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# Food trade and regional trade agreements – A network perspective

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ABSTRACT

Since the establishment of the World Trade Organization (WTO) also the number of Regional Trade Agreements (RTAs) has risen strongly, from less than 50 in 1995 to more than 350 in 2022. Increasingly overlapping RTAs imply challenges and can raise trade costs associated with the management of multiple trade rules and regulatory standards. At the same time, countries that are connected through several RTAs could be strongly integrated and their regulatory approaches well-aligned, thus reducing trade costs among them. This paper looks at the parallels in the evolution of agricultural trade and RTAs and asks how the layering of RTAs is associated with agricultural trade among their signatories and with countries outside the RTAs. Based on network measures and correlations we identify common patterns in the evolution of RTAs globally and agricultural trade of a balanced panel of 190 countries in the years 1995, 2007, 2013 and 2019. We also provide first indication on the interaction of overlapping RTAs and agricultural trade. On global average, our findings hint at a positive association between RTA and agricultural trade connectivity and suggest that this relationship could be more pronounced at the extensive margin of trade and for countries that share several RTAs, possibly indicating a stronger political integration among these countries.

## 1. Introduction

In parallel with the establishment of the World Trade Organization (WTO) in 1995 the number of regional trade agreements (RTAs)[1] started to rise – from less than 50 in 1995 to more than 350 in 2022 (WTO, 2022). Global trade in food and agriculture more than doubled during this time and trade linkages also strengthened within most regions. Multilateralism and regionalism appear to have evolved together (Baldwin, 2016), although the role of RTAs in the process of global and regional trade integration is still being discussed. While traditional RTAs and the respective literature focused mainly on tariff reductions and resulting trade creation vs trade diversion effects (e.g. Baldwin, 2008, 2006; Bhagwati, 1991; Krugman, 1989; Robinson and Thierfelder, 2002; Summers, 1991; Viner, 1950), more overlapping and increasingly deeper RTAs pose new challenges (e.g. Bhagwati, 1991, 1993, 1995; Pomfret, 2021; Thompson-Lipponen and Greenville, 2019).

Overlapping RTAs generate different trade network patterns, especially hub-and-spoke type structures with often unclear effects on both the countries with several overlapping RTAs (RTA hub countries) and the countries connected to them (their spokes) (Horaguchi, 2007; Kowalczyk and Wonnacott, 1992). In general, RTA hub countries gain preferential access to more markets which could increase their trade, and through them also the trade of their spokes. However, overlapping RTAs imply multiple sets of, often complex, trade rules, which can entail additional search and management costs (Hur, Alba and Park, 2010; Lloyd and Maclaren, 2004) and eventually even reduce the trade of their signatories.

The changes in bilateral trade of hubs and spokes in the RTA network may increase or decrease the (local, intermediate and global) connectivity of countries in the trade network. This depends on the relative trade-enhancing or cost-generating effects of the RTAs between hubs, spokes, and outsiders (Deltas, Desmet and Facchini, 2012).[2] Thus, overlapping RTAs may be conducive or obstructive to global trade network formation and countries' individual integration in the global network. Understanding the association of RTAs with (countries') trade network integration is of direct relevance in RTA policy and institutions

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[1] RTAs are defined as any reciprocal agreement between at least two signatories that may or may not be part of the same region (WTO, 2023a).

[2] For example, Deltas, Desmet and Facchini (2012) show in a theoretical model that if two countries share an RTA, and both sign a similar RTA with a third country, aggregate trade between the two original signatories decreases. If only one of the original signatories concludes an additional RTA and thus becomes a hub between the two other partners, trade between the initial two signatories increases.

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formulation and for national policymakers in their decision to engage in (overlapping) RTAs (see Davis, 2009). Especially low- and middle-income countries with limited institutional and legal capacity may be hampered in identifying optimal trade partners and terms of trading with these partners (Davis, 2009), which might ultimately lead to their marginalization in the global market.

This paper aims to explore the dynamics between (overlapping) RTAs and countries' integration in the global agricultural trade network.[3] What are the parallels in the evolution of agricultural trade and RTA networks? And what is the relationship between countries' agricultural trade and multiple layers of overlapping RTAs?

While the interlinkages between overlapping institutions and trade policy have attracted interest in political science (Davis, 2009) and studies have also quantitatively assessed RTA network effects on merchandise trade (see below and Appendix, Table A1), relatively little attention has been paid to the effects of overlapping RTAs on agricultural trade and the patterns of connectivity of countries to the trade network. Although agricultural products are often exempted from specific provisions in RTAs or receive special treatment, agriculture as a sector overall appears to be increasingly covered by the agreements (Thompson-Lipponen and Greenville, 2019). Out of 318 RTAs investigated in a recent study, 316 covered the agricultural sector (Mattoo, Rocha and Ruta, 2020). The layering of RTAs implies challenges and costs associated with multiple rules on tariffs, non-tariff measures (NTMs) and rules of origin, all of which are more prevalent and significant in agriculture than in other sectors (Bhagwati, 1991, 1993; Pomfret, 2021; Thompson-Lipponen and Greenville, 2019), possibly exacerbating challenges in this sector compared with others.

Recognizing the complexity of both the global network of RTAs and the global network of agricultural trade, the analysis uses a variety of network measures to characterize their main features and topology and identify common patterns in their evolution over time. The analysis is applied to a balanced panel of 190 countries in the years 1995, 2007, 2013 and 2019. While traditional gravity models, the most well-known empirical approach in the trade literature, are typically applied to analyse the impact of different factors including RTAs on bilateral trade relationships, network measures provide for the description of complex systems. In the context of this study, network analysis is used to identify patterns of various aspects of connectivity of countries in the global RTA and agricultural trade network.[4]

We contribute to the literature in two main ways. First, with respect to content, the analysis describes the evolution of the network of global agricultural trade in the context of RTAs, level of participation in RTAs and specifically focuses on overlapping RTAs and their association with agricultural trade patterns. Previous studies on the impact of RTAs on agricultural trade values have found mixed results that differ by agreement (Grant and Lambert, 2008; Mujahid and Kalkuhl, 2016; Sarker and Jayasinghe, 2007). For global trade of grains and using network measures and contingency tables, new RTAs have been found to increase the probability of new trade links among the signatory countries, existing RTAs increase the durability of trade links and RTAs are also associated with greater trade intensity (Falsetti, Ridolfi and Laio, 2022). Sanitary and phytosanitary (SPS) measures, which are especially important in agricultural trade, were associated with a stronger reduction in agricultural trade of countries that are not part of RTAs (Santeramo and Lamonaca, 2022). In the general trade literature, it has been shown that the effects of overlapping RTAs on the trade of hub and different spoke countries can differ (Deltas, Desmet and Facchini, 2012); overlapping RTAs can but do not necessarily lead to additional export growth of hub countries (Hur, Alba and Park, 2010; Sopranzetti, 2018); under overlapping RTAs, countries do not always choose the optimal trading regime with their respective trade partners (Thangavelu, Narjoko and Urata, 2021); and that the multiplicity of RTAs might indeed result in trade-diversion effects due to higher transaction costs caused by overlapping rules (Sorgho, 2016). However, to our knowledge, no study has more specifically assessed the association of countries' engagement (intensity) in RTAs and their local, intermediate and global integration in the agricultural trade network; and the association of overlapping RTAs and agricultural trade of the RTA signatories and countries outside the agreements.

