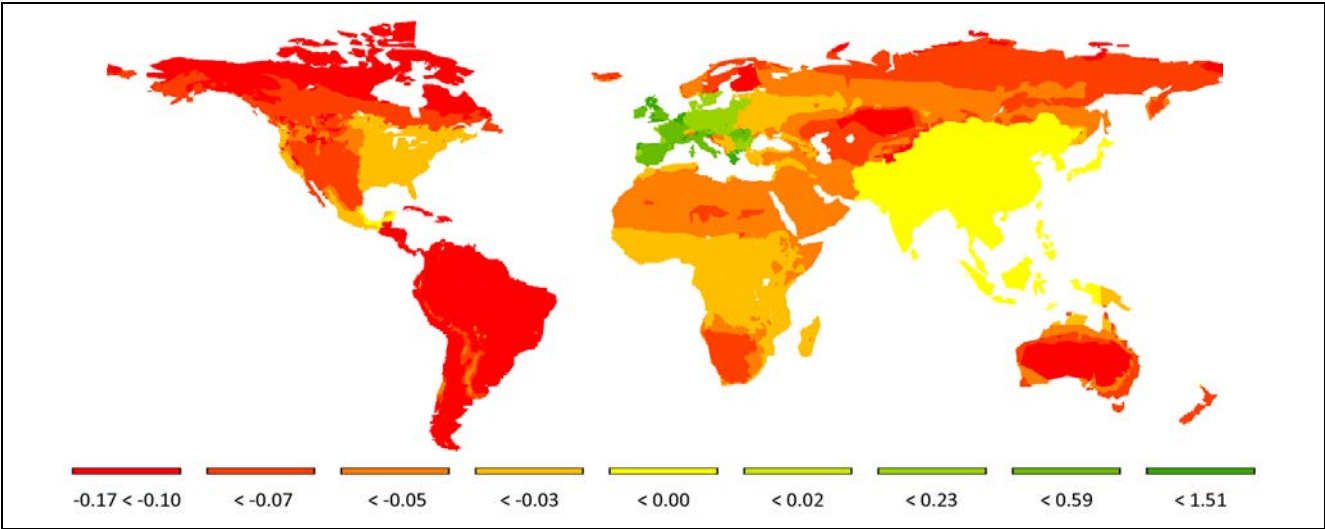
Source: model results (non-cost neutral scenario)

Figure 4. Percentage change in pastureland cover



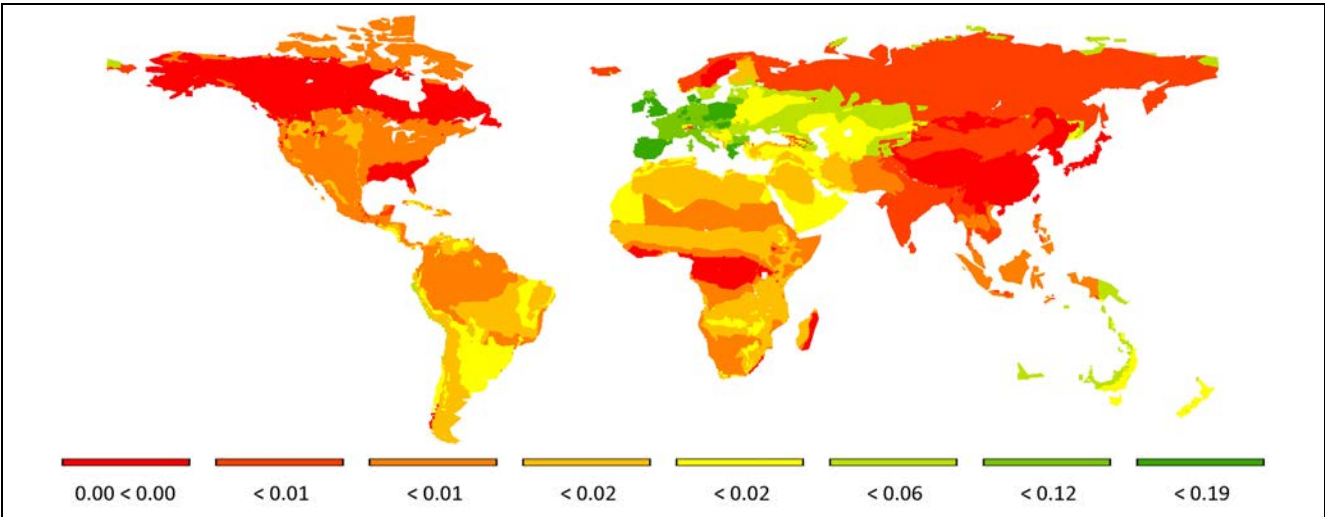
Source: model results (non-cost neutral scenario)

Figure 5. Percentage change in cropland cover



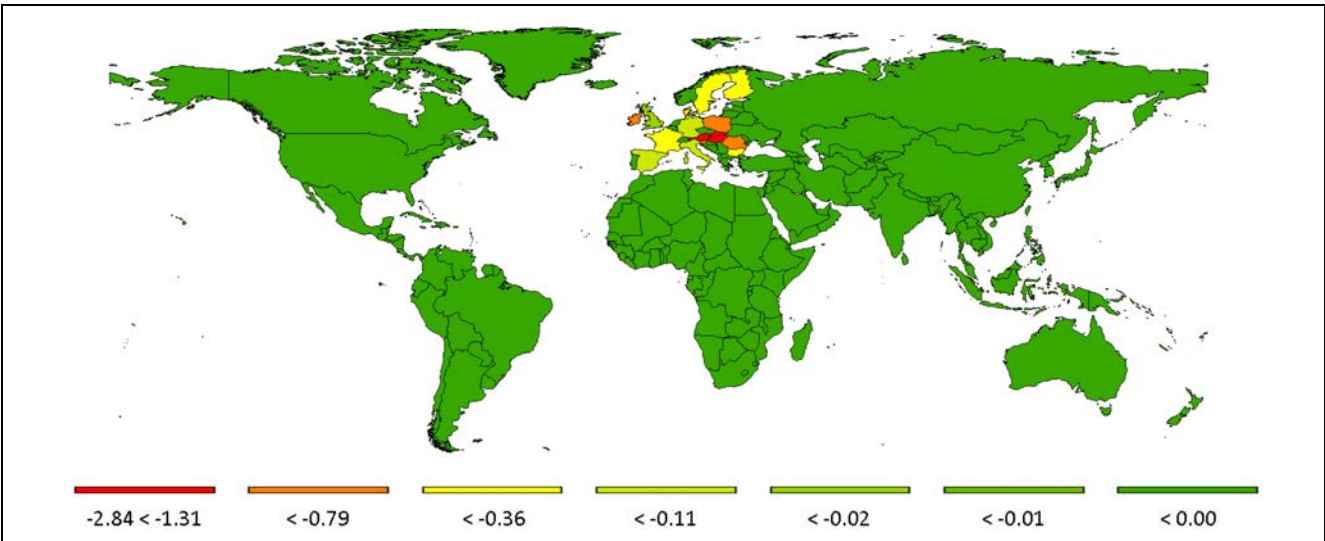
Source: model results (non-cost neutral scenario)

Figure 6. Percentage change in managed forestland cover

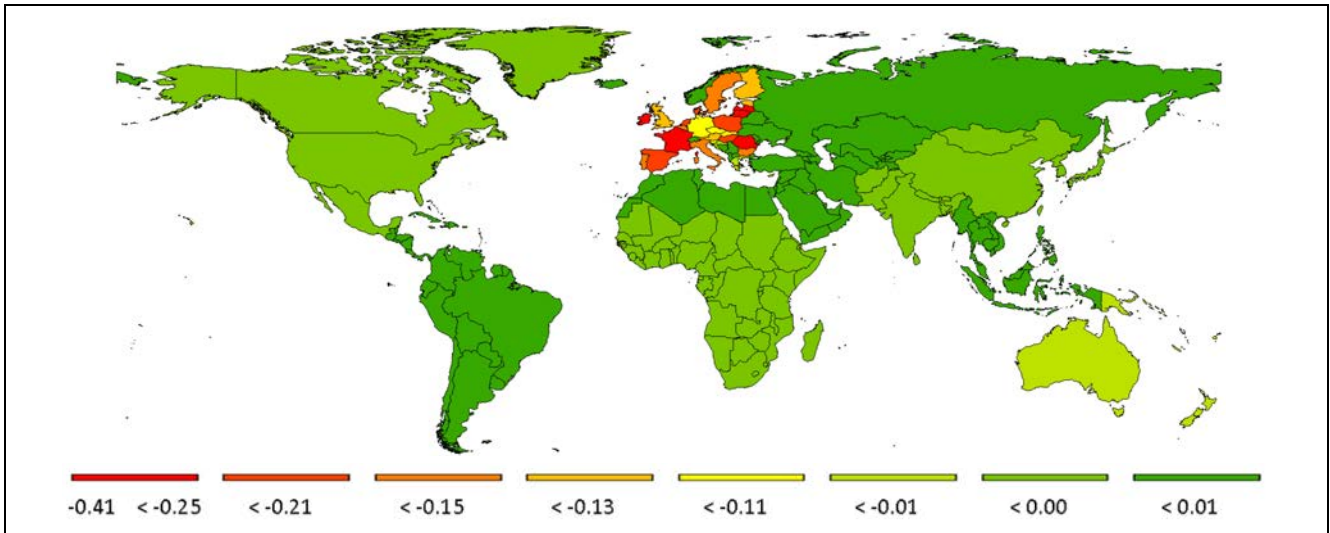


Source: model results (non-cost neutral scenario)

Figure 7. Percentage change in the use of water resources



Source: model results (non-cost neutral scenario)

Figure 8. Percentage change in CO₂ and non-CO₂ emissions [CO₂ equivalent]

Source: model results (non-cost neutral scenario)

5.4 Impact on GHG Emissions

As shown in Figure 8, no significant impact is expected for GHG global emissions. Within the EU, the reduced methane emissions from ruminant animals are compensated by higher emissions from fossil fuel use, leading to a minor net reduction across the EU of 0.4%. Under non-cost neutrality, the largest reductions in emissions are observed in Spain, France, Latvia and Slovakia. However, the net reduction in EU emissions comes at the expense of the same net increase in emissions outside the EU, leaving no significant reductions in global emissions. We also simulated a more ambitious food waste reduction scenario (10% reduction in food waste in line with the EU target of 50% reduction in food waste) to further explore the sensitivity of GHGs to food waste reduction policies. This results in an additional 0.25% reduction in GHGs, leading to cumulative reduction of 0.65% reduction in GHGs. The main reasons behind these small changes are that food waste constitutes a small proportion (3%) of total GHG emissions (MONIER et al., 2010) and that most of the reduction in CO₂ emissions due to food waste reduction technology will be compensated by the CO₂ emitted in the production of intermediate inputs that will be used elsewhere.

6 Policy Recommendations and Caveats

Our analysis shows that reduced food waste in Europe has only limited impacts on food availability in regions such as Sub-Saharan Africa, despite the far-reaching integration of global agricultural and food markets. There are multiple reasons for this. Firstly, the reduced demand for agricultural products in Europe leads to price decreases, which lead to reduced supply in Europe and beyond. That implies that a ton less food waste does not imply a ton more food available in the market. Secondly, assuming that reducing food loss comes at a cost, the average cost for processed food would increase.

We thus conclude from our findings that costly efforts to reduce food losses in Europe cannot be motivated in terms of significant contributions to global food availability or environmental benefits. That does not mean that policy interventions should be abandoned, but they should rather focus on targeted actions, reducing losses at low cost or reducing consumption of products with a high environmental footprint. Furthermore, if the existence of market failures and public goods are brought into the picture, a broader

scope for policy intervention would emerge and aggregate welfare effects would be somewhat more on the positive side. Nonetheless, we believe that considerations about the “possible” or “likely” existence of market failures are not sufficient to support food waste reduction policies. Rather, market failures and externalities should be properly identified and quantified. However, this kind of analysis goes beyond the scope of this work.

Our findings suggest that consideration of adjustment costs matter: the increase of food availability from less food waste is reduced along with pressure on natural resources, such as land and water, as agricultural production drops compared to a “free lunch” assumption. However, considering adjustments costs or not lead to similar GHGs saving. Higher saving of GHGs in the scenarios that consider adjustment costs are compensated by the induced emissions from the higher use of non-agricultural intermediate inputs.

It should be noted that a strategy of reduction of food waste has been interpreted here as a change in the production technology of the food processing industry (in Europe). This change in technology takes place by reducing the inputs of agricultural goods into food processing while scaling up the usage of all other production factors (in a cost neutral or in a cost increasing way). Therefore, we have simulated an improved efficiency in the utilization of agricultural goods, compensated by higher employment of all other factors.

How would one model compensatory costs? It is difficult to make any valuation without specifying in detail which measures would be taken to reduce the gross amount of agricultural inputs utilized. Remember that the model employed here is a macroeconomic one, meaning that behind industries and households there are millions of individuals and firms. As a consequence, there is no practical way to get any realistic estimate of implementation costs for waste reduction programs (disaggregated by industrial category). Perhaps some useful information could be obtained by interfacing the CGE model with a microsimulation model, but this would go beyond the scope of this work. Therefore, the chosen solution is proportional scaling of other production factors, which may not be very realistic but at least has the merit of not introducing additional and somehow arbitrary distortions in the simulation experiments.

One could also notice that this research has focused on the food processing industry alone, which accounts for a large share of food waste, but not the

largest one (which occurs at the final consumption stage; see, e.g., MONIER et al. (2010) and STENMARCK et al. (2016)). Although two studies on food waste at the household level do exist (BRITZ et al., 2014, and PHILIPPIDIS et al., 2019), the point we want to make here is that most of the methodology and approaches followed in this study would apply equally well to final consumption in the household.

Indeed, a representative aggregate household can be conceived as a sort of special industry, which “produces” utility using consumption goods and services. Improvements in “consumption productivity” would then mean that you could be as happy as before or even happier while consuming lower amounts of food. On the other hand, the savings obtained by purchasing less food could allow higher consumption of other items.

As it is often the case with numerical exercises, such as the one described in this paper and despite the fact that we have made use of a rich and detailed data set, the quality of data remains a critical aspect, along with the assumptions about behavioural parameters, such as substitution elasticities. Consequently, we are aware that our numerical estimates are subject to various degrees of uncertainty. Nonetheless, the overall qualitative picture and the key insights emerging from our numerical simulations are robust to alternative defined scenarios and therefore, provide useful guidance for policies in this field.

7 Conclusion

Food waste is a serious challenge across globe. The European Commission already addressed this challenge by targeting the reduction of food waste to half of its business as usual level by 2030. This study, for the first time presents a comprehensive analysis of the impact of a reduction in food waste in the EU on food availability, natural resources (i.e. water and land use change) and the environment within and outside the EU. Contrary to the literature that assigns no adjustment cost to reduce food waste, this study departs from this assumption. Accordingly, we simulate food waste reduction in food processing sectors under two different assumptions with regard to the cost of food waste: first, assuming that the costs of reducing food waste are equal to the monetary savings for the food processing industry and, second, by assuming that the costs of reducing food waste are twice as much as the savings from food waste. The scenarios assume a food

waste reduction in the food industry that is equal to 5% of the intermediate input use of food processing sectors.

For the purposes of this study, we employ a CGE model that covers a global economy with the EU at the NUTS 2 resolution, while considering the detailed representation of agriculture and food production sectors, agro-ecological land use resolutions, irrigation water as a primary factor of production and the direct and non- direct CO₂ emissions. Our result shows that consideration of adjustment costs matters. Higher adjustment costs are likely to result in smaller increase in food availability and larger reduction in primary agricultural production and use of natural resources. Moreover, we confirm that a unilateral commitment of the EU to reduce food loss and waste is likely to decrease the competitiveness of the EU food processing sector. Reduced demand for primary agricultural inputs would shrink the EU's agricultural sectors, applying pressure to farm incomes and land prices. The contribution to global food security would be minor, as the adjustments would be concentrated in the EU market. Rather, as many developing countries are importers of both primary agricultural products and of processed food, increasing global prices for processed food would harm them. We could not find any significant impact on water and land resources and emissions relevant for climate change at the global level and only very limited impact inside the EU. We note that our results are driven by the specific assumptions used in the general equilibrium model, which do not consider the possible existence of externalities and public goods. We conclude from the findings that costly efforts to reduce food loss in Europe cannot be motivated by large contributions to improved global food availability or environmental status. That does not mean that policy interventions should be abandoned, but there is a need for global coordination of food waste reduction policies. Policies in the EU should focus on targeted actions which reduce losses at low costs and focus on products with a high environmental footprint.

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Appendix A: Definition of Food Waste

Almost every study in the literature starts with a discussion about the definition of food waste and concludes that there is no consensus. The only agreement seems to be on what is not considered to be food waste, namely:

- What is consumed by humans as food is not food waste.
- What is not produced as food cannot be food waste when wasted or lost.

However, the discussion on the definition of food waste is actually about the details rather than the core of the subject. The discussions centre on the following "axes":

- Loss vs waste: many earlier definitions in the literature tend to separate food waste from food loss (see for example: FAO, 2014a; LIPINSKI et al., 2013; BCFN, 2012; FAO, 2011). Food loss is generally attributed to the earlier stages of the FSC, such as production and processing, while waste is attributed to later stages such as retail and household consumption (e.g., because of the behavioural characteristics of consumers; see FAO, 2011) and technological constraints (FILHO and KOVALEVA, 2015). However, food waste and loss have recently started to be used as synonyms (BETZ et al., 2015). Most studies reserve the wording, "food waste and loss" but do not make

any distinction between them in terms of treatment (see for example: HLPE, 2014). The disappearance of the distinction can be attributed to the different moral tones that these two words have: loss is more "innocent or unintentional" while waste is "evil or intentional" (CHABOUD and DAVIRON, 2017).

- Human consumption vs. non-human consumption: some FAO documents count food that is directed to animal feed as food waste (FAO, 2014b; FAO, 2014c; FAO, 2011) while other authors argue that since food is diverted to animal feed, a transformation of food to livestock products, it cannot be considered food waste (CHABOUD and DAVIRON, 2017). In fact, many argue that diverting non-consumed food to animal feed is a good solution for food waste (FAO, 2014d). Indeed, FAO (2014d) changes the former FAO definition of food waste by excluding food diverted to animal feed as food waste (BAGHERZADEH et al., 2014).
- Excess consumption: some studies tend to include over-eating as food waste (BCFN, 2012; Smil, 2004). However, most studies do not consider "Food that is consumed in excess of nutritional requirements" as waste (FAO, 2014c).
- Avoidable vs. non-avoidable: some UK studies introduced the concept of avoidable and non-avoidable food waste (VENTOUR, 2008; WRAP, 2009). Unavoidable food waste is "waste deriving from the preparation of food or drinks that are not and could not, be edible (for example, meat bones, egg shells, pineapple skins, etc.)". On the other hand, avoidable food waste is "food and drinks that are thrown away despite still being edible (for example, slices of bread, apples, meat, etc.)" (VENTOUR, 2008). However, some practical implications of this split are quite questionable because only the "by-products that are useful and marketable products" are counted as waste (FILHO and KOVALEVA, 2015). Furthermore, as "unavoidable" food waste does not have any real economic value, it does not make sense, at least from the economic point of view, to call these "residues" waste.
- Pre-Harvest vs post-harvest: some consider food wasted or lost at pre-harvest stages as part of food waste (FAO, 2014c; HLPE, 2014) while others do not. Particularly in the US, food waste is mostly considered to be a waste management problem and the focus is on post-harvest losses and waste (USDA, 2018).

Along with the above axes, many different definitions are given for food waste (TEUBER and JENSEN, 2016).

Each definition leads to differences on how to quantify total waste and so its economic, social and environmental impacts differ, along with the costs of reducing it. In turn, these costs would determine some "optimal amount of food waste". However, for the purposes of this study, it may not be necessary to rely on an exact definition. What matters more here is the percentage of food that is wasted at different stages of the FSC. For example, if both avoidable and non-avoidable waste are included in the definition (and so food waste accounting), inedible parts of the food products should also be included in production, which in return should not change the overall percentage of food waste. As this study considers different stages of the FSC separately, considering the food transformed into animal feed as food waste or not, considering pre-harvest losses or not, etc., should not influence the analysis beyond the feedback effects. In addition, the costs related to food waste reduction can be expected to change according to the scope of different definitions. However, as we link the costs to the benefits of the food waste reduction for each specific definition (i.e., the wider the scope, the larger the benefit and hence, the larger the cost), our main findings should be rather robust for the chosen definition of food waste.

Why then is a common definition important? Depending on the scope of the definitions, any policy action will have very different implications for different actors in the FSC. Therefore, a common definition is necessary from a legal standpoint (VAQUE, 2015). One recent definition of food waste that was given by the European Parliament as a recommendation to the Commission and Member States to use is as follows (CALDEIRA et al., 2017):

"food waste means food intended for human consumption, either in edible or inedible states, removed from the production or supply chain to be discarded, including at primary production, processing, manufacturing, transportation, storage, retail and consumer levels, with the exception of primary production losses."

This definition excludes the pre-harvest losses from the food waste and does not consider food diverted to animal feed to be waste (as these foods would not be discarded from the FSC but diverted within it). Furthermore, it does not count excess consumption as waste and it does not make any distinction between losses or waste or where the waste occurs in the FSC.

Appendix B: Supplemental Tables and Figures

Table B1. Sectoral correspondence of GTAP sectors to new sectors

No.	Code	GTAP and model sectors	Sectoral aggregation/ disaggregation	Post model aggregation
1	PDR	Paddy rice	Irrigated Paddy rice	Irrigated crop
2	WHT	Wheat	Rainfed Paddy rice	Rainfed crops
			Irrigated Wheat	Irrigated crop
			Rainfed Wheat	Rainfed crops
3	GRO	Cereal grains nec	Irrigated Cereal grains nec	Irrigated crop
			Rainfed Cereal grains nec	Rainfed crops
4	V_F	Vegetables, fruit, nuts	Irrigated Vegetables, fruit, nuts	Irrigated crop
			Rainfed Vegetables, fruit, nuts	Rainfed crops
5	OSD	Oil seeds	Irrigated Oil seeds	Irrigated crop
			Rainfed Oil seeds	Rainfed crops
6	C_B	Sugarcane, sugar beet	Irrigated Sugarcane, sugar beet	Irrigated crop
			Rainfed Sugarcane, sugar beet	Rainfed crops
7	PFB	Plant-based fibers	Irrigated Plant-based fibers	Irrigated crop
			Rainfed Plant-based fibers	Rainfed crops
8	OCR	Crops nec	Irrigated Crops nec	Irrigated crop
			Rainfed Crops nec	Rainfed crops
9	CTL	Bovine cattle, sheep and goats, horses	Bovine cattle, sheep and goats, horses	livestock
10	OAP	Animal products nec	Animal products nec	livestock
11	RMK	Raw milk	Raw milk	livestock
12	WOL	Wool, silk-worm cocoons	Wool, silk-worm cocoons	livestock
13	FRS	Forestry	Forestry	Other primary agriculture
14	FSH	Fishing	Fishing	Other primary agriculture
15	COA	Coal	Mineral extraction sectors	Mineral extraction sectors
16	OIL	Oil	Mineral extraction sectors	Mineral extraction sectors
17	GAS	Gas	Mineral extraction sectors	Mineral extraction sectors
18	OMN	Minerals nec	Mineral extraction sectors	Mineral extraction sectors
19	CMT	Bovine meat products	Bovine meat products	Processed foods
20	OMT	Meat products nec	Meat products nec	Processed foods
21	VOL	Vegetable oils and fats	Vegetable oils and fats	Processed foods
22	MIL	Dairy products	Dairy products	Processed foods
23	PCR	Processed rice	Processed rice	Processed foods
24	SGR	Sugar	Sugar	Processed foods
25	OFD	Food products nec	Food products nec	Processed foods
26	B_T	Beverages and tobacco products	Beverages and tobacco products	Processed foods
27	TEX	Textiles	Other 'traditional' bio-based	Manufacturing
28	WAP	Wearing apparel	Other 'traditional' bio-based	Manufacturing
29	LEA	Leather products	Other 'traditional' bio-based	Manufacturing
30	LUM	Wood products	Other 'traditional' bio-based	Manufacturing
31	PPP	Paper products, publishing	Other 'traditional' bio-based	Manufacturing
32	P_C	Petroleum, coal products	Petrochemicals	Manufacturing
33	CRP	Chemicals, rubber, plastic products	Petrochemicals	Manufacturing
34	NMM	Mineral products nec	Other manufactures	Manufacturing
35	I_S	Ferrous metals	Other manufactures	Manufacturing
36	NFM	Metals nec	Other manufactures	Manufacturing
37	FMP	Metal products	Other manufactures	Manufacturing
38	MVH	Motor vehicles and parts	Other manufactures	Manufacturing
39	OTN	Transport equipment nec	Other manufactures	Manufacturing
40	ELE	Electronic equipment	Other manufactures	Manufacturing
41	OME	Machinery and equipment nec	Other manufactures	Manufacturing
42	OMF	Manufactures nec	Other manufactures	Manufacturing
43	ELY	Electricity	Other services	Services
44	GDT	Gas manufacture, distribution	Other services	Services
45	WTR	Water	Other services	Services
46	CNS	Construction	Other services	Services
47	TRD	Trade	Wholesale and retail trade	Services
48	OTP	Transport nec	Other services	Services
49	WTP	Water transport	Other services	Services
50	ATP	Air transport	Other services	Services

51	CMN	Communication	Other services	Services
52	OFI	Financial services nec	Other services	Services
53	ISR	Insurance	Other services	Services
54	OBS	Business services nec	Other services	Services
55	ROS	Recreational and other services	Other services	Services
56	OSG	Public Administration, Defense, Education, Health	Other services	Services
57	DWE	Dwellings	Other services	Services

Table B2. Price and quantity changes for agri-food products (% change)

	<i>Cost neutral scenario</i>		<i>Non-cost neutral scenario</i>	
	Price	Quantity	Price	Quantity
Crops	-0.9	-0.8	-1.1	-0.8
Paddy rice	-1.4	-1	-1.8	-1.6
Wheat	-0.8	-0.6	-1	-0.6
Cereal grains nec	-1.1	-1.7	-1.3	-1.8
Vegetables, fruit, nuts	-1	-0.4	-1.2	-0.3
Oil seeds	-0.7	-0.2	-1.1	-2
Sugarcane, sugar beet	-1.1	-2.1	-1.4	-2.6
Plant-based fibers	-0.8	0.9	-0.9	1.2
Crops nec	-1	-1.1	-1.2	-1
Animals	-1.1	-1.5	-1.3	-2.6
Bovine cattle, sheep and goats, horses	-0.8	-1.6	-0.9	-2.9
Animal products nec	-1.1	-1	-1.3	-2.5
Raw milk	-1.3	-2	-1.6	-2.5
Wool, silk-worm cocoons	-0.4	0.5	-0.4	0.9
Food processing	-1.2	1.1	-0.2	0.2
Bovine meat products	-2	2.2	-0.2	0.3
Meat products nec	-2.4	2.3	-0.3	0.3
Vegetable oils and fats	-2.3	3.5	-0.5	0.8
Dairy products	-1.5	1.3	-0.3	0.5
Processed rice	-1.3	0.9	-0.2	0.1
Sugar	-1	0.9	-0.2	0.2
Food products nec	-0.9	0.6	-0.1	0
Beverages and tobacco products	-0.7	0.5	-0.1	0.1

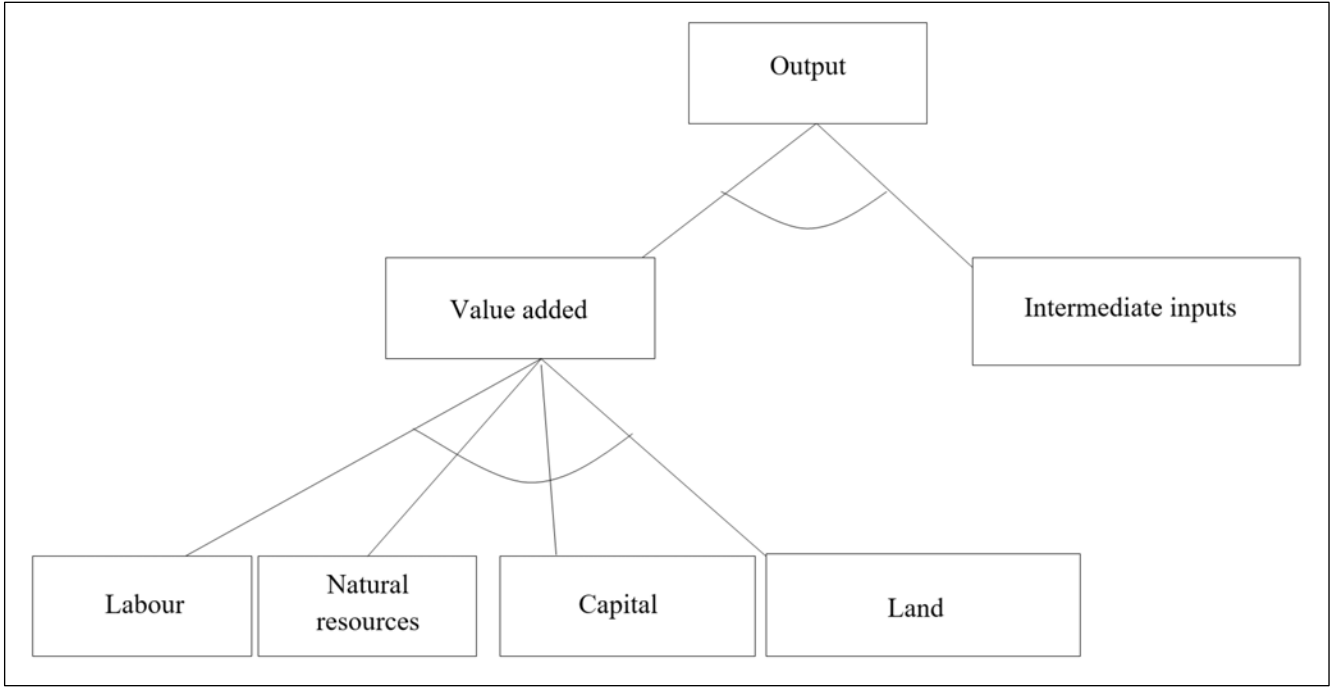
Source: model results

Table B3. Changes in agri-food markets and related environmental impacts (% change)

	<i>Non-cost neutral scenario (5 percent)</i>	
	EU	Global
Price of crops	-1.6	-0.3
Price of animals	-1.6	-0.4
Price of processed food products	-1.5	-0.5
Value added in processed food sectors	1.8	0.3
Value added in crop production	-0.2	0.1
Value added in animal production	-0.4	0.1
Land demand	-0.01	0.00
Water demand	-0.09	0.00
Farmers income	-0.2	0.05
Food consumption	0.49	0.09
Welfare	10	4

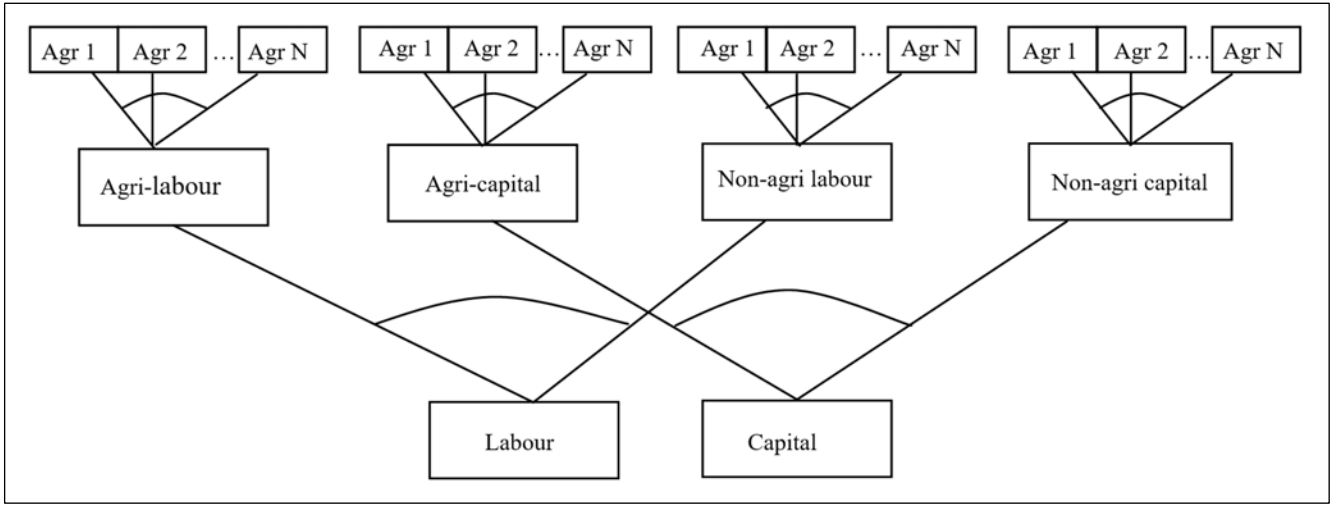
Source: model results

Figure B1. Production structure of GTAP

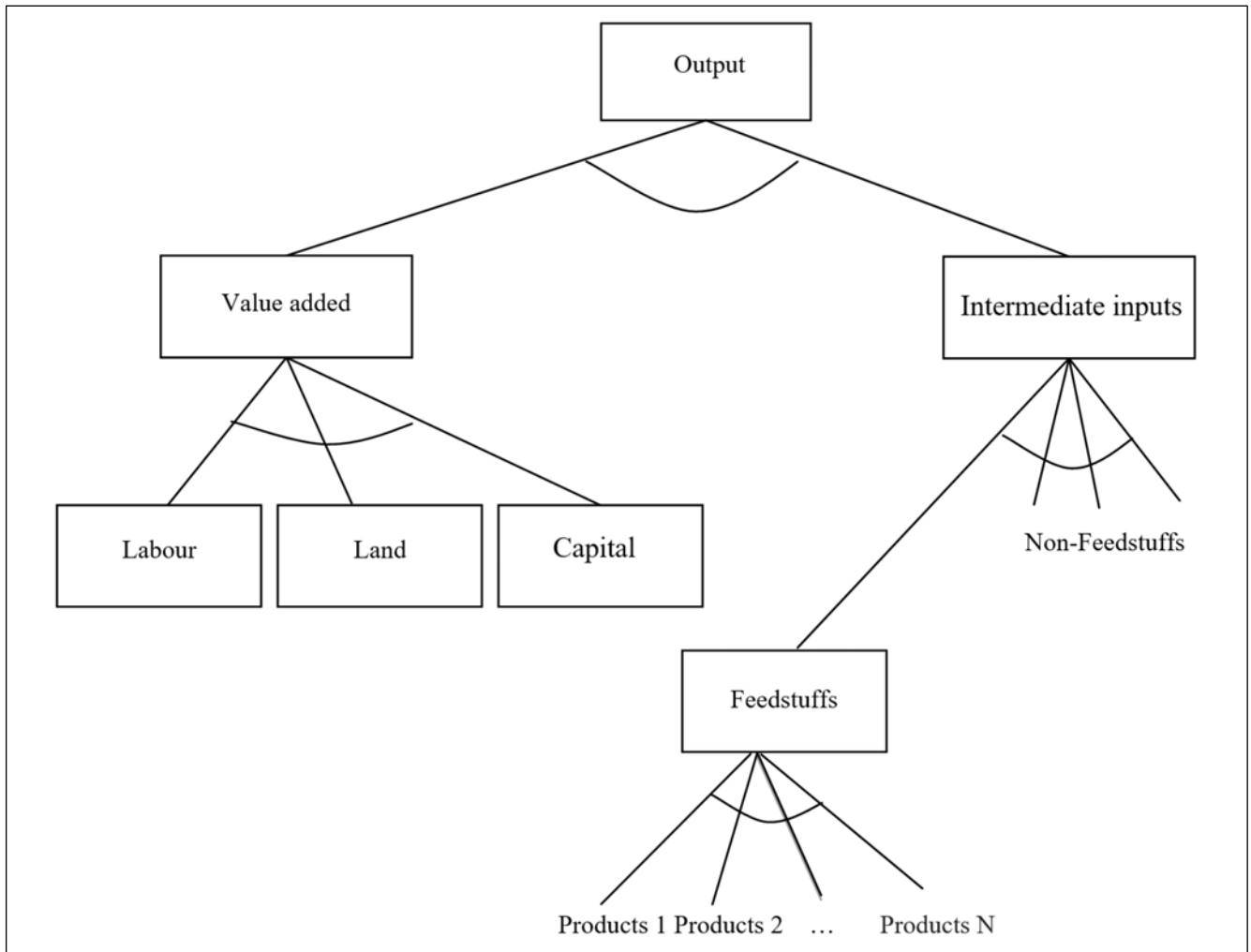


Source: HERTEL (1997)

