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# Stringency and dissimilarity of Maximum Residue Levels affect bilateral agri-food trade stability

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**Abstract**

Food standards are rising in both prevalence and stringency. They protect consumers and may enhance demand stability but also pose compliance challenges to producers, with ambiguous effects on the stability of trade relationships. We analyze the impact of importers' Maximum Residue Levels (MRLs) along with bilateral MRL dissimilarity between trade partners, on trade duration and volatility. We find that stricter MRLs in importing countries enhance trade stability, whereas MRL dissimilarities reduce it. The results suggest that importers with less strict MRLs than their trade partners can improve trade stability by reducing MRL dissimilarities. However, when importers have stricter MRLs, they might face a trade-off between the benefits of lowering discrepancies for trade stability and the downsides of reduced stringency for food safety.

**KEYWORDS**

food safety standards, regulatory harmonization, trade duration, trade volatility

**JEL CLASSIFICATION**

F14, Q17, Q18

As countries strive to improve food safety to lower consumers' health risks, the number and stringency of food safety standards are on the rise (Faour-Klingbeil & Todd, 2018; Ferro et al., 2015; Fiankor et al., 2020; Winchester et al., 2012).[1] These standards influence trade volumes, prices as well as the welfare of actors involved, and a considerable strand of research examining these relations exists (e.g., Beghin et al., 2015; Fiankor et al., 2021; Swinnen, 2016; Swinnen et al., 2015; Swinnen & Vandemoortele, 2011). However, their impact on the stability of agri-food trade relations has received little attention. Recent shocks to the international trade system, such as Covid-19 and the Russia-Ukraine war (Engemann & Jafari, 2022; Khadka et al., 2025; Ruta, 2022; WTO, 2021b) underscore the need for stable and diversified trade to ensure consistent food availability and variety (Jafari et al., 2024). Theoretically, higher standards can affect trade stability in two contrasting ways: by stabilizing demand through quality assurance as well as trading partners' fixed cost lock-ins, or by destabilizing trade due to exporters' compliance challenges, fairness concerns—such as whether the standards serve protectionist or food safety purposes[2]—and additional variable costs. The opposing effects may hinge not only on the stringency of a country's food quality standards but also on differences between countries' levels of standards (Swinnen, 2016). If countries align their standards more closely, the risk of exporters (importers) seeking alternative buyers (suppliers) may decrease or increase. Formulating policies that account for both food safety—as reflected by food quality standards—and agri-food import stability is crucial and necessitates an examination of whether food safety standards contribute to or counteract the stability of trade relations.

In this study, we investigate the role of stringency levels in importing countries' food safety standards, the dissimilarity in stringency levels between trade partners, and the direction of this dissimilarity in the import stability of agricultural and food products. We use Maximum Residue Levels (MRLs)[3] as a measure of product quality standards; MRLs are regulatory standards based on scientific assessments that define the legally tolerated volume of specific substances, such as pesticides or veterinary medicines, on products used for food and feed, and can be set by (individual) governments and organizations (European Commission, 2008; European Medicines Agency, 2024). For the analysis of the stability of bilateral trade relationships, we consider two dimensions: (i) the persistence of uninterrupted trade flows of a given product between two trading partners over consecutive years, that is, trade duration, and (ii) the fluctuations in trade values and volumes across years, that is, trade volatility.

We construct the measures of MRLs (e.g., Ferro et al., 2015; Winchester et al., 2012), trade duration (e.g., Hess & Persson, 2012; Peterson et al., 2018), and trade volatility (e.g., Guerra et al., 2019) at product level (225 different agri-food products at HS6-digit level) for 164 countries worldwide from 2005 to 2020. We then estimate the impact of MRLs (stringency and similarity) on trade duration and volatility applying discrete-time duration models (Hess & Persson, 2012) and the Poisson-pseudo maximum likelihood (PPML) estimator (Santos Silva & Tenreyro, 2006; Yotov et al., 2016), respectively.

The impact of importing countries' product quality standards and their dissimilarity to those of the exporting countries on import stability is complex and ambiguous. Superior quality products involve a greater consumer appreciation for the product, which, in turn, tends to decrease the importers' demand elasticity in response to price changes (Chenavaz, 2017; Feenstra & Romalis, 2014; Hallak & Schott, 2011). When initiating a trade relation, stringent importers bear higher fixed search costs to find an exporter that complies with the requirements. These higher costs reduce the risk of switching to alternative sourcing countries once the trade link is established (Rauch & Watson, 2003). However, stricter food safety standards in importing countries may also contribute to the destabilization of imports due to the potential difficulty exporters face in consistently meeting these stringent criteria (Mitchell, 2003) and concerns over fairness by exporters toward markets characterized by demanding and potentially trade-restrictive regulations. Dissimilarity on MRLs between importer and exporter can stabilize (established) trade relations through good reputation if the exporter adheres to stricter MRLs, or higher fixed compliance costs if the importer imposes stricter MRLs. Conversely, trade relations may be destabilized if product prices of an exporter with stricter MRLs are not competitive, or if variable compliance and control costs make the bilateral trade unprofitable when the importer enforces stricter standards.

We have found no study that analyzes the effects of countries' stringency or (direction of) incompatibility in terms of food safety standards on the duration and volatility of trade. Peterson et al. (2018) investigate the impact of the presence of exporters' sanitary and phytosanitary (SPS) requirements on US import failure rates of fruits and vegetables, finding a positive effect. Additionally, empirical studies examine the impact of food safety standards on the trade participation and intensity of agricultural and food products for different regions and product groups. Some of those studies find that standards have a positive impact on trade (Colen et al., 2012; Fiankor et al., 2019; Yang & Du, 2023),[4] while others show a negative impact (Arita et al., 2015; Disdier et al., 2008; Fernandes et al., 2019; Ferro et al., 2015; Fiankor et al., 2020; Fontagné et al., 2015; Hejazi et al., 2022) or no effect (Xiong & Beghin, 2012). Other studies find that the heterogeneity of trading partners' standards reduces bilateral trade (Hejazi et al., 2022; Winchester et al., 2012). Even though these studies do not directly analyze the impacts of standard stringency on trade stability, they provide insights into impact channels associated with stability.

We contribute to the literature in three ways. First, we provide a literature-based theoretical framework on the impact of importers' MRL stringency on the stability of trade relationships, leading us to our hypotheses. Second, we identify the impact channels of trade partners' dissimilarity in MRLs on trade stability based on literature and theory, considering also the "direction" of this bilateral dissimilarity, and thereby we contribute to the ongoing debate on the harmonization of standards as pursued by the WTO and negotiated in regional trade agreements. Third, we empirically analyze the impacts of both importers' MRL stringency and bilateral differences in those on the stability of trade duration and trade volatility. To this end, we provide a comprehensive understanding of trade dynamics driven by MRLs.

Our results show that a more stringent MRL policy of importing countries leads to longer trade duration and lower trade volatility. This indicates that stringent MRLs may not only contribute to food safety (utilization dimension of food security) but also to the import stability of agri-food products (availability dimension of food security). However, larger deviations in MRL standards between the bilateral trading partners imply shorter bilateral trade duration and higher volatility of trade. This finding shows that buyers and sellers in countries having a similar level of MRL stringency achieve longer trade relations and highlights the need for more comprehensive global harmonization.

The remainder of this paper is structured as follows. Section 2 discusses the relevance of food safety standards including MRLs, presents channels through which MRL standards can affect trade stability in terms of import variety and imported amounts, and derives hypotheses. Section 3 specifies the regressions and the choice of estimation approaches for assessing the impact of MRL standards on trade stability. Section 4 describes the data and provides some descriptive statistics of them. Section 5 presents the results and discussions; Section 6 gives policy implications, and finally, Section 7 concludes.

## BACKGROUND AND DERIVED HYPOTHESES

Under the WTO's Sanitary and Phytosanitary Agreement, countries are allowed to set standards that deviate from international standards, provided these are based on scientific evidence (FAO/WTO, 2017). Food safety concerns and protectionist practices have led countries to often set their own standards (Kareem et al., 2018), leading to a diverse array of requirements that exporters must meet to access different markets. As a consequence, to reduce the compliance costs of meeting many different parallel standards, the WTO seeks to harmonize food safety standards globally.

One product standard highly relevant for food safety is the MRL. When importing countries set their own MRL standards, producers—both domestic and those exporting to the market—must comply with these standards in accordance with the nondiscriminatory rules of the WTO (WTO, n.d.). Ensuring adherence to MRLs might involve changes in production, as well as regulatory oversight, testing, and monitoring processes. Therefore, MRLs may affect the decisions of producers and consumers in importing as well as exporting countries, and thus influence not only the safety but also the stability dimensions of food security.

Understanding the influence of MRLs on the stability of agri-food has become increasingly important, as the trade network historically and also more recently experienced instabilities. The instability of trade relationships has become increasingly evident since the 2008 financial crisis (Bennett et al., 2016; Jafari et al., 2023), and more recently with events such as Covid-19 (Engemann & Jafari, 2022) and the Ukraine–Russia war (Hussein & Knol, 2023). Both historical and more recent instabilities stress the need to analyze factors that might contribute to or counteract trade stability (e.g., Besedeš & Prusa, 2006; Engemann et al., 2023; Hess & Persson, 2011; Peterson et al., 2018). The question is how do MRLs affect the stability of bilateral trade relationships?

The impact of MRLs on the stability of trade relationships depends on several factors related to the behavior of both consumers and producers by affecting their utility and profit, respectively. Any change in those factors may result in importers' and exporters' reconsideration of trade decisions (Esteves & Rua, 2015). MRL standards may impact the fixed as well as the variable costs in exporting countries and add fixed and variable costs to importers (Xiong & Beghin, 2014). Accordingly, although sticking to MRLs may ensure certain product quality linked to the utility of consumers, it may also drive up costs allowing for mutually beneficial trade only if consumers are willing to pay for the costs of the stricter requirements. Table 1 summarizes the impact channels discussed in the following.