Second, we advance the trade literature by bringing insights from network theory to systematically analyse the evolution of the agricultural trade network and the RTA network. Previous network studies usually evaluated different levels of connectivity along the intensive margin of trade in terms of trade intensity and along the extensive margin of trade in terms of the number of trade links by country. We consider both and, adding to this, another aspect of the extensive margin of trade[5] – trade links by country and product. Moreover, we consider first- and higher-orders of connectivity and add to the literature by analysing the evolution of the connectivity of RTAs, applying network analysis.

Our findings show that connectivity in the agricultural trade network increased globally at both extensive and intensive margins and also the connectivity of countries through RTAs increased. On global average, the results hint at a possible association between RTA and agricultural trade connectivity and suggest that this relationship could be stronger at the extensive margin of trade and for countries that share several RTAs, possibly indicating a stronger political integration among these countries. However, in two specific case studies, one in Africa and one in Asia, a positive association between overlapping RTAs and trade connectivity could not be confirmed.

While identifying common patterns and a possible interaction between RTAs and agricultural trade, this paper does not establish any causality and it is recommended for follow-up research to more clearly disentangle the effects of RTAs and various confounding factors on agricultural trade, distinguish RTAs by depth and length of implementation period and also pay special attention to the treatment of the agricultural sector in the agreements in terms of coverage and level of harmonization of non-tariff measures (NTMs) such as SPS measures and rules of origin.

The rest of the paper is organized as follows: The next section provide a general overview of the evolution of agricultural trade and multilateral and regional trade agreements. This is followed by the description of methodology and data in Section 3. The results are shown and analysed in Section 4, policy conclusions are presented in section 5.

## 2. Trade agreements and trade in food and agriculture

Agricultural trade increased significantly between 1995 and 2019. The number of trade links by country, i.e., connections of countries through the trade of food and agricultural products, increased by half. The number of trade links by country and product and the volume of agricultural trade more than doubled (Fig. 1, upper panels). 36 countries acceded the WTO (Fig. 1), including important agricultural traders such as China (WTO accession in 2001), Viet Nam (accession in 2007),

[3] Agricultural trade refers to trade of all food and agricultural products. In the empirical application in this paper, it includes all food and agricultural products except fish.

[4] Gravity models implicitly address the relative distance of the countries from the overall trade network through multilateral resistance terms, which is defined as the inward resistance of importers to import from all countries on average and the outward resistance of exporters to export to all countries on average. Recent studies often rely on network methods or a combination of network methods and gravity models to analyse how trade relationships evolve among countries connected through RTAs (see Appendix, Table A1).

[5] This is inspired by, *inter alia*, Cadot et al., 2011 and Hummels and Klenow (2005), who define the extensive margin as a variation in the number of products traded and/or the number of trade partners.

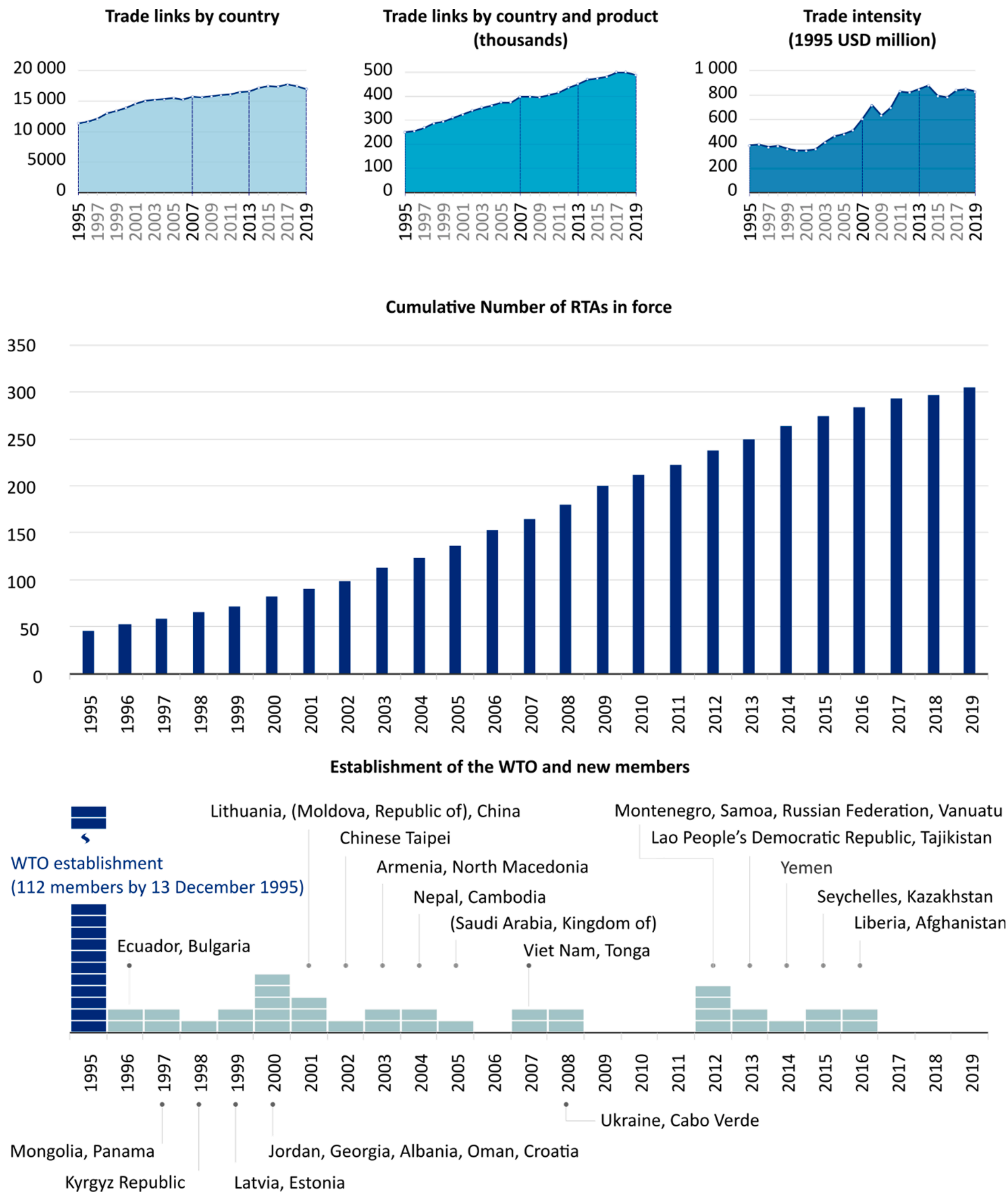


**Fig. 1.** Evolution of food and agricultural trade, regional trade agreements and WTO accessions. Source: Adapted from Jafari, Engemann and Zimmermann (2023), WTO (2023a) and WTO (2023b).

Ukraine (2008), and Russian Federation (2012). In the same time period (1995–2019), the number of RTAs increased 6-fold.

Although the absolute number of RTAs increased, it is not necessarily clear whether the connectivity of countries through RTAs increased as well. Many RTAs overlap and the number of RTAs could thus overstate actual connectivity of countries through the agreements.[6] The overlap of RTAs can deepen economic ties among a wider set of countries than those included in each of the individual RTAs but can also lead to conflicting rules and additional trade frictions among signatories to different RTAs.

