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Maritime connectivity and agricultural trade

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Abstract

Seaborne shipping is the dominant mode of transport in international trade in agricultural products, and an increasing part of seaborne agricultural trade is carried in containers. Furthermore, the majority of world containers are moved through liner shipping services, that is, regular transport services provided by global shipping companies which comprise a dense network connecting ports and countries around the world. Using a theoretically consistent gravity equation and a novel identification strategy based on the use of intra-national trade flows, this paper investigates the effect of liner shipping connectivity on international trade in agricultural products. The results show that liner shipping connectivity has a positive and statistically significative effect on agricultural trade. Moreover, this positive effect can be observed for the majority of the agricultural products analysed and is also identified for countries at different stages of development. These findings appear especially relevant in terms of the objective of increasing less developed countries' participation in global agricultural trade.

KEYWORDS

agricultural trade, gravity model, maritime connectivity, transport

JEL CLASSIFICATION

C23, F11, F14, O13, Q17

1 | INTRODUCTION

The value of global trade in agricultural products has grown significantly in the last two decades. This growth has been driven by several factors, including income growth (e.g., China), population growth (e.g., Africa) and productivity advances (e.g., Ukraine and the Russian

Federation before the current war), leading to an increasing role for developing and emerging countries. Furthermore, international trade in agricultural products has also been facilitated by changes in agricultural policies such as reduction of the support provided to domestic producers, tariff reductions and the signing of preferential trade agreements (OECD/FAO, 2021).

However, recent growth in agricultural trade has not been significant enough to make agriculture acquire relevance in terms of total trade (Poonyth, 2021). Agricultural and food product trade represents approximately one-tenth of world trade in goods. It has been argued in the literature that the prevalence of high trade costs constitutes a fundamental reason for low trade volumes in agricultural products (e.g., Eum et al., 2017; Xu, 2015). Recent empirical studies have shown that trade costs are higher for agricultural products when compared with manufactured ones, using estimated trade cost (Arvis et al., 2013) or proxying by the impact of distance (Borchert et al., 2022a). Trade policy barriers have historically been major impediments to agricultural trade. In general, agricultural and food products face higher tariff rates than manufactures (Bureau et al., 2019). Non-tariff barriers such as sanitary and phytosanitary measures as well as other technical barriers are particularly important in agricultural trade (Gourdon et al., 2020). Moreover, agricultural and food products tend to be bulky and/or perishable, so transport costs are also substantial (Beghin & Schweizer, 2021). Korinek and Sourdin (2010) confirmed that maritime freight costs are higher for agricultural products, especially for less developed countries.

Seaborne shipping is the dominant mode of transport in international trade. Around 80% of world trade in volume is transported by sea (UNCTAD, 2017). An increasing part of maritime trade is moved in containers. Since the 1970s, containerised cargo has grown much faster than other forms of maritime shipping (Notteboom et al., 2022). Agricultural trade is no exception to these trends. For instance, US and EU international trade data show that the share of seaborne trade in agricultural products is as high as 80% of volume and 70% of value. Furthermore, containerisation of agricultural and food products is also on the rise. Some agricultural products, such as fruit or grains, which have traditionally been shipped by bulk carriers, are increasingly being moved in containers (Coyle et al., 2001; Korinek, 2011). US and EU data also corroborate this fact. For instance, 35% of US agricultural seaborne trade by volume is shipped in containers. In the case of the EU, this figure is 30%.

The majority of containerised maritime trade is carried by liner shipping companies, that is, carriers that operate with scheduled departures. Liner shipping services comprise a dense network that connects ports and countries all around the world. To analyse countries' positions within this global liner shipping network, UNCTAD produces the Liner Shipping Connectivity Index (LSCI) (UNCTAD, 2021). An improvement in liner shipping connectivity may have a positive effect on trade volumes, by reducing freight costs or by creating entirely new trade opportunities. The effects of liner shipping connectivity on trade costs and volumes have been studied in recent literature (Del Rosal & Moura, 2022; Fugazza & Hoffmann, 2017; Wilmsmeier & Martínez-Zarzoso, 2010).