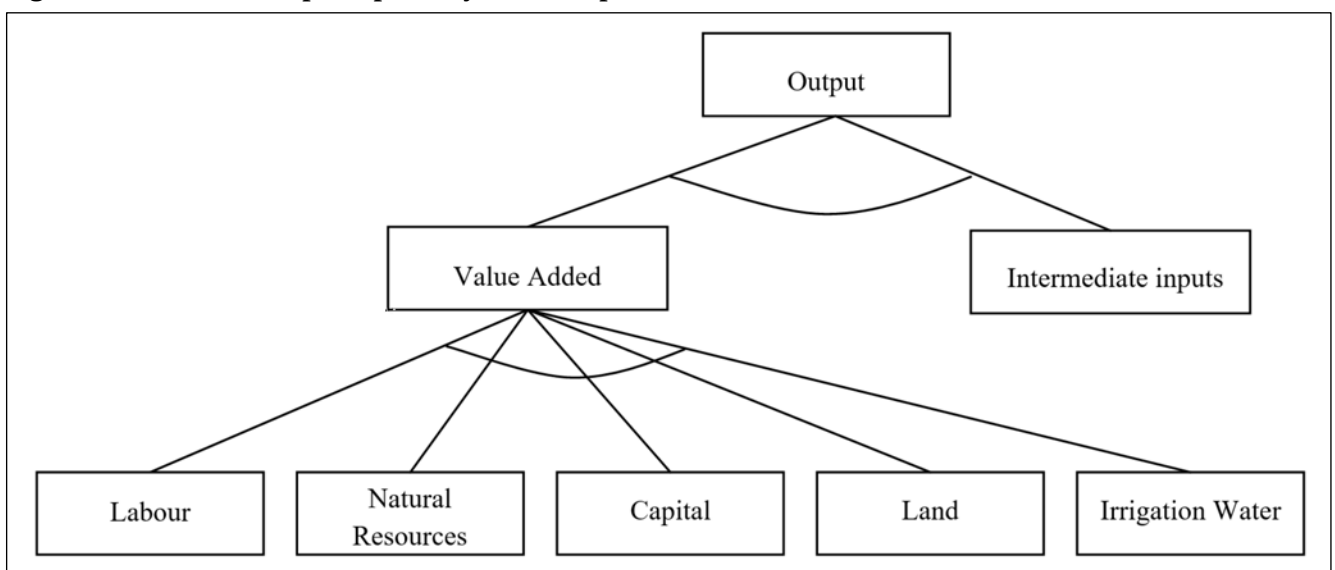
Figure B2. Primary factors supply in GTAP-AGR



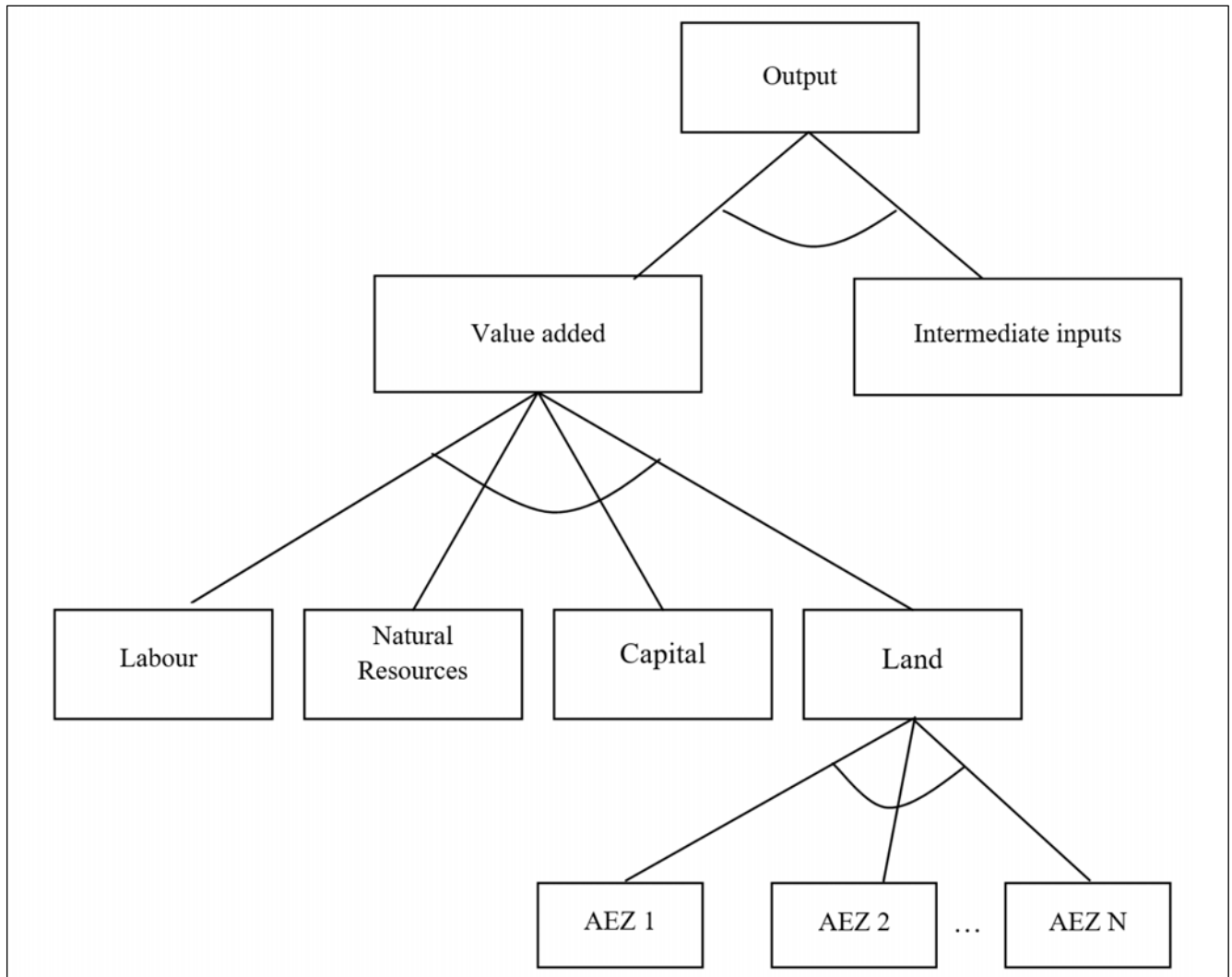
Source: authors' illustration based on KEENEY and HERTEL (2005)

Figure B3. Production structure of GTAP-AGR

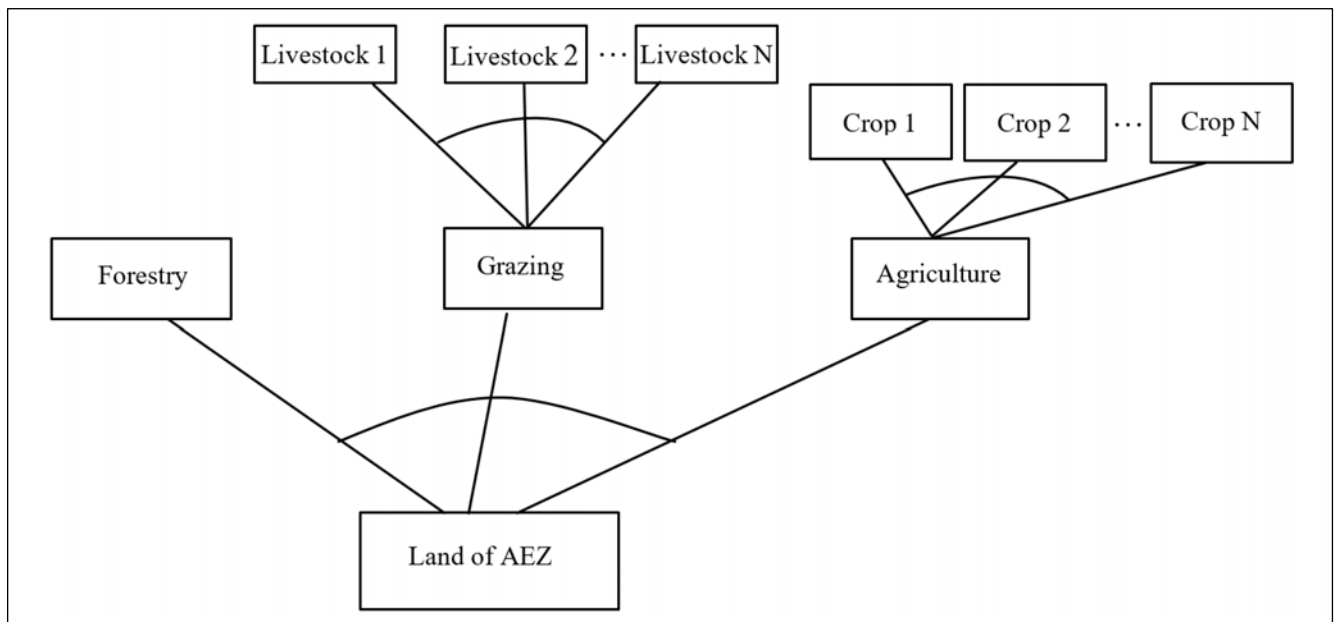
Source: KEENEY and HERTEL (2005)

Figure B4. Water as explicit primary factor in production structure

Source: authors' illustration based on HAQIQI et al. (2016)

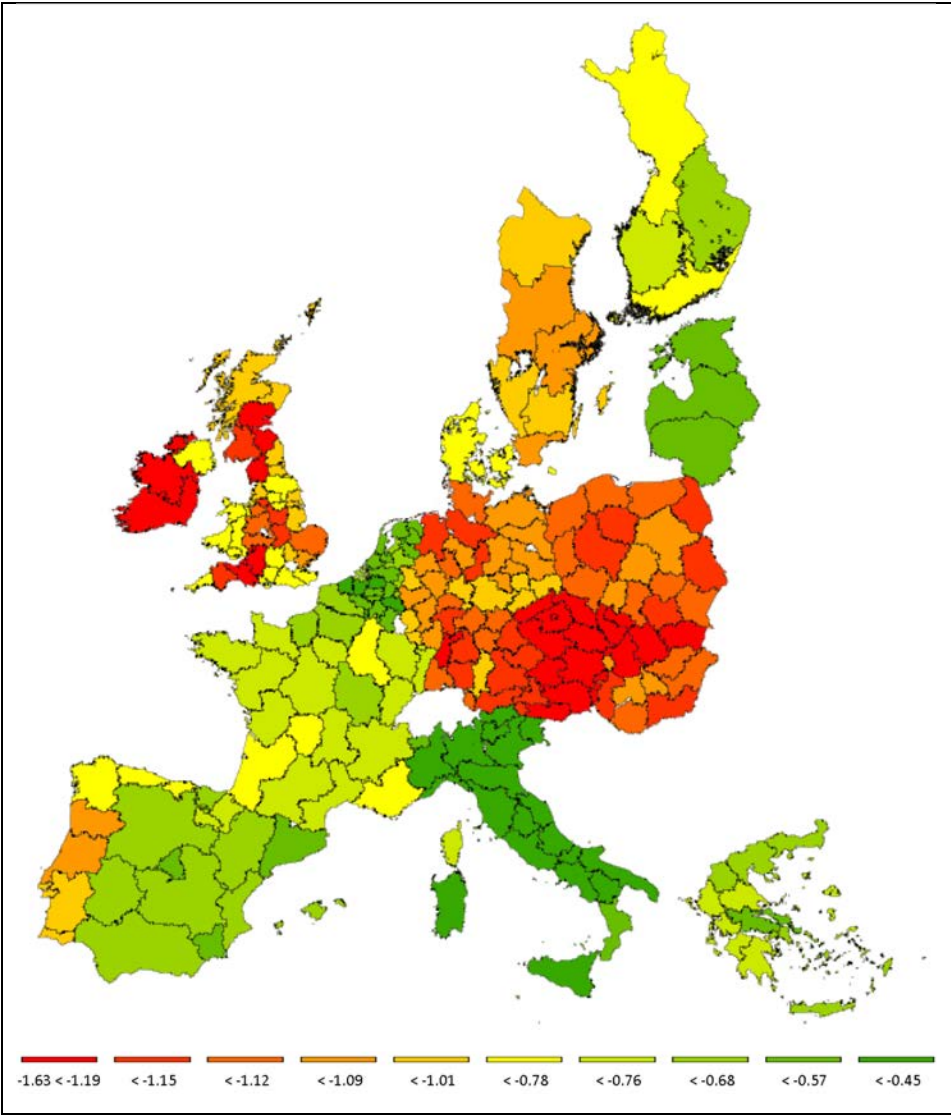
Figure B5. Production structure of GTAP-AEZ

Source: HERTEL et al. (2009)

Figure B6. Land supply in GTAP-AEZ model

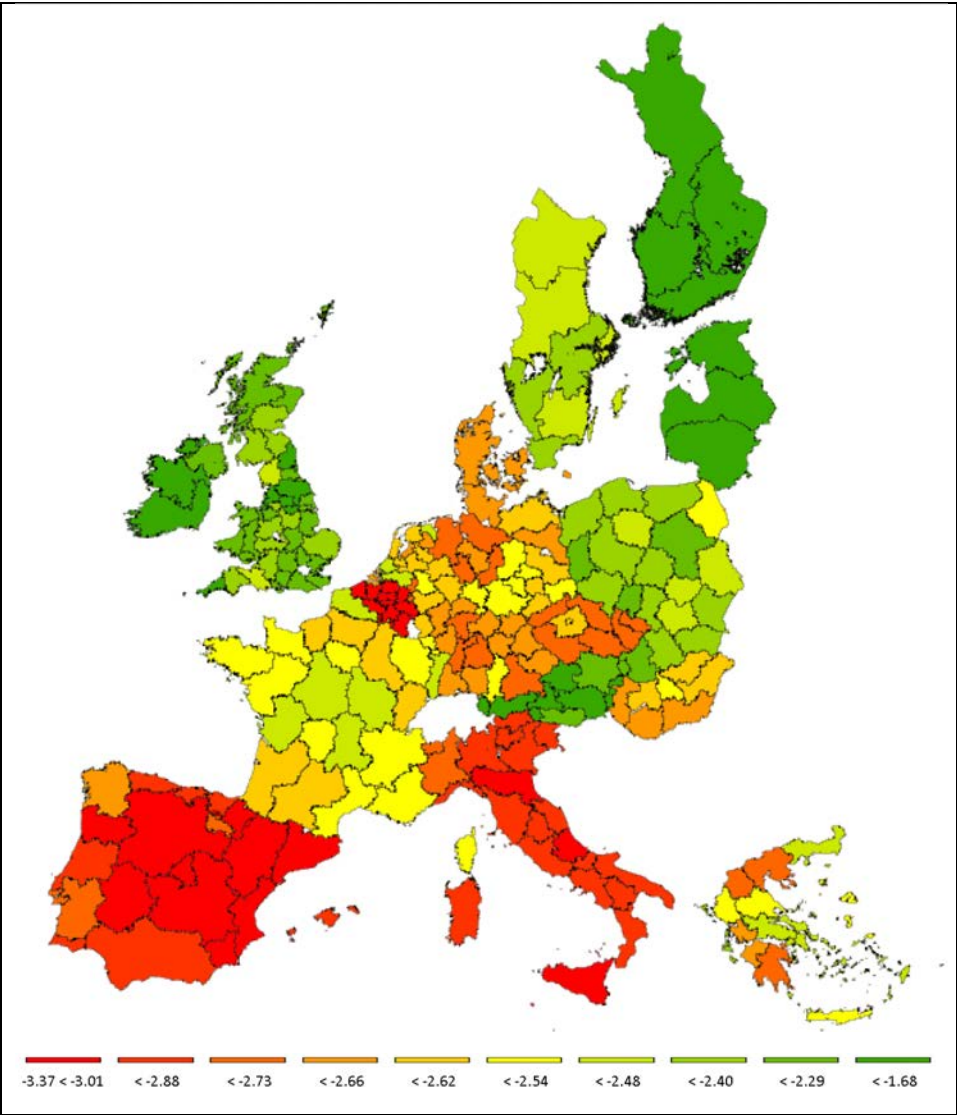
Source: HERTEL et al. (2009)

Figure B7. Change in value added for crop production



Source: model results (non-cost neutral scenario)

Figure B8. Change in value added for animal production



Source: model results (non-cost neutral scenario)



Modelling heterogeneous firms and non-tariff measures in free trade agreements using Computable General Equilibrium

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ABSTRACT

A vast body of literature supports with empirical evidence the findings of Melitz (2003) which has led to various attempts to integrate it into Computable General Equilibrium (CGE) models to distinguish the intensive and extensive trade margin and to consider love of variety effects as well as variable and fixed costs of bilateral trade. These viewpoints are especially important for modern free trade agreements (FTAs) analysis where impacts depend largely upon changes in non-tariff measures (NTMs) affecting trade cost. However, existing Melitz extensions for CGEs seem to struggle with numerical stability problems limiting sectoral and regional detail. That greatly reduces their usefulness for policy relevant analysis. We, therefore, develop a Melitz extension for a modular CGE with a focus on a numerical stability. Using the Transatlantic Trade and Investment Partnership (TTIP) proposal as an illustrative example, we treat 22 manufacturing out of 57 sectors based on Melitz in an application with ten global regions and compare our findings to an Armington specification. Our results confirm the larger welfare and trade changes under the Melitz setting suggested both by theory and by empirical findings. We finally compare the sensitivity of trade and welfare impact when the same cost savings associated with reduced NTMs are differently allocated to variable and fixed cost of bilateral trade. We find in our application that the change in traded quantities is more sensitive to bilateral variable cost while welfare increases are more driven by reduced fixed cost, reflecting love of variety effects. Overall, the application underlines that our numerically robust implementation of the Melitz model in a CGE allows applications with high sectoral detail and thus opens the door to a more widespread application in impact assessments.

1. Introduction

The rapid expansion of bilateral and regional FTAs since the mid-1990s in both number and depth (Horn et al., 2010) has led to higher demands for their quantitative impact analysis. While early FTAs mainly targeted tariff elimination, modern FTAs take into focus NTMs which are quite diverse in nature and thus affect the economy through different mechanisms (Lima, 2016). Equally, FTA negotiations and agreements encompass often highly differentiated concessions by sector and partner country. Besides gravity based approaches, impact assessment of FTAs relies mainly on global CGE models (Hertel et al., 2007) which cover bi-lateral trade and further economic transactions across all sectors and consider the interactions of various policy instruments (Devarajan and Robinson, 2002).

Since Armington (1969) proposed to treat imported and domestic varieties of the same (aggregated) goods as imperfect substitutes that approach dominated applied CGE analysis. It provides a powerful, but

relatively simple framework for studying international trade policy, not at least as it can accommodate any observed pattern of trade flows and pertinent prices (i.e., the intensive margin of trade). However, preferences for each origin in the Armington model are fixed, such that changes in trade cannot impact average imported qualities per firm on a trade link. It hence neglects potential variations at the extensive margin of trade such as trade flows in new products and with new partners which are found as important in empirical analysis (Hummels and Klenow, 2005; Chaney, 2008).

The pioneer paper by Melitz (2003) introduced firm productivity heterogeneity drawing from Hopenayn (1992) into the monopolistic competition framework by Krugman (1980). The Melitz model can be understood as an extension of the Armington approach as it combines changes at the intensive and extensive margins of trade by allowing firms to self-select new export markets based on their productivity level. Many papers applying the model (Bernard et al., 2003, 2006; 2007; Eaton et al., 2004) could reproduce salient trade patterns observed in recent

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micro-level studies. Consequently, there have been a number of efforts to introduce it into CGE models (Zhai, 2008; Balistreri et al., 2011; Oyamada, 2014; Akgul et al., 2016; and Dixon et al., 2016). The Melitz model adds to the explanatory power of Armington type models (Hosoe, 2017) by considering changes at the extensive margin of trade and in industry productivity level with implications on both trade and welfare (Melitz and Redding, 2014). However, assessment of FTAs based on Melitz-type CGE models is still scarce. For example, none of the impact assessment reports of FTAs by the EU Commission mentions an application of a Melitz-type CGE model.¹ A possible reason is the increased complexity of a Melitz compared to an Armington model, mirrored by a modest sectoral and regional resolution in published application. The paper on GTAP-HET by Akgul et al. (2016), to give an example, uses a stylized example with three regions and two sectors, only. Balistreri et al. (2011) proposes a decomposition algorithm, where partial equilibrium models for Melitz sectors interact with an Armington model for perfectly competitive one. In their example, the authors include firm heterogeneity in just one sector. Dixon et al. (2016) and Oyamada (2014) include firm heterogeneity in variants of the global trade analysis project (GTAP) model coded in General Equilibrium Modelling PACKage (GEMPACK), but seem to run into dimensionality problems. Indeed, all studies up to present offer analysis with a rather limited number of sectors treated a la Melitz. Bekkers and Francois (2016), to give an example, report a maximum of 4 countries and 3 Melitz sectors for these applications.

Some authors (Dixon et al., 2016, for example) claim that Melitz models are not necessary, as Armington models are able to replicate their trade impacts with higher than usual elasticities of substitution. Dixon et al. (2016) used a trial and error approach to find the value of substitution elasticities in Armington-type CGE models that generates almost equal overall trade impacts compared to a Melitz-type CGE model in their simple two-sector modelling exercise. Balistreri and Rutherford (2013) draw the conclusion from such exercises that Armington-type models might produce almost any desired pattern of trade if modelers consider substitution elasticities as parameters of choice. Furthermore, even an Armington model tuned to replicate simulated trade pattern of a Melitz model will still not reproduce the welfare implications of considering fix cost at industry and trade link level along with love of variety.

Additionally, the differentiation between fixed and variable costs in bi-lateral trade embodied in Melitz-type CGE models allows a more realistic quantitative assessment of NTMs (Fugazza and Maur, 2008). That seems important as ad valorem equivalent estimations of NTMs suggest that their (partly) elimination is often more important than tariff reductions in FTAs (Horn et al., 2010). The need for more advanced approaches beyond the relatively simple assumption underlying an Armington model seems also be seen by governments; the European Commission (2016), namely, asks to make full use of the available information and techniques in the impact assessment of FTAs.

Our paper aims to discuss and finally ease the use of the Melitz model in detailed CGE analysis such that both the extensive and intensive margin of trade and productivity effects can be considered. It contributes to literature as follows. We discuss the development of a Melitz model into the modular and flexible CGE modelling platform CGEBox (Britz, 2017), focusing on numerical stability when working with many sectors and regions, a point we consider salient for policy relevant applications. Further, we present a sensitivity analysis of different approaches to model NTMs in the Melitz framework and compare resulting trade and welfare impacts to a standard Armington implementation.

We take TTIP between the US and EU as an illustrative case. Both the EU and US apply a multitude of non-harmonized complex sanitary and phytosanitary (SPS) measures as well as technical barriers to trade (TBT) regulations (Arita et al., 2014) which together with other trade-related regulatory differences create obstacles to trade. Thus, TTIP aimed not

only to eliminate or to reduce tariffs, but also to unify “behind the border barriers (i.e., differences in regulations)”. It offers hence an interesting case where bilateral trade modelling, high NTMs and the complex nature of NTMs are the core. To illustrate the impact of NTMs in different model configurations, we consider NTM reductions in all sectors.

2. Modelling framework

Global CGE models are considered especially suited to provide an ex-ante appraisal of trade agreements as they consider bi-lateral trade and related barriers in a consistent behavioral framework while accounting for interlinkages between sectors. The most widely used database, GTAP, currently offers 57 sectors and 140 regions (Aguilar et al., 2016). Still, the sectoral breakdown of the GTAP database is often considered insufficient to assess detailed trade negotiations. Therefore, CGE applications are regularly complemented by analysis at the tariff line; either based on a separate partial equilibrium model or by using a pre-model aggregation from changes at the tariff line to the GTAP sector with software such as TASTE (Narayanan et al., 2010). As tariff line detail is not at the focus of our paper and the example of TTIP is only illustrative, we leave out tariff line complications in the remainder of our paper, but work with the full sectoral resolution of 57 sectors. We use here the flexible and modular CGE model CGEBox. A full documentation of all equations of that open-source platform for CGE modelling offers Britz (2017). The model, encoded in the General Algebraic Modelling Language (GAMS), can provide an exact replica of the standard GTAP model (Hertel, 1997), but also allows to mimic features of many other well-known CGEs. We extend that CGE model platform by incorporating a module based on Melitz (2003). It considers firm heterogeneity, firm entry and exit in the industry as a whole and on specific trade links, and love of variety by the different agents, resulting in monopolistic competition. Below we discuss briefly the general structure of the standard GTAP model that treats sectors as perfectly competitive and subsequently provide detail on the Melitz module.

2.1. Perfectly competitive sectors as in the standard GTAP model

Sectors with perfect competition are depicted as in the standard GTAP model (Hertel, 1997), a comparative static, global CGE model based on the Walrasian general equilibrium structure. It assumes cost-minimizing behavior under constant returns to scale production technologies along with utility maximizing consumers in competitive markets. There is a single virtual representative household in each region that owns the production factors and receives factor returns net of taxes. That so-called regional household also collects income from taxation such as tariff revenues and rents accruing from export or import licenses, depicted as exogenous ad-valorem price wedges. The regional income is then allocated to different agents (private household, government, and saving) based on a modified Cobb-Douglas (CD) utility function. The private household's demands for Armington commodities are derived from a non-homothetic constant difference elasticity (CDE) implicit expenditure function,² while government and saving demands for Armington commodities are driven by constant elasticity of substitution (CES) functions. A CES composite of domestic and import demand for each and product agent defines their Armington demands. The import demand composition from bi-lateral trade flows is depicted by a second CES nest that is not agent specific. On the supply side, production is defined as the Leontief aggregate of value added and intermediate inputs bundles; the value added composition is based on a CES aggregate of primary factors while the composition of intermediate demand is based on fixed physical input coefficients. Each sector features its own Armington nest to determine the composition of intermediate input demand for each

¹ See the documents archive of the European Commission on trade policy analysis, <http://ec.europa.eu/trade/policy/policy-making/analysis/>.

² The CDE can be classified as somewhat more flexible as the CES and linear expenditure system (LES) functional forms as it allows for marginal budget shares varying with expenditure levels (Hertel, 1997).

commodity from domestic product and imports. However, the import composition is identical across sectors and final demand, as mentioned above. The model assumes in the default layout fixed stocks for primary factors and full mobility for capital, skilled and unskilled labor, sluggish mobility for land and sector specific and thus immobile natural resources. Van der Mensbrugghe (2015) presents the implementation of the standard GTAP model in the GAMS language underlying CGEBox. Note that the standard GTAP model as detailed in Hertel (1997) is coded in GEMPACK and presents a mix of equations in levels and in linearized relative differences instead, whereas CGEBox is written in levels.

2.2. Implementation of the Melitz module

Our approach for imperfect competition sectors follows the average firm definition by Melitz (2003)³ and builds on Balistreri et al. (2011, 2013) and Akgul et al. (2016); the technical Appendix 1 provides the details of the Melitz module. Each agent's demand is depicted as a Dixit-Stiglitz composite of average firm level varieties of each importer and domestic sales. Each productivity heterogeneous firm produces one single unique variety over a continuum of varieties under conditions of monopolistic competition arising from imperfect substitution in demand for these varieties. Accordingly, the number of varieties produced in a regional industry is equal to the number of firms operating. Production in the monopolistic sectors follows Akgul et al. (2016) by introducing fixed and variable cost components at industry and trade link level. The variable costs are proportional to the quantity of output produced and use the nesting of the production function in the standard GTAP model as described above. Fixed costs are associated with establishing the firm and with operating on each bilateral trade link; they typically only use primary factors.⁴ Consistent with the large group monopolistic assumption, each small firm does not consider its impact on the aggregate price index. Therefore, the usual markup-pricing rule reflects the demand elasticity and marginal cost, in the Melitz model corrected for the average productivity effect of firms operating on each bilateral trade link.

The average productivity of firms on each trade link is determined from a Pareto distribution function as discussed in Balistreri et al. (2011) which encompasses a so-called cut-off productivity level. Only firms with productivity equal or higher than that specific threshold level for each bilateral trade link will operate on that link; the remaining entered firms are forced to exit. Hence, a zero marginal profit condition ensures that the revenue of the average firm equals its fixed and variable cost. However, ensuring zero profit for operating firms on each trade link does not ensure zero profits for the industry as a whole due to sunk costs associated with the entry of new firms in the industry. Therefore, zero profit at industry level is assured by a free entry condition in the industry, indicating that the expected profit for firms over their life time must be equal to the overall industry fixed set up costs.

2.3. Sectoral and regional aggregation

Table A2 in Appendix 2 provides details how we treat the 57 sectors in our application. We apply the Melitz module to all 22 manufacturing sectors, the remaining ones face perfect competition. That choice is motivated by literature showing the importance of considering firm heterogeneity in manufacturing sectors (Balistreri et al., 2011; and Akgul et al., 2016), including food processing sectors (Luckstead and Devadoss, 2016; Berden et al., 2009; and Olper et al., 2014). We keep the full sector detail of the GTAP database to prevent bias (Britz et al., 2016) and use post-model aggregation (Table A2) to summarize results for the Melitz

and Armington commodities. Further, in order to capture the impact of TTIP on major world regions, we aggregate the GTAP data to ten regions (EU, US, Canada, MERCOSUR, China, ASEAN 10, Mediterranean countries, Other Northern Europe,⁵ low-income countries,⁶ Other OECD and Other Regions). Post model aggregation summarizes the information for the world as a total and for a rest of the world (ROW) aggregate which excludes the EU and US.

2.4. Model parameterization and calibration

In order to apply the above-described framework, the different parameters chosen must recover the observed benchmark consisting of the global social accounting matrix (SAM) provided by the GTAP database. That global SAM comprises many small entries both in relative and absolute terms, which can affect the numerical stability during solution of a CGE. We, therefore, filter out small transactions in relative terms in a systematic way after aggregation to our ten regions while maintaining a balanced global SAM (Britz et al., 2016).

Similar to the Armington approach, a major advantage of the Melitz model is that it requires relatively little information on the industry and its consumers, namely firstly parameters which describe the productivity based on a Pareto distribution and secondly the elasticity of substitution among varieties. We use the estimate of 3.8 from Bernard et al. (2003) for the elasticity of substitution, and an estimate of 4.6 for the Pareto shape parameter from Balistreri et al. (2011).

2.5. Computational issues

Memory needs and solution time of simulations with a CGE model depend on model detail and complexity. Detail reflects both detail in the database, notably the number of regions and sectors, and assumptions such as with regard to the number of different CES nest in production and constant elasticity of transformation (CET) nests in factor supply. In a key Equation (1)⁷ of Melitz (2003) depicting the bi-lateral import demands, an increase in the number of sectors (which are a sub-set of the agents a and each produce a product i in case of a diagonal make matrix) rises by the square the number of left hand side (LHS) variables Q_{airs} and the related prices of the agents $\tilde{P}A_{airs}$:

$$Q_{airs} = \tilde{Q}_{airs} N_{isr} = \lambda_{airs} N_{isr} Q_{air} \left(\frac{P_{air}}{\tilde{P}A_{airs}} \right)^{\sigma_{ir}} \quad (1)$$

That is different from the typical implementation of the Armington system in the standard GTAP model and many similar CGEs where bi-lateral import shares and related prices are not agent specific. That explains why Melitz models are more sensitive to increased sectoral details. Our implementation, therefore, substitutes out the Q_{airs} and $\tilde{P}A_{airs}$, along with other variables and equations with a bi-lateral regional index such as free on board (FOB) and cost insurance and freight (CIF) prices and trade margins. The same holds for industry by industry transactions.⁸ Consequently, in our implementation, model size increases only moderately in regional and sector detail. However, that does not decrease the number of Jacobian and Hessian elements and thus increases the density of the Jacobian and the Hessian. Furthermore, most equations allow for sparsity such that e.g. not all elements of Q_{airs} needs to be present such that we benefit from removing small transactions as discussed above (Britz, 2017, page 68ff). Furthermore, we scale the LHS and right hand side (RHS) in all equations relating to

³ The Melitz model defines the so-called “average firm” depicting the average productivity of all firms operating on a specific trade link.

⁴ The model uses a threshold during calibration that ensures that variable costs always comprise some minimum share of primary factor cost. That implies that in some cases the fix cost nest might also comprise intermediates.

⁵ Other Northern Europe include Switzerland, Norway and Rest of European Free trade Association (EFTA).

⁶ Our mapping of regions to the low-income countries aggregate follows the current World Bank classification.

⁷ For the description of variables see the technical Appendix 1.

⁸ Note that a GEMPACK based model might automatically substitute such variables and therefore scales better when the number of sectors is increased (Horridge and Pearson, 2011).

quantities and values with factors derived from the LHS in the benchmark to support CONOPT's automatic scaling and improve numerical stability. Not at least, our implementation allows to pre-solve single country model under the shock before the full global model is solved which can speed up solution of larger model (Britz et al., 2016).

The reason why Melitz based CGEs can be hard to solve and may end up infeasible is partly based on convexity issues based on the following mechanism under a shock that reduces demand for a sector such as resulting from increased imports under an FTA. The resulting drop in output following less demand leads to two countervailing impacts in the Melitz model: firstly, average productivity increases as the least efficient firms leave the industry and trade links which decreases costs, and, secondly, fix costs are distributed over a smaller output quantity which increases per unit costs, the latter is typically the dominating effect. Consequently, also costs for using the domestic industry's own output in its production increase. That leads to reduced demand by the industry for its own output, substituted by imports, or by other inputs if the production function allows for it. The love of variety effect amplifies the impact as the shrinking output quantities go along with fewer firms operating on the domestic link.

The reduced demand by the industry for its own outputs implies that unchanged fix costs for selling to the domestic market need to be distributed over an even smaller quantity. That further decreases the competitiveness of the domestic origin and thus provokes additional demand reductions which let shrink industry output even more. If price feedback from factor and other intermediate markets does not offset these impacts, the model can end up in a vicious circle where a sector completely vanishes. That might drive the model into corner solutions where the solver ends up in infeasibilities as non-negativity bounds become binding in addition to the normal model equations such that the system of equations is no longer square. Tests have shown that PATH as an MCP solver might correctly identify the corner solution, but more often fails even under shocks where no corner solutions occur and CONOPT solves the problem. But more often both solvers declare the model as infeasible; we assume in cases where they find locally no search direction where the sum of infeasibilities decreases. In order to avoid that vicious circle of ever increasing costs, three different approaches have been successfully applied by us in test shocks with differently detailed data bases. The first one pushes up price feedback from factor markets by making the non-depreciated part of the capital sector specific. That requires additionally an assumption over the simulation horizon to determine the number of years to which the depreciation rate used in the standard GTAP model is applied. Other modifications such as using rather small elasticities of transformations for factor supply to sectors might work as well. Secondly, bi-lateral and domestic intermediate input demand by the different sector can be aggregated, such that in Equation (1) only four agents are left (final private demand, government, investment and an aggregate over all sectors). That implies not only identical shares for the bi-lateral composition of imports, but also for domestic sales and imports as a total across sectors. The latter is not assumed in the standard GTAP model. However, these two approaches sometimes fail to overcome the problem, even combined. We therefore present in here results based on the third approach which seems to work best by modifying the underlying mechanism directly. Specifically, we allow to define a maximal cost share of intermediate domestic demand for an industries own output.⁹ If that threshold is exceeded in the benchmark, Equation (1) is replaced by a standard Armington formulation where s is equal r and commodity i is produced by agent a , while variable per unit costs are used as the price.

The decision about the threshold is defined based on the benchmark data. As such, the code will not decide on its own during the solution process to switch between price markups or not. Rather, it is up to analyst to define the threshold. He might be lucky and able to run the model without that modification. If that does not work, he can stepwise

decrease the threshold to introduce only the minimal modification to solve the model. The use of this threshold can be justified as part of the intermediate domestic demand of an industry for its own output is indeed intra-firm demand which should also in reality not subject to price markups. Note that with increasing number of sectors, the share of the intermediate domestic demand of a sector for its own output will systematically become smaller in average, reducing the impact of that correction on the overall results. At the same time, unfortunately, the chance increases to find a sector/region combination where the share is quite high and price feedback from inputs markets is low. Given the manifold data corrections necessary to yield a globally balanced SAM with high sectoral and regional detail, it is not unlikely that some of these entries are artefacts from balancing. Note also that it is likely that part of what is shown as demand of an industry for its own domestic origin might be indeed intra-firm demand.

The combination of manual scaling factors, substitution out high-dimensional variables, allowing for sparsity as well as the use of a pre-solve algorithm along either with aggregation of intermediate demand across sectors or with the conceptual change might explain why we are able to solve larger shocks also with many sectors treated a la Melitz and a larger number of regions. Possibly, non-constant returns to scale might also render the interplay of solving the log-linearized equations and their updates to levels in the specialized solver inbuilt in GEMPACK less efficient, compared to using the more general nonlinear programming (NLP) solvers such as CONOPT in our GAMS application.

3. Quantifying the policy experiment

3.1. Quantification of NTMs

When simulating impacts of a potential TTIP agreement, most literature relies on the –25% reduction in the trade restrictiveness of NTMs from Berden et al. (2009) which reflects expectations of European and American entrepreneurs and regulators about the potential outcome of an agreement.