The participation of countries in RTAs and their overlap differs widely. European Union countries have signed the most RTAs (46 RTAs that have been notified to the GATT/WTO and in force), countries from Africa and Small Island Developing States are among the countries with the lowest number of RTAs (WTO, 2023b) (Fig. 2). The RTA connectivity reflects connectivity patterns of countries in food and agriculture, with European Union countries displaying some of the highest connectivity levels and countries in Africa and Small Island Developing States being among the countries with lowest connectivity to the global market and highest trade costs overall (FAO, 2022a).

We use network measures to provide additional insight on the co-evolution of countries' connectivity through agricultural trade and trade agreements and on the effects of the overlapping of multiple RTAs on countries' trade patterns.

## 3. Data and methods

### 3.1. Network analysis and indicators

Acknowledging the complexity of both RTA and agricultural trade networks, we use a data-driven approach to identify parallels in the dynamics and potential linkages between them. We use a set of network measures to identify and describe countries' trade patterns and the patterns of their connectivity through RTAs. Network measures can be described at different levels of regional aggregation. The local level which looks at individual countries (i.e. particular nodes or edges in network terminology); the intermediate level which looks at a group of nodes; or the global level which considers the network as a whole (Éber, Baggio and Fuchs, 2018; Miele et al., 2019; Morrison et al., 2022). In addition, one can consider different levels of connectivity (linkages) among countries (nodes). Direct connectivity considers only direct (bilateral) linkages between two countries; intermediate connectivity which considers second-order linkages (the trade partner of a trade partner) and smaller groups of countries trading with each other (e.g. triads), and global connectivity which considers higher-order linkages. An overview of the measures used in this paper is given in Table 1. Table 2 describes the individual measures in more detail. The mathematical representation is given in Table A2 of the Appendix. For better comparability, all measures have been normalized.

We use both binary (unweighted) and weighted network measures. Binary (unweighted) measures refer to the number of trade links by country, i.e. number of non-negative trade flows of a country (this measure is also referred to as degree in network terminology; it is obtained from the matrix of binary trade flows, the so-called adjacency matrix, in which each cell of the matrix takes a value of one if there is a non-negative trade flow between two countries and zero otherwise). We also show results applying two different types of weights. Trade links by country and product do not only consider the non-negative trade flow between two countries, but each of these trade flows is weighted by the number of different products traded through it.[7] Trade intensity refers to trade flows weighted with the aggregate value of the products traded through them. If only one direction of trade flows, i.e. either imports or exports, is considered, the network is called a directed network. In the undirected network, the direction of trade flows is ignored. Typically, weights for the undirected network are obtained by adding exports and imports and dividing by two ((exports + imports)/2).

We also calculate RTA connectivity measures and compare these with the different perspectives of trade connectivity. RTA connectivity is based on countries that are connected through at least one RTA, expressed as 1 in a binary matrix (RTA adjacency matrix). RTA intensity is based on an RTA "intensity" matrix which describes how many RTAs a specific country pair is connected through.

### 3.2. Data

Bilateral trade data are derived from FAOSTAT and comprise all food and agricultural products (425 individual items).[8] We consider bilateral trade of a balanced panel of 190 countries in the years 1995, 2007, 2013 and 2019. Due to geopolitical changes, the number of countries over time is not stable. To ensure comparability of network measures over time, we only consider those countries that were present in the dataset throughout 1995–2019. Sensitivity analysis in terms of the inclusion of all countries present in the dataset in each year (205 countries in 1995, 197 in 2007, 197 in 2013, and 198 in 2019) yielded comparable results. 1995 was selected as starting point for the analysis as the year when the WTO was established and agriculture was explicitly included in multilateral trade reforms, 2019 was the year with most recent data availability at the time of the analysis. The intermediate snapshot years were selected based on the evolution of trade as shown in Fig. 1 (upper panels); 2007 marking a turning point as the beginning of the food price crises 2007–08 and the global financial crisis, and 2013 as the year when growth in agricultural trade had already plateaued (Jafari, Engemann and Zimmermann, 2023). Due to generally higher reliability (Cadot et al., 2011), we focus on the use of import data and only mirror export data when import data were not available. The value of trade is given in USD and deflated with the 1995 US Consumer Price Index (e.g. Rose, 2004).

Data on RTAs is derived from the WTO Regional Trade Agreements database. We consider only RTAs with coverage in 'goods' and 'goods and services', excluding RTAs that only cover services. To our knowledge, the WTO Regional Trade Agreements database is the most comprehensive source of RTAs, but it does not provide detailed information about the extent of coverage of the agricultural sector in the

[6] Also, the disintegration of RTAs and subsequent formulation of more but smaller trade agreements can lead to an upward bias in the number of RTAs with unclear impact on actual connectivity (for example, Brexit led to a renegotiation of multiple bilateral agreements between the UK and its trade partners to make up for the loss of integrated agreements with the EU). The number of RTAs may reduce as a result of the formation of larger integrated areas and subsequent invalidity of smaller agreements between countries within this area. Despite a lower number of agreements actual connectivity of countries through the larger agreement could increase.

[7] Mathematically, the trade links are weighted with the number of products traded through them and we refer to their related measures as weighted network measures. In the economic literature, each product line traded is often referred to as a separate trade link, thus referring to the extensive margin of trade. We maintain this distinction throughout the paper by referring to the extensive margin of trade, calculated as weighted network measure.

[8] FAOSTAT provides official statistics for food and agriculture at global level including bilateral trade matrices. Although not used for comparison here, FAOSTAT trade data items are consistent with other items in the FAOSTAT domain and easily accessible. FAOSTAT trade data are therefore one of the preferred sources for studies of global agricultural trade. Recent examples using FAOSTAT trade data for network analysis include Burkholz and Schweitzer, 2019; Chung et al., 2020; Dupas, Halloy and Chatzimpiros, 2019; Fair, Bauch and Anand, 2017; Grassia et al., 2022; Gutiérrez-Moya, Adenso-Díaz and Lozano, 2021; Gutiérrez-Moya, Lozano and Adenso-Díaz, 2020; Konar et al., 2011; Puma et al., 2015; Sartori and Schiavo, 2015; Shutters and Muneepeerakul, 2012; and Torreggiani et al., 2018.