This paper investigates the effect of liner shipping connectivity on international trade in agricultural products. The analysis is based on the gravity equation model, which has become the standard empirical tool for analysing the effects of various determinants of international bilateral trade flows such as trade policies. However, identification of the effects of country-specific unilateral policies, economic characteristics or institutional determinants poses an important challenge with a structural, theoretically consistent gravity equation (see, for instance, Head & Mayer, 2014). In particular, the inclusion of fixed effects to control for multilateral resistance terms along the lines proposed by Anderson and Van Wincoop (2003), an econometric strategy widely used in the literature, precludes identification of the effects of country-specific characteristics. Recent literature has proposed an identification strategy based on the use of intra-national trade data (Beverelli et al., 2018; Heid et al., 2021). We follow this approach, using the International Trade and Production

Database for Estimation (ITPD-E) (Borchert et al., 2021, 2022b). This database includes trade and production data for 19 agricultural industries for a large number of countries. It is becoming increasingly used in applied agricultural trade papers such as Larch et al. (2021), focused on economic sanctions.

The rest of the paper is organised as follows: Section 2 documents the importance of containerisation in agricultural trade and discusses the UNCTAD's LSCI. Section 3 describes the empirical strategy for estimating the effects of liner shipping connectivity on agricultural trade flows and the data used in the estimations. The results are presented in Section 4 and discussed in Section 5, in which some policy implications are also considered. The last section concludes.

2 | CONTAINERISED AGRICULTURAL TRADE AND LINER SHIPPING CONNECTIVITY

Containerisation is considered the key technological change to have occurred in transportation in the twentieth century (e.g., Bernhofen et al., 2016). Since its introduction into international trade in 1966, containerised cargo has grown much faster than world exports, but also much faster than other parts of the maritime shipping business (Notteboom et al., 2022). The container has been the driver of intermodal transportation, enabling complementarity between modes of transport and allowing ‘door-to-door’ services that have transformed the transport sector (Rodrigue, 2020). Globalisation of trade would not have been possible without the introduction of the container.

Although containerisation is usually associated with manufactures trade, containers are used to carry a great variety of goods. Agriculture is no exception and containerisation is also expanding in agricultural trade. For instance, an increasing share of grain trade is being containerised, in the range of 10%–15% according to Rodrigue (2020). Prentice and Hemmes (2015) provide similar figures for containerisation for US and Canada seaborne grain exports. Korinek (2011) claimed that 25% of fruit and vegetables are shipped in containers. The increase in US exports of agricultural perishable products such as meat and fruit has been associated with the growing adoption of refrigerated containers (Coyle et al., 2001). This type of container, with integrated refrigeration units, is crucial for temperature-sensitive agricultural products and nowadays dominates the refrigerated maritime transport with a market share of 80% (Castelein et al., 2020). In 2015, vegetables and fruits was the third most important category of goods in containerised trade, accounting for 4.8% of global containerised trade by volume (Notteboom et al., 2022).

Recent EU and US data corroborate the trends found in the literature, but also show that the extent of containerisation in agricultural trade may be greater in some cases. For the period 2010 to 2020, 20% of the volume of EU[1] seaborne agricultural and food goods imports from third countries were containerised, whereas 44% of EU exports was carried in containers. Oil seeds, animal feeding stuffs and cereals, which have low levels of containerisation (around 5%), are the top EU imports by volume, whereas perishable and non-perishable foodstuffs, beverages and wood and cork are outstanding cases in EU exports, with average containerisation levels of 72%. Looking at US[2] international seaborne trade in agricultural and food goods for the same period between 2010 and 2020, 73% of imports and

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[1] See ‘Transport_NSTR’ dataset from Eurostat's Comext database, available for bulk download at https://ec.europa.eu/eurostat/data/bulkdownload (accessed 1 March 2023).