More stringent standards (lower MRLs) reduce the purchasing risk of consumers in importing countries by ensuring product quality, increasing the transparency between trade partners and reducing their information asymmetries (Besedeš et al., 2011; Fiankor et al., 2020; Mitchell, 2003; Xiong & Beghin, 2014). Stricter MRL standards, which imply higher quality of food products, may also contribute to lower price elasticity of demand (Chenavaz, 2017), that is, price changes of products with a higher quality lead, ceteris paribus, to smaller changes in demand when compared to the same price change of products with lower quality. The extent of appreciation for product quality and thus elasticities may vary across countries depending on demand side factors (Feenstra & Romalis, 2014; Hallak & Schott, 2011).

MRLs may also increase the stability because importers need to establish a trade link that aligns with the requirements, which involves fixed search and compliance/training cost (Rauch & Watson, 2003). When considering these search and compliance/training expenses, identifying a suitable supplier tends to be more costly for importers with more stringent MRLs.[5]

TABLE 1 Overview of MRLs' impact channels.

| | | Impact channels | Stability impact |
|---|---|---|---|
| Importers' stringency | | Risk reduction of consumers' purchasing decisions | + |
| | | Lower product price elasticity of demand | + |
| | | Higher search costs for buyers | + |
| | | Less/costlier diversification possibilities for importers | + |
| | | Higher sunk costs for exporters to establish trade relations | + |
| | | Higher risk of ban/rejection by importers (e.g., because of exporters' noncompliance) | − |
| | | Fairness concerns of exporters toward standards | − |
| Dissimilarity | Stricter importer | Higher fixed compliance/implementation costs faced by exporters | + |
| | | Higher variable compliance/controlling costs faced by exporters | − |
| | Stricter exporter | Higher prices in less quality-stringent importing countries due to additional (unnecessary) costs incurred in more quality-stringent countries | − |
| | | Good reputation of exporters, which can lower price elasticity of demand | + |

Among all possible suppliers, buyers (importers) search for the supplier (exporter) of a needed product with a certain quality to the lowest price possible (Rauch & Watson, 2003). With higher requirements of importers in terms of product standards, search and compliance costs would increase and the number of appropriate suppliers decrease. Once a trade relation has been established, higher fixed costs of establishing those trade relationships means that importers would be less willing to shift to alternative suppliers resulting in more stable trade relations. The lower number of suitable suppliers due to relatively strict import standards as well means that the importer has less opportunities to diversify and might be more concerned to maintain existing trade relationships. This is supported by Peterson et al. (2018), who find that a lower number of suppliers reduces the competition leading to lower hazard rates.

MRLs also involve fixed and variable costs of production affecting the stability of suppliers' export behavior (Disdier et al., 2008; Ferro et al., 2015; Hejazi et al., 2022). When starting a trade relationship, exporters expect that paying the fixed costs to fulfill the importers' quality requirements is profitable (see Melitz, 2003). The existence of fixed costs to fulfill the quality requirements implies that suppliers may be less likely to shift to alternative destination markets. However, as MRLs also involve variable costs for suppliers, significant (and unexpected) increases in the MRL-related variable costs can outweigh sunk fixed costs, making it unprofitable to continue selling to this market.

Risk of rejection by importers and fairness concerns from the exporters' perspective are additional mechanisms that may play a role for the impact of importers' MRL stringency on trade stability. Exporters might face difficulties in consistently meeting strict MRLs set by the importing country (Mitchell, 2003), which increases the risk/probability of bans or rejections due to noncompliance of exporter. This can result in less stable and inconsistent import patterns (EC, 2022; Kubiak-Hardiman et al., 2023). Furthermore, comparably high stringency in MRLs of importers can be perceived as unfairly strict and trade-restrictive (Kubiak-Hardiman et al., 2023). Such fairness concerns of exporters can lead to trade disputes and, in turn, may cause bilateral trade disruptions. For example, the EU's relatively stringent MRLs of several substances have raised trade concerns by the United States and some other countries (WTO, 2021a).

Empirical studies analyzing the impact of standard stringency on trade duration and import volatility are notably limited. Peterson et al. (2018) examine the existence of SPS measures in exporting countries on survival of US fruit and vegetable imports, concluding that SPS requirements (e.g., water treatment, fumigation) significantly increase hazard rates of trade. Besedeš and Yan (2018) examine the effects of product quality on trade duration and find a positive relation. While the two studies address trade stability in terms of duration, neither examines the impact of importers' standards. Other studies that consider importers' standards, analyze their impact on trade levels but overlook stability. The overall findings of those studies remain ambiguous (Santeramo & Lamonaca, 2019).[6] For example, Xiong and Beghin (2014) find that strict MRLs foster import demand as higher food safety is guaranteed, while the exports by the MRL setting country decrease. Given that many of the theoretical channels outlined above support a positive impact of the importer's product quality standards on stability (see Table 1), we hypothesize that a higher stringency of the importer relative to all other countries[7] leads to an increase in import stability, more specifically to a longer trade duration (H1a) and lower volatility of bilateral trade values/volumes (H1b).

Besides the stringency level of the importer, the degree of (dis-) similarity in MRLs of trade partners may also play a role for the stability of trade relations. For the similarity, bilateral variations in MRLs set by both importer and exporter are relevant. Depending on which partner has the stricter MRL, those differences can imply the excess or deficit in product quality of exporters compared to importers. How do dissimilarities in MRLs with the importer being stricter affect the stability of trade relations? In this case, exporters may pay fixed and variable costs to comply that might increase with higher dissimilarity of MRLs between the bilateral trading partners (Fontagné et al., 2015; Xiong & Beghin, 2014). Fixed costs to establish the trade link and to comply with the relatively higher stringency may increase with higher dissimilarities as investments in new production techniques get necessary (Fiankor et al., 2020). Variable (trade) costs can be induced by adjusting the input use (e.g., less-toxic treatment), logistics and quality controls needed to ensure that the product standards of the import market are met (Fontagné et al., 2015; Xiong & Beghin, 2014). The higher fixed costs may imply that suppliers are less likely to divert away from their import partner, once they established the trade link. Nonetheless, the supply to the import destination might be disrupted in case suppliers cannot comply due to factors that increase variable cost elements.

If the exporter's MRLs are more stringent than importer MRLs, the quality of the exported product may be superior and imply costs unnecessary for compliance (Mitchell, 2003), inducing higher prices. The stability might be enhanced due to a good reputation of the exporter (Colen et al., 2012), increasing import demand from this country and a decreasing price elasticity for higher quality products. Nonetheless, companies located in countries with high quality standards may be less likely to export to markets with lower quality standards (Crinò and Epifani (2012). Thus, it is questionable whether consumers in the importing country are willing to bear these additional costs of importing from a stricter partner, and not rather switch to another supplier with lower complying requirements. This would induce more instability to the trade relation.

We are not aware of any study examining the impact of bilateral dissimilarity on trade stability. However, examining the MRLs' effect on trade values, empirical research indicates that differences in standards tend to reduce trade. For instance, Drogué and DeMaria (2012) show a trade-impeding effect of regulatory heterogeneousness in the case of MRLs of apples, pears and related processed products. Fiankor et al. (2024) find that MRL heterogeneity reduces imports of Swiss firms. Similarly, Foletti and Shingal (2014) demonstrate that harmonizing MRL standards increases trade along intensive and extensive margin of trade.

This background suggests that bilateral differences of trading partners in MRLs matter beyond the stringency level of the importer. The overall impact of these differences on the stability of trade links can be either positive or negative, depending on the weight and interaction of the different channels (see Table 1). We expect that the destabilizing channels — namely, the variable costs faced by the exporter (when importer is stricter) and the potentially higher prices (when exporter is stricter) — outweigh the stabilizing channels, such as the fixed costs (when importer is stricter) and exporters' reputation (when exporter is stricter). This expectation is based on the observation that trade flows are more sensitive to changes in variable trade costs compared to changes in fixed costs (Jafari & Britz, 2018). Therefore, we hypothesize that higher bilateral differences of MRLs in established trade relations decrease the trade duration (H2a) and increase the trade volatility (H2b). Further, considering the different theoretical channels based on either the excess or deficit exporters' standards compared to importers, we hypothesize that the extent of the impact of dissimilarity on trade duration (H3a) and trade volatility (H3b) differ depending on which trading partner is stricter.

# METHODOLOGY

To examine the effects of importers' MRL standards and the bilateral differences therein on trade stability—specifically, the duration of import trade relations and the volatility of import values/volumes—our methodological approach employs two different regression models.

For the analysis of the impact of MRLs on trade duration, we rely on a discrete-time hazard model (Hess & Persson, 2012) since our data are reported in discrete units of yearly length.[8] We test hypotheses H1a, H2a, and H3a based on the following specification:

$$\begin{aligned} y_{odpkt} = {} & \delta_0 + \delta_1 MRL_{dp(t-1)} + \delta_2 \Delta MRL_{odp(t-1)} * RI_{odp(t-1)} + \delta_3 \Delta MRL_{odp(t-1)} \\ & * \left(1 - RI_{odp(t-1)}\right) + Controls_{odpk(t-1)} \delta_4 + \lambda_k + \lambda_p + \lambda_t + \alpha_{odp} + \varepsilon_{odpkt}, \end{aligned} \tag{1}$$

where $y_{odpkt}$ is the dependent binary duration variable that equals zero if the spell $k$ for the bilateral import of product $p$ from origin country $o$ to destination country $d$ survives in time $t$, and one if the spell fails. A trade spell is the period of consecutive years of trade in a trade relation without interruption, that is, the period from the first (re-)occurrence to the last occurrence of origin–destination-product specific trade (Besedeš et al., 2016; Hess & Persson, 2011). Thus, the binary duration variable informs about whether the duration of the trade spell $k$ is prolonged or determined in $t$. We consider single and first spells,[9] and also the spells that reoccur after one or more failures in the same trade relation, called multiple spells (e.g., Hess & Persson, 2011; Jaghdani et al., 2024).