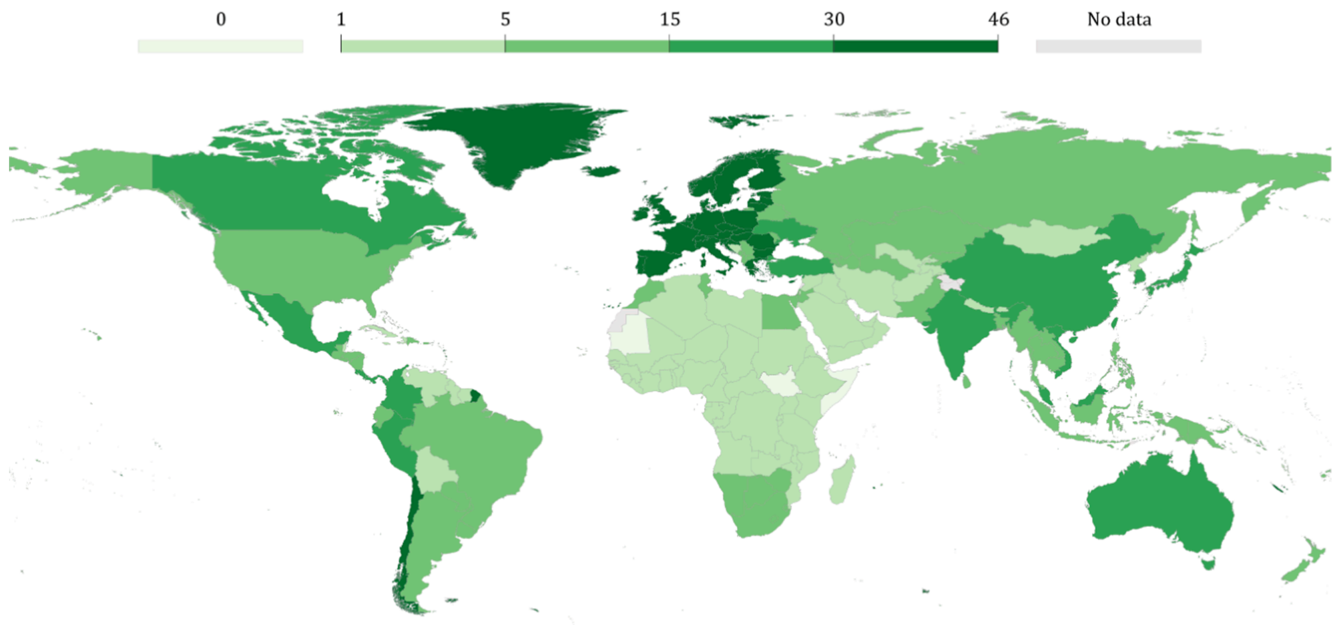


**Fig. 2.** Number of regional trade agreements by country, 2022.
Source: WTO (2023a)

**Table 1**
Overview of network measures used in the analysis.

| Network measures at different levels of regional aggregation Network measures at different levels of connectivity | **Local level** | **Intermediate/ community level** | **Global level** |
|---|---|---|---|
| **Local connectivity (direct connectivity)** | Node degree, node strength | Assortativity indices, modularity from community detection | Network density, network degree centrality (average of node degree), network strength centrality (average of node strength) |
| **Intermediate centrality (indirect connectivity)** | Node second order degree/ strength | | Network second-order centrality (average of node second order degree/strength) |
| **Global centrality (indirect connectivity)** | Node eigenvector | | Network eigenvector (average of node eigenvector) |

Note: Assortativity and community detection are based on first order degree/ strength.

RTAs. We only consider RTAs that were in force in each year of the analysis and have been notified to the WTO, excluding agreements that may be in force but have not been notified to the WTO.[9]

## 4. Results

### 4.1. Evolution of global and regional connectivity in food and agricultural trade

Table 3 shows the connectivity of countries through trade. For trade links by country, network density and average first order indegree across countries are of similar magnitude and increased between 1995 and 2019, with the strongest increase between 1995 and 2007. The connectivity through trade links by country and product and through trade intensity follow a similar pattern with a relatively strong increase of connectivity between 1995 and 2007, which continued through 2019 albeit at a slower pace.[10]

Naturally, countries' second order connectivity is higher than their first order connectivity. In line with the increase in countries' first order connectivity, the average second order connectivity increased between 1995 and 2019. For trade links by country, the second order indegree increased again strongly between 1995 and 2007 and remained at a high level between 2007 and 2019. Both second order indegree of trade links by country and product and second order instrength (trade intensity), increased between 1995 and 2007, with the increase in the time period 2013–2019 being relatively more pronounced. The average Eigenvector centrality for trade links by country, by country and product and trade intensity increased between 1995 and 2007 and has largely remained

[9] The notification of new RTAs and any changes to existing RTAs is required for all WTO members under various WTO provisions (WTO, 2023d). Nonetheless, a minority of RTAs may be notified to the WTO only at a later stage and are not considered in the database (WTO, 2021).

[10] The comparably stronger increase in trade between 1995 and 2007 can be attributed to many reasons; the inclusion of agriculture in the multilateral reform process as established by the WTO Agreement on Agriculture (AoA), China's WTO accession in 2001, the increasing rate of RTAs, the re-integration of Eastern and Central European countries after the dissolution of the Soviet Union, and strong economic growth accompanied with increasing market integration in some emerging economies all have contributed to the process. The subsequent slowdown has been explained with weaker economic growth since the global financial crisis overall, a slowing rate of growth in China more specifically, and increasingly inward-looking policies in major economies (Bordo, 2017; Irwin, 2020).

**Table 2**
Description of network indicators used in the analysis. Source: Adapted from Geyik et al. (2021) and Jafari, Engemann and Zimmermann (2023).

| Network measure | Description | Level of aggregation | Direction and weight |
|---|---|---|---|
| | Connectivity/centrality measures | | |
| Network density | Shows the proportion of actual connections (links) over potential connections (links) and thus the probability of the presence of a link between any two countries. | Global | Undirected, unweighted |
| Node degree (first-order and second-order) | The first order degree connectivity indicates the total number of trade links of a country and is identified based on binary network analysis. Outdegree refers to export flows, indegree refers to import flows. Second-order degree is defined as the sum of the first-order in-degree of all direct trade partners. | Local and global average | Directed, unweighted |
| Node strength (first-order and second-order) | First-order strength indicates the total number of trade links (per product and trade partner) or the total trade per node. Outstrength refers to export flows, instrength refers to import flows. Second-order strength is defined as the sum of the first-order strength of all direct trade partners. | Local and global average | Directed, weighted |
| Eigenvector centrality | Connectivity of a node based on the connectivity of its neighbours, the neighbours of the neighbours and so on, i.e. the connectivity of a node proportional to the sum of connectivity indices of its neighbours. | Local and global average | Directed, unweighted/ weighted |
| | Measures on regional clustering | | |
| Assortativity | Assortativity indices range from 1 showing that similar countries trade with each other (assortative network) to −1 showing the reverse (disassortative network). | Regional/ community level | Undirected, unweighted/ weighted |
| Trade clusters and modularity | Trade clusters/ communities are groups of countries that tend to trade more among each other than with countries outside the cluster/ community. | Regional/ community level | Undirected, unweighted/ weighted |

stable since then.[11]

Measures providing more insight into the distribution of connectivity indicate that, in general, countries' direct and indirect connectivity increased and became more symmetric with fewer outliers of very low or very high connectivity (Table 3). For example, for trade links, skewness, kurtosis, obesity index[12] and percentage of observations outside an interval of mean ± two standard deviations[13] decreased between 1995 and 2013. In more recent years, some measures suggest a slight reversal in the trend towards a more even and balanced global trade network (Jafari, Engemann and Zimmermann, 2023). Statistical tests reject the stochastic equality of distributions across years (Friedman test[14]; Table A2, Appendix) and the stochastic equality of distributions in 1995 and those in other years (Kolmogorov-Smirnov test[15]; Table A3, Appendix).

Previous research indicated a weakly positive assortativity by region for both trade links and trade intensity. Countries tend to trade within specific regional clusters/communities, which have become firmer over time. These clusters are more pronounced in terms of trade intensity, while trade links are formed with both countries within and outside the cluster (Jafari, Engemann and Zimmermann, 2023). Fig. 3 shows that the communities detected reflect relatively stable regional patterns over time. Only African countries are not part of a regionally stable trade community but frequently changed trade clusters between 1995 and 2019.