[2] See the US Agricultural Port Profiles from the US Department of Agriculture (https://agtransport.usda.gov/stories/s/U-S-Agricultural-Port-Profiles/7vku-v3nn/) (accessed 1 March 2023).

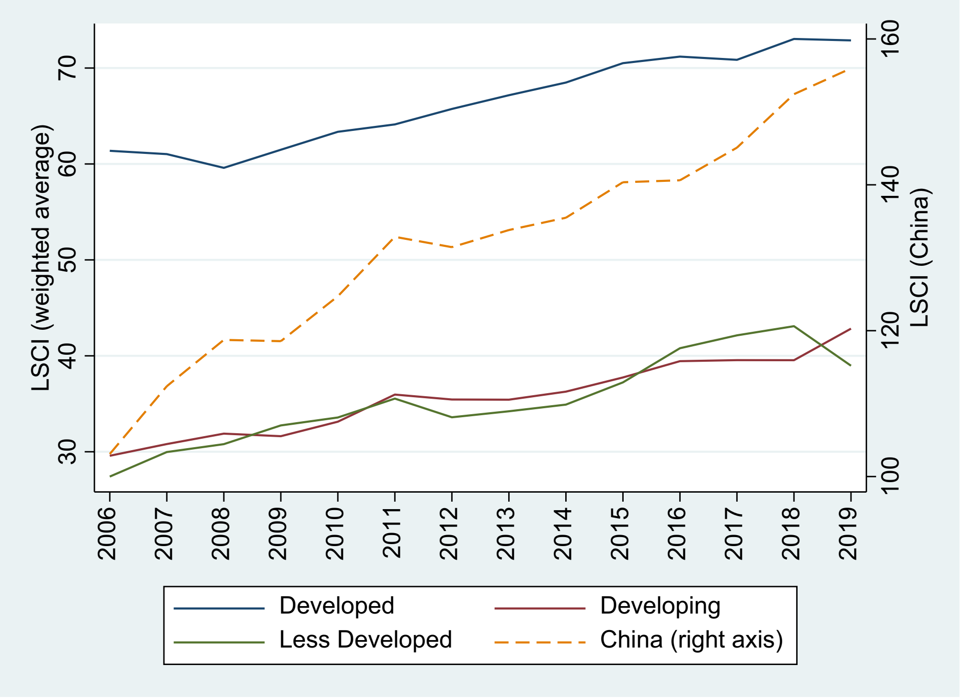

FIGURE 1 Average LSCI by country group. This figure plots average LSCI by country group, using countries' shares in agricultural trade as weights. China's LSCI scores are plotted separately and measured on the right axis. For country groups, see footnote 3. *Sources*: UNCTAD; ITPD-E.

24% of exports by volume were containerised. This more remarked asymmetry in the US case can be explained by trade composition. Soybeans, grain products and bulk grains are the three main US agricultural seaborne exports by volume, with a low level of containerisation (also around 5% on average). The top US seaborne imports are bananas and other fruit as well as beverages, wine and beer; with averaged containerisation levels of 84%. Sugar is also important in US agricultural imports, but exhibits a lower level of containerization at 17%.

Liner shipping is crucial in global container trade. Liner shipping companies operate scheduled departures, fixed port rotation, fixed frequency and published freight rates. These regular shipping services compose a dense network of connecting ports and countries all around the world, determining to a great extent countries' access to overseas markets. To analyse countries' level of integration into the liner shipping network, UNCTAD developed the Liner Shipping Connectivity Index in 2004 (UNCTAD, 2021). The LSCI is generated from actual data about container ship fleet deployment and combines six statistics: the number of companies that provide container shipping services in a country's ports, the number of shipping services, the number of container ships, their combined container capacity, maximum vessel size and the number of countries with direct connections, that is, without the need for transhipment.

The LSCI is computed for world coastal countries and for some countries with river transport services. Figure 1 depicts average LSCI by country income groups.[3] LSCI scores for China, the best-connected country by far, are separately measured on the right axis of

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[3] Developed, developing and less developed countries are categorised based on the World Bank's World Development Indicators income groupings. See Table A1 in Appendix S1.