Our specification includes several regressors of interest (see Equation 1). With the importer's restrictiveness in MRL standards for product $p$ at time $t$-$1$, $MRL_{dp(t-1)}$, we want to examine whether a higher stringency of the importer relative to all other countries lead to longer trade duration (lower the rate of trade failure). Thus, for H1a, we test $\delta_1 < 0$. Second, to examine H2a and H3a, we incorporate the bilateral difference in MRL stringency for product $p$ between origin $o$ and destination $d$, $\Delta MRL_{odp(t-1)}$, and interact this difference with two binary variables indicating which trading partner has the stricter standard: (i) $RI_{odp(t-1)}$, being one if the exporter has a deficit in MRL stringency for product $p$ in time $t$ compared to the importer, and zero otherwise; (ii) the inverse of this index $1 - RI_{odp(t-1)}$, being one if the exporter has an excess in or same MRL stringency for product $p$ in time $t$ compared to the importer, and zero otherwise. Consequently, if $\delta_2 + \delta_3 > 0$ holds, differences in MRLs of importer and exporter increase the duration of bilateral trade relations supporting H2a. Further, we use Chi-square and Z-tests to evaluate if $\delta_2 \neq \delta_3$ holds true, indicating whether it matters which trading partner is having the stricter MRLs (H3a). To further reduce potential biases associated with endogeneity that are not captured by the fixed effects, we take the one-year lags of all time-variant covariates included in the model. Nonetheless, regarding a potential reverse causality, we conjecture that the stability of trade relationships (trade duration and volatility) may not systematically influence the stringency of MRLs for two main reasons: (1) Many MRLs are set by Codex Alimentarius and are considered non-protectionist standards with science-based reference levels (Li & Beghin, 2014). For those MRLs that exceed Codex levels, several factors significantly reduce the incentive to use MRLs as protectionist measures. As implied by the national treatment principle of the WTO, MRLs must be met by both foreign and domestic producers. Moreover, many MRLs are established by supranational organizations, such as the EU, ASEAN, or the Gulf Cooperation Council. (2) Although we do not rule out the influence of trade on MRLs, we note that the likelihood that the stability of trade relationships influence the stringency of MRLs is significantly lower, if existing at all.

MRLs are quantitative measures that can be aggregated into indices enabling comparability across products and countries. We follow Ferro, Otsuki, and Wilson (2015) and construct the MRL stringency of each importer $d$ for product $p$ at time $t$, $MRL_{dpt}$ (see Equation 2). We normalize the MRL stringency for each combination of product $p$ and active substance $a$ at time $t$ ($MRL_{dpta}$) relative to the maximum and minimum MRLs across countries, $MAX_{pta}$ and $MIN_{pta}$, and take the average across active substances $a$ for each importer $d$ and product $p$ in year $t$:

$$MRL_{dpt} = \frac{1}{N(a)} \left( \sum_{n(a)=1}^{N(a)} \left( \frac{MAX_{pta} - MRL_{dpta}}{MAX_{pta} - MIN_{pta}} \right) \right) \tag{2}$$

This stringency index ranges from zero to one, where zero corresponds to the least restrictive and one to the most restrictive MRLs at the country-product-time level.

The dissimilarity index follows Winchester et al. (2012). $\Delta MRL_{odpt}$ is the normalized absolute bilateral dissimilarity of MRLs (see Equation 3) between origin country $o$ and destination country $d$ in year $t$ considering all relevant active substances $a$ for products $p$. The dissimilarity index is zero when importer and exporter MRLs are equal, and one when origin and destination countries have the most and the least stringent MRLs of a product. Unlike the index used by Xiong and Beghin (2014), which takes the exponential of the difference, we do not assume that compliance becomes marginally more difficult as stringency increases. Different from our MRL stringency measure, the dissimilarity measure is based on the MRLs set by both the importer and the exporter, thus also directly considering exporters′ variation in MRLs:

$$\Delta MRL_{odpt} = \frac{1}{N(a)} \left( \sum_{n(a)=1}^{N(a)} \left( \frac{|MRL_{opta} - MRL_{dpta}|}{MAX_{pta} - MIN_{pta}} \right) \right) \tag{3}$$

Our regression specification (Equation 1) includes *Controls* related to trade cost variables capturing whether countries are landlocked, have colonial ties, the same languages and common regional trade agreements (RTAs). It also captures bilateral physical distances, bilateral product specific applied tariffs, and product-importer-specific SPS and TBT notifications to the WTO. Trade duration studies[10] show that factors that reduce trade costs are beneficial for the achievement of longer trade duration. Further, we include GDPs of exporters and importers as measures of economic size and the initial trade volume of the spell to control for the size of the specific spell (Besedeš et al., 2024). We expect that both, greater economic size and the size of the spell imply more stable trade relations (Besedeš et al., 2006; Besedeš et al., 2024; Bojnec & Fertő, 2012).

Further, we introduce $\lambda_p, \lambda_t$, and $\lambda_k$ as product group, time and spell fixed effects, respectively. $\alpha_{odp}$ denotes the exporter-importer-product random effect. $\varepsilon_{odpkt}$ is the idiosyncratic error term. Product fixed effects control for differences across product groups, as we expect these differences to, for example, affect the costs of establishing trade links (Besedeš et al., 2006; Rauch & Watson, 2003). By introducing yearly time fixed effects, we account for common shocks, for example, global economic booms or slowdowns across years (Baldwin & Taglioni, 2006). The spell fixed effect captures experiences gained in previous spells in the trade relationship. Using relationship specific random effects controls for unobserved heterogeneity that is constant within trade relationships (Besedeš et al., 2024; Hess & Persson, 2012). We use random effects rather than fixed effects to address the incidental parameter problem, a common issue in nonlinear models with panel data that feature a large number of individuals over a limited number of years (Lancaster, 2000).

To estimate Equation 1, we follow the reasoning of Hess and Persson (2012) and rely on the conventional regression techniques for panel data with binary outcome variables, applying the probit estimator. We also test the robustness of our results using logit and cloglog estimators.

We set up a second specification to estimate the effects on trade volatility $vol_{odpt}$ as follows:

$$\begin{aligned} vol_{odpt} = \exp\big[&\delta_0 + \delta_1 MRL_{dp(t-1)} + \delta_2 \Delta MRL_{odp(t-1)} * RI_{odp(t-1)} + \delta_3 \Delta MRL_{odp(t-1)} * \left(1 - RI_{odp(t-1)}\right) \\ &+ \delta_4 Controls_{odp(t-1)} + \lambda_{od} + \lambda_{otp} + \lambda_{dtp}\big] * \varepsilon_{odpkt}. \end{aligned} \tag{4}$$

With this specification, we target to examine hypotheses H1b ($\delta_1 < 0$), H2b ($\delta_2 + \delta_3 > 0$) and H3b ($\delta_2 \neq \delta_3$) as discussed above with respect to the estimation of the impact of MRLs on trade duration (Equation 1).

The dependent variable is the trade volatility between origin $o$ and destination $d$ for each product $p$ at time $t$, $vol_{odpt}$. To quantify this variable, capturing positive and negative fluctuations around bilateral trade patterns, we use the standard deviation of the actual bilateral trade values $x_{odpt}$ from expected trade values $\widehat{x}_{odpt}$ following Guerra et al. (2019):

$$vol_{odpt} = \sqrt{\left(x_{odpt} - \widehat{x}_{odpt}\right)^2}, \tag{5}$$

whereas the expected trade values are obtained by estimating:

$$\widehat{x}_{odpt} = \widehat{\alpha} + \widehat{\beta}\mathrm{t} \tag{6}$$

with ordinary least squares (OLS) regression. The constant $\widehat{\alpha}$ and the coefficient $\widehat{\beta}$ multiplied by time $t$ yield the fitted values for the linear trend, that is, the expected trade values $\widehat{x}_{odpt}$.

We follow the gravity model literature and include importer-time-product ($\lambda_{dtp}$) and exporter-time-product fixed effects ($\lambda_{otp}$) to control for outward and inward multilateral resistances along with country-size effects, and importer-exporter fixed effects ($\lambda_{od}$) to capture time-invariant trade costs and to mitigate endogeneity issues (Anderson & Yotov, 2020; Baier & Bergstrand, 2007; Fiankor et al., 2021; Hummels, 1999). Since time-invariant country-pair variables are captured by the fixed effects in this specification, we here only include the time-variant controls, namely, SPS and TBT notifications, bilateral tariffs, and regional trade agreements as controls.

To estimate Equation 4, we rely on the PPML estimator addressing heteroskedasticity and the inclusion of zeros (Santos Silva & Tenreyro, 2006). In gravity-style trade models with high-dimensional fixed effects, the incidental parameter problem is less severe than in binary discrete-time models, as the PPML estimator can handle a large number of fixed effects (Weidner & Zylkin, 2021).