### 4.2. Evolution of connectivity through regional trade agreements

Analogous to the analysis of trade links, we build a binary RTA adjacency matrix, where a value of 1 indicates that two countries are connected through at least one common RTA and zero otherwise. Assessing the direct connectivity of countries through RTAs, we find that, in 1995, on average around 9 percent of all possible country pairs were connected through at least one RTA. This number had doubled by 2019. In 2019, on average around 18 percent of all possible country pairs were connected through an RTA (Table 4). The direct connectivity of two countries through an RTA (first-order degree) entails connectivity of countries to other countries through a maximum of two RTAs (second-order degree) or through all available RTAs (eigenvector centrality),

[11] Statistical tests (Table A2, Appendix) reject the equality of mean local connectivity of first and second order connectivity across years (Kruskal-Wallis test) and suggest that mean differences are associated with differences in mean for 1995 compared to all other years (Wilcoxon-rank test) (Table A3, Appendix). First-order and second-order connectivity as of 2007 has been high already and differences in connectivity between 2007, 2013 and 2019 are generally less significant. The same holds for the eigenvector centrality, which was high throughout the study period and differences between years statistically not significant.

[12] The obesity index (as proposed by Cooke, Nieboer and Misiewicz (2014)) and following the reasoning of Sartori and Schiavo (2015) delivers additional information on the tailedness of the distribution. It is based on the heuristic that in case of heavy-tailed distributions larger observations lie further apart than smaller observations. The obesity index indicates the probability that the sum of the largest and the smallest of four observations is larger than the sum of the other two observations. The index is calculated as $OB(X) = P(X1 + X4 > X2 + X3 | X1 \leq X2 \leq X3 \leq x4)$, where $\{X_1, X_2, X_3, X_4\}$ are observations of a specific network measure, which is independent and identically distributed. Our index is based on 10,000 random samples of four observations.

[13] Following Sartori and Schiavo (2015).

[14] We note that for the Eigenvector distribution, the Friedman test, which compares the location differences of distributions based on the median, does not reject the equality of distributions. Alternative tests such as the Fligner-Killeen test, which compares the shape of distributions based on variance differences, do reject the equality of distributions.

[15] While the Friedman test considers the differences between location of distributions, the Kolmogorov-Smirnov test considers the differences between both location and shape of distributions.

**Table 3**
Country connectivity through trade (measured in imports), measures of tail-heaviness. Source: Adapted from Jafari, Engemann and Zimmermann (2023).

| | 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 |
| | *Trade connectivity measures* | | | | | | | | | | | |
| Network density | 0.32 | 0.44 | 0.46 | 0.47 | – | – | – | – | – | – | – | – |
| First order indegree/instrength | 0.33 | 0.46 | 0.49 | 0.50 | 0.67 | 0.75 | 0.76 | 0.79 | 0.67 | 0.72 | 0.74 | 0.75 |
| Second order indegree/instrength | 0.87 | 0.93 | 0.94 | 0.94 | 0.87 | 0.89 | 0.90 | 0.93 | 0.89 | 0.90 | 0.91 | 0.92 |
| Eigenvector | 0.45 | 0.47 | 0.48 | 0.48 | 0.18 | 0.20 | 0.20 | 0.20 | 0.04 | 0.05 | 0.05 | 0.05 |
| | *Measures of tail-heaviness of first order trade connectivity* | | | | | | | | | | | |
| 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 | 0.90 | 0.89 |
| Kurtosis | 2.78 | 2.33 | 2.20 | 2.31 | 6.51 | 5.22 | 5.27 | 7.00 | 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 | 4.70 | 4.34 | 4.48 | 5.09 |
| | *Measures of tail-heaviness of second order trade connectivity* | | | | | | | | | | | |
| Percentage of observations 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 | −0.30 | −0.31 | 1.25 | 0.56 | 0.10 | 0.49 | 1.25 | 1.09 | 0.99 | 1.39 |

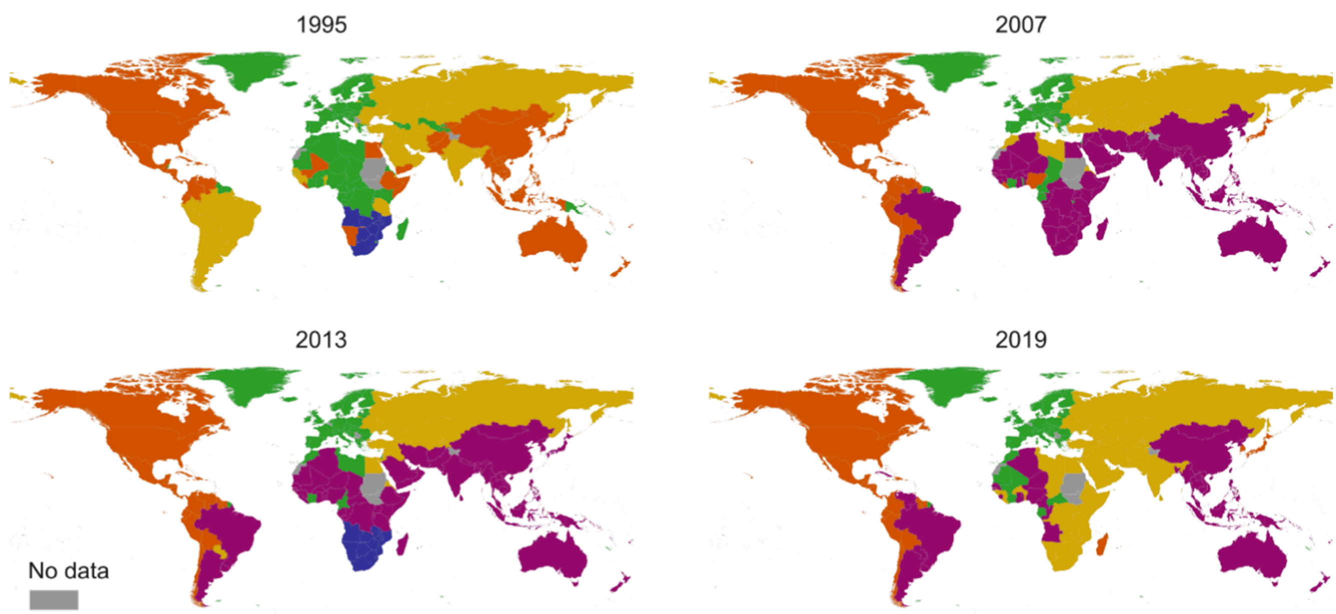


**Fig. 3.** Regional food and agricultural trade clusters, 1995–2019. Note: Based on trade intensity. Trade communities have been identified based on total food and agricultural trade defined as (exports + imports)/2.
Source: Jafari, Engemann and Zimmermann (2023)