Egger and Larch (2011) show that the impact of an FTA can be assessed as a reduction in ad-valorem equivalents (AVE) of both changes in tariffs and NTMs. Accordingly, changing NTMs in an FTA can be seen and estimated as ‘beyond tariff reductions’. Egger et al. (2015) present an approach to estimate cost saving impacts of a deep TTIP agreement based on a three step approach. First, they estimate a gravity model with country-specific fixed effects, bilateral control variables, a measure of political distance, and tariff margins by country-pair (within or outside FTAs). In order to assess cost saving effects, they add two explanatory variables: an integer value ranging from 0 (shallow) to 7 (deep) that measures the depth of existing FTAs based on Dür et al. (2014) and a dummy intra-EU relationship to distinguish EU membership and access to the EU common market from an FTA. Second, they simulate with that gravity model trade volume changes when introducing a deep FTA between the EU and US. Finally, they solve for the changes in the tariff rates that would yield the simulated bi-lateral trade volumes under a deep agreement without changing the “depth of FTA” variable. These changes in the AVE tariff rates provide an estimate for the cost saved related to the NTMs under a deep trade agreement. Egger et al. (2015) calls this the “ad valorem cost saving effects which are removable upon a deep TTIP trade agreement”, reported in Table A3 in Appendix 2¹⁰. Costs savings related

¹⁰ It should be noted that one would expect the NTMs measures of trade in commodities between the US and EU to be region specific (asymmetrical), rather than the symmetric NTM estimates. However, Egger et al. (2015) were not interested to measure the current level of NTMs between the two regions – they are indeed higher and asymmetric – but rather to see how a deep trade agreement between the US and EU could save a trade cost between two regions. Therefore, these estimates indicate the amount of NTMs that these two regions could reduce under a deep FTA.

⁹ In this study, we used 20% as a maximal share in all industries and regions.

Table 1
Scenario layout.

	Melitz Sectors included	AVEs of NTMS			
		Rent generating AVEs (40%)		Cost generating AVEs (60%)	
		Import tax (2/3)	Export tax(1/3)	Production cost equivalent	Demand shift equivalent
<i>MLZ_base</i>	✓	✓	✓	Relative reduction in bilateral fixed and variable cost	✓ Only in Armington sectors
<i>ARM</i>	×	✓	✓	×	✓
<i>MLZ_VC</i>	✓	✓	✓	Equivalent reduction in variable trade cost	✓ Only in Armington sectors
<i>MLZ_FC</i>	✓	✓	✓	Equivalent reduction in bilateral fixed cost **	✓ Only in Armington sectors
<i>Modeled as</i>		Reduction in import tariffs representing rents in importer country	Reduction in export taxes representing rents in exporter country	Converted to an equivalent reduction in bilateral fixed and variable trade cost	Converted to an equivalent reduction in demand

*If the bilateral fixed cost equivalent value of the cost generating NTMs exceeds 50% of the value of fixed cost, the remaining is allocated to variable cost.

to non-tariff barriers (NTBs) in service sectors shown in Table A3 stem from gravity estimates by Egger et al. (2015) who draw themselves on various sources, such as trade restrictions in services from the World Bank (Borchert et al., 2014), AVEs for trade barriers in services based on World Bank data (Jafari and Tarr, 2015), assessments of the General Agreement on Trade in Services (GATS) bindings and how these compare to Preferential Trade Agreement (PTA) services commitments from the WTO (Roy, 2014), and, finally, from available information on removability of the NTBs between the EU and US. We use that overall cost saving effect of moving to a deeper level of agreement in TTIP, beyond removing import duties and export subsidies. Note, as shown in Table A3, the removable NTMs are available for some aggregated sectors, only, which we apply consecutively for individual sectors within those categories. While this approach is hardly suitable for detailed empirical work, it fits our objective of pursuing an illustrative application of a CGE model with many different Melitz sectors under realistic shocks.

3.2. Modelling of NTMs

Several authors (Andriamananjara et al., 2003; Walkenhorst and Yasui, 2005; Fugazza and Maur, 2008) point out three general trade effects associated with NTMs and thus ways to allocate their cost: trade cost effects (or protectionism effects), supply shifting and demand shifting effects. The trade cost effect refers to an increase in bi-lateral export cost, for instance, costs for obtaining certification, while production costs for the exported and domestically produced quantities stay identical. Supply shifting effects result from additional cost in production for the export market, such as TBT regulations provoking compliance cost. The demand-shifting effect occurs when regulations affect consumer behavior, such as product labeling requirements. While trade cost and supply-shifting effects are always trade impeding, the impact of demand shifting effects is ambiguous. Furthermore, Fugazza and Maur (2008) underline that empirical quantification of demand shifting effects is both challenging and scarce. They acknowledge that changing the Armington elasticities might technically capture demand-shifting effects, but existing examples of that approach seem somewhat ad-hoc. Beckman et al. (2015), for instance, assume that a TTIP agreement will reduce the Armington demand elasticity by half. Furthermore, allowing for changes in the Armington elasticity on a specific trade link requires structural changes by introducing new CES nests. Although demand side shifting effects might be important for TTIP, we leave them out due to missing empirical evidence. The reader should note that the love of variety effect can be understood as demand shifting in the original Armington specification.

We, however, address in detail the supply side, i.e., cost effects, drawing on the discussed studies estimating the AVEs of NTMs. CGEs model trade cost effects of non-tariff barriers in three different ways: as a pure efficiency loss also called “sand-in-the-wheels” or “productivity shock”, as an export tax equivalent and as tariff equivalent approach.

Which approach or mix of approaches is appropriate depends on the nature of the NTMs, especially whether they are rent generating, i.e., allow market access only for certain agents, cost raising or both (Berden et al., 2009; Francois et al., 2013).

The tariff equivalent approach is appropriate when agents in the importing economy capture economic rents from NTMs. Symmetrically, rents accruing in the exporter country are modeled as an export tax equivalent. Here, Disdier et al. (2015, 2016) point out that in the presence of licensing measures, monopolistic rents can benefit the government of exporting countries if licenses are allocated via auctions or alternatively generate rents for foreign or local firms depending on the license allocation method (Junker and Heckelevi, 2012). In our modelling framework, the rents are collected via ad-valorem taxes by the government in the importer and/or exporter country where they thus generate tax income and increase at the same time demand prices in the importing country. Note that due to the regional household approach in our CGE, an allocation of the rents to private households would not change results.

The efficiency loss approach is appropriate when NTMs and other regulatory measures increase costs while no rents accrue, for instance in case of customs and administrative procedures, TBT and SPS regulations. The SAM should already capture cost increasing effects of NTMs. In its simplest form, the efficiency loss approach, however, increases the offer price of the exporter based on a wedge, i.e., not considering related cost, which hence focuses on import demand effects (Hertel et al., 2001). Owing to the Melitz structure incorporated in our CGE model, we explicitly increase production cost on the specific bi-lateral trade link instead, based on the ad valorem estimates of these costs. Without further information, we allocated them first proportionally to the fixed and variable cost of trade, subsequently, we perform a sensitivity analysis on the distribution (see section 4.3). The iceberg cost approach to model NTMs often used in Armington models has to allocate the changes fully to variable costs as fixed costs are not present. Note that both approaches assume that domestic production cost drop. Reducing bi-lateral trade margins is another possibility to capture cost savings. However, the AVE of NTMs might often far exceed these margins.

3.3. Scenario specification

We analyze in the following the impact of dismantling any import tariffs, export subsidies, and removable non-tariff barriers for all commodities between the EU and US such that a deep agreement is reached. Using that same shock, we perform sensitivity analysis, first based on the structure of the model (Melitz vs. Armington) and, second, on how cost generating impact of NTMs are captured in the Melitz framework. While removal of tariff measures is straightforward given observed tariffs, the modeler needs to decide how to allocate estimated costs of NTMs.

In case of AVE estimates of NTMs in a TTIP assessment, the literature relies for the cost allocation on the split-up of NTMs effects for the EU-US relation proposed by Berden et al. (2009). They report cost increases in

60% of the cases and rents in the remaining 40%. Both [Francois et al. \(2013\)](#) and [Egger et al. \(2015\)](#) model the 60% cost-increasing effect as a pure efficiency loss following [Hertel et al. \(2001\)](#), while the remaining 40% rent generating cases where distributed to import and export taxes on a 2/3:1/3 basis. In here, the rent generating cases are distributed the same way for all sectors, but the cost generating cases are modeled differently for Melitz sectors in three variants. For Armington sectors, we apply the usual iceberg cost of trade shocks.

[Table 1](#) presents the resulting four scenarios. The first scenario (hereafter, *MLZ_base*) considers 22 Melitz sectors (as shown in [Table A2](#)) and 35 Armington sectors. For the Melitz sectors, 60% of AVEs of NTBs for each sector and trade link are mapped into an identical relative reduction in bilateral fixed and variable cost. For the Armington sectors, the demand-shifting equivalent (DSE %) of trade cost is calculated and increases the bilateral preference shift parameter, the usual iceberg cost of trade approach. In the second scenario (*ARM*), all the sectors are considered perfectly competitive and thus use the iceberg cost of trade approach. Comparing *ARM* against *MLZ_base* thus shows the impact of considering many Melitz sectors under an identical shock. The third scenario *MLZ_VC* builds on *MLZ_base*, but allocates the trade cost shock to the trade link specific variable cost only.

The last scenario *MLZ_FC* allocates the trade cost shock on the fixed bi-lateral cost of trade. However, as fixed bi-lateral costs comprise more than just cost to comply with NTMs, we keep at least 50% of the fixed bi-lateral costs of the benchmark. If the shock exceeds that limit, the remaining shock is allocated to variable cost of trade. Comparing *MLZ_base*, *MLZ_VC* and *MLZ_FC* thus allows assessing how sensitive results are in a Melitz framework with regard to allocating cost generating impacts of NTMs.

4. Scenario analysis

While we presume that costs related to NTMs are observed in the global SAM, rents related to NTMs probably hide in capital income flows and are clearly so far not allocated bi-laterally. We therefore first run a simulation to include the rent generating effects associated with NTMs currently in place between the US and EU by introducing respectively increasing bi-lateral import and/or export taxes. That augmented database serves as the benchmark.¹¹ In the following, we first discuss the simulated impacts of removal of tariffs and trade subsidies as well as NTMs based on the first scenario (*MLZ_base*), presenting the specific outcomes for the motor vehicle sector as an illustrative case with a focus on the variables simulated in the Melitz module. The motor vehicles and parts industry (MVH) of GTAP, according to [Spearot \(2016\)](#), has one of the highest productivity dispersions across firms. Our sensitivity analysis (not shown here) also reveals that this sector has one of the highest percentage changes in response to the shocks. Subsequently, we compare the results with and without Melitz sectors focusing on changes in trade, GDP, and welfare. Finally, we analyze the sensitivity of results in the configuration with Melitz sectors where cost-generating impacts of NTMs are modeled differently.

4.1. Illustrative firm-level impact of policy shocks in a Melitz framework

[Table 2](#) shows in the rows the changes for the variables related to the average firm in the Melitz model associated with the production and sale of the “motor vehicle” sector in the EU on different bilateral trade markets. The first column refers to the domestic market, the second column denotes intra-EU trade, and the other columns show the EU trade with the US, other regions, and the total EU sale.

The results on the EU-US trade link show one typical reaction of a Melitz model: the tariff removal reduces the average CIF price for EU

Table 2

Average firm results for EU domestic sales and exports of “motor vehicle” [% change].

	Domestic sales	EU ^a	US	ROW	World
Firm price	−3.5	−2.8	14.7	−1.7	−0.5
Number of operating firms	−3.7	−0.4	322.2	5.9	30.9
Average output per firm	4.0	3.3	−24.6	2.1	2.5
Average productivity per firm	2.4	1.6	−25.8	0.4	−1.4
Industry fix costs	0.4	0.4	−13.5	0.4	−0.1
Fix costs per unit	0.2	−2.4	−72.8	−7.1	−12.8
Industry variable costs	−1.7	0.0	265.1	5.5	6.4
Variable costs per unit	−1.8	−2.8	14.7	−1.4	−0.3
Total output sold	0.2	2.8	218.4	7.3	9.2

^a The reader should note that the numbers presented in the column “EU” showing EU to EU exports are due to an aggregation effect. Sales to the domestic market of a nation are not reported as exports in the SAM. However, if we aggregate individual EU countries with GTAPAGG, the former bi-lateral trade links between two EU nations occur now inside one aggregate and become the diagonal trade flow in this column. The domestic sales of the EU aggregate are defined from adding up the domestic sales of individual EU countries.

imports into the US at unchanged per unit cost, and thus allows also new, however less productive, firms to operate on that trade link. That increases the number of varieties available in the US market by 322% and thus benefits the consumer. However, in average lower productivity lets variable per unit costs increase by about 14.7%, which is by definition equal to the change in the average FOB price before export taxation. The average firm after these changes is not only less productive, but also trades less: average output quantity per firm drops by about −24.6%. Considering both the increase in operating firms and falling average trade per firm, the traded quantity raises by about 218%. In other words, a larger part of the increase in the extensive margin (i.e., the number of operating firms) is offset by a reduction in the intensive margin of trade (i.e., the average output per firm). The large increase in the number of operating firms allows reducing per unit fix costs by about −72.8%, a change which already reflects that the average firm operating on that trade link is now less productive. Increasing the number of operating firms decreases the average productivity of the firms operating on that trade link (−25.8%), which implies that the average per unit variable costs (14.7%) and thus FOB prices increase. At the same, the average size of these firms also drops, as average output per firms decreases by about the same percentage. Together, these changes constitute a new equilibrium with zero profits for the firms operating on that trade link while monopolistic prices charged are equal to the willingness to pay for the specific quality delivered on that trade link given the number of varieties available. The finding is in line with the literature emphasizing the importance of the extensive margin of trade ([Hummels and Klenow, 2005](#); [Chaney, 2008](#)). Moreover, only small changes of the variables on the link between EU and other regions link are observed, such that overall changes in trade mainly reflect the discussed changes on the EU-US link.

Table 3

Average firm results for US domestic sales and exports of “motor vehicle” [% change].

	Domestic sales	EU	ROW	World
Firm price	−2.3	23.8	−1.7	0.6
Number of operating firms	−11.6	434.5	−9.5	23.9
Average output per firm	3.3	−30.2	2.1	2.5
Average productivity per firm	1.6	−31.3	0.4	−2.5
Industry fix costs	0.8	−13.6	0.7	0.6
Fix costs per unit	10.4	−76.8	6.7	0.0
Industry variable costs	−12.1	362.0	−6.8	−7.1
Variable costs per unit	−3.8	23.8	−1.5	0.5
Total output sold	−8.7	273.2	−5.4	−3.9

¹¹ We use the filtering approach discussed in [Britz et al. \(2016\)](#) to remove first very small transactions from the global SAM to improve solution behavior.

Table 4

Export volumes by region for “motor vehicle” [% change].

Regions	EU	US	ROW
World	5.5	20.8	0.0
EU	2.8	218.4	7.3
US	273.2		−5.4
ROW	−9.1	−11.1	−3.2

Table 5

Total export volumes by region [% change].

Regions	MLZ_base			ARM		
	EU	US	ROW	EU	US	ROW
World	3.9	19.4	−0.4	1.4	10.4	−1.0
EU	−3.6	114.5	−2.6	−4.6	77.7	−2.0
US	110.7		−2.1	74.4		−9.4
ROW	−1.0	0.6	0.7	−0.3	−2.9	1.1

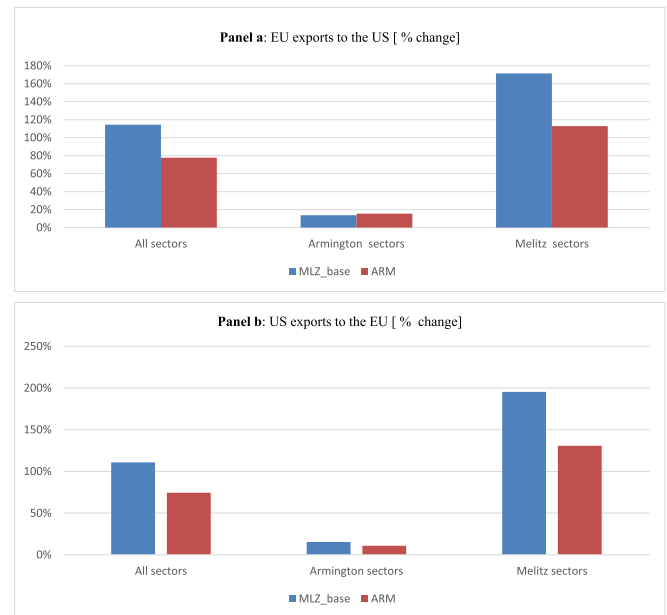
The expansion in exports combined with in average less productive firms involved in trade increases the overall input demand in the economy which in turn bids up factor and other intermediate prices. As a first order impact, production costs increase and let profits on other trade links decline. In the EU domestic market, that induces some low productive firms to exit, the number of operating firms drops by −3.7%. As firms with low productivity, output and production factors are reallocated towards higher-productivity and larger firms, average productivity of firms operating in the EU domestic market rises by 2.4%. That, in turn, leads to an ultimate drop in variable costs per unit of −1.8%. These changes result in an increase in average output per firm of 4%. The increase in average firm output compensates for the decrease in the number of firms operating in the domestic market. Consequently, domestic sales increase by 0.2%, along with lower offer prices of −3.5%, reflecting the increased competition with US imports at lower border protection and the reduced export costs to the US.

Table 3 reports changes for export flows and domestic sales of motor vehicles from the US. Note first the impact on the US-EU link: following the reduction in border protection and trade cost, less productive firms find it profitable to enter. Thus, the number of operating firm on the US-EU link increases by factor 4.38. That, in turn, lowers the average productivity on that link, such that the average firm price and output increase. Still, US exports to the EU increase considerably by factor 2.73, which reflects removal of tariffs and bilateral trade costs plus increased willingness to pay due to a higher number of varieties. Export expansion ultimately negatively affects the output sold in the domestic market by −8.7%. In summary, the total industry sale of the US of motor vehicles decreases significantly by −3.9%.

A summary of export flows for the “motor vehicle” sector provides Table 4. As the ad-valorem equivalent estimates of the expected changes in existing NTMs between the EU and US are quite high (see Table A3), EU exports to the US for motor vehicle industry increase by 218% while US exports to the EU increase by 273%. The percentage changes are comparable as the productivity of EU and US firms operating on the bilateral trade links is similar (not shown in the table) and reflects that both countries are subject to similar reduction in NTMs (see Table A3). Nonetheless, the reason that US exports to the EU experience slightly higher changes reflects mainly higher tariffs by the EU compared to the US (not shown in the table).

4.2. Impacts on trade, welfare, and GDP: Melitz vs. Armington structure

Table 5 shows simulated changes in the volume of total export flows, measured in constant million US\$, comparing the *MLZ_base* case with 22 Melitz sectors and 35 Armington ones to an Armington only configuration in *ARM*. Exports of the EU to the US increase by 114% under the Melitz configuration compared to 77% under the Armington one.

**Fig. 1.** Export flows between the US and EU.

Similar, the US exports to the EU raise by 110% with Melitz sectors compared to 74% with competitive sectors, only. Comparable relative differences in trade flows are reported by Hosoe (2017) for a simulation of Brexit in a CGE model with some Melitz sectors where he finds almost 60% higher trade impacts compared to a configuration based solely on Armington.

Looking into sectoral export trade flows - differentiated by the manufacturing sectors captured in the Melitz model and the remaining ones in Fig. 1 – underlines that manufacturing sectors dominate the overall impact independent of the model configuration. The larger simulated exports if they are depicted based on the Melitz model thus also drives economy-wide differences. However, under the Melitz configuration, the remaining competitive sectors expand somewhat less compared to a pure Armington configuration, reflecting competition between sectors in input markets.

4.2.1. Effects on welfare, and real GDP

Welfare impacts are measured based on the equivalent variation (EV) criterion (i.e., the additional income needed at benchmark prices to reach the same utility as under simulated income and prices). Global welfare increases by 253 billion US\$ if manufacturing sectors are depicted by Melitz, more than double the 108 billion US\$ found under the Armington configuration (Table 6). Higher welfare is associated with overall increased industry productivity due to firm entry and exit, reallocation of the production share among existing firms, and increases in the number of varieties on the trade links. Balistreri et al. (2011) also report considerably higher welfare gains compared to an Armington model.

Real GDP increases of 0.85% (EU) and 1.13% in (US) in *MLZ_base* compared to 0.36% (EU) and 0.77% (US) in *ARM*, reflecting these welfare gains. The impact on global real GDP follows a similar pattern.

Table 6

Impacts on welfare and real GDP.

Regions	Welfare [Billion US\$]		Real GDP [% change]	
	MLZ_base	ARM	MLZ_base	ARM
World	253	108	0.40	0.17
EU	133	56	0.85	0.36
US	162	108	1.13	0.77
ROW	−43	−56	−0.12	−0.17

Table 7

Export volumes between the EU and US [% change].

	Exports of the EU to the US			Exports of the US to the EU		
	<i>MLZ_VC</i>	<i>MLZ_base</i>	<i>MLZ_FC</i>	<i>MLZ_VC</i>	<i>MLZ_base</i>	<i>MLZ_FC</i>
Number of operating firms	206.4	270.5	538.7	247.1	321.9	620.9
Average output per firm	−5.9	−26.7	−61.7	−10.4	−30.0	−62.8
Average productivity per firm	−16.5	−18.3	−28.6	−16.2	−18.0	−28.3
Total output sold	188.2	171.5	144.8	210.9	195.5	168.5

4.3. Sensitivity analysis on allocating NTM costs

4.3.1. Trade impacts

This section compares trade, welfare, and GDP impacts under different allocations to bilateral fixed and variable costs of trade of the same costs associated with NTMs. As indicated in Table 7, the number of operating firms increases under higher allocation shares to fixed cost. Their number on the EU-US link about doubles (206% in *MLZ_VC*) if fixed costs are unchanged, almost triples (270% in *MLZ_base*) if bilateral and variable cost of trade change by the same percentage change and increases by more than factor five (538% in *MLZ_FC*) if fixed costs of trade are allowed to be reduced by up to 50%. These results are in line with the theory of firm heterogeneity suggesting that reducing bilateral fixed cost of trade allows the less productive firm establishing new trade links, which results in an increase in traded varieties.

With new firms entering the trade link, the average output per firm on the trade link (i.e., the intensive margin of trade) will decrease across the different scenarios. As shown in Table 7, higher increases in the extensive margin of trade go along with larger decreases in the intensive margin of trade (i.e., the average output per firm on that trade link). The increases in extensive margin of trade of 206%, 270%, and 538% on the EU-US trade link discussed above are associated by reductions in intensive margin of trade in *MLZ_VC* (−5.9%), *MLZ_base* (−26.7%), and *MLZ_FC* (−61.7%), respectively. These results suggest that the intensive margin of trade is more elastic with respect to the bilateral variable cost of trade.

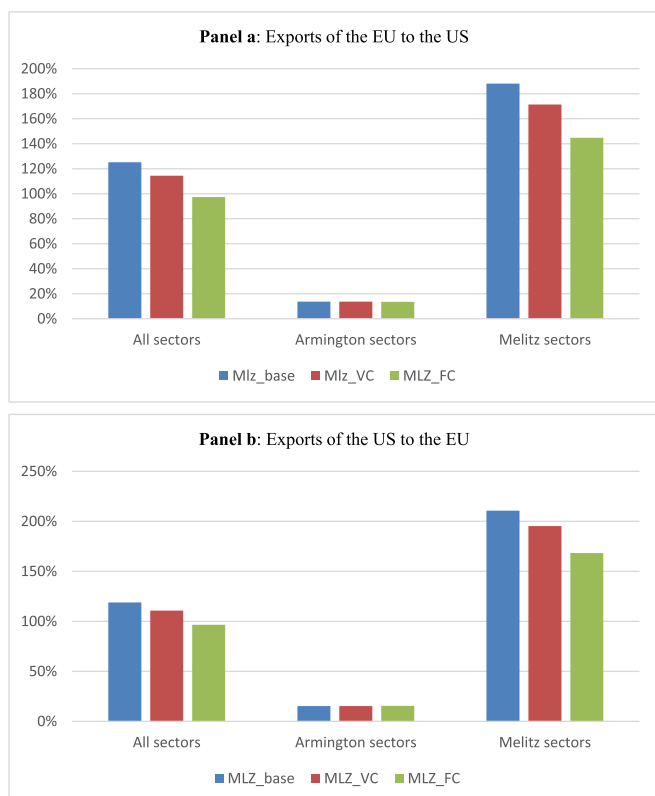
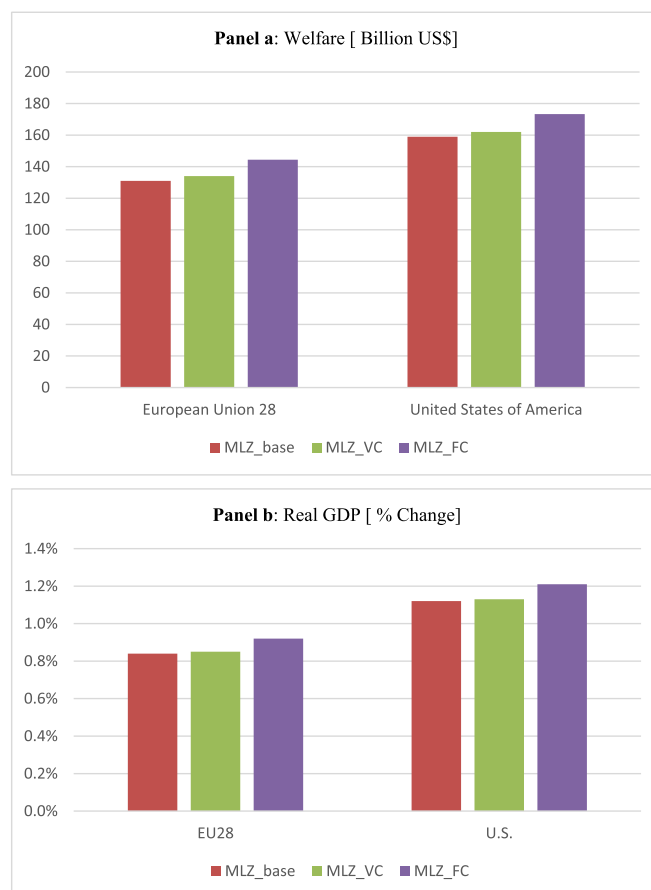
This result are also in line with the theory suggesting that once firms are operating on a given bilateral trade, the bilateral variable costs of trade affect the intensity of trade. That matches Berthou and Fontagné (2015) which found in econometric analysis that 17% of the effect of variable trade costs is reflected in the number of products exported, and the rest of the effect is channeled through the intensive margin.

The net effect of the changes at the extensive and intensive margin reveals that allocating trade costs savings solely to bilateral variable costs leads to higher overall trade changes compared to allocating a higher share of the costs to fixed one.

The analysis of trade flows for Armington commodities, Melitz commodities and total export flows in response to the changes in bilateral variable and fixed cost of trade provides Fig. 2.

4.3.2. Welfare and real GDP impact

Increases in the number of operating firms and overall industry productivity are additional sources of welfare gains in the Melitz framework not found in an Armington one. As seen from Table 7, the number of operating firm will increase more significantly when more of the bilateral trade cost reductions are allocated to the bilateral fixed costs, which also implies a larger reduction in productivity for the average firm. However,

**Fig. 2.** Exports flows between the EU and US.**Fig. 3.** Welfare and GDP effect under different imposition of NTMs.

in our example, that impact is typically offset in the different sectors by slightly larger productivity increases on the domestic trade link, while the remaining trade flows are hardly affected. The overall industry productivity, therefore, will increase which further boosts the welfare effect. The welfare impacts across regions are summarized in Panel a of Fig. 3. Both the EU and US are better off in all scenarios, but with larger differences: welfare increases are highest in *MLZ_FC* which mostly reduces bilateral fixed costs of trade and lowest in *MLZ_VC* where fixed costs are not reduced at all. These findings also are reflected in real GDP impacts as illustrated in Panel b of Fig. 3.

5. Summary and conclusion

A vast body of literature supports with empirical evidence the Melitz (2003) model, which has led to different attempts to integrate it into existing CGEs. However, to our knowledge, a robust implementation allowing for dis-aggregated analysis with many sectors and regions is still missing. We, therefore, develop a Melitz module for the modular CGE modelling platform CGEBox (Britz, 2017) with a focus on numerical stability, building on Balistreri et al. (2011, 2013) and Akgul et al. (2016). We employ the module in an illustrative application to TTIP, considering besides the EU and US further eight global regions and treat 22 manufacturing of our total 57 sectors based on Melitz (2003). We compare key results to a configuration where all sectors follows the still dominant Armington assumption in CGE analysis. Our findings of sizeable larger trade and welfare impacts compared to an Armington configuration confirm the theoretical underpinnings and empirical findings of new trade theory.

Applying the Melitz extension is especially inviting for FTA impact

assessments with their focus on bi-lateral trade impacts, not at least as the Melitz model allows to distinguish fixed and variable bilateral trade cost savings related to NTMs. We show with sensitivity analysis how allocating the overall estimated trade costs savings under TTIP differently to fixed and variable costs affects key results. As the theory suggests, fixed cost saving have a larger impact on increasing the number of operating firms on a trade link, while variable costs savings mainly increase traded quantities per firm. Overall, in our example, allocating a larger share of the cost savings to variable cost triggers larger trade generation effects, but lower welfare changes. The latter reflects the reduced welfare gains from love of variety linked to a lower increase in the number of operating firms.

Overall, the paper underlines again the advantages of the Melitz framework in empirical analysis. That holds especially in assessments of FTAs where NTMs are typically complex in nature and related cost savings large. Here, our robust open-source implementation of the Melitz model in a CGE is especially advantageous as it allows for a high sectoral resolution and thus detailed analysis of changes at the intensive and extensive margin of trade and related welfare changes.

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Appendix 1. Technical Appendix

Implementation of Melitz model into the standard GTAP model

We incorporate a module based on Melitz (2003) into the flexible and modular CGE model CGEBox (Britz, 2017). The actual implementation of the Melitz model into CGEBox draws largely on the empirical method by Balistreri et al. (2011, 2013) and Akgul et al. (2016) to introduce the Melitz (2003) model into an applied equilibrium model.

The Melitz framework focuses on intra-industry differentiation where each firm produces a single unique variety. However, data at the firm level are limited and applied equilibrium models work at aggregate levels. Fortunately, Melitz offers a numerical framework build around (marginal changes in) the average firm operating within a trade linkage. That average firm's productivity comprises all necessary information on the distribution of productivity levels of firms active in that link. That vastly eases the model's implementation by effectively eliminating any data needs at individual firm level as detailed below. Against a background of that definition of an average firm within each trade linkage, we now focus on the formulation of an empirically computable version of Melitz model and its linkages with the GTAP model.

Assume that a representative agent 'a' (private households, government, investors, intermediate inputs by the different firms) in region 'r' obtains utility U_{air} from consumption of the range of differentiated varieties of product 'i' and considering the CES utility function as proposed by Dixit and Stiglitz (1997), the aggregate demand by each agent a for commodity i in region r (Q_{air}) which is equivalent to utility ($Q_{air} \equiv U_{air}$) can be represented as:

$$Q_{air} = \left(\sum_s \int_{\omega \in \Omega_{isr}} \lambda_{aisr}^{\frac{1}{\sigma_{ir}}} Q_{aisr}(\omega)^{\frac{\sigma_{ir}-1}{\sigma_{ir}}} d\omega^{\frac{\sigma_{ir}}{\sigma_{ir}-1}} \right)^{\frac{1}{1-\sigma_{ir}}} \quad (A1)$$

where Ω_{isr} represents the set of products i sourced from region s to r and $\omega \in \Omega_{isr}$ index the varieties in the set Ω_{isr} . In this context, $Q_{aisr}(\omega)$ represents the demand quantity of commodity i for variety ω in region r by agent a which is sourced from region s , σ_i represents the constant elasticity of substitution for each commodity, and λ_{aisr} are preference weights (share parameters)¹² that reflect differences between origins not linked to diversity in varieties. Note that substitution elasticities might be differentiated by destination region r , but are uniform across agents in each region in our implementation.

The resulting CES unit expenditure function which is the dual price index on Dixit-Stiglitz composite demand in region r (P_{air}) is given by:

$$P_{air} = \left(\sum_s \int_{\omega \in \Omega_{isr}} \lambda_{aisr} P_{Aaisr}(\omega)^{1-\sigma_{ir}} d\omega \right)^{\frac{1}{1-\sigma_{ir}}} \quad (A2)$$

¹² The reader should note that the share parameters are absent in the original Melitz paper. We hence allow here a differentiation between products from different origins as in the Armington model in addition to the love of variety effect.

where $PA_{air}(\omega)$ is agent's a (purchase) price of product i for variety ω in region r sourced from region s . Using the aggregate price index in Melitz (2003) based on the definition of the average firm and considering that varieties do not differ in their marginal utility for the first unit, one can define the price index as equivalent to the dual price defined in Equation (A2)

$$P_{air} = \left(\sum_s \lambda_{air} N_{isr} \widetilde{PA}_{air}^{1-\sigma_{ir}} \right)^{\frac{1}{1-\sigma_{ir}}} \quad (A3)$$

where $\widetilde{PA}_{air}$ denotes the agent price inclusive of export, import and consumption taxes for the average firm, and N_{isr} refers to the number of firms operating on the trade link s - r . Equation (A3) generates the top level Armington price for each agent, replacing the Armington price aggregator in GTAP from the agents' domestic and import prices. Consistent with Melitz (2003), there is a one-to-one mapping among firms and varieties such that the number of firms is equal to the number of varieties on each trade linkage. In comparison to Equation (A2), which is based on the individual varieties, Equation (A3) summarizes the compositional change (i.e., change in the number of varieties), which goes along with an update of the average price. Again we assume the same substitution elasticities across agents.

The total (Q_{air}) and average per firm ($\bar{Q}_{air}$) demand for the average variety by an agent to be shipped from s to r ($\bar{Q}_{air}$) can be obtained by applying Shephard's Lemma on the expenditure function:

$$Q_{air} = \bar{Q}_{air} N_{isr} = \lambda_{air} N_{isr} Q_{air} \left(\frac{P_{air}}{\widetilde{PA}_{air}} \right)^{\sigma_{ir}} \quad (A4)$$

This equation replaces the equations determining the agent specific Armington demands for the domestic and imported good as well as the equations for bi-lateral import demand which are not agent specific in the GTAP standard model.

This reveals the main differences to a standard Armington composite: the share parameters vary with the number of operating firms (i.e., the number of varieties comprised in the bilateral trade bundles). As the agent demand for the average firm's output in region s in each industry i in region r (Q_{air}) depends on the aggregate regional demand for that industry Q_{air} , we need to determine this in equilibrium for each agent. In other word, we need to determine the demand for use of i as an intermediate input in each sector separately, and as final demand for household consumption, government consumption, investment, and for international transport margins. In the standard GTAP model, each agent has a specific preference function which determines the demand for each Armington commodity; the government and saving sector based CES preferences, while households use a CDE indirect demand function. The Armington demand for each agent and commodity is then decomposed into a domestic and import component in the first Armington nest. The second nest decomposes import demand by each region by origin, independent of the agent.

The implementation of the Melitz model thus simplifies the demand structure present in the standard GTAP model by aggregating the two Armington nests into a single one, however, note that the GTAP database does not yet differentiate in the SAM bi-lateral flows by agent. Therefore we use the same shares by origin to separate import demand for the different agents.

Assume that a small profit maximizing firm facing the constant elasticity of demand according to Equation (A4) for its variety and based on the assumption of the large group monopolistic competition, a firm will not consider its impact on the average price index and therefore follow the usual markup rule to translate their marginal cost of production (c_{is}) to the optimal price.

Firms in Melitz (2003) face different types of cost: sunk fixed cost of entry f_{is}^e , fixed cost of operating on a trade linkage f_{isr} and marginal cost c_{is} . Let φ_{isr} indicate the firm's specific productivity, which measures the amount of "variable composite unit" needed per unit of output Q_{isr} . Accordingly, the marginal cost per unit is the amount of "composite input" required per unit $\left(\frac{1}{\varphi_{isr}} \right)$ times the unit cost of the "variable composite input" (c_{is}) in industry i

of region s . Therefore, a firm wishing to supply Q_{isr} units from region s to r employs $\left(f_{isr} + \frac{Q_{isr}}{\varphi_{isr}} \right)$ units of "variable composite input." The structure of fixed costs and variable composite input demand is discussed in detail below. Let, τ_{isr} denote the iceberg cost of trade, which represent domestic production costs and not the international trade margins present in GTAP. Focusing on the average firm with a productivity $\bar{\varphi}_{isr}$ operating within a trade linkage and solving the firm's profit maximization problem, the price charged by the average firm in region s to supply region r $\widetilde{PF}_{isr}$ (inclusive of domestic transport margin) is:

$$\widetilde{PF}_{isr} = \frac{\sigma_{ir}}{\sigma_{ir} - 1} \frac{\tau_{isr} c_{is}}{\bar{\varphi}_{isr}} \quad (A5)$$

where $\frac{\sigma_{ir}}{\sigma_{ir} - 1}$ represents the constant markup ratio in industry i , which reflects market power due to product differentiation into varieties. This newly introduced equation translates the variable per unit cost function for each sector and region into offer prices by the firms on each trade link including domestic sales. In the standard GTAP model, offer prices are not differentiated by destination and are equal to per unit cost corrected for output taxes.