# DATA

The MRL data come from Lexagri International's Homologa database. The data include MRLs for 72 reporters, 742 products, and 2028 substances[11] that can be different chemical residues such as pesticides, mycotoxins, and veterinary drugs. We map the reporter and product classification in Homologa to individual countries and products at the 6-digit level of the Harmonized Systems (HS) to match with the other data, resulting in a dataset of 164 countries (see Table A1) and 225 product groups at the HS6 level. The temporal scope of the data is 2005 to 2020. Figure 1 depicts the number of reporters, the evolution of the variety of substances and products, as well as unique MRLs reported per substance and product. If two or more countries report the exact same MRL, we count it as one MRL, therefore reflecting on the number of (dis) harmonized MRLs globally. The figure reveals an increasing global trend in the number of different MRLs, with 2015 being the year with the largest rise within our study period driven by a significant expansion of substances reported. We observe a decrease in the number of MRLs in 2009 because of the EU-wide harmonization of MRLs based on Regulation (EC) No 396/2005 that came into effect in September 2008. In 2009, the number of substances significantly decreased, and the individual EU countries stopped setting their own MRLs, reducing the number of reporters to 39 (from 61 in 2008). In all other years, the number of regulated substances rises strongly, while the number of products and reporters increases only marginally.

If there is no MRL reported by an individual country in a given year, we take the value reported in the previous year (assuming an unchanged MRL). If a country has previously either not reported an MRL or has reported a less stringent MRL than the one set by the supranational organization to which it belongs (i.e., EU, Gulf Cooperation Council, ASEAN cooperation, Codex Alimentarius), we adopt the MRL provided by the supranational organization. Furthermore, if the supranational organization has also not set an MRL, we assume that the country has the least restrictive MRL stringency for that specific substance-product pair (see e.g., Drogué & DeMaria, 2012; Fernandes et al., 2019; Ferro et al., 2015; Fiankor et al., 2021).

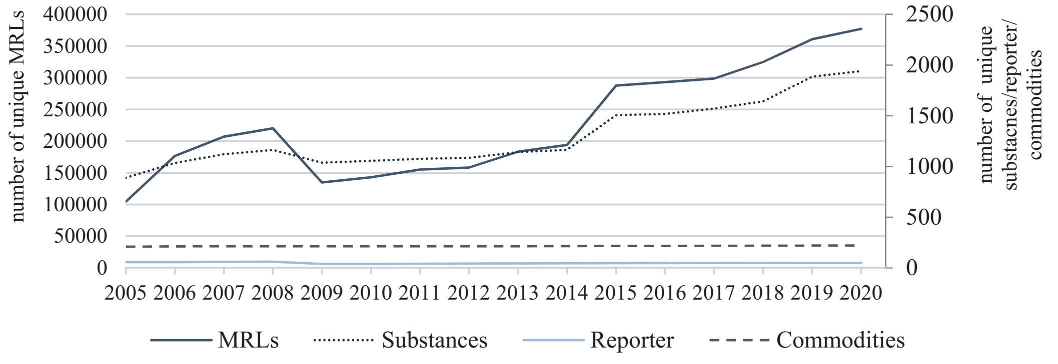


**FIGURE 1** Evolution of different MRLs across countries.
*Note*: MRLs are unique values per substance and product (at HS6-digit level) across all countries in each year. Reporters are individual countries and supranational organizations, such as Codex Alimentarius, EU, Gulf Cooperation Council, and ASEAN Cooperation. *Source*: Illustration based on data from the Homologa database (Homologa, 2021).

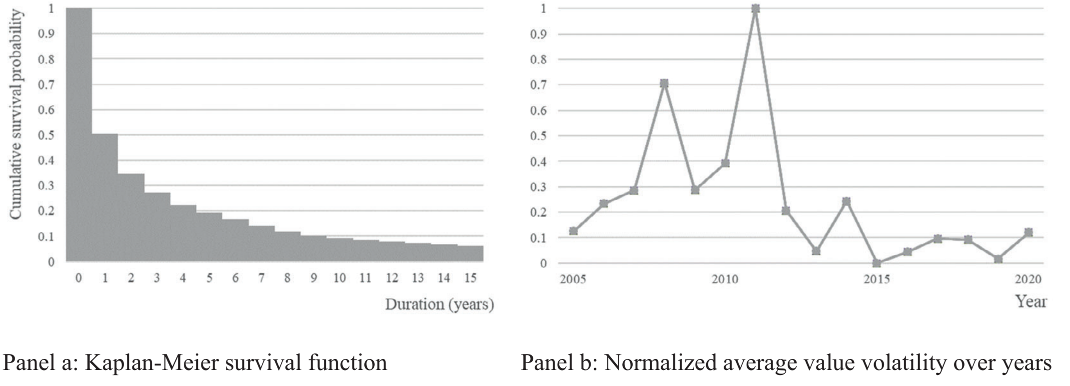


**FIGURE 2** Trade survival and trade volatility.
*Source*: Calculations and illustrations based on data from the UN Comtrade database (UN COMTRADE, 2022).

To construct bilateral trade stability measures (duration and volatility), we extract import values and quantities from the United Nations' Commodity Trade Statistics (UN COMTRADE, 2022) database at the HS-6-digit level. We interpret the missing observations as zero trade flows (World Bank, 2010).[12] As annual trade data are available before 2005, we control for left-censoring in the duration analysis.[13] Trade values are deflated by the consumer price index (World Bank, 2022a).

The duration of bilateral trade relations is often short (e.g., Besedeš et al., 2006; Engemann et al., 2023; Peterson et al., 2018). To analyze the duration of bilateral trade relations in our dataset, we apply the Kaplan and Meier (1958) estimator. It calculates the expected time until a bilateral trade relation fails after different lengths of spells (Besedeš et al., 2016). Figure 2 (Panel a) depicts the cumulative survival probability at each annual length of a spell $k$ based on the non-parametric survival estimator of the hazard function.[14] It indicates that only 50.5% of all trade relations survive after 1 year of trade at the HS-6-digit level. The survival rate reduces to 14.0% after 7 years. In subsequent years, the annual failure rate is substantially lower (up to 2.1%) and decreasing over time. In our dataset, only 4.4% of trade spells are still active after 15 years. Overall, considering the investigation period in this study, the average number of consecutive years that a trade spell survives (i.e., trade duration) is 3.62 years. These findings are also in line with the literature that has found relatively short-lived durations of trade flows at a similar product resolution level (e.g., Besedeš et al., 2006; Engemann et al., 2023; Peterson et al., 2018).

Bilateral trade values are also volatile. Figure 2 (Panel b) depicts the annual average volatility across products and countries, which is the normalized mean of product-specific standard deviations of the deflated trade values across the years. The figure indicates that the agri-food trade system has witnessed fluctuations, particularly in 2009 and 2011, during the period of the financial crisis (2008–2009) to the onset of the economic crisis in many high-income countries in 2012 when the aggregate demand for agricultural products weakened significantly (Beckman et al., 2017).

We obtain information on countries' GDP from the World Bank database (World Bank, 2022b), on bilateral applied tariffs from the United Nations Commission on Trade and Development (UNCTAD) provided by the World Integrated Trading System (WITS) database, on SPS and NTM notifications from the wiiw NTM database (Ghodsi et al., 2017), and on RTAs from the WTO Regional Trade Agreements database. We only consider RTAs that include goods. The remaining control variables are retrieved from the CEPII database (Conte et al., 2022). Table 2 shows the descriptive statistics of the variables used in the regression estimations and some additional variables. Descriptive statistics of the binary duration show that 18% of the observations represent a failure of a trade relation emphasizing the short duration depicted in Figure 2, Panel a. Furthermore, 27% of the active spells are multiple spells with up to seven spells within a trade relationship; the remaining part are first or single spells of a bilateral trade relationship. The trade volatility measure clearly demonstrates fluctuations from the linear trend, with a right skewed distribution. Importers' stringency and bilateral differences in MRLs are normalized values between zero and one, with means of 0.35 and 0.31 units.[15] The statistics of the binary restrictiveness index indicate that, in 39% of the observations, the importer is stricter than the exporter, and in 61% of the observations, they have either the same level of stringency or the exporter is stricter.

## RESULTS AND DISCUSSIONS

The main results are shown in Figure 3. First, we test the hypothesis that a higher stringency of the importer relative to all other countries leads to more stability in terms of import trade duration (H1a) and trade volatility (H1b). We find a negative effect of importers' MRL stringency on the failure of bilateral trade relationships (see Figure 3, panel A; Table A3), which implies that relatively stricter importer MRLs induce longer bilateral trade duration. The results of the PPML estimates suggest that stricter importer MRLs lead to lower trade volatility in terms of trade values. We also find a negative impact on trade volatility of volumes; however, it is not significant based on conventionally used significance levels (Figure 3, panel B; Table A4). Thus, we find support for H1a and H1b.