**Table 4**
Countries' connectivity through RTAs (based on the RTA adjacency matrix).

| | 1995 | 2007 | 2013 | 2019 | Kruskal-Wallis test |
|---|---|---|---|---|---|
| | *RTA connectivity measures* | | | | |
| First-order degree | 0.090 | 0.140 | 0.159 | 0.183 | <0.001 |
| Second-order degree | 0.113 | 0.216 | 0.272 | 0.354 | <0.001 |
| Eigenvector | 0.039 | 0.051 | 0.052 | 0.054 | <0.001 |
| | *Measures of tail-heaviness of first order RTA connectivity* | | | | |
| Percentage of observations out of interval | 4.737 | 3.684 | 4.211 | 2.105 | – |
| Kurtosis | 2.628 | 3.091 | 2.812 | 2.055 | – |
| Skewness | 0.927 | 0.773 | 0.682 | 0.446 | – |
| Obesity index | 0.673 | 0.598 | 0.581 | 0.609 | – |
| | *Measures of tail-heaviness of second order RTA connectivity* | | | | |
| Percentage of observations out of interval | 2.105 | 3.684 | 4.211 | 1.053 | – |
| Kurtosis | 2.659 | 2.164 | 1.984 | 1.770 | – |
| Skewness | 1.198 | 0.636 | 0.509 | 0.421 | – |
| Obesity index | 0.724 | 0.666 | 0.608 | 0.621 | – |

both of which increased as well between 1995 and 2019. Statistical tests of the significance of mean differences across years support these results.[16]

Countries' involvement in RTAs is not normally distributed (Fig. 4). In each of the years, the distribution of countries' connectivity through RTAs shows several humps. Many countries exploit only around 10 percent of all possible pairwise links through RTAs worldwide. In 1995, 2007 and 2013, another group of countries was connected through RTAs in around 25 percent of all possible RTA links. This had changed in 2019, when the connectivity of countries through RTAs was comparably more uniformly distributed than in previous years. In 2019, still many

[16] The Kruskal-Wallis test (Table 4) suggests significant differences in means across years. Significant differences in mean connectivity between every two consecutive years are suggested by the Kolmogorov-Smirnov and the Wilcoxon-rank test (Table A4, Appendix).

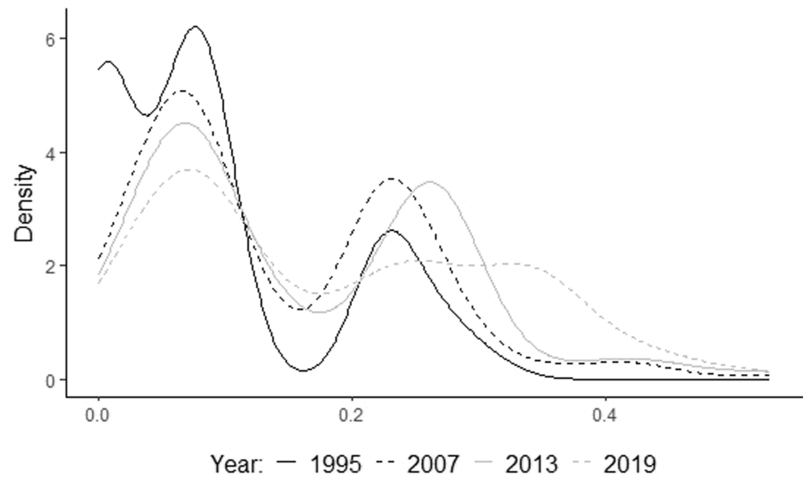


**Fig. 4.** Distribution of the connectivity of countries through RTAs, first-order degree based on RTA adjacency matrix.

countries exploited around 10 percent of total possible RTA connectivity, but another group of countries used between 25 and 35 percent of all possible connections.[17] The percentage of observations out of interval, skewness and kurtosis declined considerably between 2013 and 2019. The obesity index first declined between 1995 and 2013 and increased in the last time period between 2013 and 2019 (Table 4). Additional analysis suggests that it is mainly Oceanian countries that are relatively less connected through RTAs and European countries that have the highest RTA-connectivity (see Appendix, Fig A1). These two country groups appear to contribute to the bulk of the humps depicted in Fig. 4. While high-income countries have been well-connected through RTAs since the beginning of the study period, in recent years, especially low- and middle-income countries engaged in RTA negotiations (FAO, 2022b). Country connectivity also improved in more recent years through the conclusion of mega-RTAs such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), the Regional Comprehensive Economic Partnership (RCEP), and the African Continental Free Trade Area (AfCFTA) (FAO, 2022b).[18]

### 4.3. Co-evolution of food and agricultural trade and regional trade agreements

Countries' connectivity through RTAs (measured by the RTA adjacency matrix) is weakly positively correlated with their bilateral connectivity through trade (Fig. 5, Table A5 in the Appendix). Countries that are connected through an RTA are more likely to have an active trade relationship with each other (trade links by country), trade more products (trade links by country and product) and at higher intensity (trade intensity) through this relationship. The correlation between the RTA adjacency matrix and matrices of trade links by country and trade links by country and product increased between 1995 and 2019, with the most significant increase between 1995 and 2007. The correlation between the RTA adjacency matrix and the trade intensity matrix is very weak. It also increased between 1995 and 2007 but remained relatively stable between 2007 and 2019. Overall, while some positive association between RTA membership of each country pair and existence of a trade link between the same country pair exists, this association is very weak between common RTA membership and trade intensity. This is an interesting finding as the detection of regional trade communities suggested that regional ties would be relatively stronger at the intensive margin of trade. In a study on the timing of the effects of RTAs on both intensive and extensive margin of global aggregate trade between 1962 and 2000, Baier, Bergstrand and Feng (2014) find that deeper RTAs have larger trade effects and that RTAs affect first the intensive margin, while the extensive margin of trade is more affected in the longer term. Similar patterns are found in a sensitivity analysis considering the correlation between RTA adjacency matrix and bilateral connectivity for three different country groups: (i) without Europe, (ii) without all high-income countries, and (iii) only high-income countries (see Appendix, Table A5). Correlations are generally slightly stronger for high-income countries, but still positive for all countries even when excluding high-income countries or only Europe.

Fig. 5 (and Table A6, Appendix) looked at bilateral connectivity, i.e. the connectivity of country pairs. Table 5 shows another aspect, namely the correlation between the number of countries a given country is connected with through an RTA, i.e. the number of countries with which a country has signed an RTA, and its direct and indirect connectivity through imports. The number of countries' RTA partners is positively correlated with their first order connectivity in terms of trade links by country, by country and product and their trade intensity (with the exception of the year 1995, when RTA membership and trade intensity were weakly negatively correlated). For all three, trade links by country, trade links by country and product and trade intensity, the correlation with the number of RTA signatories increased strongly between 1995 and 2007 and continued to increase at a slower pace through 2019. Again, the correlation is stronger between the number of RTA partners and a country's connectivity through the extensive than through the intensive margin. Similar results are obtained for the correlation between the number of countries a country is connected with through RTAs and indirect connectivity through imports (Table 5, lower part). For both second order indegree and eigenvector centrality, the correlation strongly increased between 1995 and 2007 and continued to increase through 2019. In both cases, the correlation was stronger for links than for trade intensity. Overall, these results suggest that RTAs foster linkages of countries through trade, but do not necessarily determine the intensity of trade among them, or, as we do not explicitly consider timing or causality in our analysis, that countries with closer ties at the extensive margin of agricultural trade are more likely to conclude RTAs among each other than countries that trade at a higher intensity with each other.