The average price in Equation (A5) therefore depends on the price of variable composite input c_{is} , which is a function of the price of intermediates and primary factors. Given the assumption of constant return to scale and the way technology is presented in the standard GTAP model, the unit cost function for sector i in region s c_{is} in GTAP is given by the Leontief composite of the value added bundle (CES aggregate of factors of production) and the aggregate of intermediate demand (Leontief aggregate of intermediate demands). In the CGEBox, m_{px}^{13} is a macro defined as producer price, which constitute per unit costs corrected for production taxes. To be consistent with our Melitz formulation, the unit cost inclusive of production tax is directly introduced in the markup Equation (A5). It should be emphasized that the presence of fixed cost in the Melitz model is the source of increasing returns to scale in a monopolistically competitive industry: if firms expand production, the fixed cost can be distributed over a greater quantity of outputs such that per unit cost decreases.

¹³ http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

While observed data on quantities traded and related prices allow identifying the necessary attributes of an average firm, additional information is needed to gain information about the marginal firm (i.e., the firm that earns zero profit). Obviously, the distance in productivity between the average and marginal firm reflects properties of the underlying distribution. We rely here on a Pareto Productivity distribution, which has analytical tractability.

Let M_s indicate the number of firms choosing to incur the fixed entry cost (i.e., total industry size), each individual firm receives its productivity φ draws from a Pareto distribution with Probability Density Function (PDF):

$$g(\varphi) = \frac{a}{\varphi} \left(\frac{b}{\varphi} \right)^a \quad (\text{A6})$$

and Cumulative Distribution Function (CDF).

$$G(\varphi) = 1 - \left(\frac{b}{\varphi} \right)^a \quad (\text{A7})$$

where b is the minimum productivity and a is a shape parameter. Lower values of the shape parameter imply higher productivity dispersion among firms. As discussed in Melitz (2003), $a > \sigma_{ir} - 1$ should be applied in order to ensure a finite average productivity level in the industry.

On each bilateral trade linkage, the given fixed bilateral trade cost, variable costs and demand define jointly a certain cut off productivity level (φ_{sr}^*) at which firms will receive zero profit. A firm with the productivity equal to that threshold level ($\varphi_{sr} = \varphi_{sr}^*$) will therefore face zero profits and act as the marginal firm from region s supplying r . Those firm whose productivity is above the threshold level ($\varphi_{sr} > \varphi_{sr}^*$) will receive a positive profit and will operate on the $s - r$ link and those firm with productivity that is below the threshold level ($\varphi_{sr} < \varphi_{sr}^*$) will not operate on the $s - r$ linkage. Focusing on the fixed operating cost f_{isr} in composite input units, the marginal firm on s - r linkage receives zero profit at:

$$c_{isr} f_{isr} = \frac{r(\varphi_{isr}^*)}{\sigma_{ir}} \quad (\text{A8})$$

where $r(\varphi_{isr}^*) = p(\varphi_{isr}^*)q(\varphi_{isr}^*)$ denotes the revenue of marginal firm at the productivity equal to the cut off level ($\varphi_{isr} = \varphi_{isr}^*$).

The zero cut off productivity level in each bilateral market φ_{isr}^* can be obtained by solving Equation (A8). However, it is numerically easier to define this condition in terms of the average rather than the marginal firm. To do this, we define the productivity and revenue of the average firm relative to that of the marginal firm. Following Melitz (2003), average productivity is defined as the CES aggregation of productivities of all firms operating on a given trade link:

$$\tilde{\varphi}_{isr} = \left[\frac{1}{1 - G(\varphi_{isr}^*)} \int_{\varphi_{isr}^*}^{\infty} \varphi_{isr}^{\sigma_{ir}-1} g(\varphi) d\varphi \right]^{\frac{1}{1-\sigma_{ir}}} \quad (\text{A9})$$

If these productivities are Pareto distributed, we can write¹⁴:

$$\tilde{\varphi}_{isr} = \left[\frac{a}{(a + 1 - \sigma_{ir})} \right]^{\frac{1}{1-\sigma_{ir}}} \varphi_{isr}^* \quad (\text{A10})$$

Equation (A10) provides the relationship between the productivities of the average and marginal firm.

Using optimal firm pricing according to Equation (A5) and given the input technology, the ratio of revenues of the firms with marginal productivity $r_{isr}(\varphi^*)$ in relation to the revenue of the firm with the average productivity $r_{isr}(\tilde{\varphi})$ is defined as:

$$\frac{r_{isr}(\varphi^*)}{r_{isr}(\tilde{\varphi})} = \left(\frac{\varphi^*}{\tilde{\varphi}} \right)^{\sigma_{ir}-1} \quad (\text{A11})$$

Solving Equation (A10) for $\frac{\varphi^*}{\tilde{\varphi}}$, substituting it into (11), and then solving the resulting equation for $r_{isr}(\varphi^*)$ and replacing its value in Equation (A8), defines a relation between the bilateral fixed cost at current composite input price (the LHS of (12) below), the average firms revenue ($\tilde{P}F_{isr} \tilde{Q}_{isr}$), the shape parameter of the Pareto distribution of the productivities and the substitution elasticity of demand:

$$c_{isr} f_{isr} = \frac{(a + 1 - \sigma_{ir})}{a \sigma_{ir}} \tilde{P}F_{isr} \tilde{Q}_{isr} \quad (\text{A12})$$

Note that average firm's sale in region s in each industry i to region r ($\tilde{Q}_{isr}$) at the equilibrium is composed of the demand for use of i by different agents.¹⁵

The optimal pricing in the markup Equation (A5) requires information on the average productivity on each bilateral trade link. In Melitz (2003), the

¹⁴ One could use industry specific shape parameter (a_i) given the availability of data at sectoral level. In this study we assume that all firms entering in different industries draw their productivity from the Pareto distribution function with same characteristics (i.e., same scale and shape parameter).

¹⁵ $\tilde{Q}_{isr} = \sum_a \tilde{Q}_{aisr}$.

probability that a firm will operate is $1 - G(\varphi_{isr}^*)$, which is equal to the fraction of operating firms over total number of firms choosing to draw their productivity $\left(\frac{N_{is}}{M_{is}}\right)$. Using the Pareto cumulative distribution function from Equation (A7) and inverting it we have:

$$\varphi_{isr}^* = \frac{b}{\left(\frac{N_{is}}{M_{is}}\right)^{\frac{1}{a}}} \quad (\text{A13})$$

Substituting Equation (A13) into Equation (A10) results in Equation (A14) introduced into the model.

$$\tilde{\varphi}_{isr} = b \left[\frac{a}{(a+1-\sigma_{ir})} \right]^{1-\sigma_{ir}} * \left(\frac{M_{is}}{N_{isr}} \right)^{-\frac{1}{a}} \quad (\text{A14})$$

Next, the number of firms selecting to enter the market M_{is} is determined. Based on the free entry condition, the last firm that enters has expected profits over its life time, which just offset the sunk cost of entry. Industry entry of a firm requires a one-time payment of f^{ie} . A firm that enters a market faces a probability of δ to suffer a shock, which forces its exit in each future period. Therefore δM_{is} firms are lost in each period. Based on Melitz (2003), in a stationary equilibrium, the number of aggregate variables must remain constant over time, including industry size. This requires that the number of new entrants in every period is equal to the number of firms lost δM_{is} . Therefore, total entry cost is equal to $c_{is} \delta M_{is} f^{ie}$. Each firm faces the same expected share on that cost (i.e., $c_{ir} \delta f^{ie}$ if risk neutral behavior and no time discounting is assumed). The firm's expected share of entry costs must be equal to the flow of expected profit on the condition that firm will operate:

$$\tilde{\pi}_{isr} = \frac{\tilde{P}F_{isr} \tilde{Q}_{isr}}{\sigma_{ir}} - c_{is} f_{isr} \quad (\text{A15})$$

The probability that a firm will operate on the s-r trade linkage is given by the ratio of $\frac{M_{is}}{N_{is}} G(\varphi_{isr}^*) = \frac{N_{is}}{M_{is}}$. Thus, the free entry condition ensures that the expected industry profits (i.e., the profits summed up over all potential bilateral trade links) is equal to the annualized flow of the fixed costs of entry

$$c_{is} \delta f^{ie} M_{is} = \sum_r N_{isr} \tilde{P}F_{isr} \tilde{Q}_{isr} \frac{\sigma_{ir} - 1}{a \sigma_{ir}} \quad (\text{A16})$$

where zero profit condition in Equation (A12) is used to replace the fixed operating cost $c_{is} f_{isr}$. With the number of entered firm established in Equation (A16), we now turn to total composite input demand of the industry Y ,¹⁶ which consists of three components: sunk entry costs of all entrants ($\delta M_{is} f^{ie}$), operating fixed cost $\left(\sum_s N_{isr} f_{isr}\right)$ on each trade linkage, and variable costs $\left(\sum_r N_{isr} \frac{\tau_{isr} \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}}\right)$. Therefore, composite input demand is defined as:

$$Y_{is} = \delta M_{is} f^{ie} + \sum_r N_{isr} \left(f_{isr} + \frac{\tau_{isr} \tilde{Q}_{isr}}{\tilde{\varphi}_{isr}} \right) \quad (\text{A17})$$

This equation replaces the output balance equation in the standard GTAP model which ensures that exports and domestic sales for each sector are equal to input composite demand. Table A1.1 summarizes the full set of Melitz equations, and shows the variables through which Melitz model is linked into the structure of the GTAP standard model.

Table A1.1
Equilibrium conditions.

Equation	Equilibrium condition	Paired variable
(A3)	Sectoral Aggregation	P_{air} : Sectoral price index
(A4)	Firm-level demand	$\tilde{P}_{isr}$: Average firm price
(A5)	Firm-level Pricing	$\tilde{Q}_{isr}$: Average firm quantity
(A12)	Zero cut off condition	M_{is} : Number of operating firms
(A14)	CES Weighted Average productivity	N_{is} : Average firm productivity
(A16)	Free entry condition	N_{isr} : Number of entered firm
(A17)	Factor market clearing condition	c_{is} : Sectoral composite input price

Production structure for sectors in the Melitz module

This section briefly introduces the production technology for the Melitz commodities which is based on Akgul et al. (2016). The main differences to the GTAP standard model are production function nestings specific to variable and fixed costs. The production nesting for variable and fixed cost is shown in Figure A1 where the total cost is the sum of variable and fixed costs, the latter is added up from fixed cost per firm which entered the industry and fixed cost on each trade link per firm operating on that link.

The variable cost nest uses both a value-added and an intermediate composite based on constant returns to scale (CRS) technology, and in the default case, the fixed cost nest only uses value-added. However, if the overall total cost share of value-added in a sector is small, also the fixed nests comprise a share of intermediate composite. This alternative is identified with the intermediate composite in brackets. The value added and intermediate bundles

¹⁶ Y corresponds to XP the GTAP in GAMs model.

are CES composite of primary factors of production and intermediate inputs, respectively. The total value added (not shown here) is the sum of value added used in both variable and fixed cost nestings. Similarly, the total use of intermediate commodities and primary factors (not shown here) are the sum of their use in fixed and variable cost nestings.

In the variable cost nests for the Melitz sectors, primary factors or intermediate inputs used are proportional to output, i.e. average output per firm on each trade link times firm operating on the link, summed up over all trade links, corrected for average productivity. On the other hand, the fixed cost nests reflect solely the number of firms which entered the industry and the trade links, and not average output per firm.

Each intermediate commodity used by a Melitz sector could be either a Melitz or Armington commodity, and the intermediate input bundle is a CES composite of these commodities, in the default configuration based on fixed input coefficients. For the Armington goods, we retain the standard GTAP model assumption of domestic and import distinction where imports are sourced at the border (not shown). There is no separate domestic and imports distinction for Melitz commodities, but only one aggregator with love-variety effects which comprises domestic sales and all bi-lateral imports.

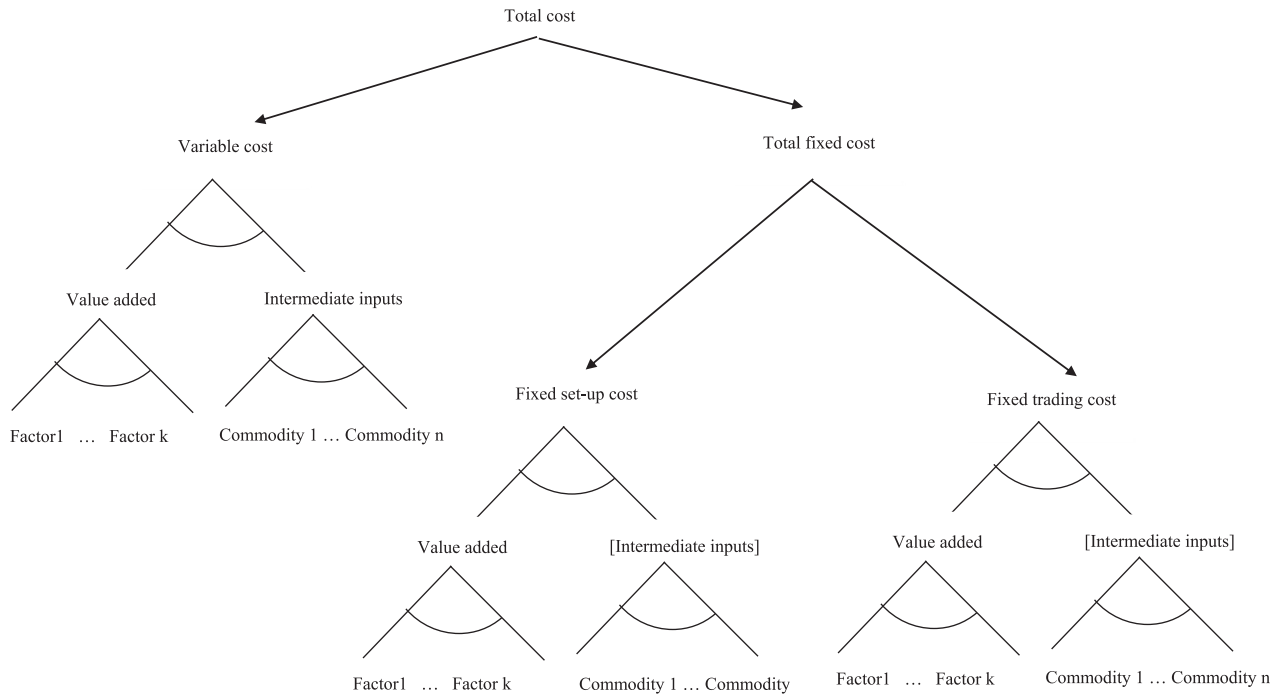


Fig. A.1. Production structure in Melitz sectors.

Comparison of the modelling framework with the existing frameworks

We compare our modelling framework with that of Balistreri et al. (2011, 2013) and Akgul et al. (2016) in Table A1.2. Balistreri et al. (2011) provide the basis of our implementation to which we add modifications introduced by Akgul et al. (2016) and ourselves. The second column of the table reports the original equation numbers found in these two papers. If Akgul et al. (2016) use the same equation layout as in Balistreri et al. (2011), we report only the number from Balistreri et al. (2011). The last column of the table presents the extensions of the model introduced by us.

Table A1.2

Comparison of the modelling framework with the existing frameworks.

Equation	Comparison with literature	Modifications to the Equation
(A3)	Identical to Equation (6) in Balistreri et al. (2011)	We add preference weights (share parameters) to keep the same structure as in the Armington version of the equations. The number of firms operating in the benchmark is set to unity.
(A4)	Identical to Equation (5) in Akgul et al. (2016). Similar equation appears in previous studies, but Akgul et al. (2016) explicitly shows the number of firms operating.	
(A5)	Identical to Equation (23.14) in Balistreri and Rutherford (2013). Equation in similar form appear in the other studies, but partially with different imposition of iceberg cost and tariffs. The layout for the differentiation of variable and fixed cost follows Fig. 1 in Akgul et al. (2016).	1 We build on Akgul et al. (2016) by differentiating the composition of variable and fixed cost as discussed in this appendix under the headline “Production structure for sectors in the Melitz module”. 2 A procedure improving numerical stability is introduced as discussed in Section 2.5 which allows removing the love of variety effect and price markup for intermediate demand for the domestic origin by the same sector.
(A12)	Identical to Equation (18) in Balistreri et al. (2011)	With changes according to 1. in Equation (A5), see above
(A14)	Identical to Equation (16) in Balistreri et al. (2011)	
(A16)	Identical to Equation (21) in Balistreri et al. (2011)	With changes according to 1. in Equation (A5), see above
(A17)	Identical to Equation (22) in Balistreri et al. (2011)	

Appendix 2. Supplementary Table

Table A2

Correspondence of GTAP Sectors to sectors with information on AVEs of NTMs.

No.	Code	GTAP and model sectors	Concordance of GTAP sectors and the sectors with information on AVEs of NTMs	Industry structure
1	PDR	Paddy rice	Primary agriculture	PC
2	WHT	Wheat	Primary agriculture	PC
3	GRO	Cereal grains nec	Primary agriculture	PC
4	V_F	Vegetables, fruit, nuts	Primary agriculture	PC
5	OSD	Oil seeds	Primary agriculture	PC
6	C_B	Sugar cane, sugar beet	Primary agriculture	PC
7	PFb	Plant-based fibers	Primary agriculture	P C
8	OCR	Crops nec	Primary agriculture	PC
9	CTL	Bovine cattle, sheep and goats, horses	Primary agriculture	PC
10	OAP	Animal products nec	Primary agriculture	PC
11	RMK	Raw milk	Primary agriculture	PC
12	WOL	Wool, silk-worm cocoons	Primary agriculture	PC
13	FRS	Forestry	Primary agriculture	PC
14	FSH	Fishing	Primary agriculture	PC
15	COA	Coal	Primary Energy	PC
16	OIL	Oil	Primary Energy	PC
17	GAS	Gas	Primary Energy	PC
18	OMN	Minerals nec	Primary Energy	PC
19	CMT	Bovine meat products	Processed foods	FH
20	OMT	Meat products nec	Processed foods	FH
21	VOL	Vegetable oils and fats	Processed foods	FH
22	MIL	Dairy products	Processed foods	FH
23	PCR	Processed rice	Processed foods	PC
24	SGR	Sugar	Processed foods	PC
25	OFD	Food products nec	Processed foods	FH
26	B_T	Beverages and tobacco products	Beverages and tobacco	FH
27	TEX	Textiles	Other manufactures	FH
28	WAP	Wearing apparel	Other manufactures	FH
29	LEA	Leather products	Other manufactures	FH
30	LUM	Wood products	Other manufactures	FH
31	PPP	Paper products, publishing	Other manufactures	FH
32	P_C	Petroleum, coal products	Petrochemicals	FH
33	CRP	Chemical, rubber, plastic products	Chemical and pharmaceuticals	FH
34	NMM	Mineral products nec	Other manufactures	FH
35	I_S	Ferrous metals	Metals and fabricated metals	FH
36	NFM	Metals nec	Metals and fabricated metals	FH
37	FMP	Metal products	Metals and fabricated metals	FH
38	MVH	Motor vehicles and parts	Motor vehicles	FH
39	OTN	Transport equipment nec	Other machinery	FH
40	ELE	Electronic equipment	Electrical machinery	FH
41	OME	Machinery and equipment nec	Other machinery	FH
42	OMF	Manufactures nec	Other manufactures	FH
43	ELY	Electricity	Public services	PC
44	GDT	Gas manufacture, distribution	Public services	PC
45	WTR	Water	Public services	PC
46	CNS	Construction	Construction	PC
47	TRD	Trade	Distribution	PC
48	OTP	Transport nec	Other transport	PC
49	WTP	Water transport	Maritime transport	PC
50	ATP	Air transport	Air transport	PC
51	CMN	Communication	Communications	PC
52	OFI	Financial services nec	Banking	PC
53	ISR	Insurance	Insurance	PC
54	OBS	Business services nec	Other business services	PC
55	ROS	Recreational and other services	Personal and recreational Services	PC
56	OSG	Public Administration, Defense, Education, Health	Public services	PC
57	DWE	Dwellings	Public services	PC

Notes: FH: Firm heterogeneity, PC: Perfect Competition (Armington).

Table A3

AVE % cost reductions.

	EU NTBs	US NTBs
Goods		
Primary agriculture	15.8	15.8
primary energy	16.1	16.1
Processed foods	33.8	33.8
Beverages and tobacco	42	42
Petrochemicals	24.2	24.2

(continued on next page)

Table A3 (continued)

	EU NTBs	US NTBs
Chemicals, pharmaceuticals	29.1	29.1
Metals, fabricated metals	16.7	16.7
Motor vehicles	19.3	19.3
Electrical machinery	1.8	1.8
Other machinery	6.2	6.2
Other manufactures	3.6	3.6
Services		
Construction	4.6	2.5
Air transport	12.5	5.5
Maritime	0.9	6.5
Other transport	14.9	0
Distribution	0.7	0
Communications	0.6	1.8
Banking	0	0
Insurance	0	0
Professional and business	17.7	21
Personal, recreational	14.4	2.5
Public services	*	*

Source: Egger et al. (2015).

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Full Research Article

The impacts to food consumers of a Transatlantic Trade and Investment Partnership[#]

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Abstract. Primary agriculture is a textbook example of competitive supply with many producers outputting homogenous products, in contrast to firms in the processed food sector produce heterogeneous products while differing in productivity. Our model of trade reform explicitly accounts for the differences between the markets for primary agriculture and food processing. To demonstrate this point, we use a computable general equilibrium (CGE) model to quantify potential impacts of a trade agreement between the EU and US. Crucially, our heterogeneity-firm setup allows for the allocation of NTMs as ‘fixed costs’, which provides an alternative angle to previous literature that only considered NTM costs in a more conventional framework (e.g., tariff equivalent). Further, the use of this framework allows us to provide detailed welfare impacts, providing more information on the impacts to consumers who purchase mainly processed food and little primary agricultural output, a point often unrepresented in previous analysis of NTM reform.

Keywords. Trade Policy, Imperfect competition, Heterogeneous firms, Simulations.

JEL Codes. F12, F14, F47.

1. Introduction

Primary agriculture is a textbook example of competitive supply with many producers outputting homogenous products while firms in the processed food sector produce heterogeneous products. Thus, there are important differences in productivity, size, and exporting behavior among these firms that should be reflected in quantitative analysis. While manufacturing has typically received the firm heterogeneity treatment, the potential Transatlantic Trade and Investment Partnership (TTIP)¹ provided an instance of using

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¹ We note that the chances for implementation in the near future is slim; however, negotiations have not officially ended (unlike the Trans-Pacific Partnership). The United States Trade Representative still maintains a webpage devoted to the potential agreement. <https://ustr.gov/ttip>

an agri-food sector (i.e., food processing) that exhibits firm heterogeneity characteristics. Luckstead and Devadoss (2016) analyze the potential impact of TTIP assuming heterogeneity of firm involved in food processing. However, that study uses a single sector model that neglects feedback with other sectors, including agriculture as a major upstream link of the processed food sector.

The potential TTIP agreement generated a large amount of research, which may not be surprising given that the agreement would have linked the world's two largest economies. Although the above mentioned paper incorporated a firm heterogeneity setup in their analysis of TTIP, most research still considers firms as homogenous (e.g., Arita *et al.* 2014, 2017; Beckman *et al.* 2015; Beckman and Arita, 2017; Berden *et al.* 2009; Disdier *et al.* 2015; Egger *et al.* 2015; Fontagne *et al.* 2013; Welfens and Irawan 2014; Beghin *et al.*, 2016). Despite their traditional model approaches, these papers make two points relevant to trade policy analysis. First, tariffs are usually low in developed countries (relative to developing countries), especially for manufacturing and services. However, in developed countries, agriculture is usually more protected relative to other sectors, with higher tariffs, tariff-rate quotas, and non-tariff measures (NTMs).² Second, for developed countries, NTMs are becoming more of a trade barrier tariffs, with almost all of the papers that compare the two concluding that NTM removal (even partial removal) could generate larger trade gains than those from tariff removal. The NTM topic is also relevant for firm heterogeneity, since under the standard Armington assumption, NTMs are typically treated simply as ad-valorem equivalents (AVEs). This differs from the heterogeneous firm layout e.g. used in Akgul *et al.* (2016) or Luckstead and Devadoss (2016), that treats them (partly) as fixed costs of trade.

Our work here builds on the previous TTIP analysis, by starting with the view that reforming agri-food trade might generate the largest relative trade gains. We focus on the processed food sector as it accounts for the largest share of bilateral trade in agri-food between US-EU, and because it can be characterized as exhibiting all the signs of a sector with heterogeneous firms.³ Berden *et al.* (2009) note that one percent of processed food firms account for 52 percent of total sales. these large firms regularly modify and improve the characteristics of their products to meet the requirements and changing preferences of different consumer groups and to differentiate themselves from competitors.⁴ Following most TTIP analysis, we employ a CGE model that encompasses all sectors and their interactions, but integrate a firm heterogeneity approach for processed food and all other types of manufacturing. This firm heterogeneity specification allows us to provide more information on impacts to consumers with evidence on the impacts to consumer welfare from a change in the number of new varieties entering the processed food sector, information that is not available in a standard perfect competition setup. Our model also details welfare impacts in general, providing information on an aspect of TTIP so far largely ignored.

² One could examine the average Most Favoured Nation (MFN) tariffs reported to the World Trade Organization to confirm this point. The EU trade-weighted MFN rate for agriculture is 8.7% compared to 2.8% for non-agriculture. The U.S. rates are 2.3% and 4.0%. The largest gap is likely for Japan: 1.4% and 12.9%.

³ Particularly relevant to TTIP, the EU and US account jointly for one third of global trade in processed food (UN Comtrade, 2015); and they trade (bilaterally) more processed food products than any other partners globally (FAS/USDA, 2014; Olper *et al.*, 2014).

⁴ In addition, high product differentiation and considerable differences in firms' size and productivity has led some (e.g., Neff *et al.*, 1996; Francois *et al.*, 2013) to label the processed food sectors as monopolistic competition, which is often used to characterize firms with heterogeneity.

2. Modeling framework

Global CGE models are generally considered well suited for ex-ante appraisal of trade agreements as they consider bilateral trade and trade barriers in a consistent microeconomic behavioral framework and account for interlinkages between sectors. Here we use the flexible and modular CGE model by Britz and Van der Mensbrugghe (2017) extended by the heterogeneous firm module of Jafari and Britz (2018a) (see the online appendix for its detailed documentation⁵). Next, we discuss briefly the general structure of the model.

2.1 Perfect competitive sectors

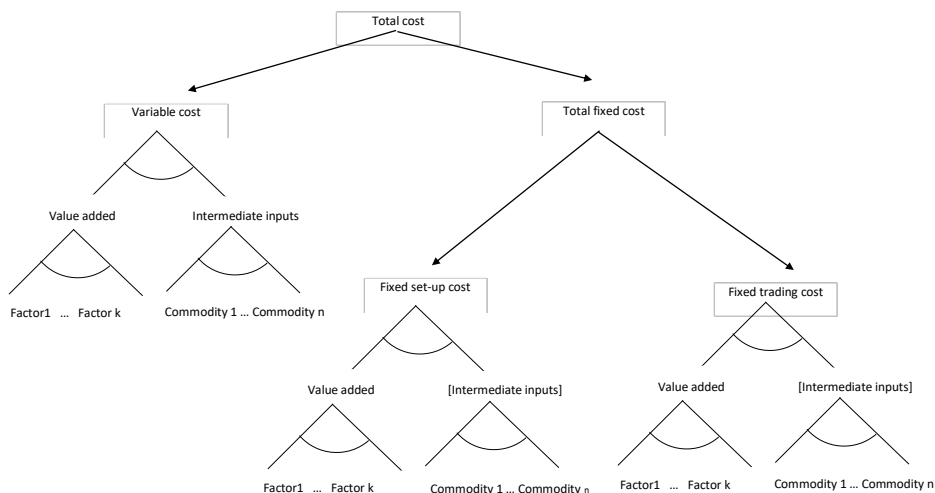
Sectors with perfect competition are depicted as in the standard GTAP model (Hertel, 1997), with cost-minimizing behavior under constant returns to scale (CRS) production technologies along with utility maximizing consumers in competitive markets. Relevant to this work, the perfect competition sectors use an Armington trade setup where a constant elasticity of substitution (CES) function, specific for each agent, i.e. final consumers, government, savings and the different production sector, drives competition between domestically produced products and imports. A second CES nest, which is not agent specific, depicts the import demand composition from bilateral trade flows. Hence, the Armington setup considers commodities produced in the same region as homogenous, but different from commodities stemming from other regions. For example, all dairy products from the EU are assumed to be of the same quality and fetching the same price. On the supply side, production is defined as the Leontief aggregate of value added and intermediate inputs bundles; the value added composition is based on a CES aggregate of primary factors while the composition of intermediate demand is based on fixed physical input coefficients.

2.2 Heterogeneous sectors

In each sector there is a continuum of firms that are heterogeneous with regard to productivity, and each firm produces its own distinct variety. While firms are free to enter or exit the market, entrance requires covering fixed costs. Firms learn about their productivity level once they enter the market, and then choose to stay or exit. Firms with too low of a productivity level will not be able to cover their fixed cost, and therefore exit the industry. For those that survive, only the most productive ones are involved in exports since they can cover the fixed costs of exporting, while less productive firms only serve the domestic market.

In this framework, the number of firms operating on the domestic market and on the bilateral trade links depends on the characteristics of the domestic market and bilateral trade costs. Since each firm produces a single distinct variety, the total number of varieties available in any given country depends on the number of firms operating in the domestic market and the number of firms exporting to that country. Accordingly, the total number of varieties available to consumers in a given country is determined endogenously. In this

⁵ Jafari and Britz (2018) published that online appendix as part of their paper, provided here again for ease.

Figure 1. Production structure in Melitz sectors.

Source: Authors' illustration.

context, any policy shock that leads to changes in variable or fixed costs can change the fraction of firms operating on domestic and on trade links, and therefore the number of varieties available to consumers.

On the demand side, the composite demand of each agent for each commodity is defined as the Dixit-Stiglitz composite of demand for average firm level varieties around the world⁶. That index can be interpreted as a standard CES aggregator where the import quantity impact is additionally multiplied by the change in the number of operating firms providing a love of variety effect.

Each heterogeneous firm produces one single unique variety and therefore, the number of varieties produced in a regional industry is equal to the number of operating firms. The production structure is shown in Figure 1, where total cost is the sum of variable and fixed costs per firm, the latter consists of fixed costs to enter the enter the industry and fixed cost on each trade link. The variable cost nest uses both primary factors and intermediates based on a constant return to scale technology, while fixed cost only relate to primary factors. However, if the overall total cost share of value-added in a sector is small, the fixed cost nest also comprises a share of intermediate composite. This alternative is identified by the intermediate composite in brackets. The value added and intermediate bundles are CES composites of primary factors of production and intermediate inputs, respectively. The total value added (not shown here) is the sum of value added used in both variable and fixed cost nesting. Similarly, the total uses of intermediate commodities and primary factors (not shown here) are the sum of their use in fixed and variable cost nesting.

⁶ The heterogeneous firm model defines the so-called “average firm” depicting the average productivity of all firms operating on a specific trade link.

Consistent with the monopolistic competition assumption, each firm applies a markup pricing rule, i.e. it collects rent stemming from producing a specific variety, which covers its fixed costs. Marginal production costs are corrected for the average productivity effect of firms operating on each bilateral trade link. The average productivity of firms on each trade link is determined from a Pareto distribution function which encompasses a so-called cut-off productivity level. Only firms with productivity equal to or higher than that specific threshold level for each bilateral trade link will operate on that link, while the remaining firms are forced to exit. The number of operating firms on a link is derived from a zero profit condition where the revenue of the average firm must be equal to its bilateral fixed cost. However, ensuring zero profit for operating firms on each trade link does not ensure zero profits for the industry as a whole, due to the sunk costs associated with the entry of new firms in the industry. Therefore, zero profit at the industry level is assured by a free entry condition in the industry, indicating that the expected profit for firms over their lifetime must be equal to the overall industry fixed set up costs.

Trade liberalization filters through this type of model differently than in the standard Armington setup, beginning with the reallocation of resources between firms. For example, a policy that decreases bilateral export cost will encourage some firms that initially did not export (those with low productivity) to start trading. This leads both to an increase in the number of exporters and a decrease in the average productivity of exporters (since those firms that just entered the export market were less productive to begin with). Due to fixed cost per firm, an increase in the number of exporters implies that the industry as a whole uses more resources. This increases input prices in the domestic market, leading to some lower productive firms to exit the domestic market. As a result, the average productivity in the domestic market increases. Since some of the least productive firms exit the industry, the productivity for the industry increases and generates a welfare gain (as those firms that now enter the export market are relatively more productive than those leaving the domestic market). On the importing side, similar adjustments in industry structure take place while consumer benefits from more varieties being present on the import side.

2.3 Model parameterization and calibration

A major advantage of this firm heterogeneity model is that it does not require as much information on industries and consumers as the original Melitz (2003) model. Indeed, only two parameters are needed for each sector: one that describes the productivity distribution of the industry (based on a Pareto distribution) and another that is the elasticity of substitution among domestic and imported varieties. We use the estimate of 3.8 from Bernard *et al.* (2003) for the elasticity of substitution, and an estimate of 4.6 for the Pareto shape parameter from Balistreri *et al.* (2011).

2.4 Sectoral and regional aggregation

Table A1 in the Appendix provides details on how we treat the sectors in our application. We generally keep the full sectoral detail of GTAP sectors to prevent bias (Britz *et al.*,

2016) but aggregated the processed food sectors in the GTAP data base for two reasons. First, while there is in consensus in the literature that the processed food sector in general should be treated with heterogenous firms, there is no information on if some sectors (e.g., meat or dairy production) should be excluded and treated as homogenous instead. Second, as discussed below in more detail, data on the potential NTM reduction between the EU and the US suitable for our analysis is available only at the aggregated level.

To capture the impact of a proposed TTIP agreement on third countries, we aggregate the GTAP data base to 10 regions (European Union, United States, Canada, MERCOSUR, China, ASEAN 10, Mediterranean countries, Other Northern Europe⁷, low-income countries, Other OECD and Rest of World). Our mapping of regions to the low-income countries aggregate follows the current World Bank classification.

3. Quantifying the policy experiment

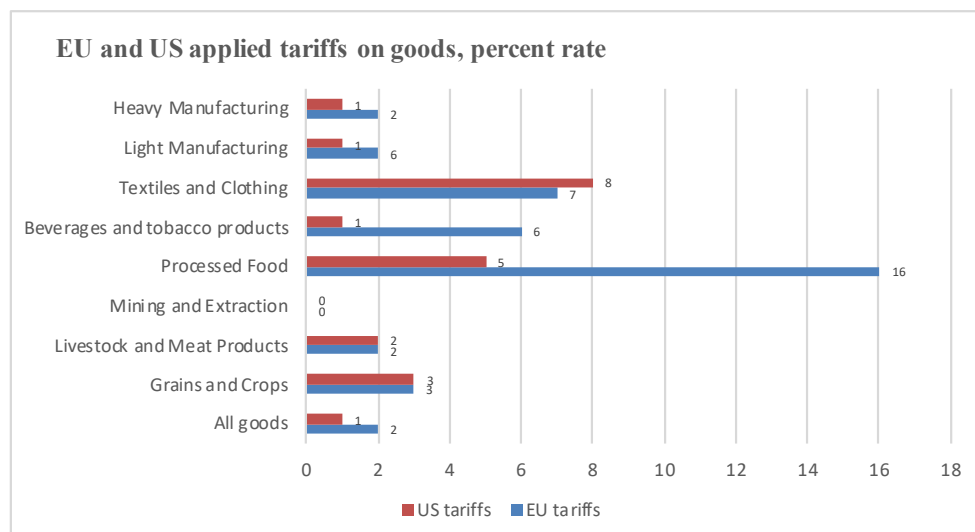
The model is calibrated based on version 9 of the Global Trade Analysis Project (GTAP) database (Aguiar *et al.*, 2016), which provides a snapshot of world economy in 2011. Figure 2 reports bilateral ad-valorem trade weighted tariffs from the database. It reveals that processed food, beverage and tobacco products, and textile and clothing are the sectors subjected to the highest tariffs. In most cases, the applied rate of the EU is lower than that for the US.

NTMs are not explicit in the data base and need to be incorporated before they can be subjected to policy experiments. The AVEs of NTMs that are potentially removable if a deep trade agreement is reached are taken from Egger *et al.* (2015), the estimated AVE for processed food is 33.83%.⁸ It is not based on the latest negotiations status of TTIP, but rather more generally reflects the expected change if the two trade partners move to a deep FTA agreement given the empirical evidence from past FTAs.

We analyze two scenarios (see Table 1): the first scenario considers completely removing import tariffs for all commodities between the EU and the US, while the second one adds NTM reform. Removing existing tariffs is straightforward as they are part of the data base, whereas the second scenario requires allocating the NTM costs estimated by Egger *et al.* (2015). CGE models treat the trade cost effects of NTMs as either rent-generating or cost creating. Modeling the rent-generating effect is straightforward using either an “export tax equivalent” – changing export taxes or a “tariff equivalent” approach—changing import taxes, depending on where the rent are assumed to occur. Changes in the cost generating basis of NTMs are modeled by changing the variable portion of trade costs (since there are no fixed costs in an Armington model). However, NTM costs often reflect a ‘fixed cost’ component. For example, the US is able to export beef to the EU, but that beef is produced differently than how most beef sold domestically in the US is produced. To be able to export beef to the EU, US producers must have separate facilities or incur other fixed cost type of costs. As our firm heterogeneity structure is able to account for

⁷ Other Northern Europe include Switzerland, Norway and Rest of European Free trade Association (EFTA)

⁸ It should be noted that one would expect the NTMs between the US and the EU to be region specific (i.e., asymmetric). However, Egger *et al.* (2015) estimated the trade cost equivalents of a deep trade agreement between two regions. Therefore, these estimates should not be interpreted as the current level of NTMs but rather as the trade costs that two regions could reduce due to NTM removal when moving to a deep FTA.