The increase in duration might be driven by the less elastic demand of consumers in the importing country due to higher product quality and the risk reduction for consumers. Further, this importers' stringency is relative to all other countries' stringency, which implies that for a

**TABLE 2** Descriptive statistics of data.

| | Mean | Std. dev. | Min | Max | Obs. |
|---|---|---|---|---|---|
| Importer MRL stringency | 0.35 | 0.37 | 0 | 1 | 5,589,475 |
| Bilateral MRL differences | 0.31 | 0.39 | 0 | 1 | 5,589,475 |
| MRL stringency "direction" index | 0.39 | 0.49 | 0 | 1 | 5,589,475 |
| Duration (survival = 0, failure = 1) | 0.18 | 0.38 | 0 | 1 | 2,376,840 |
| Trade (yes = 0/no = 1) | 0.63 | 0.48 | 0 | 1 | 5,589,475 |
| Trade volatility (1000 t) | 1.21 | 56.89 | 0 | 60,058 | 5,589,475 |
| Trade volatility (million USD) | 0.95 | 19.95 | 0 | 11,917 | 5,589,475 |
| Trade volume (1000 t) | 1.10 | 56.89 | 0 | 60,058 | 5,589,475 |
| Trade value (million USD) | 0.88 | 19.95 | 0 | 11,917 | 5,589,475 |
| Initial volume (1000 t) | 2.03 | 60.73 | 0 | 16,341 | 2,376,840 |
| Spell count | 1.38 | 0.70 | 1 | 7 | 2,376,840 |
| Multiple spell | 0.27 | 0.44 | 0 | 1 | 1,951,729 |
| Common language (binary) | 0.15 | 0.35 | 0 | 1 | 5,410,115 |
| Colonial ties (binary) | 0.05 | 0.22 | 0 | 1 | 5,410,115 |
| Landlocked (binary) | 0.26 | 0.44 | 0 | 1 | 5,410,115 |
| Bilateral distance (km) | 5238 | 4355 | 59.62 | 19,772 | 5,410,115 |
| Importer GDP (billion USD) | 957 | 2443 | 0.04 | 19,975 | 5,585,559 |
| Exporter GDP (billion USD) | 1370 | 3174 | 0.03 | 19,975 | 5,571,834 |
| TBT (count) | 17.19 | 44.33 | 0 | 924 | 5,589,475 |
| SPS (count) | 38.02 | 178.75 | 0 | 4436 | 5,589,475 |
| Tariff (ad valorem) | 11.32 | 40.66 | 0 | 3000 | 5,589,475 |
| RTA (binary) | 0.49 | 0.50 | 0.00 | 1.00 | 5,589,475 |

*Source*: Calculation based on data retrieved from Homologa (2021), UN COMTRADE (2022), World Bank (2022b), World Bank (2022a), Conte et al. (2022), Ghodsi et al. (2017) and UNCTAD and WITS databases.

relatively stricter importer, trade diversification is more challenging. Shifting to other trade partners is costlier and more difficult due to fewer already compliant export partners or higher costs to comply with the standards. Our findings indirectly align with those of previous studies suggesting import-enhancing/stabilizing impacts through higher product quality, higher costs for establishing a trade relation (e.g., search costs, fixed compliance costs) and reduction of information uncertainty (e.g., Besedeš & Yan, 2018; Chenavaz, 2017; Fiankor et al., 2021; Xiong & Beghin, 2014).

Second, we examine whether higher bilateral differences in MRLs between importer and exporter lower the import duration (H2a) and increase the import volatility (H2b). Compared to the importer MRL stringency, the bilateral MRL measure captures directly the variation of exporter's standard setting. Our results (Figure 3) show that higher bilateral differences in trading partners' MRL stringency increase trade failure and volatility ($\delta_2 + \delta_3 > 0$), thus supporting the two hypotheses, H2a and H2b. We further run regressions excluding the interaction terms, supporting our findings (Tables A5 and A6).

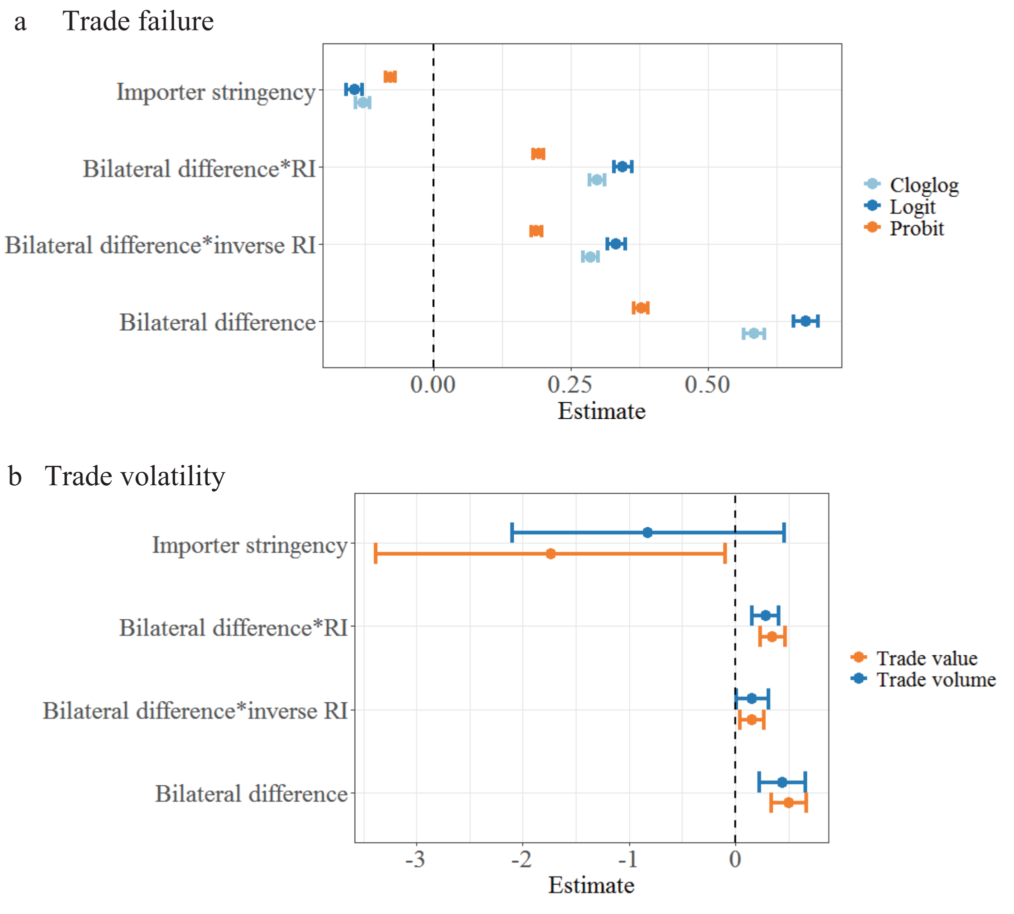


**FIGURE 3** Impact of MRL standards on the failure and volatility of trade relations.
*Note*: 95% confidence intervals are reported. Product, year, and spell-fixed effects and importer-exporter-product random effects are included in binary choice models shown in Panel A (see also Table A3). Importer-year-product, exporter-year-product and exporter-importer fixed effects are included in the regression models of trade volatility shown in Panel B (see also Table A4). The impact of the overall MRL difference is calculated based on the estimates of the interaction terms of the bilateral difference and the directions of stringency excess $(\delta_2 + \delta_3)$.

Third, we analyze if the impacts of bilateral differences in MRLs change depending on whether the exporter or the importer is stricter (Table 3). The results depict that in both cases MRL dissimilarities tend to promote trade failure and volatility. We fail to reject the null hypothesis that $\delta_2 = \delta_3$, which implies no support for H3a, hypothesizing that the effect on trade duration is different conditioned on the direction of dissimilarity in stringency. Further, we do not find clear evidence that the effect of trading partners' MRL differences on trade volatility is significantly different depending on the direction of stringency excess (H3b). We reject $\delta_2 = \delta_3$ for trade value volatility but fail to reject the null for trade volume volatility based on the tests shown in Table 3. In this respect, impacts on trade volume volatility are, on average, larger when importers are in stricter countries than exporters, compared to the same discrepancies when the exporters' country is stricter. This suggests that the variable compliance cost channel (see Table 1) has the most pronounced effect in this dimension of trade stability.

**TABLE 3** Equality tests of the impact of bilateral MRL differences, depending on stringency direction, on import stability.

| Stability dimension | Model | *z*-value | *p*-value | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|
| Duration | Probit | 0.606 | 0.545 | | |
| | Logit | 1.051 | 0.293 | | |
| | Cloglog | 1.256 | 0.209 | | |
| Volatility | Value | 2.360 | 0.018 | 5.899 | 0.015 |
| | Volume | 1.248 | 0.212 | 1.984 | 0.159 |

*Note:* Based on z- and $\chi^2$-tests for the duration analysis and trade volume volatility, we fail to reject the null hypothesis that the coefficients of the two interaction terms (bilateral MRL differences with restrictiveness indices) are equal. This suggests that the effect of MRL stringency differences on trade duration does not significantly differ depending on the direction of the stringency gap. However, for trade value volatility, we reject $H_0$ at $p < 0.05$, indicating that the direction of the stringency excess matters for this aspect of trade stability.

Shorter import duration associated with higher MRL differences may be driven by compliance costs. This is in line with the trade duration literature finding that higher bilateral trade costs lead to shorter lengths of trade relations (see Bacchetta et al., 2012; Besedeš et al., 2006; Hess & Persson, 2011). Where the exporter is stricter than the importer, additional production costs unnecessary to meet the importer's standard result in higher prices for consumers. This may in turn result in importers shifting to alternative sources. When the importer is stricter than the exporter, the compliance and controlling costs that increase with larger standard differences may lead exporters to divert to other destinations (higher trade failure). This is the case, if these costs are higher than the extra revenue that exporters might receive in the importing countries due to recognition of their product quality, making the trade relation unprofitable, against previous expectations of the trading partners (Xiong & Beghin, 2014). Looking at the impact of MRL dissimilarities on the volatility of trade values/volumes, we also consider the mentioned channels as relevant. These channels seem to outweigh the possible trade stabilizing effect through exporters' good reputation of higher product quality and higher fixed compliance costs that reduce switching to another seller/buyer.

In addition to our main findings, the coefficients of control variables (Tables A3 and A5) suggest that trade failures have a positive relationship with bilateral tariffs and distances, and a negative relation with the other control variables, namely importers' TBT and SPS, common RTAs, common language, colonial ties, initial trade volumes, GDPs, and being landlocked. Trade volatility (Tables A4 and A6) has a negative relationship with tariffs but positively relates to importers' number of TBTs and SPSs. This is in contrast to the relation of these control variables with trade failure. We expect that higher tariffs may result in firms completely leaving the trade link or fewer firms with higher productivity staying on the trade link and selling to a smaller fraction of consumers that have lower demand elasticity to price changes. The former might explain why higher tariffs increase trade failure and the latter why trade of those that stay in the trade relationship remains less volatile. Differences in the relations with SPS and TBTs may arise from the various fixed and variable costs and demand-shifting effects associated with these trade policies that can influence trade duration and trade volatility differently. Also, theory does not provide a conclusive implication on the direction of the correlation.