### 4.4. Layering of overlapping RTAs and food and agricultural trade

The correlations shown above give some insight in the co-evolution

[17] Supporting the results, the Friedman test rejected the stochastic equality of distributions across years. The Kolmogorov-Smirnov test (Table A4, Appendix) rejected the stochastic equality of distributions for every two consecutive years.

[18] The RCEP and the AfCFTA have not been notified yet to the WTO and are therefore not included in this analysis.

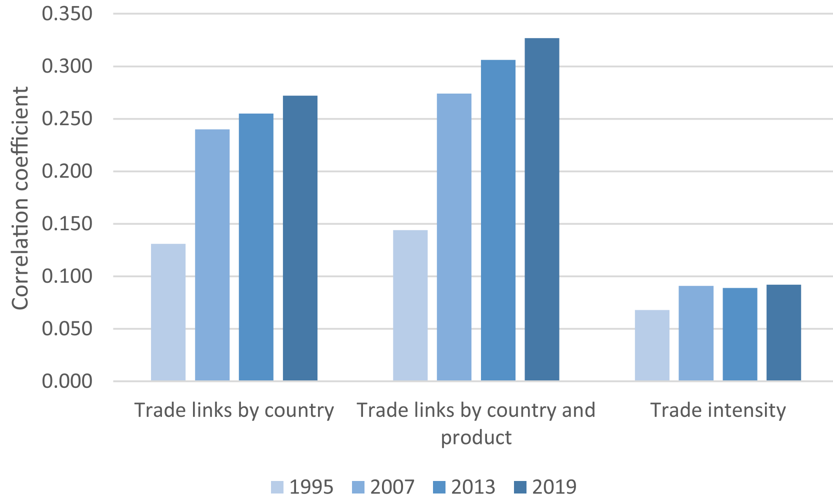


**Fig. 5.** Pearson correlation of countries' connectivity through RTAs (RTA adjacency matrix) with countries' bilateral connectivity through imports.

**Table 5**
Pearson correlation of number of partnerships under RTAs (first order indegree) and direct/indirect connectivity through imports.

| | First order indegree | | | |
|---|---|---|---|---|
| | 1995 | 2007 | 2013 | 2019 |
| | *First order indegree/instrength* | | | |
| Trade links by country | 0.140 | 0.378 | 0.405 | 0.467 |
| Trade links by country and product | 0.017 | 0.258 | 0.338 | 0.448 |
| Trade intensity | −0.025 | 0.139 | 0.170 | 0.201 |
| | *Second order indegree/instrength* | | | |
| Trade links by country | 0.190 | 0.387 | 0.438 | 0.484 |
| Trade links by country and product | 0.033 | 0.309 | 0.382 | 0.408 |
| Trade intensity | 0.016 | 0.169 | 0.201 | 0.243 |
| | *Eigenvector* | | | |
| Trade links by country | 0.174 | 0.395 | 0.424 | 0.478 |
| Trade links by country and product | 0.029 | 0.300 | 0.386 | 0.506 |
| Trade intensity | −0.032 | 0.138 | 0.145 | 0.200 |

of the number of RTAs and countries' connectivity through agricultural trade. This section looks at the relationship between the layering of RTAs and agricultural trade. Do countries that are connected through several RTAs trade more among each other? How does the layering of RTAs affect the connectivity of hub countries that are engaged in different RTAs and spoke countries that are connected with the hub through only one RTA?

To see if countries that are connected through several RTAs also trade more among each other, we created an RTA "intensity" matrix. The RTA intensity matrix builds on the RTA adjacency matrix in which one was replaced with the number of RTAs a specific country pair is connected with. Table 6 shows the correlation between the RTA intensity matrix and the trade matrices in the year 2019. Both extensive and intensive margin are positively correlated with the RTA intensity matrix, i.e. countries that are connected through several RTAs also tend to trade more among each other. While this relationship is only weak for trade links by country and trade intensity, trade links by country and product are stronger correlated with the RTA intensity matrix. Again, similar patterns are found for the sensitivity analysis considering all countries without Europe, all countries without high-income countries and only high-income countries (Appendix, Table A8).

**Table 6**
Correlation of (import) trade matrices and the RTA intensity matrix in 2019.

| | RTA intensity matrix |
|---|---|
| Trade links by country | 0.162 |
| Trade links by country and product | 0.446 |
| Trade intensity | 0.126 |

The global level results and averages for country groups may mask heterogeneity at the level of specific countries and RTAs. In particular, in regions with overall relatively low levels of economic integration, overlapping RTAs may be associated with different trade patterns. We consider two case studies in which we more closely study the relationship between different layers of RTAs and agricultural trade. While the global and country-group results presented above hint at a positive association between overlapping RTAs and trade among the signatory countries of these RTAs, the (potentially) staged association between layers of RTAs and trade patterns has not been considered yet. We use a measure of assortativity to identify the relationships at different levels of RTA integration in the case studies. Based on data quality and to represent less-researched regions and country-income groups, we chose Uganda as a low-income country in Africa and Viet Nam as a lower-middle income country in Asia and their respective RTAs as case studies.

For the first case study, Uganda as a country with only two RTAs has been chosen. Together with Kenya, Uganda is signatory to the Common Market for Eastern and Southern Africa (COMESA) and the East African Community (EAC). We focus on three questions applied to 2019: (1) Is the assortativity higher among countries that share several overlapping RTAs as suggested by the correlation above (two groups: countries in both RTAs and all others). (2) Is the assortativity higher among all signatory countries involved in the sample RTAs than with outside countries (two groups: countries in both vs countries in one of the RTAs; excluding all countries that are not part of COMESA or EAC)? And (3), do the signatory countries of all involved RTAs trade more among each other than with countries outside the RTAs, i.e. is the assortativity higher among countries that are in either one of the RTAs (or in both) and outside countries (two groups: all countries that are at least in one of the RTAs vs all others)? Table 7 shows that the assortativity is generally very low in the African case study. It is weakly positive for countries in both RTAs vs all other countries and slightly stronger positive for the broader set of countries that is signatory to at least one of the RTAs vs all other countries. The assortativity is weakly negative for countries in both RTAs vs countries in either one of the RTAs, implying that Kenya and Uganda tend to trade more with their partners in the RTAs than among each other. Overall, the results suggest a weak positive relationship between the two RTAs and trade among the signatories of these RTAs, but the integration is not necessarily stronger among the countries that share both RTAs. As observed above, the assortativity tends to be

**Table 7**
Assortativity in the Uganda case study in 2019 (based on undirected trade).

| | Countries in both RTAs vs all others (1) | Countries in both RTAs vs countries in either one (2) | Countries in at least one RTA vs all others (3) |
|---|---|---|---|
| Trade links by country | 0.0105 | −0.0387 | 0.0330 |
| Trade links by country and product | 0.0101 | −0.0572 | 0.0406 |
| Trade intensity | 0.0058 | −0.0421 | 0.0267 |

Note: The figures show the assortativity of trade for each pair of different country groupings (in the first row) across different trade matrices (in the first column). We divide each cell of each trade matrix by the total value of cells in that matrix before calculating the assortativity measures. For matrices of trade links by country and by country and product, the total values are the sums of the trade links in each respective matrix.

stronger at the extensive than at the intensive margin.,[19][20]