Figure 2. Applied MFN tariff on transatlantic trade.

Source: Data extracted from version 9 of the Global Trade Analysis Project (GTAP) database (Aguilar *et al.*, 2016).

fixed cost, we explicitly change variable and fixed costs for EU-US trade links drawing on Jafari and Britz (2018a). One should note that NTMs could also have demand side effects when regulations affect consumer behavior, typically captured by changing either the consumer willingness to pay (as in Walmsley and Minor, 2016) or Armington elasticities. Although TTIP might provoke such demand side shifting effects, we leave them out due to missing empirical evidence.

Breden *et al.* (2009) suggested 60% of NTMs in EU-US are cost generating and 40% are rent generating. The latter is then allocated by 2/3 to import duties and 1/3 to export taxes following Francoise *et al.* (2013) and Egger *et al.* (2015), (see Table 1). The cost portion of the NTM is allocated to variable and bilateral fixed costs in equal shares following Jafari and Britz (2018a).

4. Scenario analysis

While we presume that costs related to NTMs are already observed in the global SAM, rents related to NTMs probably hide in capital income flows and are clearly so far not allocated bi-laterally. We therefore first run a simulation to include the rent generating effects associated with NTMs currently in place between the US and the EU by introducing respectively increasing bi-lateral import and/or export taxes. That augmented database serves as the benchmark. In the following, we discuss the simulated impacts of both scenarios on trade, production, and welfare. Then, we turn to the specific outcomes for the food processing sector with a focus on the information given by the firm heterogeneity model.

Table 1. Scenario layout.

	Tariffs shocks	AVEs shocks			
		Total AVEs reduction divided into the last three columns	Import tax	Export tax	Bilateral fixed and variable trade cost
	(1)	(2)	(2)*0.4*2/3	(2)*0.4*1/3	(2)*0.6
Scenario 1	-100% reduction for all economic sectors	-	-	-	-
Scenario 2	-100% reduction for all economic sectors	-33.83%	-9.0%	-4.50%	-20.3%
Modeled as	Reduction in bilateral import tariff		Reduction in import tariffs representing rents in importer country	Reduction in export taxes representing rents in exporter country	Converted to an equivalent reduction in bilateral fixed and variable trade cost

Source: authors.

4.1 Effects on trade flows

Table 2 shows simulated changes in the volume of aggregate exports. Removing import tariffs (scenario 1) increases EU exports to the US increase by 4.78%, while US exports to the EU increase by 6.8%.⁹ Adding NTM reform on top of tariff removal boosts bilateral trade further, by 9.7% from the EU to the US, and by 8.5% from the US to the EU. However, with increases of 0.2% (tariff removal only) and 0.5% (NTM reform included), respectively, the changes in global EU exports are minor; while total US exports expand more significantly (by 1.4% and 2.6%). These findings are comparable with Francois *et al.* (2013). Some regions including China, ASEAN 10, “low-income countries”, and “Other Northern Europe” have marginally increases in their exports to either the EU or US, depending on the scenario. In the first scenario, Canada has a decrease in their bilateral exports to both regions, but in the second scenario, Canada has an increase in their exports to the EU. In summary of these changes in regional trade flows, overall world trade increases marginally by 0.3% and 0.4%, respectively.

Table 3 focuses on export flows for the processed food sector. The higher tariff protection in that sector leads to larger changes compared to the results reported above: EU exports to the US of processed food increase by 39% while US exports to the EU increase by 121% (for tariff removal). These findings are consistent with the partial-equilibrium model results of Luckstead and Devadoss (2016), but the magnitude of the impacts found here is different due to the use of different elasticities and feedback effects in our CGE modelling. As the AVE estimates of the expected changes in existing NTMs between the

⁹ Bilateral changes are not presented here, but are available upon request from the authors.

Table 2. Change in aggregate exports by region [% change].

Regions	Scenario 1			Scenario 2		
	EU	US	Total	EU	US	Total
World	0.2	1.1	0.3	0.4	1.8	0.4
EU	-0.2 ¹	4.8	0.2	-0.3	9.7	0.5
Other Northern Europe	0.1	0.2	0.2	0.0	-0.4	-0.1
US	6.8		1.4	8.5		2.6
Canada	-0.1	-0.3	-0.2	1.3	-0.1	0.2
Mercosur	-0.2	0.1	0.0	-0.1	-0.5	-0.1
China	0.0	0.3	0.2	0.5	-0.5	0.1
ASEAN 10	-0.4	0.5	0.7	0.2	-0.7	0.2
Other OECD	-0.2	0.0	0.0	0.5	-0.6	0.0
EU Mediterranean Partners	-0.3	0.3	-0.1	0.1	-0.5	0.0
Low Income	-0.3	0.3	-0.1	0.1	-0.1	0.0
Rest of World	-0.2	0.1	0.0	0.1	-0.5	0.0

Notes: exporters in rows, importers in columns.

Source: model results.

¹ The reader should note that the numbers presented in the column "EU" showing EU to EU exports is due to an aggregation effect. Sales to the domestic market of a nation are not reported as exports in the SAM. However, if we aggregate individual EU countries, the former bi-lateral trade links between two EU nations occur now inside one aggregate and become the diagonal trade flow in this column. The domestic sales of the EU aggregate are defined from adding up the domestic sales of individual EU countries.

EU and US are quite high and exceed existing tariff levels, bilateral trade volumes increase considerably for processed food in the second scenario. EU exports to the US almost quadruple, while US exports to the EU multiply by more than seven. This leads to changes in total exports of processed food for the EU by almost 9% and by 63% for the US. The trade diversion effects of that second scenario in the processed food sector is accordingly sizeable: most EU trading partners lose about 4% of their exports while exports to the US from the non-EU countries decreases by around 10%.

Trade impacts for primary agriculture are minor (see Table A2 and A3) which reflects low tariffs (see Figure 2) and low exports values. EU exports of primary agricultural products to the US amount to about 83 million, vice versa it is 6 million. Our analysis also shows that the impact on average manufacturing trade between two regions is small (see Table 4.4) due to low tariffs between the regions.

4.2 Effects on domestic output quantities

Table 4 presents information on production changes across all sectors. For processed food, the EU faces a decrease in both scenarios, while the US increases its production. However, the increase in US production is small, as the 63% increase in exports is mostly offset by an increase in imports (46 %) (See Table 3). Opposite and stronger effects are simulated for beverages and tobacco, with a 5% increase in EU production and a 16%

Table 3. Export volumes by region for “processed food” [% change].

Regions	Scenario 1			Scenario 2		
	EU	US	Total	EU	US	Total
World	1.5	5.3	1.1	7.2	46.2	7.4
EU	0.2	39.4	1.2	-1.7	394.2	9.3
Other Northern Europe	-0.7	-0.1	-0.4	-5.4	-10.8	-4.4
US	120.9		9.4	748.5		63.4
Canada	-1.0	-0.4	-0.4	-5.7	-11.3	-8.6
Mercosur	-0.7	0.0	-0.2	-3.9	-9.1	-1.6
China	-0.7	0.0	-0.1	-3.9	-9.3	-2.4
ASEAN 10	-1.0	-0.3	-0.3	-3.7	-8.9	-1.7
Other OECD	-0.7	-0.1	-0.1	-3.8	-9.3	-2.7
EU Mediterranean Partners	-0.6	0.0	-0.3	-4.5	-9.7	-2.5
Low Income	-0.6	0.0	-0.3	-4.5	-9.5	-2.5
Rest of World	-0.7	0.0	-0.2	-4.1	-9.4	-2.1

Source: model results.

decrease in the US. This happens for two reasons: 1) the EU has larger base exports of beverages and tobacco relative to the US; 2) the US has relatively higher tariffs on beverages and tobacco compared to processed food. Other sectors of the economy show only marginal changes. An exception is the output of “Textiles and Clothing”, which has a 2.5% increase in the EU in the first scenario. This gain disappears in the second scenario as resources flow to beverages and tobacco in order to meet the large increase in production. Overall, the domestic output of processed food sectors in the EU is simulated to increase by 1.4% in the second scenario, while US output drops by 2.9%. This result is different from that found in other TTIP studies. Those studies generally conclude that the US has large production gains at the expense of the EU.

4.3 Effects on welfare

Welfare impacts are measured based on the equivalent variation (EV) criterion, i.e., the amount of money to be added to the regional household’s benchmark income at benchmark prices to reach the same utility as under simulated income and prices. There are global welfare gains of 5.6 billion USD when tariffs are removed (see Table 5), of which 2.8 billion USD accrue to the EU and 5 billion USD to the US (the results are comparable with Francois *et al.*, 2013); the remaining countries, with the exception of China, have losses below 1 billion USD. Both changes in the intensive and extensive margin of trade are important in determining the welfare changes in other countries: Following a reduction in trade barriers between the US and EU, the intensive margin of trade between the two regions increases, diverting trade with other countries and causing welfare to decrease. However, a reduction in trade barriers between the EU and US helps increase the average productivity of firms operating on the domestic market and/or operating on

Table 4. Industrial output by sector [% change].

Sectors	EU		US	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Total	0.00	-0.01	0.02	0.00
Processed food	-0.11	-0.05	0.30	0.46
Beverages and Tobacco	0.13	5.67	-0.23	-16.00
Grains and Crops	-0.13	0.29	0.23	-0.24
Livestock	-0.08	0.03	0.22	0.23
Mining and Extraction	-0.01	-0.05	-0.05	0.07
Textiles and Clothing	2.52	-0.01	0.28	1.11
Light Manufacturing	-0.09	-0.24	0.51	0.15
Heavy Manufacturing	-0.13	-0.40	-0.25	0.30
Utilities and Construction	0.00	0.00	0.05	-0.01
Transport and Communication	0.02	0.07	0.01	0.02
Other Services	-0.01	0.01	-0.01	0.02

Source: model results.

trade links other than EU-US trade link. This results in an increase in the intensive margin of trade (i.e., increase in varieties) in other countries, which is welfare increasing. The total welfare impact on third countries is therefore determined based on the total volume of trade, i.e., the sum of changes in intensive and extensive margins of trade.

All regions are better off compared to the first scenario if NTMs are also reduced, several regions besides the EU and US now experience welfare increases, which results in a global welfare gain of 22.4 billion USD. The removal of NTMs increases average domestic productivity, simulating the extensive trade margin, and improving welfare compared to the first scenario. Still, welfare losses occur in Canada, Mercosur, ASEAN 10, and other OECD countries. The EU has the largest additional welfare gains, increasing from 2.8 billion USD to 13.8 billion USD under the second scenario. The US has an additional 5 billion USD added in the second scenario to reach a total of 7.8 billion USD. The welfare improvements in the second scenario match findings by Balistreri *et al.* (2011) who reports that NTM reduction in the Melitz (2003) framework increases welfare considerably.

Further, our welfare decomposition analysis reveals that the largest portion of welfare gains are associated with the scale effect (associated with the increase in returns to scale), the productivity effect (expansion in market shares of efficient firms), and variety effects (i.e., increases in the number of varieties face by consumers). While term of trade and allocative efficiency contribution is small, the fixed cost effect (due to the increase in firms fixed cost payments) reduces welfare (Table 6).

4.4 Firm-level impact of policy shocks in processing food sectors

Table 7 shows the change to the average firm (as shown in rows) associated with the production and sale of processed food in the EU for different bilateral trade markets. The

Table 5. Changes in welfare [Billion USD].

Regions	Scenario 1	Scenario 2
World	5.6	22.4
EU	2.8	13.8
Other Northern Europe	-0.2	0.1
US	5.0	7.8
Canada	-0.1	-0.1
Mercosur	-0.1	-0.1
China	0.0	0.6
ASEAN 10	-0.2	-0.1
Other OECD	-0.7	-0.2
EU Mediterranean Partners	-0.2	0.2
Low Income	-0.1	0.1
Rest of World	-0.7	0.3

Source: model results.

Table 6. Welfare decomposition analysis.

	Scenario 1	Scenario 2
EU	2.8	13.8
Allocative efficiency	0.0	0.5
Term of trade effect	0.1	1.1
Variety effect	1.3	5.2
Scale effect	1.9	9.7
Productivity effects	0.9	4.2
Fixed cost effects	-1.3	-6.9
Other effects	-0.1	0.0
US	5.6	22.4
Allocative efficiency	0.3	0.9
Term of trade effect	-0.1	1.7
Variety effect	1.8	4.7
Scale effect	3.6	11.7
Productivity effects	2.6	8.5
Fixed cost effects	-2.3	-5
Other effects	-0.2	-0.1

Source: Authors' calculations based on model results.

first column refers to the domestic market, the second column denotes intra-EU trade, the third and fourth columns show EU trade with the US and other regions not included in the transatlantic trade block (hereafter referred as nonTTIP). The last column relates to overall industry performance.

Table 7. Average firm results for EU domestic sales and exports of processed food [% change].

	Scenario 1					Scenario 2				
	Domestic sales	EU	US	nonTTIP	Total sale	Domestic sales	EU	US	nonTTIP	Total sale
Firm price	-0.2	-0.1	9.5	0.0	0.8	-0.9	-0.9	17.6	0.0	1.3
Number of operating firms	-0.6	0.1	52.7	0.0	4.3	-2.9	-2.7	666.5	0.9	55.8
Avg. output per firm	0.2	0.1	-8.7	0.1	0.1	1.0	1.0	-35.5	0.1	0.8
Avg. productivity per firm	0.1	0.0	-8.8	0.0	-0.9	0.7	0.7	-35.7	0.0	-2.9
Industry Fix costs	0.0	0.0	0.0	0.0	0.0	0.1	0.1	-24.2	0.0	-0.1
Fix costs per unit	0.3	-0.2	-28.3	0.0	-2.1	2.0	1.9	-84.7	0.0	-7.3
Industry Variable costs	-0.6	0.1	52.7	0.0	-0.2	-3.0	-2.6	481.2	1.2	-0.4
Variable costs per unit	-0.3	-0.1	9.5	0.0	0.8	-1.1	-0.9	17.6	0.0	1.2
Total output sold	-0.4	0.2	39.4	0.1	0.0	-1.9	-1.7	394.2	1.3	0.7

Source: Based on model results.

The changes in the EU-US trade link for the tariff removal scenario shows a typical reaction of the firm heterogeneity model: tariff removal reduces the average import price in the US, allowing less productive EU firms to operate on that trade link. This increases the number of firms and varieties exported to the US (52%), providing benefits to US consumers. Per unit fix costs drops by 28%; however, lower average productivity increases the variable costs per unit by about 9.5%. There is an increase in total output sold to the US of 39%, but increasing the number of operating firms decreases the average productivity of the firms operating on that trade link (-8.8%).¹⁰ Thus, the average size of these firms also drops – average output per firm decreases by about the same percentage. The average firm exporting to the US after these changes is less productive and smaller. Together, these changes constitute a new equilibrium with zero profits for the firms operating on that trade link, while monopolistic prices charged are equal to the willingness to pay for the specific quality delivered on that trade link given the number of varieties available.

The impacts of the second scenario on EU-US bilateral trade are more pronounced: besides tariff removal, we also shock variable and fix costs related to NTMs for EU-US bilateral trade. This amplifies the effect compared to the first scenario, as now all firms face a higher willingness to pay in bilateral trade, and experience cost savings before supply and demand adjust. This allows far less efficient firms to operate in bilateral trade: the number of the EU firms exporting to the US increases by 666%¹¹ while average productivity (35%) and firm size (-35%) on the trade link drop. Average per unit variable costs increase by 18%, which translates into changes in the average firm price, while total output for EU-US bilateral trade almost quadruples. The fix cost of the industry operating on

¹⁰ Note that in Table 7 and subsequent tables, even though the number of operating firms increases, the total output change is small because each firm now produces less output. This is equivalent to saying that large increases in the extensive margin are compensated by a reduction in the intensive margin of trade.

¹¹ Only a small share of firms operate on the link before trade liberalization which are the firms with the highest productivity. Given the shape of the productivity distribution, a significant decrease in bilateral trade cost leads to a non-proportional increase in that share and increase at the same time also the number of traded varieties on the link.

Table 8. Average firm results for US domestic sales and exports of processed food [% change].

	Scenario 1				Scenario 2			
	Domestic sales	EU	nonTTIP	Total sale	Domestic sales	EU	nonTTIP	Total sale
Firm price	-0.1	24.6	0.0	2.3	-2.0	35.6	0.0	3.1
Number of operating firms	-0.6	174.9	-0.9	15.1	-5.0	1421.0	4.0	132.0
Avg. output per firm	0.3	-19.6	0.3	0.2	1.9	-44.2	0.0	1.6
Avg. productivity per firm	0.2	-19.7	0.0	-1.9	1.4	-44.5	0.0	-4.1
Industry Fix costs	0.1	0.1	0.0	0.1	-0.1	-24.4	0.0	-0.2
Fix costs per unit	0.4	-54.7	0.0	-4.6	3.1	-91.1	0.0	-8.0
Industry Variable costs	-0.4	175.2	-0.4	0.4	-5.5	1050.5	3.6	-0.4
Variable costs per unit	-0.1	24.6	0.0	2.2	-2.5	35.6	0.0	2.9
Total output sold	-0.3	120.9	-0.3	0.4	-3.1	748.5	3.7	1.3

Source: Based on model results

that link decreases by 24%, reflecting our assumption of reduced trade costs (see Table 1). However, the original reduction is partly offset by the loss in average productivity, and at the same time distributed to a much higher output quantity. The combined impact on per unit fix costs on that link drops by around -85%. The finding is in line with the literature emphasizing the importance of the extensive margin of trade (e.g., Hummel and Klenow, 2005; Chaney, 2008; among others). No significant changes occur on the EU-nonTTIP link, such that overall changes in trade reflect only the discussed EU-US bilateral changes.

The expansion in exports combined with an on average less productive firm that trades, increases the overall input demand in the economy. This in turn bids up factor and other intermediate prices. As a first order impact, production costs increase and profits on other trade links decline, which induces some of the less productive firms to exit the EU domestic market. The number of operating firms in the domestic market decreases by 0.6% and 2.9% in the first and second scenario. As firms with lower productivity exit, factors are reallocated towards higher-productive and larger firms, thus the average productivity of firms operating in the domestic market rises by 0.1% and 0.7%. This leads to a decline in variable per unit costs of 0.3% and 1.1%, and an increase in average output per firm of 0.2% and 1%. However, the increase in average firm output does not compensate for the decrease in the number of firms operating in the domestic market. Consequently, domestic sales decline by 0.4% and 1.9%. This, along with lower firm prices of -0.2% and -0.9%, reflects the increased competition with US imports.

The impact on export flows of processed food from the US to the EU is presented in Table 8. Note first the impact on US-EU trade: following the reduction in border protection and trade cost, less productive firms find it profitable to enter the trade market. Thus, the number of operating firm on the US-EU link increases by a factor of 1.7 in the first scenario and by 14¹² in the second scenario. This lowers average productivity on that link, such that there are increases in the average firm price and output. Still, US exports to the

¹² Please see footnote 12.

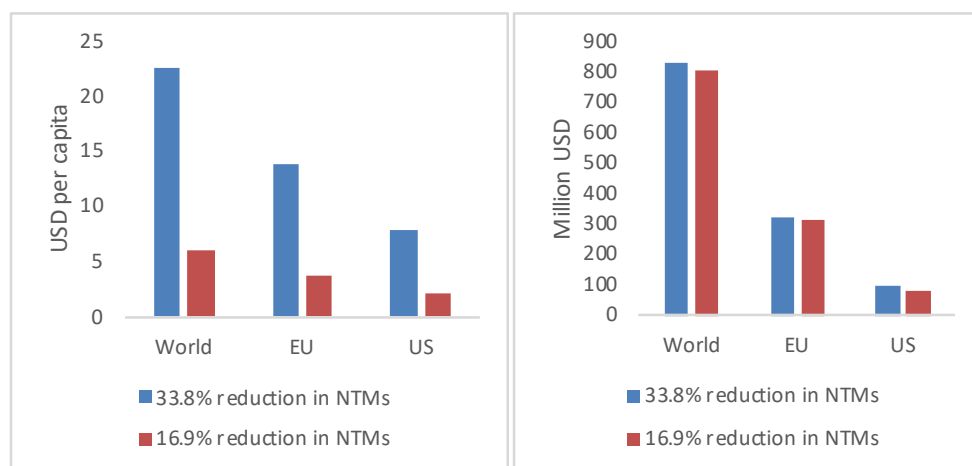
EU increase considerably (by a factor of 1.2 and 7.5), which reflects tariff removal plus an increased willingness to pay due to a higher number of varieties. Export expansion ultimately negatively affects the output sold in the domestic market by 0.3% in the first scenario and 3% in the second. Accordingly, total US processed food sales increases by only 0.4% (in the first scenario) and 1.3% (in the second).

5. Sensitivity analysis

The policy shock, model structure and parameterization jointly determine the model results. We check their robustness with regard to welfare and the volume of exports in the processed food sector. Given the uncertainties on the future of TTIP negotiations, we first perform a sensitivity analysis with regard to tariff and NTM reduction. To do so, we impose a 50% tariff shock (similar to Francois *et al.*, 2013) instead of the 100% removal in the benchmark. This essentially takes into account agricultural products that could be exempted from tariff removal. Our results (not shown here) indicate negligible impacts on trade in processed food and welfare and a small impact on overall primary agriculture trade. We also perform a sensitivity analysis for the NTM reduction scenario, but allowing for only half of the reduction in NTM costs. Figure 3 shows that the simulated changes in trade in processed food are 75-95% and welfare gains are 27-30% lower compared to the earlier results.

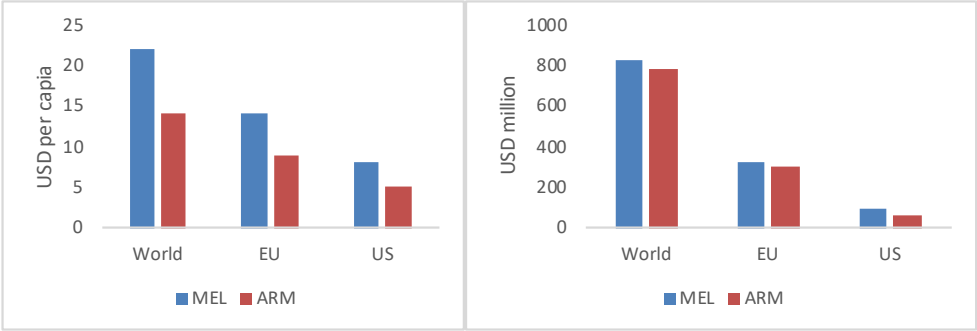
Next, we compare changes in welfare and trade in processed food in the tariff/NTM removal between model setups, i.e. processed food and all manufacturing sectors have the firm heterogeneity setup (*MEL*), and the more conventional structure where all the sectors follow the standard Armington specification (*ARM*). Welfare in *ARM* scenario is about 40-50% and trade effects are 10-30% lower compared to the firm heterogeneity configura-

Figure 3. Change in welfare [Equivalent variant per capita in constant USD] and export volumes [Million constant USD] under lower reduction of NTMs.



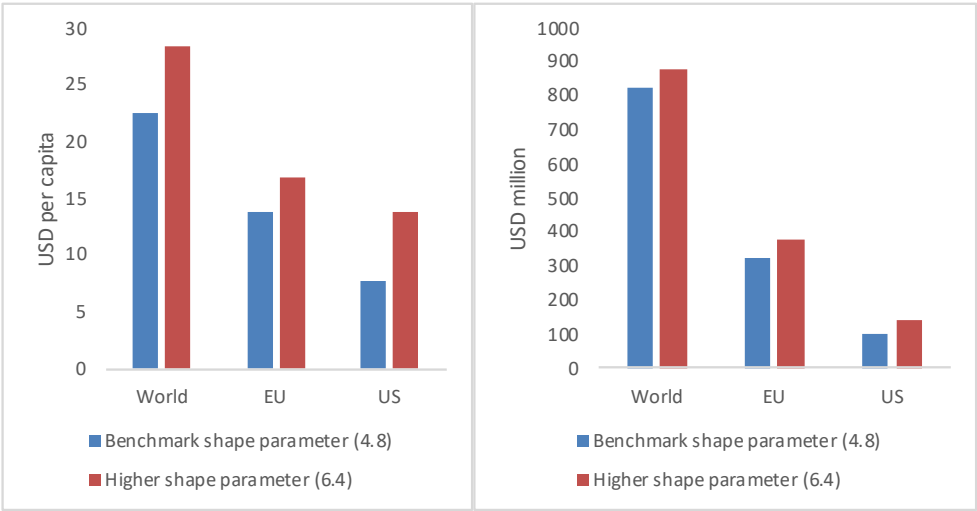
Source: Simulation results.

Figure 4. Change in welfare [Equivalent variant per capita in constant USD] and export volumes [Million constant USD] under the under Melitz and Armington specification.



Source: Simulation results.

Figure 5. Change in welfare [Equivalent variant per capita in constant USD] and export volumes [Million constant USD] under different shape parameters of the Pareto distribution of firm productivity.



Source: Simulation results.

tion (Figure 4). Comparable relative differences in welfare and trade flows are reported by Hosoe (2017), and Jafari and Britz (2018b) for a simulation of Brexit in a CGE model.

Lastly, an additional sensitivity analysis shows that trade expansion and welfare gains are higher under a higher shape parameter, i.e. if the distribution of firms' productivity becomes steeper. In Figure 5, we compare the results when the shape parameter is one-third higher than the benchmark value. The gain in welfare is 30-80% and trade in processed food is 20-40 % higher than under the default parameters across different regions. The results are comparable with Zhai (2008), who simulated a 50% reduction in manufac-

turing tariffs across the world. We also test the implication of increasing the benchmark Armington elasticities by one-third but keeping the original shape parameter. Our results (not shown here) reveals that that under this assumption, exports are about 10-12% lower across regions, with only a modest impact 4-5% increase in welfare.

6. Conclusion

This study employs a CGE model with a firm heterogeneity setup for processed food and manufacturing to simulate impacts of a potential TTIP agreement on the EU, the US and other countries. This setup allows us to trace the impacts on the intensive and extensive margin of trade as well as on firm productivity. In addition, in accounting for firm heterogeneity by allowing fixed costs to vary, we can more flexibly allocate NTM compared to the more conventional Armington set-up. We simulate the impacts of (i) removing all bilateral tariffs currently in place between the EU and the US; and (ii), an additional removal of NTMs in food processing sectors. Dismantling bilateral import tariffs leads to bilateral trade impacts that are below +10%, and limited welfare and trade diversion effects. As empirical estimates in the previous literature of the welfare impacts of NTMs suggest that these form considerable barriers, and the results of our second scenario are consistent with those of the earlier studies. In particular, EU welfare increases from 2 billion USD under the first scenario to 13.8 billion USD under the second. The larger increase in exports for food processing stems almost entirely from more firms exporting, which underlines the importance of the Melitz model in the analysis. However, increased exports are offset by lower domestic sales in both regions, such that overall industry output changes little. A sensitivity analysis on the core parameters used in the model shows the robustness of the overall results.

Our results differ from previous analysis of TTIP, which suggested that the US would see larger increases than the EU in agri-food production and exports. While this is still somewhat the case for primary agriculture, our results indicate that the EU could see larger production gains for processed food with the U.S. experiencing a decrease in output. Our results also indicate that tariff removal alone could benefit both regions once productivity gains are considered—something that cannot be shown with the typical Armington model setup. In the end, consumers could benefit most from a TTIP agreement as prices are likely to fall and the diversity of products available increase.

Our study could only draw on rather aggregate estimates of the costs caused by NTMs in the food processing sector. Thus, as the sector is highly heterogeneous, future work could try to provide more disaggregated estimates of costs related to NTMs and their composition (rents in importer and exporter country, variable or fixed cost of trade, demand shifting etc.). That would clearly not only improve the analysis of a potential TTIP agreement, but more generally economic impact assessment of FTAs and multilateral trade liberalization.

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Appendix. Supplemental tables

Table A1. Sectoral correspondence of GTAP 9 sector to new sectors.

Number	Code	Description	Pre model Aggregation	Post model aggregation	Market Structure
1	PDR	Paddy rice	Paddy rice	Grains and Crops	PC
2	WHT	Wheat	Wheat	Grains and Crops	PC
3	GRO	Cereal grains nec	Cereal grains nec	Grains and Crops	PC
4	V_F	Vegetables, fruit, nuts	Vegetables, fruit, nuts	Grains and Crops	PC
5	OSD	Oil seeds	Oil seeds	Grains and Crops	PC
6	C_B	Sugar cane, sugar beet	Sugar cane, sugar beet	Grains and Crops	PC
7	PFB	Plant-based fibers	Plant-based fibers	Grains and Crops	PC
8	OCR	Crops nec	Crops nec	Grains and Crops	PC
9	CTL	Bovine cattle, sheep and goats, horses	Bovine cattle, sheep and goats, horses	Livestock	PC
10	OAP	Animal products nec	Animal products nec	Livestock	PC
11	RMK	Raw milk	Raw milk	Livestock	PC
12	WOL	Wool, silk-worm cocoons	Wool, silk-worm cocoons	Livestock	PC
13	FRS	Forestry	Forestry	Mining and Extraction	PC
14	FSH	Fishing	Fishing	Mining and Extraction	PC
15	COA	Coal	Coal	Mining and Extraction	PC
16	OIL	Oil	Oil	Mining and Extraction	PC
17	GAS	Gas	Gas	Mining and Extraction	PC
18	OMN	Minerals nec	Minerals nec	Mining and Extraction	PC
19	CMT	Bovine meat products	Processed food	Processed food	FH
20	OMT	Meat products nec			
21	VOL	Vegetable oils and fats			
22	MIL	Dairy products			
23	PCR	Processed rice			
24	SGR	Sugar			
25	OFD	Food products nec			
26	B_T	Beverages and tobacco products	Beverages and tobacco products	Beverages and tobacco products	FH
27	TEX	Textiles	Textiles	Textile and clothing	FH
28	WAP	Wearing apparel	Wearing apparel	Textile and clothing	FH
29	LEA	Leather products	Leather products	Light Manufacturing	FH
30	LUM	Wood products	Wood products	Light Manufacturing	FH
31	PPP	Paper products, publishing	Paper products, publishing	Light Manufacturing	FH
32	P_C	Petroleum, coal products	Petroleum, coal products	Heavy Manufacturing	FH

Number	Code	Description	Pre model Aggregation	Post model aggregation	Market Structure
33	CRP	Chemical, rubber, plastic products	Chemical, rubber, plastic products	Heavy Manufacturing	FH
34	NMM	Mineral products nec	Mineral products nec	Heavy Manufacturing	FH
35	I_S	Ferrous metals	Ferrous metals	Heavy Manufacturing	FH
36	NFM	Metals nec	Metals nec	Heavy Manufacturing	FH
37	FMP	Metal products	Metal products	Light Manufacturing	FH
38	MVH	Motor vehicles and parts	Motor vehicles and parts	Light Manufacturing	FH
39	OTN	Transport equipment nec	Transport equipment nec	Light Manufacturing	FH
40	ELE	Electronic equipment	Electronic equipment	Heavy Manufacturing	FH
41	OME	Machinery and equipment nec	Machinery and equipment nec	Heavy Manufacturing	FH
42	OMF	Manufactures nec	Manufactures nec	Light Manufacturing	FH
43	ELY	Electricity	Electricity	Utilities and Construction	PC
44	GDT	Gas manufacture, distribution	Gas manufacture, distribution	Utilities and Construction	PC
45	WTR	Water	Water	Utilities and Construction	PC
46	CNS	Construction	Construction	Utilities and Construction	PC
47	TRD	Trade	Trade	Transport and Communication	PC
48	OTP	Transport nec	Transport nec	Transport and Communication	PC
49	WTP	Water transport	Water transport	Transport and Communication	PC
50	ATP	Air transport	Air transport	Transport and Communication	PC
51	CMN	Communication	Communication	Transport and Communication	PC
52	OFI	Financial services nec	Financial services nec	Other Services	PC
53	ISR	Insurance	Insurance	Other Services	PC
54	OBS	Business services nec	Business services nec	Other Services	PC
55	ROS	Recreational and other services	Recreational and other services	Other Services	PC
56	OSG	Public Administration, Defense, Education, Health	Public Administration, Defense, Education, Health	Other Services	PC
57	DWE	Dwellings	Dwellings	Other Services	PC

Notes: FH: Firm heterogeneity, PC: Perfect Competition (Armington).

Table A2. Export volume by region for “crop products” [% change].

Exporters	Partners										
	EU	Other Northern Europe	US	Canada	Mercosur	China	ASEAN 10	Other OECD	EU Mediterranean Partners	Low Income	Rest of World
<i>First scenario</i>											
World	0.3	0.0	1.4	-0.2	-0.2	-0.3	-0.2	-0.2	-0.3	-0.2	-0.3
EU	-0.3	0.0	16.4	0.5	-0.2	0.0	0.0	0.4	-0.1	-0.1	0.0
US	15.1	-1.1		-0.7	-1.3	-1.2	-1.1	-0.7	-1.2	-1.2	-1.2
<i>Second Scenario</i>											
World	0.5	-1.8	2.8	-1.7	-0.6	-0.5	-1.2	-0.8	-0.4	-0.3	-0.5
EU	-0.1	-1.7	17.4	-0.1	-0.7	0	-0.8	0.2	-0.1	-0.2	-0.1
US	14.1	-4	0	-2.8	-2.9	-2.5	-3.2	-2.1	-2.4	-2.5	-2.5

Table A3. Export volume by region for “livestock products” [% Change].

Exporters	Partners										
	EU	Other Northern Europe	US	Canada	Mercosur	China	ASEAN 10	Other OECD	EU Mediterranean Partners	Low Income	Rest of World
<i>First scenario</i>											
World	0.2	-0.2	1.3	0.0	-0.1	-0.2	-0.1	0.0	-0.2	-0.1	-0.1
EU	0.0	-0.2	9.9	0.2	-0.2	-0.1	-0.1	0.2	-0.2	-0.1	-0.1
US	11.5	-0.5		-0.1	-0.6	-0.4	-0.4	-0.2	-0.5	-0.4	-0.4
<i>Second Scenario</i>											
World	-0.5	-0.9	-2.2	4.9	-0.1	0	-0.2	1.2	0.2	-0.1	0
EU	-0.6	-0.8	9.4	3.4	0	0.3	0	0.9	0.2	0.3	0.2
US	13.5	1.5	0	5.8	2.1	2.6	2.2	3	2.5	2.5	2.4

Table A4. Export volume by region for overall manufacturing sectors [% Change].

Exporters	Partners										
	EU	Other Northern Europe	US	Canada	Mercosur	China	ASEAN 10	Other OECD	EU Mediterranean Partners	Low Income	Rest of World
<i>First scenario</i>											
World	0.3	-0.1	1.3	0.0	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	0.0
EU	-0.2	0.0	3.9	0.3	-0.1	0.0	0.1	0.1	0.1	0.1	0.1
US	5.2	-0.4		-0.2	-0.5	-0.5	-0.4	-0.4	-0.4	-0.3	-0.4
<i>Second Scenario</i>											
World	0.4	-0.1	1.4	-0.4	-0.4	-0.1	0.0	-0.1	-0.1	-0.1	-0.1
EU	-0.3	-0.1	3.6	-0.3	-0.5	-0.3	-0.2	-0.3	-0.2	-0.2	-0.2
US	5.3	-0.4	0.0	-0.6	-0.9	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5

RESEARCH

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Risks and opportunities from key importers pushing for sustainability: the case of Indonesian palm oil

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Abstract

Growing concerns in the major importing countries on the socio-environmental sustainability of oil palm farming may affect the import demand of palm oil and hence the economy of the exporting countries. This paper develops a comparative static, partial equilibrium model to examine the impact of potential reductions in EU imports of Indonesia's palm oil on palm oil output, prices, factor markets, trade, deforestation, and peatland conversion in Indonesia. Results suggest that there would be only small impacts on the major environment-economic variables in Indonesia in a scenario with a moderate reduction EU import demand, for example, due to sustainability concerns. However, the impacts would be more profound if sustainability concerns also affect other import regions and trigger a similar decline in import demand in other markets. The way forward for Indonesia and other palm oil producers and exporters is to adopt a common set of sustainability criteria, encompassing the elements of transparency, regulatory compliance, best agricultural practices, environmental responsibility, the livelihood of small farmers, as well as human and community rights.

Keywords: Sustainable palm oil, Agricultural trade policy, Sustainability criteria, Forest conversion for oil palm, Trade-environment linkages, Indonesia

JEL classification: Q17, Q18, Q51, Q56

Background

The impact of trade on economic growth, poverty alleviation, and welfare of many resource-rich developing countries is beyond doubt. However, export growth also influences natural resource use and factor allocation. Mega-scale forest exploitation by large exporter countries which results in significant loss of biodiversity and climate change effects has now attracted increasing global attention and scrutiny. If these result in shifting consumer preferences or tighter legal regulations in view of sustainability concerns, substantial repercussions on trade flows and consequently the socio-economic conditions of the exporting countries might follow.