Figure 1. Following China, developed countries including East Asian countries such as Singapore and South Korea, European countries such as Germany and the United Kingdom, and other developed countries such as the United States, show high scores on the LSCI. The average LSCI for developing and less developed countries is lower, although liner shipping connectivity shows an improvement in many cases. Among the countries with worse connectivity are several small island countries such as Micronesia as well as landlocked countries with river to sea connections such as Paraguay. In general, recent data from the LSCI indicate a widening gap between the best and worst-connected countries; see UNCTAD (2021) for further details.

The LSCI proxies for accessibility to global trade through containerised seaborne shipping (Notteboom et al., 2022). An improvement in shipping connectivity may produce a reduction in freight costs, which would have a positive effect on trade volumes, and/or a direct effect on trade volumes, creating entirely new trade opportunities. Previous literature (e.g., Wilmsmeier & Martínez-Zarzoso, 2010), including papers referring to agricultural trade (Arvis et al., 2013), identified a positive effect of liner shipping connectivity in reducing trade costs. Other papers identified a positive effect of liner shipping connectivity in boosting trade (Del Rosal & Moura, 2022; Fugazza & Hoffmann, 2017). The importance of the quality of transport and trade-related infrastructures for agricultural trade has been argued in the literature, especially for developing countries (Moïsé et al., 2013), but the potential positive effect of the LSCI on agricultural trade has not been specifically addressed with a structural gravity model. This is the main objective of this paper, to analyse the effect of liner shipping connectivity on agricultural trade using a novel identification strategy within a structural gravity estimation framework.

3 | EMPIRICAL MODEL AND DATA

Gravity models have been extensively used for assessing the impact that trade policies and agreements, institutional determinants and other economic characteristics may have on bilateral trade between countries or regions. Following the recommendations and best practices for estimating structural gravity models (e.g., Baier et al., 2018; Head & Mayer, 2014; Yotov et al., 2016), our first model is estimated with pooled data across agricultural products:

$$\begin{aligned} X_{ijkt} = \quad & \exp[\beta_0 + \beta_1 \ln DISTANCE_{ij} + \beta_2 CONTIGUITY_{ij} + \beta_3 LANGUAGE_{ij} + \beta_4 COLONY_{ij} + \beta_5 WTO_{ijt} \\ & + \beta_6 PTA_{ijt} + \beta_7 INTER_{ij} + \gamma \ln LSCI_{it} \times INTER_{ij} + \eta_{ikt} + \mu_{jkt}] + \varepsilon_{ijkt} \end{aligned} \tag{1}$$

where X_{ijkt} denotes bilateral trade of agricultural product k from exporter i to importer j in year t. Equation (1) includes several gravity and trade policy variables usually used in empirical gravity models to proxy for unobservable trade costs: $\ln DISTANCE_{ij}$ is the natural logarithm of bilateral distance; $CONTIGUITY_{ij}$ takes the value of 1 if countries i and j share a common border and 0 otherwise; $LANGUAGE_{ij}$ takes the value of 1 if countries i and j share a common language and 0 otherwise; $COLONY_{ij}$ takes the value 1 if countries i and j have colonial ties and 0 otherwise; WTO_{ijt} takes the value of 1 if both countries i and j are members of the World Trade Organisation in year t and 0 otherwise; and PTA_{ijt} takes the value of 1 if both i and j are engaged in a preferential trade agreement of any type in year t and 0 otherwise.