# POLICY IMPLICATIONS

The results suggest that an increase in importers' MRL stringency, when controlling for the dissimilarity of their MRLs with trading partners, enhances trade stability by reducing both trade failure and volatility. Additionally, when the MRLs of trading partners are more similar, controlling for the importers' stringency, trade volatility decreases. Since changes in MRLs may affect these dissimilarities, drawing policy implications regarding the impacts of MRLs on import stability requires a simultaneous consideration of both the effects of MRL stringency and dissimilarity with trade partners.

This simultaneous consideration suggests that when importers have less stringent MRLs than exporters, ambitious food safety policies aimed at protecting consumer health—reflected by lower MRLs—can also improve food security by enhanced import stability. In this case, the enhanced stability would result from both the direct impact of MRL setting and the alignment of regulatory standards. When importers have more stringent MRLs than their trade partners, setting even stricter MRLs may not be desirable t as larger dissimilarity lowers trade stability. The results further imply that countries should not set strict MRLs without considering the consequences for bilateral MRL dissimilarity. This emphasizes—again—the importance of policies that aim at global regulatory harmonization based on scientific evidence.

The results also have implications for trade partner selection and harmonization efforts that could contribute to stable trade relationships: choosing trade partners with the same or close standards can contribute to food security by stabilizing import trade relations. The effect of MRL harmonization on trade stability may depend on how the harmonization is implemented. Harmonizing MRLs may enhance trade stability for importers with relatively less strict MRLs, but it could reduce stability for importers with currently more stringent MRLs. These costs are particularly likely to arise when the MRLs set by countries genuinely relate to product quality rather than protectionist purposes. The potentially different impacts of MRL harmonization on importers with high versus low MRLs suggest the existence of a tipping point for MRLs with optimal import trade stability. Coordinated efforts are desirable that not only reduce excessively strict MRL standards hindering trade but also raise low MRL standards to a level that promotes adequate product quality. Since substantial dissimilarities in MRL standards are related to different country income groups, investing in capacity building, research, and collaboration efforts can support low-income countries to comply with stringent MRL standards, thereby enabling access to these export markets (Curzi et al., 2018; Jongwanich, 2009).

# CONCLUSIONS

Both food safety and food availability in variety and volume are important policy goals directly linked to achieving food security. Food safety standards, such as MRLs, play a crucial role in promoting food safety; their number and stringency are on the rise and vary between countries. This may affect the stability of import trade relationships, which is key for keeping a steady availability of food.

This study analyzes the impact of the stringency of MRLs and dissimilarities among trade partners therein on the duration of trade relations and volatility of import values, using discrete-time hazard and fixed effects models. Our analysis involves data on 225 agri-food products at the HS 6-digit level and 164 countries, spanning the years 2005 to 2020.

Results show that more stringent MRLs of importing countries enhance trade stability (lower trade failure and trade volatility). In a similar vein, the stability of trade relations increases with lower differences in MRL standards of importers' and exporters' countries. The negative effects of bilateral MRL differences on both trade failure and trade value volatility are similar regardless of which country—exporter or importer—is stricter.

The simultaneous consideration of the results implies that, when importers have relatively high MRLs, that is, low MRL stringency, setting their MRLs to a stricter level does not imply a trade-off between food safety and stability of food availability but rather contributes to stable food availability by reducing import failure. When importers have already relatively low MRLs, that is, stringent MRLs compared to other countries, further tightening these standards may come at the cost of negative impacts caused by the growing disparity between their standards and those of their trade partners. Accordingly, importers that already set standards stricter than the global average should consider that such discrepancies may destabilize trade relationships, especially if these standards hinder trade rather than being based on scientific evidence.

Our findings regarding MRL dissimilarity extend prior evidence on the benefits of regulatory harmonization for food trade in general to food trade stability. Furthermore, the trade-offs regarding the impact of MRL stringency and dissimilarity on trade stability suggest that harmonization may also negatively affect trade stability for importers with relatively strict MRLs, who may need to relax them. Therefore, harmonizing MRLs should balance between trade stability and their role in ensuring product safety.

We explicitly do not draw implications for the case of food standards in general. MRLs are important, but there exist numerous food safety standards that might play an important role for the stability of trade relationships either standalone or via interaction with MRLs. We focus on MRL data because of its particular relevance for agri-food products and data accessibility for many countries and products, which is not the case for other standards. Further, we look at the overall effects of MRL policies for each product and do not distinguish between different substances. Examining the effect on bilateral trade values, Hejazi et al. (2022) find that insecticides are the most trade-restrictive among chemicals, whereas strict herbicide policies have a potential demand-enhancing effect. While these discoveries pertain to alterations in trade values rather than the stability of trade, it is important to note that different substances possess their own unique characteristics in terms of compliance cost and consumers risk perception. These distinctive attributes can lead to varying effects on trade stability. Finally, countries' quality of institutions may play a role in the standard enforcement (Swinnen, 2016). Thus, considering the impact of different types of substances and/or their interactions to identify possible contrary or mutually reinforcing effects, and the interaction of standards with countries institutional quality on the stability of trade offers potential scope for future research.

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## ENDNOTES

[1] According to WTO rules, countries can set their own standards as long as they are based on science. This results in a rising number of food safety standards. Contrarily, the WTO aims to harmonize these regulations internationally in order to achieve a more transparent and efficient trade system (FAO/WTO, 2017).

[2] Standards may also act as non-tariff barriers to trade (Kareem et al., 2018), which can be particularly challenging for less developed countries that generally have lower standards (Curzi et al., 2018; Jongwanich, 2009).

[3] Also sometimes referred to as Maximum Residue Limits (e.g. FAO/WHO, n.d.).

[4] Fiankor et al. (2019) find a trade-enhancing effect of GlobalGAP standards when exporting to high-value markets, and Yang and Du (2023) show that both voluntary and mandatory standards increase the volume of agricultural trade between China and the Belt & Road countries.

[5] We note that these search and compliance costs also depend on further characteristics such as the differentiation level of the products (Besedeš et al., 2006).

[6] Several studies find a negative impact on trade (e.g. Arita et al., 2015; Disdier et al., 2008; Fernandes et al., 2019; Fiankor et al., 2021; Fontagné et al., 2015), whereas others (Fiankor et al., 2019; Yang & Du, 2023) a positive effect on trade.

[7] The MRL stringency of importers shows the stringency level relative to all other countries. Therefore, it does not reflect the bilateral differences between importer and exporter.

[8] Many studies use the Cox models. However, Hess and Persson (2012) discuss several drawbacks: (i) difficulties to control for unobserved heterogeneity, (ii) continuous-time specification, but data is grouped into discrete units, and (iii) limits the independent variables from exerting a constant effect on the hazard rate.

[9] If a specific trade link has not been previously established, its initial occurrence is referred to as the first spell of trade. If this trade flow ceases and is later resumed, this initial trade period is a single spell (Hess & Persson, 2011).

[10] In standard heterogenous-firm trade models, higher trade barriers lead to negative effects for the extensive margin of trade (Melitz, 2003; Chaney 2008; Crozet and Koenig 2010), which is supported by empirical trade duration studies (e.g. Bacchetta et al., 2012; Besedeš and Prusa 2006b; Hess & Persson, 2011; Nitsch (2009); Engemann et al., 2023) finding that variables related to higher trade costs cause higher failure rates.

[11] We have retrieved the data from (Homologa, 2021) the in June 2021. MRLs are reported at different levels (i) individual country level and (ii) supranational organization level (EU, Gulf Cooperation Council, ASEAN cooperation, Codex Alimentarius binding for all WTO members). See Tables A1 and A2 for a list of products and countries covered by the reported MRLs. The list of substances is available upon request.

[12] Replacing missing values with zeros is common when using UN Comtrade data. According to the World Bank (2010) "No trade information for any given product (or product category) indicates a non-traded product according to the reporting country". Kareem et al. (2018) state "[…] the UN COMTRADE data reports trade values, even for very small values (up to $1), indicating that rounding to zeros is not an important cause of zero observation as most zeros are caused by economic reasons such as lack of profitability." Linders and Groot (2006) also refer to the Comtrade data and mention "We assume that all missing observations in principle indicate that bilateral exports are considered to be absent by the reporting country."

[13] Left-censoring means that the trade spell was already ongoing before the study period, which can lead to estimation biases (Hess & Persson, 2012). To control for that, we follow Peterson et al. (2018) and use the preceding data.

[14] KM survival estimator is calculated by multiplying the ratios of observations without the event ($n_j$-$d_j$) over those at risk $n_j$ over time $\widehat{S}(t) = \prod_{t(j)<t} \frac{n_j - d_j}{n_j}$ (Kaplan & Meier, 1958).

[15] The correlation of the importer MRL stringency and MRL dissimilarity is 0.147.