Global palm oil production has gained prominence over the past two decades, as it offers a number of competitive advantages over other competing oils, especially its lower cost and being free from trans-fatty acids. Global consumption of palm oil has

also increased rapidly in the past decades, owing to its multiple uses both in the food industry as well as non-food sectors, including the biofuel industry.

A major share of the total palm oil production in the world comes from Indonesia and Malaysia, the largest producers of palm oil (Table 1). In 2011, palm oil production by Indonesia and Malaysia was respectively around 48 and 38% of global production. These two countries also accounted for 91% of world palm oil export. While exports of palm oil are dominated by two countries, imports are less concentrated. As indicated in Table 1, India and China are the largest importers of crude palm oil in the world, followed by the European Union (EU) where imports are for a number of uses and, in recent years, increasingly for biofuels.

The EU has aimed to increase its use of renewable energy from biofuels with one of the potential feedstocks being palm oil. However, it has been argued that the production of “palm oil-based biofuel” and associated conversion of forests and peatlands would cause even higher global emissions than those from the conventional fossil fuels that were supposed to be avoided (Butler 2008). Indonesia’s oil palm growth has also been linked to forest fires that lead to transboundary smoke haze pollution. It is accepted that a large share of oil palm expansion in Indonesia occurred on converted forests and peatlands, however with some controversy on the exact magnitudes. Finally, the impacts of oil palm expansion on the livelihood of local and forest-based indigenous communities further fuel the debate on the socio-environmental sustainability of this development (German et al. 2011). Various agencies have suggested that the EU should impose restrictions on palm oil imports (Butler 2012; EurActive 2013). The Indonesian oil palm industry was reportedly alarmed by the possibility of the EU issuing more stringent sustainability requirements on companies exporting palm oil to EU member states. Any imposition of stricter standards may hamper increased imports of Crude Palm Oil (CPO) as a biodiesel feedstock, particularly from Indonesia (AsiaPulse News 2008; Butler 2008).

The EU effort was apparently directed to induce changes in oil palm farming practices, which was seen as a major source of deforestation, peatlands conversion, and climate change impact (Butler 2008). However, after the debate (and campaigns by the major palm oil producing countries), the European Commission (EC) in 2012 agreed to consider palm oil-based biodiesel as sustainable in the sense of the Renewable Energy

Table 1 World major players of palm oil, 2011

Producers and exporters					Importers		
Country	Production Share	Export Share ^a	Production ^b	Export ^b	Country	Import Share	Import ^b
Indonesia	0.476	0.445	23,900	17,200	India	0.171	6640
Malaysia	0.377	0.465	18,911	17,993	People’s Republic of China	0.159	6165
Other countries	0.147	0.090	7369	3487	EU	0.142	5513
					Pakistan	0.051	1985
					Other	0.477	18,550
Source	Malaysian palm oil (2014a, 2014b)				Malaysian palm oil (2014c)		

^aIncludes re-exporting countries

^bThousand tons

Directive (Directive 2009/28/EC), if it is certified by the Roundtable on Sustainable Palm Oil (RSPO) scheme.

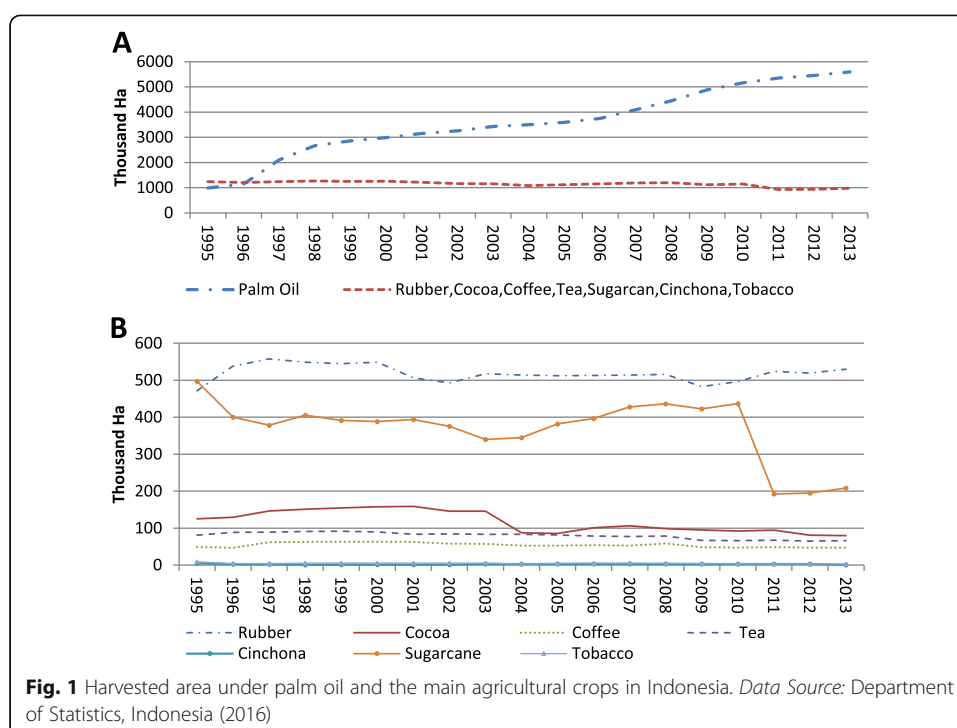
The RSPO was founded in 2004 specifically to promote the adoption of credible, global, and sustainability standards among palm oil growers via the engagement of multiple stakeholders and supply chain members. It promotes the use of the RSPO label to support palm oil plantations that have satisfied certain sustainability criteria. The move by the EC may boost the exports of RSPO certified palm oil into Europe, as palm oil may receive favorable treatment over other crop-based biofuels (Butler 2012), but the fraction of certified Indonesian palm oil plantations is still low (Focus 2016). The latest development on the issue is that the European Parliament's Environment Committee has agreed to support the EC to require companies to measure the amount of "indirect land use change" (ILUC) attributed to biofuel. This was taken despite the strong contention among palm oil exporter countries that the science on the climate impacts of ILUC has been inconclusive as well as the potential repercussions on food prices (Dave 2013).

The trade impacts of non-RSPO certified CPO being banned from the EU biofuel sector and additional ILUC constraints possibly reinforced are difficult to assess. In the past, companies have often found ways to circumvent binding restrictions. RSPO certification is only required for the biofuel sector but not for other uses. Given the aforementioned background, this study develops a comparative static, partial equilibrium model of the Indonesian palm oil sector with explicit linkages to key trading partners to appraise the impact on the major enviro-economic variables in Indonesia of a rather modest reduction in demand for Indonesian palm oil in the EU markets due to sustainability restrictions. The paper investigates the effects of this reduction in palm oil imports on Indonesia's oil palm growth, trade, and environmental impacts. Additionally, the study also considers the impact of a more drastic but rather unlikely scenario where all importers of Indonesia's palm oil are imposing similar sectoral and trade measures so that import demand from all importers would decline accordingly. Policy and management implications, with special emphasis on the roles of sustainability criteria and certification for palm oil producers, are the main topic for the concluding section of the paper.

Overview of the oil palm sector in Indonesia

Importance and dynamics of the sector

Panel A of Fig. 1 depicts the rapid expansion of Indonesia's oil palm planted area that was about 5.59 million hectares in 2013, increasing on average by 252,000 ha per year from 1995 onwards. Panel B of the figure also provides the trends of other crops that are basically stagnating, with a recent drop in sugar cane area apparently due to specific factors. A continuation of oil palm area expansion seems very likely, in response to population growth and policies that promote the use of palm and other oils in biofuels, despite the myriad of pressures and campaigns against oil palm expansion. However, a halt or slowdown of this trend by a potential imposition of more stringent sustainability requirements in major export markets might have far reaching implications on Indonesia's socio-economic development, global vegetable oil markets, as well as climate change mitigation.



The rapid expansion of palm oil area has given rise to a sharp increase in production and exports of CPO from Indonesia. About 72% of Indonesia's CPO production is exported (refer to Table 1). In 2009, the largest share went to the Indian market (46%), followed by the EU (22%), and Malaysia¹ (11%) (See Table 2).

Environment and socio-economic aspects of palm oil production in Indonesia

Two of the most daunting challenges faced by the oil palm industry in Indonesia are deforestation and peatland destructions, which are associated with a high level of carbon emissions (Obidzinski et al. 2012). Replacing natural tropical forests and even secondary forest with oil palm also causes serious biodiversity loss in Indonesia (Koh and Wilcove 2008; Yaap et al. 2010). Obidzinski et al. (2012) report evidence suggesting that plantation development has even targeted forest land (as opposed to, say, shrub land) in Indonesia. It is critical and highly debated to which extent oil palm expansion resulted in deforestation and whether it has been the prime driver of deforestation

Table 2 Exports of Indonesian palm oil to destination markets, 2009

	India	Netherlands	Malaysia	Singapore	Italy	Germany, federated	China	ROW	Total
Export (kt)	4402	1057	1054	607	629	395	336	1087	9567
Share ^a of destination in Indonesian total	0.46	0.11	0.11	0.06	0.07	0.04	0.04	0.11	1
Share ^b of Indonesia in destination total imports	0.84	0.32	0.68 ^c	—	0.49	0.46	0.44	0.09 ^d	0.57

^aTrade data (2010)

^bRifin (2010)

^cShare for Malaysia is from palm data tracker: <http://www.palmoilanalytics.com/data> (and refers to 2009)

^dImport of Singapore is included (Singapore just re-exports the CPO that has come from Indonesia or Malaysia)

(Casson 2000; Zakaria et al. 2007; Ministry of Environment 2009; Tan et al. 2009; Gibbs et al. 2010). In this study, we rely on Gunarso et al. (2013) who compiled detailed land use matrices and found that 1.1 Mha of forest land (of various types) and 0.7 Mha of peatland were converted to oil palm plantations in the decade 2000–2010 which represent 19 and 35% of the total deforestation and peatland conversion, respectively. This estimate ignores the possibility that conversion to oil palm plantations may occur via several interim steps (secondary forest, shrub land). Land converted from forest land to shrub land from 2000 to 2005 and then from shrub land to oil plantations between 2005 and 2010 is not part of the 19% share which only covers the direct conversion from forest to oil palm plantations. If we simply compute the ratio of additional oil palm expansion over the additional land conversions from 2000–2010 compared to 2000–2005 according to Gunarso et al. (2013), we would attribute 95% of forest conversion and 68% of peatland conversion to oil palm expansion, but we will mainly rely on the previously mentioned lower shares in the model specification to remain on the conservative side in terms of environmental impacts.

Another issue is the socio-economic impact of oil palm expansion on the rural community. It is generally accepted that oil palm plantations are an important source of employment in rural areas (Basiron 2007; Bunyamin 2008; Feintrenie et al. 2010). However, because oil palm cultivation requires a certain amount of experience and capital expenditures, Obidzinski et al. (2012) argue that these benefits seem to accrue to those endowed with a minimum level of income and agricultural skills, and hence, oil palm development is likely to benefit migrant smallholders with previous experience in oil palm plantation more than native people with no prior exposure.

Furthermore, oil palm plantations, especially large-scale estates, have frequently been associated with negative social impacts on rural communities and indigenous people (Telapak 2000; Marti 2008; Sirait 2009; Friends of the Earth Europe (FoE) (FoE) 2010). For example, oil palm development in Central Kalimantan has adversely affected the shifting cultivation practices of the local communities, causing food insecurity (Orth 2007). Marti (2008) found many cases of human rights abuse by plantation companies, especially during land acquisition and plantation development. Other studies indicate that conflicts occur due to a lack of recognition of customary rights, breached agreements, and disregard for the environment (Casson 2000; Colchester et al. 2006). As a consequence, various studies documented social conflicts between palm oil companies and local communities in Indonesia (McCarthy 2010; Colchester M 2010) that sometimes even led to companies ceasing operation (Obidzinski et al. 2012).

Overall, the push toward implementation of more stringent sustainability criteria may be expected to limit the expansion of oil palm plantation on peatlands and forests. Furthermore, as far as they also cover a comprehensive set of criteria relevant for human rights and social aspects, they might also improve the working condition of workers and reduce social conflicts.

Relevant sustainability standards for oil palm production

In Indonesia, three sustainability standards are particularly relevant: the Roundtable on Sustainable Palm Oil Standard (RSPO), the Indonesian Sustainable Palm Oil Standard (ISPO), and the Malaysian Palm Oil Standard (MSPO).

From the perspective of international trade, RSPO labeling can be categorized as a private “standard.” RSPO is an international no profit organization that gathers different stakeholders in the palm oil supply chain to promote the use of sustainable palm oil production. RSPO generally focuses on sustainable production methods of oil palm. Private standards are not mandatory but they are becoming de facto an entry requirement for trading with many large-scale operators and leading value chains (Giovannucci and Purcell 2008).

However, Indonesia and Malaysia have opted to set up their own standards and product labels as an alternative to the RSPO standard and certification. ISPO is a mandatory standard in Indonesia while MSPO is not yet mandatory in Malaysia. But MSPO is also relevant for Indonesia as Malaysia is one of the major buyers of Indonesian palm oil. Table 3 compares the main areas of difference between RSPO, ISPO, and MSPO.

As shown in the table, ISPO and MSPO have less stringent criteria than RSPO, which in some instances requires companies to go beyond the national law. As a consequence, a reinforced application of the RSPO standard, for example, in Europe, would decrease demand from non-RSPO members even if Indonesian oil palm producers comply with their own, more lenient standard ISPO.

Methods

An analysis of how a shift in commodity export and/or import demand affects output price and quantity, primary factors demand, and ultimately forest and peatlands conversion requires knowledge of (i) trade policy-output supply linkages, (ii) linkages between the primary factor markets to output supply, and (iii) the relationship of total land demand to forest and peatland conversion that are thought to represent the key environmental variables linked to oil palm expansion in Indonesia.

In this study, we develop a comparative static, single-commodity model of Indonesian palm oil sector to capture the impact of a shift in export demand for Indonesian palm oil. In the model, CPO is exported to two markets—the EU and the Rest of the World. Trade policy or consumer preference shocks affect CPO demand, supply, and as a consequence on the related demand for factors of production, land, labor, capital, and agrochemicals. In turn, changes in the demand for land in oil palm production affect forest and peatland conversion.

The modeling framework linking trade and environmental impacts in this study is a so-called market (equilibrium) displacement model as introduced by Muth (1964) and Floyd (1965). In general, it is a comparative static model based on total differentiation of a system of equations but manipulated to be expressed in terms of elasticities rather than slopes. Hertel used the approach in a model of a single farm sector that has become common in agricultural economics (see, for example, Hertel 1989; Alston et al. 1995; Gunter et al. 1996; Salhofer 1996; Jamal 1997; Alston and James 2002; Jamal 2003, Ciaian and Swinnen 2006; Ciaian and Kancs 2009; Jafari and Jamal 2015, 2016; among others). We develop a single commodity model similar to Hertel (1989) and apply this to the Indonesian oil palm sector.

For a comparative static analysis, the model is expressed in terms of variables which are all in percentage change, i.e. $\hat{D}_y^M = \frac{d D_y^M}{D_y^M}$,² see Jafari and Jamal (2015, 2016) for details of the mathematics. Table 4 depicts the symbols and descriptions for all

Table 3 Main areas of difference between ISPO, MSPO, and RSPO

	ISPO	MSPO	RSPO
Environment	Relies on national legislation	Relies on national legislation	Relies on a comprehensive guideline for compliance with environmental provisions
High conservation value land (HCV)	Requires HCV identification, but does not define identification procedures in details	Does not mention HCV protection	Requires HCV identification, and identification procedure is clearly defined
Peatland	Under specified conditions, planting on peatland is allowed	Developed guidelines for best practices on peatland	Encourages voluntary commitments to avoid planting on peatlands
New planting cutoff dates ^a	Does not provide a cutoff date	Does not provide a have cutoff date	It provides cutoff date
Social	Does not provide extensive social impact assessment requirements	Requires a social impact assessment and a system for complaints, but this is not outlined in details.	Requires comprehensive social impact assessment
Free, prior and informed consent (FPIC) standards	No explicit reference to this standard	Mentioned that FPIC shall be recorded	Provides detailed guidelines
Workers right	Does not have a requirement for employee/worker contracts. Employees/workers must be enrolled in the government's social security program.	Requires a policy on workers' rights, in accordance with national standards, and provides some detail on what this should entail.	Provides details guidelines on worker rights, health, and safety.
Compliance	Requires full compliance with all criteria	Requires that internal audit procedure are documented and evaluated, in order to implement necessary corrective action through continuous improvement action plans	Requires full compliance with all criteria

Source: Based on Efficacy (undated)

^aA date after which new plantings should not replace primary forest or areas required to maintain HCV areas

Table 4 Definitions of variables of model

Endogenous variables	
D_y^M	Market demand for final output ($y = \text{CPO}$)
$D_y^{\text{EU}}, D_y^{\text{ROW}}$	Demand for y from EU and Rest of the World (ROW), respectively.
$D_y^{\text{Dom}}, S_y^{\text{Dom}}$	Domestic demand and domestic supply for y , respectively.
D_i, S_i	Derived demand for and supply of i th primary input
p_y^M	Market price of y
$p_y^{\text{EU}}, p_y^{\text{ROW}}$	Export price of y to EU and rest of the world (ROW)
$D_{\text{frst}}, D_{\text{ptls}}$	Demand for forest and peatland conversion, respectively
Parameters	
$\varepsilon_y^{\text{Dom}}$	Own price elasticity of domestic demand for y .
$\varepsilon_y^{\text{EU}}, \varepsilon_y^{\text{ROW}}$	Export price elasticity of EU and rest of the world (ROW) demand for y .
σ_{ij}	Allen substitution elasticity between input i and j
$\alpha_y^{\text{EU}}, \alpha_y^{\text{ROW}}$	Share export demands from of EU and ROW for y in total market demand
α_y^{Dom}	Share of domestic demand for y in total market demand
c_i	The cost share of i th primary input with respect to total cost of producing y
v_i	supply price elasticity of i th input
γ, μ	Forest and peatland conversion elasticities with respect to total land demand, respectively.
Exogenous variables (policy shocks)	
U_y^{Dom}	Price equivalent shift factor in domestic demand schedules for y
$U_y^{\text{EU}}, U_y^{\text{ROW}}$	Price equivalent shift factors in EU and ROW export demand schedules for y

endogenous and exogenous variables in the model. The structure of the model which is specified for a long-run partial equilibrium model under the assumption of perfect competition in the market is given in Table 5.

Let D , S , and P refer to the demand, supply, and price of inputs or outputs, respectively. Subscripts y refer to output, while i and j refer to input quantities or prices. Superscript M refers to market quantities and domestic market prices such that p_y^M reads as price of market demand for y . Superscript Dom refers to domestic demand (or supply) while superscripts EU and ROW denote EU or rest of the world (ROW) export demand or prices. Parameters ε and α denote elasticities and market shares, such that $\varepsilon_y^{\text{EU}}$ represents the elasticity of EU demand for exports in response to changes in p_y^{EU} , while α_y^{EU} reads as the demand share of EU in total market demand.

Consider the final product (CPO) which is produced by firms in the domestic market and consumed by consumers both in domestic and foreign markets. Assuming that consumers have homothetic preferences, such that the market shares are parameters, Eq. (1) in Table 5 gives the change in market demand for the final product ($\hat{D}_y^M$) as a function of changes in domestic and export demands. Eqs. (2) through (4) describe the domestic and export demand responsiveness of prices. In this equation, U represents a shift factor in the demand schedule expressed in price equivalent form, and $\hat{U}_y^{\text{EU}}$ reads as the percentage shift for EU demand with the same impact as a price change of the same magnitude but opposite sign. The method of incorporating the shifters follows Jamal (1997 and 2003).

Equation 5 describes the derived demand for inputs i and j under locally constant return to scale. Output constant demand elasticities are then the product of their cost share (c) and the Allen partial elasticity of substitution (σ). Adding the output change effect gives the total change in input demand under locally constant returns (Eq. (5)). The

Table 5 Single commodity partial equilibrium model of the Indonesian oil palm

Commodity demand equations	
$\hat{D}_y^M = (1 - \alpha_y^{EU} - \alpha_y^{ROW}) \hat{D}_y^{Dom} + \alpha_y^{EU} \hat{D}_y^{EU} + \alpha_y^{ROW} \hat{D}_y^{ROW}$	1
$\hat{D}_y^D = (\hat{p}_y^M - \hat{U}_y^{Dom}) \epsilon_y^{Dom}$	2
$\hat{D}_y^{EU} = (\hat{p}_y^{EU} - \hat{U}_y^{EU}) \epsilon_y^{EU}$	3
$\hat{D}_y^{ROW} = (\hat{p}_y^{ROW} - \hat{U}_y^{ROW}) \epsilon_y^{ROW}$	4
Derived demand under locally constant return to scale condition	
$\hat{D}_i = \sum_{j=1}^n c_j \sigma_{ij} \hat{p}_j^M + \hat{s}_y^{Dom}$	5
Zero profit condition	
$\hat{p}_y^M = \sum_{i=1}^n c_i \hat{p}_i^M$	6
Input supply equations for two subsector	
$\hat{s}_i = v_i \hat{p}_i^M$	7
Forest and peatland conversion functions	
$\hat{D}_{Fst} = \gamma \hat{D}_{Land}$	8
$\hat{D}_{Ptls} = \mu \hat{D}_{Land}$	9
Factor market clearing conditions	
$\hat{D}_i = \hat{s}_i$	10
Commodity market clearing conditions	
$\hat{D}_y^M = \hat{s}_y$	11

next two equations describe the responsiveness of land and non-land input supply to a change in rents or return under the assumptions that $0 < v < \infty$. Equations 8 and 9 show forest and peatland conversion as functions of total demand for oil palm land, where the coefficients γ and μ represent the corresponding elasticities with respect to land supply for oil palm. In essence, these equations model the relative propensity of land supply from deforested land and peatland conversion due to increases in overall demand for land input. The last two equations describe the market clearing conditions, where any surpluses or deficits in inventory of palm oil outputs and inputs are assumed constant.

Mathematically, Eqs. (1)–(11) form a linear system that can be solved given the non-singularity of the related matrix of coefficients. Necessary and sufficient conditions for non-singularity are squareness of the system and linear independence of equations. The general system of algebraic equations can be represented compactly as $AX = C$. Here A is the Jacobian matrix (coefficients of the endogenous variables of the model), X represents the matrix of endogenous variables (prices and quantities) while the right-hand side matrix denotes the exogenous variables (policy shocks). Thereafter, we can apply Cramer's rule to solve for the endogenous variables.

Baseline parameters for the exogenous variables in the model

The baseline, exogenous parameters required to implement the model include the Allen elasticities of substitution between primary inputs, factor cost shares and supply elasticities, demand elasticity values, and responsiveness of conversion to total palm land use. These coefficients and parameters are crucial as the validity of simulation results depend on the representativeness of the values. The parameters including their sources for the 2009 base year are depicted in Tables 6 and 7.

Table 6 Allen elasticities and cost shares

	Land	Labor	Agrochemical	Capital
Land	-0.3	0.078	-0.042	0.645
Labor	0.078	-0.79	0.492	0.895
Agro chemical	-0.042	0.492	-1.007	0.378
Capital	0.645	0.895	0.378	-4.147
Factor cost share	0.36	0.31	0.19	0.14

Source: Rhomus (2006)

This study was fortunate to have access to the estimates of the Allen elasticities of substitution between primary inputs for the case of oil palm plantations in Indonesia's province of Riau. While recognizing that Indonesia is a large country with large differences among regions, we still consider oil palm production technology and management to be quite comparable across areas within the country. Hence, we take the estimates from Rhomus (2006) to be representative for substitution elasticities between the primary inputs for the entire country. Their pattern indicates in general a rather low substitutability between pairs of inputs (Table 6). This denotes there is only moderate scope for greater use of capital or mechanization at the farm level to sustain or generate output growth if land is not increased at the same time. The own price elasticity of land supply is also quite inelastic (0.3). Therefore, an export demand decline is likely to decrease demand (Eq. 5) for all inputs, but for land, the decrease in prices would be strongest. Changing land demand then leads to changes in forest or peatland conversion.

Model application

This study simulates two scenarios to examine the impact of a moderate reduction in export demand for Indonesian palm oil on selected economic and environmental

Table 7 Elasticity values, market shares, and conversion rates

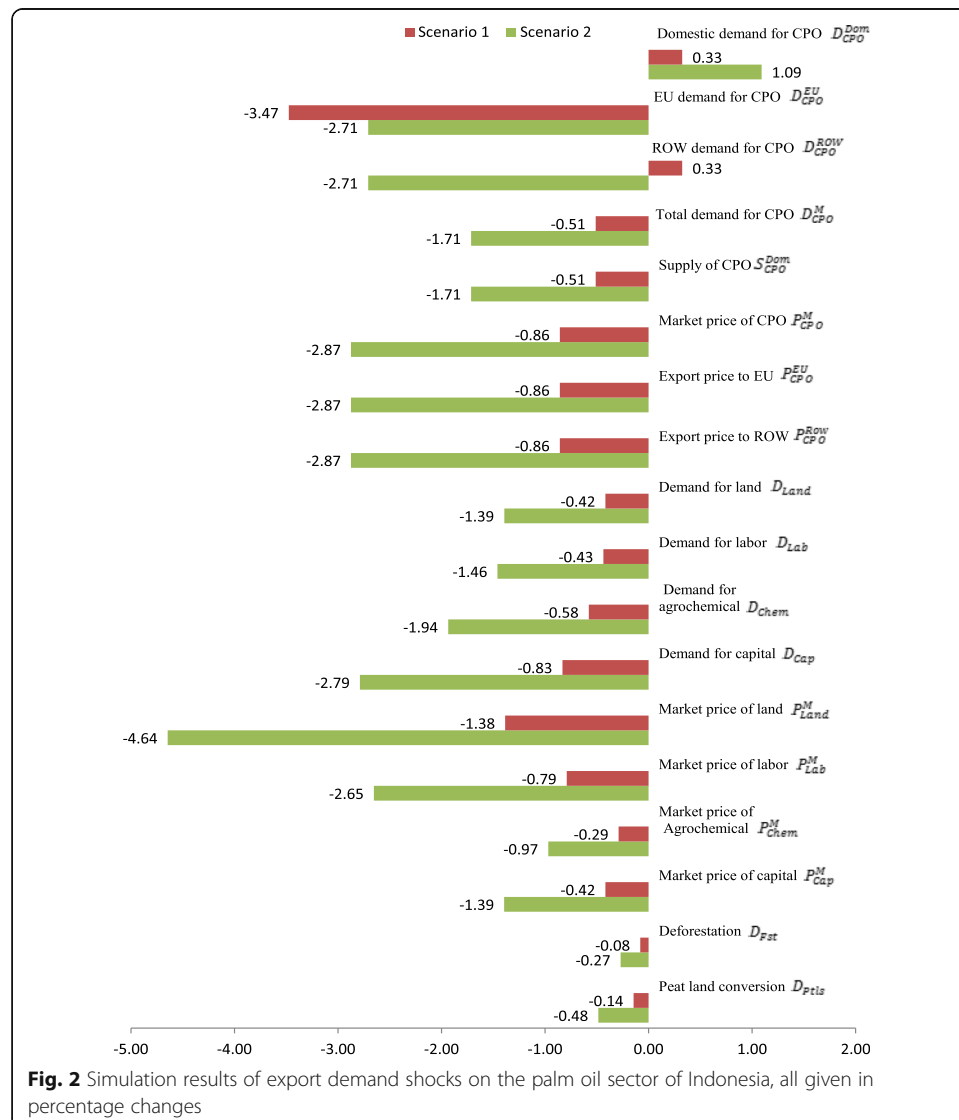
	Variables description	Value	Sources
ε_{yEU}	Palm oil own price demand elasticity in the European Union	-0.38	FAPRI (2013) elasticities database
ε_y^{ROW}	Palm oil own price demand elasticity in the rest of the world	-0.38	
ε_{yDom}	Palm oil own price demand elasticity in Indonesia	-0.38	
α_{yEU}	CPO export demand share of total output to EU markets	0.22	Calculated based on Trade data (2010)
α_y^{ROW}	CPO export demand share of total output to ROW markets	0.52	
α_{yDom}	CPO domestic demand share	0.26	
v_{Land}	Elasticity of land supply	0.3	Salhofer (2000); Jafari and Jamal (2015, 2016, 2011); Jamal and Jafari (2011).
v_{Lab}	Elasticity of labor supply	0.55	
v_{Cap}	Elasticity of capital supply	2	
v_{Chem}	Elasticity of agrochemical supply	2	
γ	Elasticity of forest conversion with respect to oil palm expansion	0.19	Gunarso et al. (2013)
μ	Elasticity of peatland conversion with respect to oil palm expansion	0.35	

variables in Indonesia. The first scenario examines the impact of a 10% reduction in the price equivalent shift factor of the EU demand schedule for Indonesian CPO, which approximately corresponds to a 4% horizontal shift.³ The second scenario considers the simultaneous impact of a 10% price equivalent demand shock on Indonesian CPO in the EU as well as in the ROW export markets.

These demand function shifters reflect changes in consumer preferences or the implementation of stricter legal sustainability criteria in the EU (or other markets) that would reduce the imports of palm oil from Indonesia. The second scenario is very pessimistic from the Indonesian perspective, but stronger impacts would also follow from a more drastic drop in EU demand, even if other regions would not reduce their import demand.

Results and discussions

The effects of both demand shocks on selected endogenous variables are listed in Fig. 2. The direction and magnitude of the changes in the variables are shown for each



scenario in a histogram with horizontal bars. Bars to the left show the reductions, and bars to the right show the increases of selected variables. The length of the bars indicate the magnitude of the changes. These changes should be interpreted as the percentage changes from a baseline trend, given the policy shocks, *ceteris paribus*. The simulated long-run impacts on the variables representing the output and input markets in Indonesia comply with expectations on their sign given the model structure. As can be seen in Fig. 2, based on the moderate reduction in export demand in both scenarios, palm oil supply, demand for inputs and the related conversion of forest and peatland would also decline only moderately.⁴

In the first scenario, equilibrium market and export prices decrease by -0.86% while export demand in Europe declines by -3.47% . The reduction in Indonesian export prices would provoke a minor increase in demand for CPO which is equal in magnitude ($+0.33\%$) in the Indonesian domestic and rest of the world markets as demand elasticities have been assumed the same (-0.38 , see Table 7). Our result is supported by Rina et al. (2010) who also expect that any reduction of Indonesian palm oil exports in European markets would be mitigated by increased exports elsewhere. However, according to our results, the increase in domestic and the ROW export demand for Indonesian CPO will not be able to completely compensate the reduction in European demand, and hence, total (market) demand for Indonesian CPO decreases. Consequently, the demand for land, labor, agrochemicals, and related capitals would fall as well. The reduction in agricultural land demand (-0.42%) would ultimately also reduce forest and peatland conversion by -0.08 and -0.14% , respectively.

For the second scenario, the direction of the impacts of the downward shift in export demand for Indonesian CPO on the variables of interest is the same as in the first scenario; however, the size of impacts is evidently larger. For instance, the modest decline in land demand in the first scenario (demand shock confined to the EU) would be reinforced from -0.42% to a more pronounced drop in land demand by -1.39% under the second scenario, hence more than double the previous impact. The impacts on land conversion would be, based on our assumed elasticities with respect to land demand, a decline of deforestation and peatland conversion by -0.27 and -0.48% , respectively, which are more than three times the impacts of scenario 1. The above results clearly confirm that a reduction in global demand would be only partially offset by increases in domestic demand in Indonesia. For this reason, this scenario has more sizable domestic impacts. Overall, the changes of the variables of interest are small, especially in the first scenario. Import restrictions decrease the overall import demand in both scenarios. The reduction is smaller in the first one because a part of the reduction in EU import demand is compensated by an increase in ROW demand. This reduction in import demand decreases market prices and consequently increases the domestic demand, but the net effects on total market demand and output are negative. Consequently, demand for primary factors of production, including the land input, declines, but this decline is more moderate than the reduction in outputs. Finally, the reduction in land leads to lower forest and peatland conversion rates.

Conclusions

The oil palm industry is a crucial element of the economy of Indonesia and a key export commodity. Sustainability concerns in importing countries and associated shifts in

consumer preferences away from palm oil involve a risk to major exporters like Indonesia. In aggregate modeling, shrinking export markets would mean losses of export revenues and factor income, hitting vested interests of beneficiaries from the palm oil industry. However, only a fraction of global demand in terms of countries and single agents is likely to value sustainability higher than price competitiveness. Therefore, even a sizable demand shock in the EU would not warrant serious national concern, as Indonesia is likely to sustain her total exports to a large extent.

If import demand slows down, deforestation and peatland conversion would be slowed down as well. Environmental damage from deforestation and peatland conversion, including biodiversity loss and sizeable CO₂ emissions, could be alleviated. It is acknowledged that environmental effects do not only depend on land conversions but also on the management of oil palm production which is related to the use of agrochemicals and capital. But their use would even decline stronger than the land input in our scenarios such that the intensity of oil palm production would also be lower. However, any additional environmental benefits in terms of avoiding negative externalities could only be quantified with more disaggregate modeling approaches.

Coming to the socio-economic implications of these import restraint scenarios, we note that Indonesia would see income losses among migrant palm oil workers and, of course, among the owners of palm oil plantations. However, the economic dynamics of an expanding sector has also been linked by other authors to land ownership conflicts and other social problems. We might expect that these tensions in social relations and land ownership issues in rural communities would be moderated if their key economic stimulus is weakened. The downside socio-economic effects of a decrease in oil palm production are losses of employment, but these are unlikely to be serious for the resident rural poor population (in contrast to migrant workers).

However, non-negligible parts of Indonesian society would not welcome an import ban, in spite of some environmental benefits and positive socio-economic aspects. To avoid the pressure from important customers of palm oil producing countries, Indonesia (and Malaysia)⁵ would, in turn, need to re-evaluate and realign their agri-environment policies, including international commitment to address emerging sustainability concerns which also covers socio-environmental sustainability of oil palm expansion. Some years ago, it appeared that the RSPO would simply need to raise its sustainability standards to resolve the matter decisively. However, the RSPO is no longer the sole flagship certification body for the global palm oil industry. Given the emergence of two national certification frameworks (ISPO and MSPO), it seems that the two major palm oil producers are taking separate ways in responding to the sustainability demands of affluent consumers.

A promising, perhaps optimistic way forward for Indonesia (and Malaysia) is to agree on a cooperative solution through a process that shall involve the various stakeholders within the palm oil sector. RSPO-certified palm oil has been well acknowledged by the EU, providing a ready platform for palm oil to make further inroads into the major affluent markets. Hence, it should be in the common interest of the ISPO, MSPO, and RSPO frameworks to adopt a shared set of sustainability criteria, encompassing the common elements of transparency, regulatory compliance, best agricultural practices, environmental responsibility, the livelihood of small farmers, as well as human and local community rights. This would provide a unified, credible, and globally accepted

certification program that has good chances to avoid the pressure from declining export demand and, in the long run, even to support a further expansion. It would also pave the way for oil palm producers to have a common stance and stronger influence in related international forums and negotiations.

Endnotes

¹Malaysia herself is one of the top CPO exporters alongside Indonesia. Due to increasing labor shortages and restricted land area in Malaysia, Malaysian oil palm companies have expanded to Indonesia and these Indonesian-based plantations are now exporting palm oil back to their home country.

²It is important to note that the *hat* notation symbolizes percentage changes in variables while *d* reflect the absolute changes in the variable)

³A 4% quantity shock is small compared to the standard error of Indonesian exports to major EU importers around the trend, which was 13% of the mean in the last decade.

⁴Note that the equations in the model have been linearized, and hence, the impacts of even higher demand shocks would be simply a multiple of the impacts shown below. For instance, a tripling in the demand shock would also give three times the impact of the original shocks. With higher shocks, though, approximation errors would be higher as well such that our scenarios were limited in scope on purpose.

⁵We refer to Malaysia as the shift in consumers demand preferences in Europe and other markets may not only affect Indonesia.

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Authors' contributions

YJ participates in the acquisition of data, development of the model, and drafting the article. JO makes a substantial contribution to conception and design of the paper and analysis of results. HPW revised the paper critically for important intellectual content. SJ makes substantial contributions to conception of the legal standing of standards in the article. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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Estimates of Ad Valorem Equivalents of Barriers Against Foreign Suppliers of Services in Eleven Services Sectors and 103 Countries

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1. INTRODUCTION

INTEREST in estimates of the impact of services barriers has significantly increased since the early 1980s. In part, this is due to the recognition of the growing importance of services as a share of national value added and as a share of global trade. By 2007, services as a share of national value added ranged from 74 per cent in high-income OECD countries to 48 per cent in low-income countries.¹ Escaith (2008) estimated that cross-border trade in services accounted for almost fifty per cent of total goods and services trade when trade is measured on a value-added basis; when we include the value of sales by foreign affiliates, the share of services trade in total trade rises further. In addition, with the inclusion of the General Agreement on Trade in Services (GATS) as a major pillar of the WTO agenda and the inclusion of services in regional trade agreements, services commitments have become an important aspect of international trade negotiations. Estimates of what is at stake in these services trade negotiations depend in the first instance on estimates of the ad valorem equivalents (AVEs) of the barriers faced by foreign suppliers of services.