The second case study focuses on Viet Nam as anchor country. In 2019, Viet Nam had signed 15 RTAs. Together with nine other countries, it forms the ASEAN Free Trade Area (AFTA).[21] ASEAN, as country group, has also bilateral and trilateral agreements with other countries (e.g. ASEAN-Australia-New Zealand and bilateral agreements with other Asian countries including Japan and the Republic of Korea). Viet Nam is also part of the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) and the Global System of Trade Preferences among Developing Countries (GSTP). In addition, the country has signed bilateral agreements with Chile, the EU, the Eurasian Economic Union (EAEU), Japan, and the Republic of Korea. This implies that Viet Nam is connected with several countries through several agreements.[22] For simplicity, we compare (1) the assortativity among ASEAN countries vs all other countries, (2) the assortativity of ASEAN countries vs the other countries that are part of any of the agreements with Viet Nam (excluding all other countries), and (3) all countries that are part of one of the agreements with Viet Nam vs all other countries. Table 8 shows the results for the three layers in 2019. Interestingly, the assortativity for all three layers is negative (though very weakly) for both extensive and intensive margin. At least in agriculture, trade of the ASEAN and broader Asia-Pacific region appears to be relatively stronger with countries in other regions than within the region (see also Jafari, Engemann and Zimmermann, 2023). Not least the results of the Viet Nam case study strongly suggest that apart from RTAs also other factors determine agricultural trade patterns, which should be controlled for in future analysis of agricultural trade in the context of overlapping RTAs.

[19] In order to determine the statistical significance of the assortativity measures, we applied two different sets of tests. We first tested, based on the z-score values, whether the assortativity calculated from the observed network is statistically different from the expected value of the assortativity from the randomly rewired networks from the original network for 10 000 times. The results presented in the Appendix (see Appendix, Table A9) support the statistical significance of the observed assortativity measures. A robustness check comparing the mean of bilateral trade within the two groups discussed (for the different layers) and that of the countries between the groups was performed using Kolmogorov-Smirnov and Wilcoxon rank tests (see Appendix, Table A9).

[20] A sensitivity analysis by excluding Europe has been conducted for both case studies (see Appendix, Table A10). The results of the sensitivity analysis consistently show the same sign and are of the approximately same magnitude than those shown in Table 7 and Table 8.

[21] The ten countries in AFTA are: Brunei Darussalam, Myanmar, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Viet Nam, and Thailand.

[22] Altogether, Viet Nam has RTAs with 45 non-ASEAN countries and the ten ASEAN countries.

**Table 8**
Assortativity of in the Viet Nam case study in 2019 (based on undirected trade).

| | Countries in ASEAN vs all others (1) | ASEAN countries vs the other countries that are part of any of the Viet Nam agreements (2) | All countries that are part of one of the Viet Nam agreements vs all others (3) |
|---|---|---|---|
| Trade links by country | −0.0051 | −0.0040 | −0.0106 |
| Trade links by country and product | −0.0349 | −0.0180 | −0.0530 |
| Trade intensity | −0.0259 | −0.0120 | −0.0460 |

Note: The figures show the assortativity of trade for each pair of different country groupings (in the first row) across different trade matrices (in the first column). We divide each cell of each trade matrix by the total value of cells in that matrix before calculating the assortativity measures. For matrices of trade links by country and by country and product, the total values are the sums of the trade links in each respective matrix.

## 5. Conclusions and policy implications

This study made a first attempt to understand agricultural trade patterns in the context of an increasing number and increasingly overlapping RTAs. Based on network measures and correlations we described the co-evolution of agricultural trade patterns and RTAs and provide first indication on some of the interaction of overlapping RTAs and agricultural trade. For the time period 1995–2019, our findings show that connectivity in the agricultural trade network increased globally at both extensive and intensive margins. At the same time, also the connectivity of countries through RTAs increased. In 2019, countries traded more with each other and had RTAs with more countries than in 1995. Countries that are connected with more countries through RTAs, tend to have a higher trade connectivity, especially at the extensive margin. Country pairs that are connected through at least one RTA, are also more likely to trade food and agricultural products with each other and the number of products traded through each link is likely to be higher. Country pairs that are connected through more than one overlapping RTA also show stronger trade connectivity, especially at the extensive margin. However, in two specific case studies a positive association between overlapping RTAs and trade connectivity could not be confirmed.

Overall, the results hint at a possible relationship between RTA and agricultural trade connectivity and suggest that this relationship could be stronger at the extensive margin of trade. This would be in line with results by Baier, Bergstrand and Feng (2014), who found that deeper RTAs have a greater impact on merchandise trade and that RTAs, in the long-term, have relatively stronger effects on the extensive margin of trade (as we do not explicitly consider the timing of RTAs, our sample includes both "old" and "new" RTAs). Stronger effects on the extensive margin of trade in agriculture have also been found for developing countries exporting to the European Union under EU preferential trade agreements (Scoppola, Raimondi and Olper, 2018). The positive association between RTA and agricultural trade connectivity also appears to be more pronounced for countries that share several RTAs, possibly indicating a stronger political integration between these countries. Strong cooperation and policy coherence among countries can counteract an unclear or even conflicting regulatory environment created by overlapping RTAs. Still, in a world with many different trade rules, there is a risk that especially countries with lower negotiating and implementation capacity could be left out of the integration process (Crawford and Laird, 2001).

Connectivity to more countries and through trade of more food products is also important for countries' resilience to trade or domestic production shocks and can contribute to dietary diversity (FAO, 2022a; Sartori and Schiavo, 2015). Countries that are relatively less integrated in the global market have been found to be more prone to shocks to their food security (Grassia et al., 2022). While trade and RTA connectivity generally increased, our study also shows that the majority of possible trade links is not covered by an RTA, reinforcing the need for further trade rule integration and harmonization at both regional and multilateral levels.

Future research may more clearly distinguish between effects of common RTAs on countries' agricultural trade and the marginal effects of any additional RTA on trade and connectivity patterns (Sorgho, 2016). More efforts should also be made to clearly disentangle the effects of RTAs and various confounding factors that have not been controlled for in our analysis. For instance, the classical gravity model can explain agricultural trade patterns by considering explanatory variables such as country's involvement in RTAs and additional variables that capture geographic characteristics affecting agricultural trade patterns. While these models primarily focus on analyzing direct trade relationships, impacts on higher orders of connectivity within the trade network could be examined by moving beyond classical gravity models. This includes exploring the structure of trade among hub and spoke countries within the RTA network and their interactions with countries outside the agreements. One approach to achieving this is by combining network analysis techniques with classical gravity models (Sopranzetti, 2018; Huang et al., 2020; Reyes, Wooster, & Shirrell, 2014). Furthermore, RTAs could be distinguished by depth and length of the implementation period of the agreements. For agriculture specifically, a better understanding of the coverage of the agricultural sector in various RTAs and the level of harmonization of NTMs of specific importance in agriculture across RTAs should be developed.

## CRediT authorship contribution statement

**Yaghoob Jafari:** Conceptualization, Data curation, Formal analysis, Software, Funding acquisition, Writing-original draft, Writing-review &editing. **Helena Engemann:** Conceptualization, Data curation, Formal analysis, Software, Funding acquisition, Writing-original draft, Writing-review &editing. **Andrea Zimmermann:** Conceptualization, Data curation, Formal analysis, Writing-original draft, Writing-review &editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2023.102516.

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