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# APPENDIX A

**TABLE A1** List of countries.

| Code | Name | ISO3 | Code | Name | ISO3 | Code | Name | ISO3 |
|---|---|---|---|---|---|---|---|---|
| 4 | Afghanistan | AFG | 276 | Germany | DEU | 586 | Pakistan | PAK |
| 8 | Albania | ALB | 288 | Ghana | GHA | 591 | Panama | PAN |
| 12 | Algeria | DZA | 300 | Greece | GRC | 598 | Papua New Guinea | PNG |
| 28 | Antigua and Barbuda | ATG | 308 | Grenada | GRD | 600 | Paraguay | PRY |
| 31 | Azerbaijan | AZE | 320 | Guatemala | GTM | 604 | Peru | PER |
| 32 | Argentina | ARG | 324 | Guinea | GIN | 608 | Philippines | PHL |
| 36 | Australia | AUS | 328 | Guyana | GUY | 616 | Poland | POL |
| 40 | Austria | AUT | 340 | Honduras | HND | 620 | Portugal | PRT |
| 44 | Bahamas | BHS | 348 | Hungary | HUN | 624 | Guinea-Bissau | GNB |
| 48 | Bahrain | BHR | 352 | Iceland | ISL | 634 | Qatar | QAT |
| 50 | Bangladesh | BGD | 356 | India | IND | 642 | Romania | ROU |
| 51 | Armenia | ARM | 360 | Indonesia | IDN | 643 | Russian Federation | RUS |
| 52 | Barbados | BRB | 372 | Ireland | IRL | 646 | Rwanda | RWA |
| 56 | Belgium | BEL | 376 | Israel | ISR | 659 | Saint Kitts and Nevis | KNA |
| 64 | Bhutan | BTN | 380 | Italy | ITA | 660 | Anguila | AIA |
| 68 | Bolivia | BOL | 384 | Côte d'Ivoire | CIV | 662 | Saint Lucia | LCA |
| 70 | Bosnia Herzegovina | BIH | 388 | Jamaica | JAM | 670 | St. Vincent and the Grenadines | VCT |
| 72 | Botswana | BWA | 392 | Japan | JPN | 682 | Saudi Arabia | SAU |
| 76 | Brazil | BRA | 398 | Kazakhstan | KAZ | 686 | Senegal | SEN |
| 84 | Belize | BLZ | 400 | Jordan | JOR | 690 | Seychelles | SYC |
| 90 | Solomon Isds | SLB | 404 | Kenya | KEN | 694 | Sierra Leone | SLE |
| 96 | Brunei Darussalam | BRN | 410 | Rep. of Korea | KOR | 702 | Singapore | SGP |
| 100 | Bulgaria | BGR | 414 | Kuwait | KWT | 703 | Slovakia | SVK |
| 104 | Myanmar | MMR | 417 | Kyrgyzstan | KGZ | 704 | Viet Nam | VNM |
| 108 | Burundi | BDI | 418 | Lao People's DR | LAO | 705 | Slovenia | SVN |
| 112 | Belarus | BLR | 422 | Lebanon | LBN | 710 | South Africa | ZAF |

(Continues)

**TABLE A1** (Continued)

| Code | Name | ISO3 | Code | Name | ISO3 | Code | Name | ISO3 |
|---|---|---|---|---|---|---|---|---|
| 116 | Cambodia | KHM | 426 | Lesotho | LSO | 716 | Zimbabwe | ZWE |
| 120 | Cameroon | CMR | 428 | Latvia | LVA | 724 | Spain | ESP |
| 124 | Canada | CAN | 434 | Libya | LBY | 740 | Suriname | SUR |
| 132 | Cap Verde | CPV | 440 | Lithuania | LTU | 748 | Eswatini | SWZ |
| 144 | Sri Lanka | LKA | 442 | Luxembourg | LUX | 752 | Sweden | SWE |
| 152 | Chile | CHL | 450 | Madagascar | MDG | 756 | Switzerland | CHE |
| 156 | China | CHN | 454 | Malawi | MWI | 760 | Syria | SYR |
| 170 | Colombia | COL | 458 | Malaysia | MYS | 762 | Tajikistan | TJK |
| 174 | Comoros | COM | 462 | Maldives | MDV | 764 | Thailand | THA |
| 184 | Cook Isds | COK | 466 | Mali | MLI | 768 | Togo | TGO |
| 188 | Costa Rica | CRI | 470 | Malta | MLT | 780 | Trinidad and Tobago | TTO |
| 191 | Croatia | HRV | 480 | Mauritius | MUS | 784 | United Arab Emirates | ARE |
| 196 | Cyprus | CYP | 484 | Mexico | MEX | 792 | Turkey | TUR |
| 203 | Czechia | CZE | 498 | Rep. of Moldova | MDA | 798 | Tuvalu | TUV |
| 204 | Benin | BEN | 499 | Montenegro | MNE | 800 | Uganda | UGA |
| 208 | Denmark | DNK | 500 | Montserrat | MSR | 804 | Ukraine | UKR |
| 212 | Dominica | DMA | 504 | Morocco | MAR | 807 | North Macedonia | MKD |
| 214 | Dominican Rep. | DOM | 508 | Mozambique | MOZ | 818 | Egypt | EGY |
| 218 | Ecuador | ECU | 512 | Oman | OMN | 826 | United Kingdom | GBR |
| 222 | El Salvador | SLV | 516 | Namibia | NAM | 834 | United Rep. of Tanzania | TZA |
| 231 | Ethiopia | ETH | 524 | Nepal | NPL | 840 | USA | USA |
| 233 | Estonia | EST | 528 | Netherlands | NLD | 854 | Burkina Faso | BFA |
| 242 | Fiji | FJI | 548 | Vanuatu | VUT | 858 | Uruguay | URY |
| 246 | Finland | FIN | 554 | New Zealand | NZL | 860 | Uzbekistan | UZB |
| 250 | France | FRA | 558 | Nicaragua | NIC | 862 | Venezuela | VEN |
| 258 | French Polynesia | PYF | 562 | Niger | NER | 876 | Wallis and Futura Isl. | WLF |
| 266 | Gabon | GAB | 566 | Nigeria | NGA | 882 | Samoa | WSM |
| 268 | Georgia | GEO | 578 | Norway | NOR | 894 | Zambia | ZMB |
| 270 | Gambia | GMB | 583 | FS Micronesia | FSM | | | |

**TABLE A2** List of included products (HS-6-digit).

| | | | | | | |
|---|---|---|---|---|---|---|
| 02 - Meat and edible meat offal | | | | | | |
| 020110 | 020230 | 020322 | 020423 | 020622 | 020721 | 020741 |
| 020120 | 020311 | 020329 | 020430 | 020629 | 020722 | 020742 |
| 020130 | 020312 | 020410 | 020441 | 020641 | 020723 | 020743 |
| 020210 | 020319 | 020421 | 020442 | 020649 | 020731 | 020750 |
| 020220 | 020321 | 020422 | 020443 | 020710 | 020739 | 020900 |
| 04 - Dairy produce; birds' eggs; natural honey, etc. | | | | | | |
| 040110 | 040210 | 040229 | 040299 | 040811 | 040891 | |
| 040120 | 040221 | 040291 | 040700 | 040819 | 040899 | |
| *06 - Trees and other plants* | | | | | | |
| 060290 | 060314 | | | | | |
| 07 - Vegetables and certain roots and tubers; edible | | | | | | |
| 070110 | 070410 | 070700 | 070940 | 071120 | 071333 | 071490 |
| 070190 | 070420 | 070810 | 070951 | 071130 | 071335 | |
| 070200 | 070511 | 070820 | 070959 | 071140 | 071340 | |
| 070310 | 070521 | 070910 | 070970 | 071220 | 071350 | |
| 070320 | 070610 | 070920 | 070990 | 071233 | 071410 | |
| 070390 | 070690 | 070930 | 071040 | 071320 | 071420 | |
| 08 - Fruit and nuts, edible; peel of citrus fruit or melons | | | | | | |
| 080119 | 080240 | 080430 | 080550 | 080820 | 081020 | 081090 |
| 080120 | 080250 | 080440 | 080590 | 080910 | 081030 | 081190 |
| 080130 | 080290 | 080450 | 080610 | 080920 | 081040 | 081310 |
| 080211 | 080300 | 080510 | 080711 | 080930 | 081050 | 081320 |
| 080221 | 080410 | 080520 | 080720 | 080940 | 081060 | 081330 |
| 080231 | 080420 | 080540 | 080810 | 081010 | 081070 | |
| 09 - Coffee, tea, mate and spices | | | | | | |
| 090111 | 090500 | 090810 | 090910 | 090940 | 091020 | 091050 |
| 090210 | 090610 | 090820 | 090920 | 090950 | 091030 | 091099 |
| 090411 | 090700 | 090830 | 090930 | 091010 | 091040 | |
| 10 – Cereals | | | | | | |
| 100,110 | 100,200 | 100,400 | 100,590 | 100,630 | 100,810 | 100,890 |
| 100,190 | 100,300 | 100,510 | 100,610 | 100,700 | 100,820 | |
| 11 - Products of the milling industry; malt, starches, inulin, wheat gluten | | | | | | |
| 110,100 | 110,210 | 110,220 | 110,290 | | | |
| 12 - Oil seeds and oleaginous fruits; miscellaneous grains, etc. | | | | | | |
| 120,100 | 120,600 | 120,750 | 120,810 | 120,925 | 121,190 | 121,410 |
| 120,210 | 120,710 | 120,760 | 120,910 | 120,930 | 121,291 | 121,490 |
| 120,400 | 120,720 | 120,791 | 120,921 | 121,110 | 121,299 | |
| 120,510 | 120,740 | 120,799 | 120,922 | 121,120 | 121,300 | |

(Continues)