In this paper, we present our estimates of the ad valorem equivalents of the discriminatory barriers against foreign suppliers of services in 11 services sectors in 103 countries. The estimates are based on a recently available data set on the discriminatory regulatory barriers against foreign suppliers of services in these sectors and countries that was produced by the World Bank. The database contains significantly greater coverage of the regulatory regimes in services in developing countries than what has been available heretofore.² The database provides data on the following services sectors: (i) accounting, (ii) legal, (iii) air transport, (iv) rail transport, (v) road transport, (vi) maritime transport, (vii) insurance, (viii) banking, (ix) fixed line

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¹ From the World Development Indicators database. See Francois and Hoekman (2010, table 1).

² The OECD provides a database of regulatory barriers in services and services trade restrictiveness indices for 40 countries focusing on the OECD and BRICS countries. The data are available at <http://www.oecd.org/tad/services-trade/services-trade-restrictiveness-index.htm>. See also Golub (2009) for a measure over time of restrictions on FDI in services in 50 developing and 23 developed countries.

telecommunications, (x) mobile telecommunications and (xi) retail distribution. These sectors are well chosen among the many services sectors since they are among the most important in international trade. Further, these sectors are important inputs into manufacturing production, and evidence has shown that greater access to business services that are inputs into manufacturing has significant productivity impacts on the manufacturing sector.³ Although Borchert et al. (2014) have produced services trade restrictiveness indices from this database, this paper is the first to produce ad valorem equivalents based on this database. As a result, we are able to provide much wider coverage of ad valorem equivalents of the barriers than previous efforts that were based on assessments of the regulatory regimes in the services sectors.

Following the initial work of Hoekman (1995), estimates of the ad valorem equivalents of barriers against foreign service suppliers can be grouped into two methodological categories: (i) gravity model estimates, and (ii) estimates that rely on the collection of information on the regulatory barriers against foreign suppliers of services, typically convert that information into indices of restrictiveness and then use the restrictiveness index in econometric regressions to get AVEs.⁴ The gravity approach has been employed by Francois (1999), Kimura and Lee (2004), Walsh (2006) and Francois et al. (2007). These authors regress the total bilateral cross-border trade in services on the national incomes of the two countries, distance between them, and dummy variables to reflect common border, common language or other variables. For example, Francois (1999) assumes that the difference between the actual and predicted trade flows reflects trade barriers. Assuming a demand elasticity allows a conversion of the quantity differences into a price impact or AVE of the inferred barriers to services trade. One limitation of this approach is that the estimates are based on cross-border trade in services; but in services, it is often sales through foreign direct investment that are more important.⁵ As Francois and Hoekman (2010) note, a well-known limitation of this approach is that the AVE is not related to any specific regulatory barrier. In our experience in estimating these AVEs in business services sectors in Russia, Armenia, Georgia, Kenya, Tanzania, Kazakhstan, Belarus and Malaysia,⁶ we find that in-country officials are often deeply sceptical or unconvinced of such estimates unless the researcher can point to specific regulatory barriers that explain the ad valorem equivalent in particular sectors; but when specific barriers can be referenced, the story typically becomes convincing. Further, without tying the AVEs and the costs of the barriers to specific regulatory barriers, the analyst is not able to recommend potential policy reforms.

Consequently, we prefer the second approach and our methodology is firmly rooted in it. In addition to the single country studies of many sectors mentioned above, the second

³ Several studies using firm-level data have established a link between increased access to services and increases in productivity. Using panel-level data and controlling for FDI endogeneity, Arnold et al. (2011) for the Czech Republic; Fernandes and Paunov (2012) for Chile; Shepotylo and Vakhitov (2012) for Ukraine; and Arnold et al. (2015) for India find a significant positive relationship between FDI in services following liberalization (especially allowing foreign entry) and the performance of downstream domestic firms in manufacturing. See Francois and Hoekman (2010) for a review of the evidence from other sources.

⁴ See Deardorff and Stern (2006) and Dee (2005) for comprehensive reviews of the literature on estimates of the ad valorem equivalents of the barriers faced by foreign suppliers of services. See also Francois and Hoekman (2010). Walsh (2006) has an extensive review of the gravity approach.

⁵ Francois et al. (2007) bring foreign direct investment data into the approach.

⁶ The first five of these country studies are available at <https://drive.google.com/?pli=1#folders/0B0V-tBs4-hXYjA3MTQ5MDctNTAxYy00M2I4LWI3NDAtZGRiNDI3NmYwOGU2>

approach has been employed in single sectors for many countries by Kalirajan (2000), Kalirajan et al. (2000), Kang (2000), Nguyen-Hong (2000) and Warren (2000b)⁷ Doove et al. (2001), Copenhagen Economics (2005) and Dihel and Shepherd (2007) and have estimated AVEs employing this approach for many countries and in multiple sectors. This approach collects information on the regulatory regime in a particular services sector in a country and typically converts that information into an index of restrictiveness.⁸ Then, the impact of services restrictiveness on a measure of price or cost is estimated econometrically, where a vector of independent variables that impact the price or cost of the service is included in the estimation to control for their impact. This approach is necessarily done on a sector-by-sector basis. The Australian Productivity Commission has pioneered work along these lines, and many of the studies it supported were collected in Findlay and Warren (2000). Although data on the full vector of variables impacting price or cost may not be known for many countries, if the restrictiveness index is known, estimates of the AVE of services barriers may be obtained using this approach assuming that the estimated coefficient on the restrictiveness index applies in these countries.

Lacking information on the regulatory regimes in services for most countries, the authors above were generally able to estimate ad valorem equivalents of the services barriers in less than 30 countries.⁹ Consequently, our country coverage is considerably broader, especially for developing countries, and also widens the available sector coverage.

In the next section, we explain the methodology and data sources. We present our results in Section 3.

2. METHODOLOGY

a. Basic Concepts

(i) The Ad Valorem Equivalent

Consider a simple partial equilibrium model of a service sector under perfect competition. Without loss of generality for the calculation of the ad valorem equivalent (AVE), we assume that the country concerned is small so that the supply curve by foreign services providers is perfectly elastic.¹⁰ The foreign supply curve could apply either to the case of cross-border supply of services or to sales by foreign affiliates from foreign direct investment. We

⁷ Bottini et al. (2011) estimate the impact of barriers in banking and telecommunications on performance variables in four Middle Eastern countries.

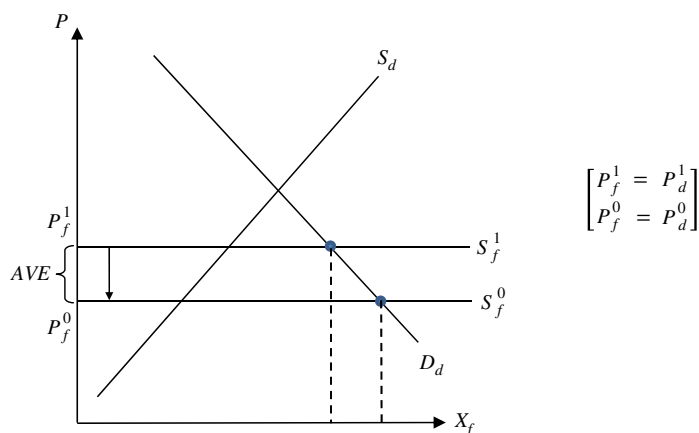
⁸ Deardorff and Stern (2006) discuss alternate, but less common, ways to use the information on the regulatory barriers in subsequent regressions. See Dihel and Shepherd (2007) for one variation of this approach.

⁹ Kalirajan et al. (2000) produced estimates for 27 countries (mostly Asia-Pacific) in banking; Nguyen-Hong (2000) produces estimates for 20 economies in engineering services; Kang (2000) produces estimates for 23 countries in transportation services; Warren (2000b) produces estimates for 20 countries in communications; Dihel and Shepherd (2007) produce estimates for 26–28 countries in banking, insurance, telecommunications and engineering services; Copenhagen Economics (2005) estimates the barriers for 19 European Union countries. Doove et al. (2001) produce estimates for 35 economies in air transport services, 47 countries in telecommunications and 51 economies in electricity prices.

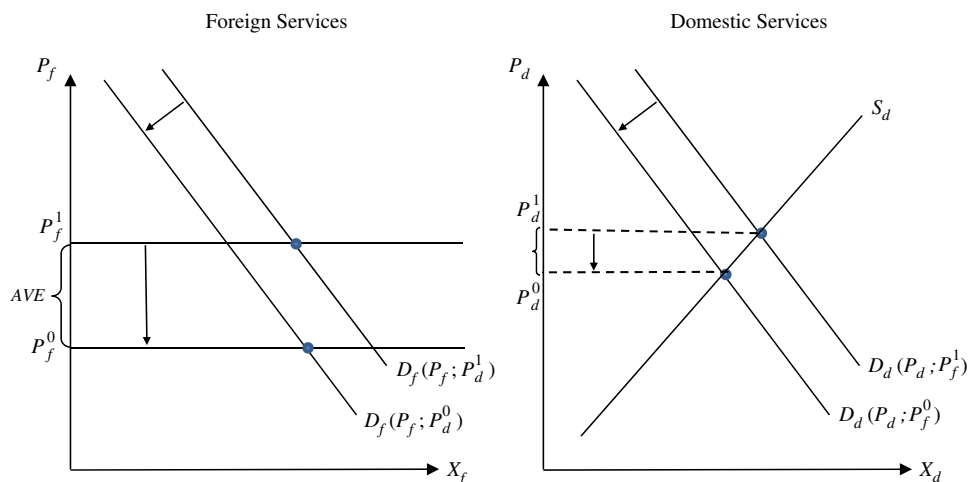
¹⁰ If the foreign supply curve is upward-sloping, the reduction in the barriers against foreign suppliers will lead to a smaller decrease in the price of foreign services than shown in Figure 1. But the difference between the foreign supply prices with and without discriminatory restrictions will still be the ad valorem equivalent.

FIGURE 1
Ad Valorem Equivalent (AVE) of Barriers (Discriminatory Restrictions)

(a) Small Country: The Case of Perfect Substitutes



(b) Small Country: The Case of Imperfect Substitutes



illustrate the case below where we assume that only discriminatory restrictions exist. Then, the ad valorem equivalent is shown in Figure 1. When services provided by foreigners and those provided by domestic suppliers are perfect substitutes, the upper diagram of Figure 1 applies. When services provided by foreigners and those provided by domestic suppliers are imperfect substitutes, the lower diagram of Figure 1 applies. In either case, the AVE is measured as:

$$AVE(\%) = [(P_f^1 - P_f^0)/P_f^0] \cdot 100,$$

where P_f^1 is the price of services provided by foreign suppliers with restrictions and P_f^0 is the price of services provided by foreign suppliers without discriminatory restrictions.¹¹

(ii) *Discriminatory versus Non-discriminatory Barriers*

Many restrictions affect both foreign and domestic suppliers of services. For example, a ban on entry for all firms could be non-discriminatory. Even if these barriers have a relatively more adverse effect on the costs of foreign firms, we call these non-discriminatory restrictions. If the non-discriminatory restrictions are also removed or reduced, the foreign supply price would fall further. In this case, the AVE of all the barriers that foreign suppliers of services confront can be decomposed into two parts: AVEs of discriminatory restrictions and those of non-discriminatory restrictions. An issue in the literature has been the disentangling of the impact on price of a service of the discriminatory and non-discriminatory components of services regulations. The data set we use in this paper provides information on discriminatory barriers only. Consequently, we only provide estimates of the AVE of discriminatory barriers.¹²

b. *Data Sources*

With two exceptions mentioned below, the data for the estimates of the discriminatory barriers faced by foreign suppliers of services come from the recently released World Bank database of survey information on 11 services sectors mentioned above in 103 countries. See Borchert et al. (2014) for a guide to the database.

The World Bank survey employed a 169-page questionnaire of the regulatory regimes of these 11 sectors that was completed by law firms resident in each of the non-OECD 103 countries. For OECD countries, the questionnaire was completed based on a variety of available reports. The database focuses exclusively on the discriminatory barriers faced by foreign suppliers of services and, except for the European Union countries, ignores preferential commitments and focuses exclusively on MFN barriers. For European Union countries, however, they took a weighted average of MFN and intra-EU policies.¹³ Based on these data and the methodology they developed, Borchert et al. (2014) produced 'services trade restrictiveness indices', for all 11 sectors in all of the 103 countries.¹⁴

¹¹ In some model applications, the AVE cannot be greater than one (e.g. Balistreri et al., 2009; Jensen et al., 2010), so these researchers may use the domestic price with restrictions in the denominator; then, the AVE is less than or equal to one. It is straightforward to convert the AVE with the domestic price with restrictions to one with an unrestricted domestic price in the denominator. In particular, if AVE is the ad valorem equivalent with restricted prices in the denominator and AVE* is the ad valorem equivalent with unrestricted prices in the denominator, then AVE* may be derived from AVE as $AVE^* = AVE/[1 - AVE]$ and $AVE = AVE^*/[1 + AVE^*]$.

¹² In work in Armenia, Georgia, Russia, Kenya, Tanzania, Belarus and Malaysia, our colleagues have supplemented the data from the World Bank questionnaire with other sources which then allowed them to estimate the AVE of the non-discriminatory barriers as well. See, for example, Idrisov (2010) for Russia. The first five of these papers are available at <https://sites.google.com/site/davidgtarr/Home/estimates-of-aves-of-services-barriers-1>.

¹³ The decision to account for preferential services policies within EU countries is in contrast with the OECD services trade restrictiveness indices which ignore preferential liberalisation throughout. See: <http://www.oecd.org/tad/services-trade/methodology-services-trade-restrictiveness-index.htm>

¹⁴ Landlocked countries were not included in the maritime sector survey, so the database is for less than 103 countries in this sector. The underlying data and the services trade restrictiveness indices of these authors are available at <http://firesearch.worldbank.org/servicetrade/>.

Information on two questions came from additional sources. Regarding barriers to maritime transport services, information on participation in a 'United Nations Liner Code' came from the Convention on a Code of Conduct for Liner Conferences.¹⁵ Information related to intellectual property rights in retail services was based on whether the country is on the priority 301 watch list of the United States Trade Representative (USTR).¹⁶

c. Calculation of Services Trade Restrictiveness Indices from the World Bank Database According to the Methodology of the Australian Productivity Commission

Although Borchert et al. (2014) calculated services trade restrictiveness indices (*STRIs*) based on the World Bank database and a methodology they developed, to date, the World Bank database of discriminatory services barriers has not been transformed into ad valorem equivalents. We use the data of the World Bank and transform it by building on a series of studies supported by the Australian Productivity Commission. First, these authors developed a methodology for calculating *STRIs* in several business services sectors. This included studies by Kalirajan (2000), McGuire and Schuele (2000), McGuire et al. (2000), and Nguyen-Hong (2000). *STRIs* were calculated and, crucially, ad valorem equivalents were also estimated (usually in separate studies). Since we need to use the regressions of the Australian authors for the ad valorem equivalent estimates, we first need to score the data on discriminatory regulatory barriers of the World Bank database consistent with the *STRI* methodology employed by the Australian authors.¹⁷ In the case of the European Union countries, transformation of the World Bank database includes weighting the intra-EU and extra-EU services regulatory regimes. We ignored preferential arrangements other than for the EU.

For the *STRIs* in each of these service sectors, the Australian authors first developed a set of regulatory categories of potential restrictions and listed possible regulatory outcomes within each category. They collected data and assessed the regulatory regimes of many countries. Predetermined weights were assigned to each category based on the researchers' *a priori* assessment of the importance of each category to performance outcomes of the sector.

These indices are subject to criticisms of various kinds as a determinant of the price impact of the restraints. It would have been better to estimate the weights assigned to different categories, rather than assign them on an *a priori* basis. But limitations on the size of the sample prevented this. Related to this, although cross-border supply of services generally is an inferior substitute for supply of services with a commercial presence, for some sectors, or at least services within a sector, cross-border supply might substitute well for supply with a commercial presence. For example, some insurance or re-insurance services might compete well through online sales or cross-border negotiations in re-insurance. Then, if the market is open to cross-border supply, restrictions in the commercial presence area would have a smaller impact on the price of the service. Conversely, if firms can enter easily with a commercial presence, restrictions on cross-border supply would likely have less of a price impact. It is difficult to construct an index that could capture all of these nuances, and our indices fail to capture them. Other limitations are mentioned in the caveats section.

¹⁵ See: http://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XII-6&chapter=12&lang=en

¹⁶ See <http://www.ustr.gov/about-us/press-office/reports-and-publications/2011/2011-special-301-report>.

¹⁷ The scoring methodology of Borchert et al. (2014) differs in significant ways from that of the Australian authors.

The sum of the weights is equal to one in all cases. Regulatory outcomes within each category in each sector were developed and scored, with a score of 1 being the most restrictive and zero implying no restriction. The estimated score for each category is obtained by multiplying the selected score by the weight that is assigned to each restriction category. The *STRI* for the sector in a country is obtained by summing the weighted score for each category across all restriction categories. In this manner, their evaluations of each restriction category were transformed into a services trade restrictiveness index that ranged from zero to one, with one being completely blocked to foreign services suppliers and zero implying no discriminatory barriers against foreign services suppliers.

In this study, for several sectors the list of restrictions and weights in our *STRIs* are identical to those of the Australian authors. In particular, the restrictions and weights are the same as those of McGuire et al. (2000) in maritime services; McGuire and Schuele (2000) in banking services; Kalirajan (2000) in distribution services; and Nguyen-Hong (2000) in professional services. In the absence of explicit matrices of restrictions for the other sectors, it was necessary to develop *STRIs* with weights and restrictions based on those of the Australian authors. In particular, in air transport, rail transport and road transport, they were developed by Kimura et al. (2004a), based on the categories of restrictions on maritime services in McGuire et al. (2000). In insurance services, Kimura et al. (2004b) developed the restriction list and weights based on banking services in McGuire and Schuele (2000). In fixed and mobile line services, Kimura et al. (2004c) developed a list based on categories in Warren (2000a) in telecommunications supplemented by categories in financial sectors and transport sectors in McGuire and Schuele (2000) and McGuire et al. (2000).

Finally, but crucially, for our *STRIs* we define a mapping from the World Bank database to the list of restrictions (or matrices) of the Australian authors. In the case of the European Union countries, a case-by-case assessment was required to assess the notes on the intra-EU policies in the World Bank database. In this manner, we score the regulatory regimes of the 11 sectors in the 103 countries according to the Australian authors' criteria; that is, we calculate services trade restrictiveness indices according to the methodology of the Australian authors.

There is considerable overlap in the categories of services restrictiveness in the World Bank database and the Australian authors scoring matrices, but the mapping is not one to one. Defining the mapping from the World Bank database to the criteria of the various Australian authors involved judgments in many cases. When there was not a clear one-to-one mapping, we used the closest proxy from the World Bank database. We attempted to use all the information in the World Bank database, but in a few cases, no reasonable proxy was available. In these cases, we deleted the category from the matrix of the Australian authors and rescaled the remaining categories so that the sum of the category weights equalled one. The mapping for the banking sector is included as Table 1 to illustrate the procedure. The detailed mappings for all sectors are shown in Jafari and Tarr (2014). Complete documentation of the scoring and data are provided in Excel spreadsheets online.¹⁸

Although Table 1 and the other tables in Jafari and Tarr (2014) should be self-explanatory, we discuss a few examples to clarify the mapping procedure. First, consider the mapping for regulation of banking services. The first category in the McGuire and Schuele matrix for banking is

¹⁸ See the folders: '*STRI* mapping of data', '*STRI* scoring 103 countries' and 'Intra-EU *STRI* scoring and Calculations' at the link: <https://drive.google.com/?pli=1&authuser=0#folders/0B0V-tBs4-hXY-jA3MTQ5MDctNTAxYy00M2I4LWI3NDAtZGRiNDI3NmYwOGU2>

TABLE 1
Example from the Banking Sector: Mapping from World Bank Database to Categories of McGuire and Schuele

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
<i>Restrictions on Commercial Presence</i>				<i>Restrictions on Commercial Presence</i>			
Licensing of banks	0.1			Licensing of banks	0.1		
Issues no new licence/no new licence is allowed.	0.1	1		Market entry is not allowed (mode 3).	0.1	1	
Issues up to 3 new licences with only prudential requirements/licences are issued through complicated (discriminately) and costly procedure.	0.1	0.75		Market entry is allowed, but three of the following restrictions apply: (i) there is a limit on the number of licences available, (ii) licence is allocated at the discretion of regulatory body, and (iii) licence is not granted if publicly available criteria fulfilled.	0.1	0.75	
Issues up to 6 new licences with only prudential requirements/licences are generally issued with application fee and several requirements.	0.1	0.2		Market entry is allowed, but two of the following restrictions apply: (i) there is a limit on the number of licences available, (ii) licence is allocated at the discretion of regulatory body, and (iii) licence is not granted if publicly available criteria fulfilled.	0.1	0.2	
Issues up to 10 new licences with only prudential requirements/licences are generally issued with application fee.	0.1	0.1		Market entry is allowed, but one of the following restrictions apply: (i) there is a limit on the number of licences available, (ii) licence is allocated at the discretion of regulatory body, and (iii) licence is not granted if publicly available criteria fulfilled.	0.1	0.1	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
<i>Restrictions on Commercial Presence</i>				<i>Restrictions on Commercial Presence</i>			
Issues new licences with only prudential requirements/licences are generally issued with application fee.	0.1	0		Market entry is allowed, but none of the following restriction apply: (i) there is a limit on the number of licences available, (ii) licence is allocated at the discretion of regulatory body, and (iii) licence is not granted if publicly available criteria fulfilled.	0.1	0	
Form of commercial presence	0.1			Form of commercial presence	0.1		
Measures that restrict or require a specific type of establishments.	0.1	1		One of the following forms of establishment is restricted: (i) green field branch, (ii) joint venture, (iii) greenfield subsidiary, (iv) acquisition.	0.1	1	
No restriction on establishment.	0.1	0		None of the following forms of establishment is restricted: (i) green field branch, (ii) joint venture, (iii) greenfield subsidiary, (iv) acquisition.	0.1	0	
Direct investment: equity participation permitted	0.2			Direct investment: equity participation permitted	0.2		
The score is inversely proportional to the maximum equity participation permitted in an existing domestic bank.	0.2	1-s		The score is inversely proportional to the maximum foreign equity participation permitted in a professional firm. If s = maximum foreign equity participation permitted in a professional firm.	0.2	1-s	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i> <i>Restrictions on Commercial Presence</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i> <i>Restrictions on Commercial Presence</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
Joint venture arrangements	0.1			Joint venture arrangements	0.1		
Issues no new banking licences and no entry is allowed through a joint venture with a domestic bank.	0.1	1		No entry is allowed through a joint venture with a domestic bank.	0.1	1	
Bank entry is only through a joint venture with a domestic bank.	0.1	0.5		There are specific requirements for foreign firms to enter the local market through a joint venture (none of the following forms of establishment is allowed: (i) green field branch, (ii) greenfield subsidiary, (iii) acquisition, (iv) there is a maximum foreign equity permitted which imposes a <i>de facto</i> joint venture requirement).	0.1	0.5	
No requirement for a bank to enter through a joint venture with a domestic bank.	0.1	0		No restriction	0.1	0	
Permanent movement of people	0.02			Permanent movement of people	0.02		
No entry of executives, senior management and/or specialists	0.02	1		Percentage of domestic residents/ citizens on the board of directors required is 100%.	0.02	1	
Executives, specialists and/or senior management can stay up to 1 year.	0.02	0.8		Percentage of domestic residents/ citizens on the board of directors required is above 75% and below 100%.	0.02	0.8	
Executives, specialists and/or senior management can stay up to 2 years.	0.02	0.6		Percentage of domestic residents/ citizens on the board of directors required is above 50% and below 75%.	0.02	0.6	
Executives, specialists and/or senior management can stay up to 3 years.	0.02	0.4		Percentage of domestic residents/ citizens on the board of directors required is above 25% and below 50%.	0.02	0.4	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i> <i>Restrictions on Commercial Presence</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i> <i>Restrictions on Commercial Presence</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
Executives, specialists and/or senior management can stay up to 4 years.	0.02	0.2		Percentage of domestic residents/ citizens on the board of directors required is above 0% and below 25%.	0.02	0.2	
Executives, specialists and/or senior management can stay a period of 5 years or more.	0.02	0		Percentage of domestic residents/ citizens on the board of directors required is 0%.	0.02	0	
<i>McGuire and Schuele Categories</i> <i>Cross-border Trade</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i> <i>Cross-border Trade</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
Raising funds by foreign banks	0.1			Raising funds by foreign banks	0.1		
Banks are not permitted to raise funds in the domestic market/foreign banks are not permitted to have cross-border deposits of the host country banks, corporations and households.	0.1	1		Restrictions on raising capital domestically	0.1	1	
Banks are restricted from raising funds from domestic capital market/ foreign banks are permitted to have cross-border deposits of only some types of the host country residents or any type of the host country residents with specific ceiling amount.	0.1	NA					
Banks are restricted in accepting deposits from the public/foreign banks are permitted to have cross-border deposits of the host country banks, corporations and households with licences.	0.1	NA					

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
<i>Cross-border Trade</i>				<i>Cross-border Trade</i>			
Banks can raise funds from any source with only prudential requirements/foreign banks are permitted to have cross-border deposits of any type of residents without restrictions.	0.1	0		No restrictions on raising capital domestically.	0.1	0	
Lending funds by foreign banks.	0.1			Proxy for Lending funds by foreign banks.	0.1		
Banks are not permitted to lend to domestic clients/foreign banks are not permitted to have cross-border lending to the host country banks, corporations and households.	0.1	1		Restrictions on all four categories: repatriation of earnings, transactions in local currencies, licensing discrimination and 'other' discrimination.	0.1	1	
Banks restricted to a specified lending size or lending to government projects. Foreign banks are permitted to have cross-border lending to only some types of the host country residents or any type of the host country residents with specific ceiling amount.	0.1	0.75		Restrictions on three of the four categories.	0.1	0.75	
Banks are restricted in providing certain services such as credit cards, leasing and consumer finance/foreign banks are permitted to have cross-border lending to the host country banks, corporations and households with licences.	0.1	0.5		Restrictions on two of the four categories.	0.1	0.5	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
<i>Cross-border Trade</i>				<i>Cross-border Trade</i>			
Banks are directed to lend to housing and small business.	<i>0.1</i>	<i>0.25</i>		Restriction on one of the four categories.	<i>0.1</i>	<i>0.25</i>	
Banks can lend to any source with only prudential restrictions/foreign banks are permitted to have cross-border lending to any type of the host country residents without restrictions.	<i>0.1</i>	<i>0</i>		No restrictions.	<i>0.1</i>	<i>0</i>	
<i>Other Restrictions</i>				<i>Other Restrictions</i>			
Other business of banks – insurance and securities -	<i>0.1</i>			Restriction on banking services	<i>0.1</i>		
Banks can only provide banking services.	<i>0.1</i>	<i>1</i>		Access denied to both deposit insurance and the central bank discount window.	<i>0.1</i>	<i>1</i>	
Banks can provide banking services plus one other line of business – insurance or security services.	<i>0.1</i>	<i>0.5</i>		Access denied to either deposit insurance or the central bank discount window.	<i>0.1</i>	<i>0.5</i>	
Banks have no restriction on conducting other lines of business.	<i>0.1</i>	<i>0</i>		Access provided to both deposit insurance and the central bank discount window.	<i>0.1</i>	<i>0</i>	
Direct investment: restrictions on certain types of services.	<i>0.1</i>			Direct investment: restrictions on certain types of services.	<i>0.1</i>		
Restrictions on providing some types of banking services.	<i>0.1</i>	<i>1</i>		Access denied to the main payment system.	<i>0.1</i>	<i>1</i>	
No restriction on providing any type of banking services.	<i>0.1</i>	<i>0</i>		Access provided to the main payment system.	<i>0.1</i>	<i>0</i>	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
Expanding the number of banking outlets	0.05			Expanding the number of banking outlets	0.05		
One banking outlet with no new banking outlet permitted.	0.05	1		Both branches (outlets) and ATMs are restricted.	0.05	1	
Number of banking outlets is limited in number and location.	0.05	0.75		Restriction on either branches (outlets) or ATMs.	0.05	0.75	
Expansion of banking outlets is subject to non-prudential regulatory approval.	0.05	0.25	NA				
No restrictions on banks expanding operations.	0.05	0		No restriction on number of outlets or number of ATMs.	0.05	0	
Composition of the board of directors	0.02			Composition of the board of directors	0.02		
The score is inversely proportional to the percentage of the board that can comprise foreigners.	0.02			The score is inversely proportional to the percentage of the board that can comprise foreigners. If b = maximum percentage of the board that can comprise foreigners.	0.02	$1-b$	
Temporary movement of people	0.01			Temporary movement of people (we used information on temporary movement of people for accounting services)	0.01		
No temporary entry of executives, senior managers and/or specialists.	0.01	1		No limitation on the duration of stay initially allowed for IPC.	0.01	1	
Temporary entry of executives, senior managers and/or specialists up to 30 days.	0.01	0.75		Duration of stay initially allowed for IPC is up to 1 month.	0.01	0.75	

TABLE 1 *Continued*

<i>McGuire and Schuele Categories</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>	<i>The World Bank Data</i>	<i>Weight</i>	<i>Score</i>	<i>Weighted Score</i>
Temporary entry of executives, senior managers and/or specialists up to 60 days.	0.01	0.5		Duration of stay initially allowed for IPC is up to 2 months.	0.01	0.5	
Temporary entry of executives, senior managers and/or specialists up to 90 days.	0.01	0.25		Duration of stay initially allowed for IPC is up to 3 months.	0.01	0.25	
Temporary entry of executives, senior managers and/or specialists over 90 days.	0.01	0		Duration of stay initially allowed for IPC is over 3 months.	0.01	0	
Total	1				1		

Note:

The bold print represents categories or types of restrictions.

licensing of banks. The category has a weight in the McGuire and Schuele matrix of 0.1, and there are five possible scores for the category. If no new licence is allowed, the score is 1, for a weighted score of 0.1. If licences up to three licences are issued through a complicated, discriminatory and costly procedure, the McGuire and Schuele score is 0.75, for a weighted score of 0.075. If up to six licences are issued with an application fee and several requirements, the McGuire and Schuele score is 0.2, for a weighted score of 0.02. If up to ten licences are issued with only prudential requirements and an application fee, the McGuire and Schuele score is 0.1, for a weighted score of 0.01. If licences are issued with only prudential requirements and an application fee, the McGuire and Schuele score is 0, for a weighted score of 0. If the World Bank database indicates that 'market entry is not allowed', we score this category in the McGuire and Schuele matrix at 1. The World Bank database notes three possible restrictions on the issuance of licences: (i) there is a limit on the licences available, (ii) the licence is issued at the discretion of the regulatory body, and (iii) the licence may be denied despite fulfilment of all publicly available criteria. If the World Bank database indicates all three categories of restrictions apply, we score this category of the McGuire and Schuele matrix at 0.75. If two of these restrictions apply, we score this category at 0.2. If one of these restrictions applies, we score the category at 0.1. If none apply in the World Bank database, we score this McGuire and Schuele category at zero.

There is a category 'equity participation permitted', which has a weight of 0.2 in the McGuire and Schuele matrix for banking. The score in the McGuire and Schuele matrix is $1-s$, where s is the maximum equity share in a bank that is permitted for foreign firms. The World Bank database produces this information precisely, so the mapping from the World Bank database to McGuire and Schuele is one to one and very clear in this case.

To give examples where the mapping is more problematical, consider accounting services, where the list of regulatory categories is adapted from Nguyen-Hong. (We call this list and similar lists by the other Australian authors on whose work we build as the 'Australian categories'.) We had to take proxies in the case of the category 'Activities reserved by law to the profession', which has a weight of 0.05. This category in the Australian list is scored at one if four or more activities are reserved to the profession. If there are two categories reserved to the profession, the Australian score is 0.5; for one or zero categories reserved to the profession, the score is 0.25 and zero, respectively. In this case, we took the closest relevant proxy in the World Bank database, which was: for how many of the following actions is an economic needs test required: intra-corporate transfer (ICT), independent professionals as employee of a local firm (IPC) and service-supplying employee (SSE) of a firm based abroad. If an economic needs test is required for three (two, one, zero), we score the Australian matrix at 1, 0.5, 0.25 and 0, respectively.

Another example of no clear mapping is the case of restrictions on advertising, marketing and solicitation in the Australian matrix for accounting. We want to use all the information available in the World Bank database, so from the World Bank database we use the information on 'minimum wage is required for IPC, ICT or SSE', as our proxy for this category in the Australian matrix.

d. Transforming our Services Trade Restrictiveness Indices into Ad Valorem Equivalents

We rely on the papers by Warren (2000b) in telecommunications (for both fixed line and mobile), Kalirajan et al. (2000) in financial services (for both banking and insurance), Kang (2000) in transportation services (for all four transportation sectors), Nguyen-Hong (2000) in professional services (for both accounting and auditing, and legal services) and Kalirajan (2000) for retail distribution services. Except for Warren, in all studies the authors regressed a

measure of the price or costs of services against their *STRIs* and other relevant variables in a cross-country regression at a point in time to determine the impact of the regulatory barriers on the price of services.¹⁹ Through these regressions, the authors estimated the ad valorem equivalents of the regulatory barriers in the countries of their sample.

Our methodology, which is explained in detail in Jafari (2014), assumes that the average of the international regressions of the price or cost impact estimated by the Australian authors mentioned in the previous paragraph applies to our 103 countries and 11 sectors. Based on those estimates, we calculate *AVEs*. Here we provide a brief overview of the estimating equations used by these authors.

(i) *Banking and Insurance*

For banking services, Kalirajan et al. (2000) use the net interest margin of banks as their price performance variable. From their estimation, the ad valorem equivalent (in percentage terms) of the *STRI* in banking services may be calculated from the following relationship:

$$100 \times (NIM_i - NIM_{i0})/NIM_{i0} = 100 \times [(NIM_i/NIM_{i0}) - 1] = 100 \times (e^{0.73*STRI_i} - 1), \quad (1)$$

where NIM_i is the net interest margin in banking in country i , NIM_{i0} is the net interest margin when all restrictions in banking are removed in country i , and $STRI_i$ is the services trade restrictiveness index in banking in country i . In equation (1), the denominator is a price measure without any restrictions. This implies that the ad valorem equivalent may exceed 100 per cent. We employ the same equation for insurance services.

(ii) *Transportation Services*

In the case of the four transportation services sectors, we used the econometric estimates of Kang (2000) for maritime services. But given the expanded set of countries in our data set, it was necessary to adapt the calculation of the ad valorem equivalents. Kang uses shipping margins as the proxy for shipping price. The shipping margins from country i (exporter) to country j (importer), M_{ij} , are defined as:

$$M_{ij} = \frac{IM_{ij}}{EX_{ij}},$$

where IM_{ij} represents the observed CIF value reported by importing country j for all products imported from country i and EX_{ij} represents the observed FOB value of all exports reported by the i th country as exported to the j th country. The shipping margins are estimated as functions of a set of variables, the most important of which are bilateral restrictions (our *STRIs*), the distance between the trading partners and the scale of bilateral trade. Given that Singapore typically ranks number one on the World Bank doing business measure of 'Trading Across Borders', we assume that *STRIs* in transportation services that are less than or equal to the value for Singapore imply an *AVE* equal to zero. Further, assuming that variables other than the restrictiveness index do not change, we obtain differences in the expected shipping margin of country i , $E(M_i)$, and the average expected shipping margin of countries in the same development category, as a function of differences in the *STRIs*. Then, we calculate the *AVEs* as:

¹⁹ Warren (2000b) estimated quantity impacts and then, using elasticity estimates and a quantity measure, was able to obtain price impacts and ad valorem equivalents.

$$AVE_i = [(E(M_i) - 1) - (E(M_{\text{Singapore}}) - 1)] / (E(M_i) - 1). \quad (2)$$

In the case of transportation services, unlike all other cases, we took the percentage price change as a percentage of the domestic price with restrictions. Thus, in the case of our four transportation services sectors only, the maximum ad valorem equivalent is 100 per cent.²⁰

(iii) *Fixed Line and Mobile Telephone Services*

In the case of telecommunications, Warren (2000b) estimated the quantity impacts of policy restrictions and other variables including *per capita* income and population density and then used an estimate of the price elasticity of demand to get the price impact of policy restrictions. Define b^f and b^m as the estimated coefficients of the *STRIs* on the change in quantities in fixed line and mobile, respectively, and e_i as the elasticity of demand. Warren (2000b) defines:

$$(Q_i^{m*} - Q_i^m) / Q_i^m = QI_i^m \text{ and } (P_i^{m*} - P_i^m) / P_i^m = PI_i^m \text{ and}$$

$$(Q_i^{f*} - Q_i^f) / Q_i^f = QI_i^f \text{ and } (P_i^{f*} - P_i^f) / P_i^f = PI_i^f,$$

where Q_i^f and Q_i^m are the quantity of fixed lines and mobile phone subscribers per 100 inhabitants, respectively; the same variable with an asterisk is the estimated quantity assuming no policy restrictions. P is a price variable defined analogously to the quantity variable. Warren (2000b) estimates that:

$$(Q_i^{f*} - Q_i^f) / Q_i^f = QI_i^f = b^f * STRI_i^f / Q_i^f = e_i PI_i^f, \quad (3a)$$

$$(Q_i^{m*} - Q_i^m) / Q_i^m = QI_i^m = b^m * STRI_i^m / Q_i^m = e_i PI_i^m. \quad (3b)$$

The ad valorem equivalents in fixed line and mobile are then:

$$[(1 / (PI_i^f + 1)) - 1] \cdot 100 = [(P_i^f - P_i^{f*}) / P_i^{f*}] \cdot 100 = AVE_i^f (\%) \quad \text{if } PI_i^f > -1, \quad (4a)$$

$$[(1 / (PI_i^m + 1)) - 1] \cdot 100 = [(P_i^m - P_i^{m*}) / P_i^{m*}] \cdot 100 = AVE_i^m (\%) \quad \text{if } PI_i^m > -1. \quad (4b)$$

Since the price without restrictions must be non-negative, we impose the following constraint: $PI_i^f > -1$, and $PI_i^m > -1$.²¹

(iv) *Professional Services*

In professional services, as the only available study on professional services, we use the study by Nguyen-Hong (2000) on engineering firms as our proxy for legal and accounting services. Nguyen-Hong used a cross-sectional data set of 84 engineering firms in 20 countries. He used price-cost margins as his dependent variable, which he regressed against the firm's

²⁰ As explained above, it is straightforward to convert to *AVE* with the unrestricted price in the denominator from the data provided on the *AVE* with the restricted price in the denominator.

²¹ For a few countries, the initial fixed line penetration rate is so low that combined with a high *STRI*, equation (3a) yields a value that is less than negative one; this implies a negative price of telecom services without restrictions. Since it occurs in cases of either extremely high barriers or extremely low fixed line penetration rates, we assign an *AVE* in these cases equal to the highest *AVE* for countries in our sample for which we can calculate an *AVE*. That value is 915 per cent, based on the estimate for Cambodia.

market share, cost of capital, sales growth, diversification index, three types of services trade restrictiveness indices and some other variables. Based on his methodology, the price-raising or rent-creating impact of the foreign discriminatory restrictions in country i can be estimated from the following equation:²²

$$\begin{aligned}\text{Price Impact } (i) &= \left[\frac{p - p_0}{p_0} \right] (i) = \left(\frac{p}{c} \right) (\beta e + \beta o) (1 - m) \text{STRI } (i) \\ &= 1.33 * (0.37 + 0.26) * 0.94 * \text{STRI } (i),\end{aligned}\quad (5)$$

where p and p_0 refer to prices with and without restrictions, respectively, c is variable costs, βe and βo are the estimated coefficients of the impact of the indices of market access and operations barriers on foreign firms, respectively, and m is the sample mean of firms' market shares. We have only one STRI that combines both types of barriers of Nguyen-Hong, so we use our STRI for both coefficients, and we use sample means of Nguyen-Hong for m and $\frac{p}{c}$.

(v) Distribution Services

Kalirajan (2000) employed a methodology very similar to Nguyen-Hong, starting with his estimation of price-cost margins based on many variables. The principle methodological differences were that Kalirajan estimated the cost-raising impacts of the barriers and developed a single STRI . Based on his estimating equation, we may calculate the AVE of the discriminatory restrictions from the cost-raising impact, that is, as:

$$\begin{aligned}\text{Cost Impact } (i) &= \left[\frac{c - c_0}{c_0} \right] (i) = PQ * \beta \text{STRI } (i) / [cQ - PQ \beta \text{STRI } (i)] \\ &= \beta \text{STRI } (i) / [(c/P) - \beta \text{STRI } (i)],\end{aligned}\quad (6)$$

where c and c_0 are variable costs with and without restrictions, respectively, P and Q are price and quantity with restrictions, and β is the estimated coefficient for the impact of a change in the STRI .

3. RESULTS AND CAVEATS

a. Results

The results for the 103 countries of the services trade restrictiveness indices that we have calculated based on the World Bank database and the Australian methodology are presented in Table 2. The results for the 103 countries estimated ad valorem equivalents are presented in Table 3. To assist with interpretation, in Table 4, we present the STRIs and AVEs by sector, but aggregated to three levels of development. In Table 5, we show our STRIs and AVEs by sector, aggregated by geographic region. Full details of the calculations are available online.²³

Not surprisingly, Table 4 shows that professional services are among the sectors with the highest AVEs in high-income countries, but high-income countries have uniformly lower estimated AVEs than transition, developing countries or least developing countries.

²² This methodology underestimates the costs of the barriers since it ignores the impact of the barriers on costs of the service.

²³ Links for the STRI calculations are provided above. For the ad valorem equivalent calculations, see the folder 'Ad Valorem Equivalents Calculations' at <https://drive.google.com/?pli=1#folders/0B0V-tBs4-hXYjA3MTQ5MDctNTAxYy00M2I4LWI3NDAtZGRiNDI3NmYwOGU2>

TABLE 2
Estimation of Services Trade Restrictive Indices

Sector	Albania	Algeria	Argentina	Armenia	Australia	Austria	Bahrain	Bangladesh	Belarus	Belgium	Bolivia	Botswana	Brazil	Bulgaria	Burundi	Cambodia	Cameroon	Canada	Chile	China	Colombia
Accounting	0.30	0.71	0.27	0.33	0.42	0.42	0.26	0.13	0.38	0.36	0.33	0.27	0.54	0.23	0.48	0.52	0.32	0.31	0.24	0.40	0.51
Legal	0.15	0.66	0.23	0.25	0.28	0.49	0.92	0.66	0.70	0.28	0.34	0.44	0.75	0.51	0.66	0.92	0.44	0.51	0.35	0.92	0.35
services																					
Air transport	0.33	0.75	0.51	0.34	0.17	0.40	0.32	0.15	0.01	0.06	0.02	0.52	0.44	0.14	0.10	0.03	0.07	0.47	0.06	0.41	0.02
Rail transport	0.35	1.00	0.13	0.26	0.21	0.31	0.25	1.00	1.00	1.00	0.26	0.37	0.10	0.23	1.00	0.15	0.31	0.21	0.00	0.10	0.00
Road transport	0.28	1.00	0.20	0.23	0.11	0.94	0.25	0.30	0.20	0.94	0.26	0.37	0.10	0.29	0.32	0.15	0.25	0.14	0.00	0.13	0.00
Banking	0.11	0.18	0.02	0.11	0.02	0.02	0.18	0.08	0.17	0.02	0.01	0.22	0.23	0.01	0.26	0.12	0.01	0.04	0.01	0.28	0.17
Insurance	0.15	0.33	0.17	0.17	0.28	0.15	0.30	0.27	0.45	0.13	0.31	0.28	0.21	0.18	0.35	0.21	0.30	0.17	0.19	0.26	0.30
Fixed line	0.07	0.18	0.14	0.26	0.20	0.27	0.39	0.94	0.83	0.25	0.29	0.61	0.27	0.32	0.40	0.52	0.14	0.59	0.11	0.58	0.35
Mobile line	0.24	0.09	0.06	0.18	0.22	0.24	0.27	0.33	0.07	0.24	0.05	0.41	0.26	0.23	0.26	0.44	0.05	0.54	0.10	0.51	0.36
Retail	0.11	0.33	0.05	0.05	0.13	0.16	0.11	0.11	0.40	0.00	0.09	0.13	0.09	0.05	0.00	0.35	0.10	0.16	0.10	0.40	0.11
Maritime transport	0.07	0.26	0.11	n/a	0.37	n/a	0.26	0.40	n/a	0.24	n/a	n/a	0.31	0.23	0.17	0.21	0.20	0.31	0.19	0.30	0.13
Sector	The Democratic Republic of the Congo	Costa Rica	Czech Republic	Denmark	Dominican Republic	Ecuador	Egypt	Ethiopia	Finland	France	Georgia	Germany	Ghana	Greece	Guatemala	Honduras	Hungary	India	Indonesia	Islamic Republic of Iran	Ireland
Accounting	0.37	0.71	0.25	0.64	0.45	0.36	0.71	0.25	0.30	0.30	0.12	0.56	0.37	0.19	0.23	0.28	0.17	0.50	0.64	0.82	0.41
Legal	0.46	0.66	0.11	0.47	0.27	0.28	0.92	0.92	0.43	0.25	0.70	0.64	0.32	0.55	0.36	0.20	0.29	0.92	0.92	0.81	0.40
services																					
Air transport	0.13	0.06	0.40	0.41	0.06	0.17	0.42	0.99	0.06	0.41	0.16	0.41	0.02	0.40	0.07	0.45	0.40	1.00	0.46	0.89	0.41
Rail transport	1.00	0.51	0.31	0.31	0.30	0.19	1.00	0.35	1.00	1.00	0.36	0.31	0.23	1.00	1.00	0.41	0.38	1.00	1.00	0.55	0.31
Road transport	0.35	0.29	0.94	0.94	0.25	0.13	0.13	1.00	0.00	0.94	0.29	0.94	0.00	0.94	0.30	0.68	0.94	1.00	1.00	0.55	0.94
Banking	0.04	0.23	0.02	0.03	0.21	0.52	0.49	0.99	0.02	0.02	0.09	0.03	0.40	0.02	0.01	0.32	0.02	0.18	0.21	0.99	0.03
Insurance	0.98	0.24	0.14	0.15	0.21	0.40	0.41	0.98	0.14	0.15	0.16	0.15	0.32	0.14	0.32	0.18	0.14	0.44	0.32	0.98	0.15
Fixed line	0.34	0.28	0.26	0.27	0.28	0.26	0.41	0.94	0.26	0.27	0.13	0.27	0.42	0.26	0.12	0.16	0.41	0.43	0.28	0.94	0.27
Mobile line	0.34	0.25	0.24	0.25	0.26	0.08	0.35	0.88	0.24	0.25	0.10	0.25	0.38	0.24	0.09	0.05	0.40	0.38	0.25	0.47	0.25
Retail	0.10	0.21	0.02	0.05	0.09	0.08	0.41	0.85	0.02	0.17	0.04	0.05	0.11	0.02	0.09	0.08	0.26	0.48	0.35	0.33	0.17
Maritime transport	0.32	0.31	n/a	0.32	0.23	0.25	0.64	0.80	0.24	0.62	0.26	0.32	0.37	0.27	0.26	0.24	n/a	0.36	0.47	0.39	0.25
Sector	Italy	Ivory Coast	Japan	Jordan	Kazakhstan	Kenya	Republic of Korea	Kuwait	Kyrgyzstan	Lebanon	Lesotho	Lithuania	Madagascar	Malawi	Malaysia	Mali	Mauritius	Mexico	Mongolia	Morocco	Mozambique
Accounting	0.46	0.65	0.26	0.26	0.29	0.34	0.31	0.52	0.52	0.48	0.20	0.25	0.31	0.42	0.26	0.76	0.13	0.30	0.31	0.35	0.26
Legal	0.43	0.71	0.29	0.92	0.39	0.92	0.92	0.83	0.42	0.81	0.16	0.33	0.51	0.62	0.92	0.63	0.83	0.38	0.34	0.59	0.26
services																					
Air transport	0.43	0.12	0.44	0.37	0.06	0.01	0.42	0.42	0.34	0.94	0.15	0.40	0.14	0.33	0.37	0.05	0.06	0.37	0.01	0.06	0.04

TABLE 2 *Continued*

Sector	Italy	Ivory Coast	Japan	Jordan	Kazakhstan	Kenya	Republic of Korea	Kuwait	Kyrgyzstan	Lebanon	Lesotho	Lithuania	Madagascar	Malawi	Malaysia	Mali	Mauritius	Mexico	Mongolia	Morocco	Mozambique
Rail transport	0.31	1.00	0.74	1.00	0.30	1.00	0.22	1.00	1.00	1.00	1.00	0.38	0.35	0.26	1.00	0.23	1.00	1.00	1.00	0.00	0.25
Road transport	0.94	0.34	0.10	1.00	0.30	0.00	0.10	0.47	0.23	0.45	0.20	0.00	0.43	0.21	0.49	0.23	0.26	1.00	0.00	0.10	0.23
Banking	0.02	0.22	0.02	0.43	0.17	0.02	0.02	0.24	0.01	0.22	0.01	0.02	0.22	0.22	0.38	0.06	0.05	0.02	0.06	0.02	0.01
Insurance	0.13	0.17	0.15	0.16	0.30	0.44	0.43	0.48	0.34	0.36	0.21	0.14	0.28	0.26	0.45	0.26	0.21	0.49	0.16	0.31	0.03
Fixed line	0.25	0.36	0.25	0.09	0.39	0.45	0.42	0.93	0.16	0.40	0.21	0.26	0.31	0.46	0.53	0.45	0.16	0.32	0.29	0.31	0.88
Mobile line	0.24	0.23	0.24	0.53	0.25	0.29	0.37	0.55	0.19	0.23	0.25	0.24	0.26	0.45	0.32	0.39	0.23	0.19	0.21	0.25	0.20
Retail	0.12	0.05	0.00	0.17	0.08	0.05	0.16	0.59	0.08	0.22	0.13	0.02	0.04	0.10	0.43	0.07	0.02	0.10	0.08	0.05	0.09
Maritime transport	0.33	0.19	0.32	0.22	n/a	0.16	0.35	0.44	n/a	0.60	n/a	0.22	0.12	n/a	0.35	n/a	0.20	0.29	n/a	0.48	0.13
Sector	Namibia	Nepal	Netherlands	New Zealand	Nicaragua	Nigeria	Oman	Pakistan	Panama	Paraguay	Peru	Philippines	Poland	Portugal	Qatar	Romania	Russian Federation	Rwanda	Saudi Arabia	Senegal	South Africa
Accounting	0.52	0.63	0.32	0.32	0.24	0.38	0.48	0.13	0.62	0.33	0.32	0.99	0.25	0.41	0.40	0.39	0.37	0.27	0.64	0.59	0.41
Legal services	0.70	0.92	0.48	0.26	0.20	0.34	0.48	0.70	0.92	0.28	0.25	0.92	0.07	0.11	0.69	0.44	0.66	0.19	0.92	0.83	0.92
Air transport	0.17	0.47	0.41	0.17	0.50	0.25	0.32	0.37	0.40	0.12	0.34	0.42	0.40	0.40	0.36	0.37	0.39	0.07	0.37	0.74	0.43
Rail transport	0.40	1.00	0.31	0.20	0.43	1.00	1.00	0.10	1.00	0.31	0.20	0.43	0.40	0.31	1.00	0.29	0.09	1.00	0.00	1.00	0.15
Road transport	0.31	0.25	0.94	0.10	0.74	0.14	0.24	0.10	0.30	0.31	0.20	0.43	0.10	0.94	0.45	0.23	0.00	0.21	1.00	0.19	0.15
Banking	0.22	0.15	0.03	0.02	0.06	0.02	0.26	0.20	0.12	0.19	0.16	0.41	0.02	0.02	0.97	0.06	0.24	0.18	0.20	0.17	0.08
Insurance	0.33	0.33	0.15	0.15	0.30	0.54	0.26	0.34	0.18	0.31	0.28	0.23	0.14	0.14	0.46	0.19	0.50	0.32	0.29	0.17	0.35
Fixed line	0.60	0.57	0.27	0.26	0.09	0.03	0.93	0.31	0.27	0.32	0.13	0.56	0.26	0.26	0.93	0.22	0.06	0.37	0.42	0.24	0.36
Mobile line	0.61	0.38	0.31	0.24	0.03	0.05	0.46	0.05	0.11	0.42	0.11	0.37	0.24	0.24	0.88	0.26	0.02	0.35	0.35	0.23	0.42
Retail	0.07	0.13	0.05	0.00	0.09	0.16	0.28	0.40	0.85	0.06	0.08	0.20	0.02	0.02	0.23	0.05	0.28	0.41	0.63	0.05	0.06
Maritime transport	0.15	n/a	0.27	0.30	0.26	0.13	0.35	0.45	0.23	n/a	0.22	0.49	0.32	0.24	0.30	0.14	0.36	n/a	0.31	0.16	0.19
Sector	Spain	Sri Lanka	Sweden	United Republic of Tanzania	Thailand	Trinidad and Tobago	Tunisia	Turkey	Uganda	Ukraine	United Kingdom	United States of America	Uruguay	Uzbekistan	Venezuela	Vietnam	Yemen	Zambia	Zimbabwe		
Accounting	0.49	0.80	0.38	0.55	0.83	0.08	1.00	0.95	0.51	0.45	0.27	0.60	0.28	0.35	0.51	0.54	0.83	0.33	0.49		
Legal services	0.48	0.48	0.09	0.66	0.77	0.38	0.87	0.92	0.62	0.28	0.22	0.41	0.24	0.28	0.51	0.66	0.92	0.34	0.61		
Air transport	0.46	0.42	0.40	0.30	0.41	0.12	0.41	0.48	0.01	0.21	0.41	0.45	0.36	0.04	0.67	0.46	0.06	0.09	0.41		
Rail transport	1.00	1.00	0.31	0.46	0.32	1.00	0.40	1.00	0.22	1.00	0.31	0.20	1.00	1.00	0.00	0.58	1.00	0.19	0.60		
Road transport	0.94	0.00	0.11	0.09	0.32	0.14	0.34	0.23	0.20	0.20	0.94	0.13	0.30	0.23	0.00	0.60	0.34	0.30	0.52		
Banking	0.03	0.38	0.03	0.16	0.38	0.02	0.13	0.02	0.02	0.16	0.03	0.03	0.08	0.05	0.22	0.06	0.13	0.07	0.28		
Insurance	0.15	0.36	0.14	0.39	0.36	0.15	0.35	0.17	0.21	0.30	0.15	0.15	0.31	0.30	0.47	0.33	0.33	0.30	0.37		
Fixed line	0.22	0.37	0.26	0.29	0.62	0.13	0.31	0.30	0.31	0.18	0.27	0.25	0.66	0.31	0.17	0.61	0.61	0.93	0.50		
Mobile line	0.22	0.41	0.25	0.17	0.50	0.24	0.22	0.23	0.65	0.21	0.25	0.24	0.12	0.23	0.22	0.53	0.17	0.25	0.37		
Retail	0.17	0.11	0.16	0.09	0.11	0.28	0.35	0.06	0.04	0.19	0.05	0.11	0.04	0.32	0.11	0.43	0.51	0.05	0.70		

TABLE 2 *Continued*

<i>Sector</i>	<i>Spain</i>	<i>Sri Lanka</i>	<i>Sweden</i>	<i>United Republic of Tanzania</i>	<i>Thailand</i>	<i>Trinidad and Tobago</i>	<i>Tunisia</i>	<i>Turkey</i>	<i>Uganda</i>	<i>Ukraine</i>	<i>United Kingdom</i>	<i>United States of America</i>	<i>Uruguay</i>	<i>Uzbekistan</i>	<i>Venezuela</i>	<i>Vietnam</i>	<i>Yemen</i>	<i>Zambia</i>	<i>Zimbabwe</i>
Maritime transport	0.25	0.38	0.25	0.34	0.25	0.27	0.53	0.28	n/a	0.18	0.17	0.38	0.29	n/a	0.29	0.29	0.24	n/a	n/a

Note:
The ‘n/a’ cells in maritime transport sector are referred to ‘not applicable’ cells where the country is landlocked.

TABLE 3
Estimated Ad Valorem Equivalents of Services Barriers*

<i>Sector</i>	<i>Albania</i>	<i>Algeria</i>	<i>Argentina</i>	<i>Armenia</i>	<i>Australia</i>	<i>Austria</i>	<i>Bahrain</i>	<i>Bangladesh</i>	<i>Belarus</i>	<i>Belgium</i>	<i>Bolivia</i>	<i>Botswana</i>	<i>Brazil</i>	<i>Bulgaria</i>	<i>Burundi</i>	<i>Cambodia</i>	<i>Cameroon</i>	<i>Canada</i>	<i>Chile</i>	<i>China</i>	<i>Colombia</i>
Accounting	24	56	21	26	34	33	20	10	30	29	26	21	43	18	38	41	26	25	19	32	41
Legal services	12	52	18	20	22	39	73	52	55	22	27	35	59	40	52	73	34	40	28	73	28
Air transport	59	81	74	61	0	18	58	0	0	0	0	75	71	0	0	0	0	22	0	68	0
Rail transport	62	84	0	42	1	12	37	84	84	35	42	65	0	3	84	0	56	1	0	0	0
Road transport	47	84	0	20	0	34	37	53	0	34	42	65	0	10	57	0	37	0	0	0	0
Banking	9	14	2	9	2	2	14	6	14	1	1	18	18	1	21	9	1	3	1	22	14
Insurance	11	28	13	13	23	12	24	22	39	10	26	23	17	14	29	16	25	14	15	21	25
Fixed line	3	10	3	6	2	3	11	915	9	3	17	64	6	5	915	915	29	5	915	13	11
Mobile line	1	0	0	0	1	0	1	2	0	1	0	1	1	0	5	2	0	2	1	2	1
Retail	2	5	1	1	2	3	2	2	6	0	2	2	2	1	0	6	2	3	2	6	2
Maritime transport	0	42	0	n/a	16	n/a	42	68	n/a	4	n/a	n/a	55	3	0	6	0	12	0	53	0
<i>Sector</i>	<i>The Democratic of the Congo</i>	<i>Costa Rica</i>	<i>Czech Republic</i>	<i>Denmark</i>	<i>Dominican Republic</i>	<i>Ecuador</i>	<i>Egypt</i>	<i>Ethiopia</i>	<i>Finland</i>	<i>France</i>	<i>Georgia</i>	<i>Germany</i>	<i>Ghana</i>	<i>Greece</i>	<i>Guatemala</i>	<i>Honduras</i>	<i>Hungary</i>	<i>India</i>	<i>Indonesia</i>	<i>Islamic Republic of Iran</i>	<i>Ireland</i>
Accounting	29	56	20	50	36	29	56	19	24	24	9	44	29	15	18	22	13	40	50	65	33
Legal services	36	52	8	37	21	22	73	73	34	19	55	50	25	43	28	16	23	73	73	64	31
Air transport	0	0	18	19	0	0	69	84	0	19	0	19	0	18	0	71	18	84	72	83	19
Rail transport	84	74	12	12	53	0	84	62	35	35	64	12	26	35	84	69	17	84	84	76	12
Road transport	62	50	34	34	37	0	0	84	0	34	50	34	0	34	53	80	34	84	84	76	34
Banking	3	19	1	2	17	46	44	106	2	1	7	2	34	2	1	26	2	14	16	106	2
Insurance	104	20	10	11	16	34	35	105	11	11	13	11	26	10	26	14	10	38	27	105	11
Fixed line	915	4	5	3	14	9	18	915	5	2	2	2	915	2	5	8	6	191	8	13	3
Mobile line	1	1	1	1	1	0	1	37	0	1	0	0	1	1	0	0	1	2	1	2	1

TABLE 3 *Continued*

Sector	The Democratic of the Congo	Costa Rica	Czech Republic	Denmark	Dominican Republic	Ecuador	Egypt	Ethiopia	Finland	France	Georgia	Germany	Ghana	Greece	Guatemala	Honduras	Hungary	India	Indonesia	Islamic Republic of Iran	Ireland			
Retail	2	3	0	1	1	1	7	14	0	3	1	1	2	0	2	1	4	8	6	5	3			
Maritime transport	58	56	n/a	13	20	39	79	82	5	27	40	13	65	8	43	29	n/a	63	72	67	6			
Sector	Italy	Ivory Coast	Japan	Jordan	Kazakhstan	Kenya	Republic of Korea	Kuwait	Kyrgyzstan	Lebanon	Lesotho	Lithuania	Madagascar	Malawi	Malaysia	Mali	Mauritius	Mexico	Mongolia	Morocco	Mozambique			
Accounting	36	51	21	21	23	26	25	41	41	38	16	20	25	33	21	60	10	23	25	27	20			
Legal services	34	56	23	73	31	73	73	65	33	64	13	26	40	49	73	50	65	30	27	47	20			
Air transport	20	0	20	65	0	0	19	69	61	84	0	18	0	59	65	0	0	16	0	0	0			
Rail transport	12	84	30	84	53	84	2	84	84	84	84	17	62	42	84	20	84	35	84	0	37			
Road transport	34	60	0	84	53	0	0	72	20	71	0	0	70	5	73	20	42	35	0	0	20			
Banking	1	17	1	37	14	2	2	19	1	18	1	1	18	18	32	4	3	2	5	2	1			
Insurance	10	13	12	12	24	38	37	42	28	30	16	10	23	21	39	21	17	43	13	26	2			
Fixed line	3	n/a	2	5	7	915	3	25	8	9	109	5	915	915	17	915	2	9	22	13	915			
Mobile line	0	n/a	1	1	1	1	1	1	0	1	1	0	2	6	1	2	1	1	1	1	2			
Retail	2	1	0	3	1	1	3	9	1	4	2	0	1	2	7	1	0	2	1	1	1			
Maritime transport	13	0	12	20	n/a	0	15	71	n/a	78	n/a	3	0	n/a	63	n/a	0	10	n/a	73	0			
Sector	Namibia	Nepal	Netherlands	New Zealand	Nicaragua	Nigeria	Oman	Pakistan	Panama	Paraguay	Peru	Philippines	Poland	Portugal	Qatar	Romania	Russian Federation	Rwanda	Saudi Arabia	Senegal	South Africa	Spain	Sri Lanka	Sweden
Accounting	41	50	25	25	19	30	38	10	49	26	25	78	20	33	31	31	29	21	50	46	32	39	63	30
Legal services	55	73	38	21	16	27	38	55	73	22	20	73	6	8	54	35	52	15	73	65	73	38	38	7
Air transport	0	72	19	0	74	37	58	65	67	0	61	70	18	18	64	16	66	0	65	81	70	21	69	18
Rail transport	68	84	12	0	70	84	84	0	84	56	0	70	18	12	84	10	0	84	0	84	0	35	84	12
Road transport	56	37	34	0	81	0	30	0	53	56	0	70	0	34	71	3	0	5	84	0	0	34	0	0
Banking	18	12	2	1	5	2	21	16	9	15	13	35	1	1	103	5	19	14	16	13	6	2	32	2
Insurance	27	27	11	12	25	48	21	28	14	26	23	18	10	10	40	15	44	27	24	13	29	11	30	11
Fixed line	63	759	3	3	10	35	68	64	8	33	6	51	6	3	33	5	1	915	14	60	23	2	10	2
Mobile line	2	3	1	1	0	0	1	0	0	1	0	1	0	1	2	1	0	3	0	1	1	1	1	1

TABLE 3 *Continued*

Sector	Nam- ibia	Nepal	Nethe- rlands	New Zealand	Nica- ragua	Nigeria	Oman	Pakistan	Panama	Para- guay	Peru	Philip- pines	Poland	Port- ugal	Qatar	Rom- ania	Russian Federation	Rwanda	Saudi Arabia	Senegal	South Africa	Spain	Sri Lanka	Sweden
Retail	1	2	1	0	2	3	4	6	14	1	1	3	0	0	4	1	4	7	10	1	1	3	2	3
Maritime transport	0	n/a	8	11	43	0	63	71	25	n/a	11	73	13	4	53	0	63	n/a	55	0	0	6	66	6
Sector	United Republic of Tanzania	Thailand	Trinidad and Tobago	Tunisia	Turkey	Uganda	Ukraine	United Kingdom	United States of America	Uruguay	Uzbekistan	Venezuela	Viet Nam	Yemen	Zambia	Zimbabwe								
Accounting	44	65	6	79	75	40	36	22	47	22	28	40	43	65	26	39								
Legal services	52	61	30	69	73	49	22	17	33	19	22	40	52	73	27	48								
Air transport	54	69	0	69	22	0	4	19	21	64	0	79	72	0	0	69								
Rail transport	72	57	84	68	35	18	84	12	0	84	84	0	77	84	0	77								
Road transport	0	57	0	60	3	0	0	34	0	53	20	0	77	60	53	75								
Banking	13	32	2	10	2	2	13	2	2	6	4	18	4	10	5	23								
Insurance	33	30	12	29	14	16	24	11	12	25	24	41	28	28	24	31								
Fixed line	915	37	3	12	6	915	3	2	2	11	25	3	20	160	915	267								
Mobile line	1	1	0	1	1	4	0	0	1	0	1	1	1	1	2	2								
Retail	1	2	4	6	1	1	3	1	2	1	5	2	7	8	1	11								
Maritime transport	61	36	45	75	9	n/a	0	0	17	50	n/a	50	51	30	n/a	n/a								

Notes:

(i) The 'n/a' cells are referred to as 'not applicable' cells. In maritime transport, if the country is landlocked, then estimating *STRIs* and consequently *AVEs* are not applicable. *For fixed and mobile line sectors 'n/a' cells indicate that the supplementary data on the subscription rate is not available.*

(ii) *For the four transport sectors, the ad valorem equivalent (*AVE*) or the tariff equivalent (*TE*) we have calculated has the domestic price in the denominator. For other sectors, the tariff equivalent contains the unrestricted shipping margins in the denominator. To make the conversion, if *TE* is the ad valorem equivalent with restricted country shipping margins in the denominator and *TE** is the ad valorem equivalent with unrestricted country shipping margins in the denominator, then *TE** may be derived from *TE* as $TE^* = TE/[1 - TE]$.

TABLE 4
Services Trade Restrictions Index (*STRI*) and Ad Valorem Equivalents (*AVEs*) by
Sector and by Level of Development

<i>Sector</i>	<i>STRI</i> s			<i>AVEs</i> *		
	<i>OECD and Other EU Countries</i>	<i>Transition and Other Developing Countries</i>	<i>Least Developed Countries</i>	<i>OECD and Other EU Countries</i>	<i>Transition and Other Developing Countries</i>	<i>Least Developed Countries</i>
Accounting	0.37	0.44	0.42	29	35	33
Legal services	0.39	0.59	0.58	31	46	46
Air transport	0.35	0.32	0.21	15	44	17
Rail transport	0.47	0.59	0.59	16	58	56
Road transport	0.54	0.32	0.30	18	38	31
Banking	0.02	0.21	0.17	2	18	15
Insurance	0.18	0.32	0.35	14	27	31
Fixed line	0.28	0.37	0.51	35	69	764
Mobile line	0.26	0.27	0.35	1	1	4
Retail	0.09	0.21	0.19	1	3	3
Maritime transport	0.29	0.30	0.29	9	40	31

Note:

* For the four transport sectors, the ad valorem equivalent (*AVE*) or the tariff equivalent (*TE*) we have calculated has the domestic price in the denominator. For other sectors, the tariff equivalent contains the unrestricted shipping margins in the denominator. To make the conversion, if *TE* is the ad valorem equivalent with restricted country shipping margins in the denominator and *TE** is the ad valorem equivalent with unrestricted country shipping margins in the denominator, then *TE** may be derived from *TE* as $TE^* = TE/[1 - TE]$.

From Table 5, we see that fixed line telephone services in South Asia and especially in sub-Saharan Africa stand out as the sector and regions with the highest *AVEs*. There are 13 countries with *AVEs* of 915 per cent, with 12 of them in sub-Saharan Africa. Given that our calculated *STRI*s in fixed line do not appear dramatically higher than in mobile telephone services, the very high *AVEs* in fixed line may appear puzzling. The explanation is that the *AVE* is calculated based on an estimate of the quantity impacts of the barriers. In particular, it depends on the number of subscribers per 100 inhabitants (see equations (3a), (3b), (4a) and (4b)). Given much higher penetration of mobile telephone subscribers than fixed line in many developing countries, especially in many sub-Saharan countries, we will often get much higher *AVEs* in fixed line for comparable *STRI*s in fixed line and mobile telephone services. State-owned telecom monopolies traditionally have typically done an extremely poor job of providing telephone service in sub-Saharan Africa. For example, in Kenya and Tanzania, which are two of the countries with an estimated 915 per cent *AVE* in fixed line, there is less than one fixed line subscriber per 200 inhabitants.²⁴ But mobile telephone services have been a game changer in sub-Saharan Africa in terms of widening access to telephone service. In

²⁴ If the initial fixed line penetration rate is extremely low and there is a high *STRI*, equation (3a) yields a value that is less than negative one. Since this implies a negative price of telecom services without restrictions, we cannot use equation (3a) in these cases. Since it occurs only in cases of very high effective barriers, we assign an *AVE* in these cases equal to the highest *AVE* for countries in our sample for which we can calculate an *AVE*. That value is: 915 per cent, based on the estimate for Cambodia.

TABLE 5
Services Trade Restrictions Index (*STRI*) and Ad Valorem Equivalents (*AVEs*) by Sector and by Geographical Region

Sector	<i>STRI</i> s							<i>AVEs</i> *						
	North America	Europe and Central Asia	East Asia and the Pacific	South Asia	Latin America and the Caribbean	Middle East and North Africa	Sub-Saharan Africa	North America	Europe and Central Asia	East Asia and the Pacific	South Asia	Latin America and the Caribbean	Middle East and North Africa	Sub-Saharan Africa
Accounting	0.46	0.33	0.49	0.44	0.35	0.57	0.42	36	26	38	34	27	45	33
Legal services	0.42	0.43	0.61	0.74	0.42	0.80	0.58	34	34	48	58	33	63	46
Air transport	0.26	0.23	0.30	0.48	0.31	0.44	0.22	10	24	31	58	37	59	23
Rail transport	0.26	0.52	0.54	0.82	0.48	0.71	0.51	28	49	45	67	41	66	53
Road transport	0.19	0.20	0.35	0.33	0.31	0.49	0.25	18	19	35	35	31	56	26
Banking	0.02	0.10	0.14	0.20	0.14	0.34	0.18	1	8	12	16	12	32	16
Insurance	0.23	0.26	0.26	0.35	0.32	0.39	0.32	18	22	21	29	27	34	28
Fixed line	0.20	0.27	0.37	0.52	0.28	0.53	0.44	16	7	90	388	60	30	545
Mobile line	0.14	0.18	0.29	0.31	0.20	0.37	0.35	0	0	1	2	1	1	3
Retail	0.11	0.14	0.16	0.25	0.16	0.32	0.17	2	2	3	4	3	5	3
Maritime transport	0.29	0.21	0.32	0.40	0.26	0.39	0.24	8	16	30	67	34	57	18

Note:

* For the four transport sectors, the ad valorem equivalent (*AVE*) or the tariff equivalent (*TE*) we have calculated has the domestic price in the denominator. For other sectors, the tariff equivalent contains the unrestricted shipping margins in the denominator. To make the conversion, if *TE* is the ad valorem equivalent with restricted country shipping margins in the denominator and *TE** is the ad valorem equivalent with unrestricted country shipping margins in the denominator, then *TE** may be derived from *TE* as $TE^* = TE/[1 - TE]$.

2014, in Kenya, there were 70 mobile telephone subscribers per 100 inhabitants, while in Tanzania, there were 57 per 100 inhabitants.

Table 4 shows that mobile telephone and retail distribution services have the lowest *AVEs*, in part explained by the penetration rates of mobile telephones. We generally find high estimates of *AVEs* in developing and least developed countries in transport services, especially rail transportation services. All the transportation *AVEs* are highly volatile if the price without restrictions is in denominator. We present the transport *AVEs*, unlike the others, as a percentage of the price of service with restrictions, but they are easily converted to *AVEs* as a percentage of the price of services without restrictions.²⁵

Finally, an issue in the literature is whether the barriers to foreign providers of services raise costs or create rents. In the event of the latter, for the welfare analysis of liberalisation, it would also be important to know whether the rents are captured by domestic agents or foreign agents. To decompose the *AVEs* into cost-increasing or rent-creating shares, it would be necessary to have better information on the regulatory regimes. Our estimates do not provide information on this issue.

b. Caveats

Some of the more important caveats are the following.

1. The weights for the categories of limitations are assumed based on the judgment of the researchers as to their importance. With a larger sample, it would be possible to estimate the impact of separate categories of restrictions on the performance variable rather than make *a priori* judgment.
2. The additive nature of our *STRIs* fails to fully take into account nuances of the substitution possibilities between cross-border supply and supply by commercial presence regarding their impacts on the price of the service.
3. We had to map the data in the World Bank database to the Australian-based list of restrictions. In many cases, this is not a one-to-one mapping and we have had to take the closest proxies available or modify the subcategories of the Australian list of restrictions.
4. The impacts could change over time, but we are relying on cross-country econometric estimates of the impact of a change in our *STRIs* on the price or cost of the service that were done about fourteen years ago.
5. Differences from the average that are not explained by the econometric model are ignored.
6. For some sectors, such as road transportation and communications, no list of restrictions or estimated *AVEs* was developed by the Australian authors. In these cases, we developed lists of restrictions based on the closest categories from comparable sectors of the Australian authors. These estimates in these sectors are subject to an additional level of scepticism, since we must make a further assumption that the regression results apply for comparable sectors; for example, the results for banking apply to insurance.

²⁵ If *AVE* is the ad valorem equivalent with restricted prices in the denominator and *AVE** is the ad valorem equivalent with unrestricted prices in the denominator, then *AVE** may be derived from *AVE* as $AVE^* = AVE/[1 - AVE]$.

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