**TABLE A2** (Continued)

| | | | | | |
|---|---|---|---|---|---|
| 14 - Vegetable plaiting materials; vegetable products nes | | | | | |
| 140,110 | 140,490 | | | | |
| 15 - Animal or vegetable fats and oils and their cleavage products | | | | | |
| 150,710 | 150,910 | 151,110 | 151,219 | 151,229 | 151,319 |
| 150,790 | 150,990 | 151,211 | 151,221 | 151,311 | 151,521 |
| 17 - Sugars and sugar confectionery | | | | | |
| 170,310 | | | | | |
| *18 - Cocoa and cocoa preparations* | | | | | |
| 180,100 | 180,400 | 180,500 | | | |
| *20 - Preparations of vegetables, fruit, nuts or other parts of plants* | | | | | |
| 200,911 | 200,919 | 200,930 | 200,950 | 200,970 | 200,990 |
| 200,912 | 200,920 | 200,940 | 200,960 | 200,980 | |
| *24 - Tobacco and manufactured tobacco substitutes* | | | | | |
| 240,110 | 240,120 | 240,130 | 240,310 | 240,391 | 240,399 |

**TABLE A3** Impact of MRL standards on the trade failure – main results.

| | (1) Probit | (2) Logit | (3) Cloglog |
|---|---|---|---|
| Importer stringency | −0.080*** | −0.145*** | −0. 130*** |
| | [−0.088, −0.071] | [−0.160, −0.130] | [−0.143, −0.117] |
| Bilateral difference*RI | 0.191*** | 0.345*** | 0. 298*** |
| | [0.182, 0.201] | [0.329, 0.361] | [0.285, 0.311] |
| Bilateral difference*inverse RI | 0.187*** | 0.333*** | 0. 286*** |
| | [0.178, 0.196] | [0.317, 0.348] | [0.273, 0.299] |
| Tariff | 0.021*** | 0.035*** | 0. 030*** |
| | [0.019, 0.022] | [0.032, 0.038] | [0.027, 0.032] |
| TBT & SPS | −0.000*** | −0.000*** | −0.000*** |
| | [−0.000, −0.000] | [−0.000, −0.000] | [−0.000, −0.000] |
| RTA | −0.067*** | −0.116*** | −0. 099*** |
| | [−0.073, −0.061] | [−0.126, −0.105] | [−0.108, −0.090] |
| Common language | −0.078*** | −0.078*** | −0. 066*** |
| | [−0.089, −0.067] | [−0.090, −0.065] | [−0.076, −0.055] |
| Colonial ties | −0.049*** | −0.135*** | −0. 113*** |
| | [−0.055, −0.043] | [−0.155, −0.116] | [−0.130, −0.097] |
| Landlocked | −0.046*** | −0.086*** | −0. 073*** |
| | [−0.053, −0.038] | [−0.096, −0.075] | [−0.081, −0.064] |
| Distance | 0.042*** | 0.071*** | 0. 058*** |
| | [0.039, 0.045] | [0.065, 0.076] | [0.054, 0.063] |

**TABLE A3** (Continued)

| | (1) Probit | (2) Logit | (3) Cloglog |
|---|---|---|---|
| GDP importer | −0.029*** | −0.048*** | −0. 042*** |
| | [−0.030, −0.027] | [−0.052, −0.047] | [−0.044, −0.040] |
| GDP exporter | −0.075*** | −0.128*** | −0. 107*** |
| | [−0.076, −0.073] | [−0.131, −0.126] | [−0.109, −0.105] |
| Initial trade volume | −0.080*** | −0.138*** | −0. 117*** |
| | [−0.080, −0.079] | [−0.139, −0.137] | [−0.118, −0.116] |
| Constant | 2.447*** | 4.262*** | 3.210*** |
| | [2.389, 2.505] | [4.162, 4.362] | [3.127, 3.292] |
| Overall MRL difference | 0.378** | 0.678* | 0.584** |
| | [0.365, 0.391] | [0.656, 0.700] | [0.565, 0 0.602] |
| Observations | 2,167,173 | 2,167,173 | 2,167,173 |
| Relationships | 372,822 | 372,822 | 372,822 |
| Log Likelihood | −983,077 | −985.354 | −987,8854 |
| $\rho$ | 0.118*** | 0.098*** | 0.109*** |

*Note:* 95% confidence intervals are reported. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Standard errors are heteroskedasticity robust. Spell and year fixed effects and country-pair-product random effects are included in all regressions. $\rho$ is the variance of the random effect, which is significant across models. The impact of the overall MRL difference is calculated based on the estimates of the interaction terms with the directions of stringency excess ($\delta_2 + \delta_3$). Continuous variables are in natural logarithm and time-invariant variables are lagged by 1 year.

**TABLE A4** Impact of MRL standards on the volatility of trade values and volumes.

| | (1) Volume | (2) Value |
|---|---|---|
| Importer stringency | −0.822 | −1.738 * |
| | [−2.103, 0.459] | [−3.380, −0.096] |
| Bilateral difference*RI | 0.284 *** | 0.350 *** |
| | [0.158, 0.409] | [0.232, 0.468] |
| Bilateral difference*inverse RI | 0.158 * | 0.155 ** |
| | [0.006, 0.311] | [0.044, 0.266] |
| Bilateral difference | 0.442*** | 0.504*** |
| | [0.224, 0.660] | [0.338, 0.671] |
| TBT & SPS | 0.016 *** | 0.015 *** |
| | [0.007, 0.024] | [0.007, 0.023] |
| Tariff | −0.185 *** | −0.241 *** |
| | [−0.210, −0.160] | [−0.267, −0.215] |
| RTA | 0.052 | 0.057 |
| | [−0.137, 0.240] | [−0.033, 0.147] |
| Observations | 5,151,437 | 5,151,437 |
| (Pseudo) $R^2$ | 0.936 | 0.920 |

*Note:* 95% confidence intervals are reported. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Standard errors at the country-pair level. Exporter-importer, importer-year-product, and exporter-year-product fixed effects are included in both regressions. The impact of the overall MRL difference is calculated based on the estimates of the interaction terms with the directions of stringency excess ($\delta_2 + \delta_3$).

**TABLE A5** Impact of MRL standards on the duration of trade, including overall bilateral differences.

| | (1) Probit | (2) logit | (3) Cloglog |
|---|---|---|---|
| Importer stringency | −0.08*** | −0.14*** | −0.13*** |
| | [−0.09,-0.07] | [−0.15,-0.13] | [−0.14,-0.11] |
| Bilateral difference | 0.19*** | 0.34*** | 0.29*** |
| | [0.18, 0.20] | [0.33, 0.35] | [0.28, 0.30] |
| Tariff | 0.02*** | 0.04*** | 0.03*** |
| | [0.02, 0.02] | [0.03, 0.04] | [0.03, 0.03] |
| TBT & SPS | −0.00*** | −0.00*** | −0.00*** |
| | [−0.00,-0.00] | [−0.00,-0.00] | [−0.00,-0.00] |
| RTA | −0.07*** | −0.12*** | −0.10*** |
| | [−0.07,-0.06] | [−0.13,-0.11] | [−0.11,-0.09] |
| Common language | −0.05*** | −0.08*** | −0.06*** |
| | [−0.05,-0.04] | [−0.09,-0.06] | [−0.08,-0.05] |
| Colonial ties | −0.08*** | −0.14*** | −0.11*** |
| | [−0.09,-0.07] | [−0.16,-0.12] | [−0.13,-0.10] |
| Landlocked | −0.05*** | −0.09*** | −0.07*** |
| | [−0.05,-0.04] | [−0.10,-0.08] | [−0.08,-0.06] |
| Distance | 0.04*** | 0.07*** | 0.06*** |
| | [0.04, 0.04] | [0.07, 0.08] | [0.05, 0.06] |
| GDP importer | −0.03*** | −0.05*** | −0.04*** |
| | [−0.03,-0.03] | [−0.05,-0.05] | [−0.04,-0.04] |
| GDP exporter | −0.07*** | −0.13*** | −0.11*** |
| | [−0.08,-0.07] | [−0.13,-0.13] | [−0.11,-0.11] |
| Initial trade volume | −0.08*** | −0.14*** | −0.12*** |
| | [−0.08,-0.08] | [−0.14,-0.14] | [−0.12,-0.12] |
| Constant | 2.45*** | 4.26*** | 3.21*** |
| | [2.39, 2.50] | [4.16, 4.36] | [3.13, 3.29] |
| Observations | 2,167,173 | 2,167,173 | 2,167,173 |
| Relationships | 371,822 | 371,822 | 371,822 |
| Log Likelihood | −983,078 | −985,354 | −987,886 |
| $\rho$ | 0. 118*** | 0.098*** | 0. 101*** |

*Note:* 95% confidence intervals are reported. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Standard errors are heteroskedasticity robust. Year, product group and spell fixed effects, and exporter-importer-product random effects are included in all regressions. $\rho$ is the variance of the random effect, which is significant across estimations. Continuous variables are in natural logarithm and time-invariant variables are lagged by 1 year.

**TABLE A6** Impact of MRL standards on the volatility of trade values and volumes, including overall bilateral differences.

| | (1) Volume | (2) Value |
|---|---|---|
| Importer stringency | −0.791 | −1.691 * |
| | [−2.074, 0.493] | [−3.341, −0.041] |
| Bilateral difference | 0.217 *** | 0.248 *** |
| | [0.108, 0.327] | [0.165, 0.331] |
| TBT&SPS | 0.016 *** | 0.015 *** |
| | [0.007, 0.024] | [0.007, 0.023] |
| Tariff | −0.185 *** | −0.241 *** |
| | [−0.210, −0.160] | [−0.267, −0.215] |
| RTA | 0.051 | 0.058 |
| | [−0.137, 0.240] | [−0.032, 0.147] |
| Observations | 5,151,437 | 5,151,437 |
| (Pseudo) $R^2$ | 0.936 | 0.920 |

*Note:* 95% confidence intervals are reported. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Standard errors at the country-pair level. Exporter-importer, importer-year-product, and exporter-year-product fixed effects are included in the regressions. Continuous variables are in natural logarithm, and time-invariant variables are lagged by 1 year.