A theory-consistent gravity model estimation requires accounting for unobserved multilateral resistance terms (MRTs) along the lines of those proposed by Anderson and van Wincoop (2003). With panel data, MRTs can be accounted for by time-varying directional fixed effects. When the product dimension is also present in the model, the MRTs should be product-specific as well (Yotov et al., 2016). In Equation (1), η_{ikt} and μ_{jkt} are the exporter-product-year and importer-product-year fixed effects, respectively. In principle, the inclusion of a proper set of fixed effects to account for MRTs makes identification of the effects of trade determinants that vary at country level impossible (Head & Mayer, 2014). However, it is important to remark that X_{ijkt} includes intra-national ($i = j$) trade flows. This fact explains the presence of the indicator variable $INTER_{ij}$, which takes the value of 1 for international trade flows (X_{ijkt}, $i \neq j$) and 0 otherwise, and the interaction term $\ln LSCI_{it} \times INTER_{ij}$, where $\ln LSCI_{it}$ is the natural logarithm of the LSCI for country i in year t. This specification follows the strategy recently proposed by Beverelli et al. (2018) and Heid et al. (2021) for identifying the effects of country-specific trade determinants such as non-discriminatory trade policies, institutions and economic characteristics. This strategy allows us to identify the impact of the variable of interest on international trade relative to domestic trade.[4]

The error term is ε_{ijkt}. The gravity model expressed in exponential form in Equation (1) includes zero trade flows and will be estimated using a Poisson Pseudo Maximum Likelihood (PPML) estimator.[5] Among other advantages, the PPML estimator is robust to the presence of heteroscedasticity, a problem that may be significant in trade data (Santos Silva & Tenreyro, 2006).

Endogeneity is also a potential problem in estimation of the effects of trade policy variables. In the present case, however, the potential reverse causality bias that may arise in the estimation of the trade effects of transportation channels is more relevant (Baier et al., 2018). Liner shipping connectivity may boost trade, but actual trade flows also influence the services offered by liner shipping companies. In fact, as was previously commented, the LSCI is computed according to the deployment of the world container ship fleet. The inclusion of country-pair fixed effects (with product dimension, country-pair-product fixed effects) is recommended for addressing the endogeneity of the right-hand variables in the gravity equation (Baier et al., 2018; Baier & Bergstrand, 2007). Del Rosal and Moura (2022) recently showed that this method effectively controls for the reverse causation bias that may arise with liner shipping connectivity. The inclusion of country-pairs also controls for observable and unobservable time-invariant bilateral trade costs (Agnosteva et al., 2014). The drawback of including these fixed effects is that time-invariant gravity regressors cannot be identified. The inclusion of country-pair-product fixed effects modifies Equation (1) as follows:

$$X_{ijkt} = \exp\left[\beta_0 + \beta_5 WTO_{ijt} + \beta_6 PTA_{ijt} + \gamma \ln LSCI_{it} \times INTER_{ij} + \eta_{ikt} + \mu_{jkt} + \phi_{ijk}\right] + \varepsilon_{ijkt} \quad (2)$$

where ϕ_{ijk} are country-pair-product fixed effects.

Endogeneity concerns make Equation (2) the reference gravity model to obtain unbiased estimates of γ, the elasticity of international trade relative to domestic trade with respect to the LSCI. Product-level estimates of γ can also be obtained by estimating the gravity equation for each class of agricultural products k:

$$X_{ijkt} = \exp\left[\beta_0^k + \beta_5^k WTO_{ijt} + \beta_6^k PTA_{ijt} + \gamma^k \ln LSCI_{it} \times INTER_{ij} + \eta_{ikt} + \mu_{jkt} + \phi_{ijk}\right] + \varepsilon_{ijkt} \quad (3)$$

In this product-level specification, γ^k is the elasticity of international trade in agricultural product k with respect to the LSCI. Analogously to the pooled regressions, this elasticity measures the impact of liner shipping connectivity on international trade of agricultural product

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[4] As a reviewer pointed out, maritime connectivity is studied at the country level and the identification of its effects relies on differences between domestic and international trade flows, so the identification strategy does not exploit differences in bilateral connectivity. It is thus worth exploring what happens if a bilateral index for the maritime connectivity is used instead in order to check if the proposed identification strategy may produce some bias in the estimates. This alternative is investigated as a robustness check.

[5] An alternative suggested by Head and Mayer (2014) consists of specifying the dependent variable as trade shares. This alternative is also explored as a robustness check.

k relative to its domestic trade. As long as Equation (3) is estimated separately for each class of agricultural product k, η_{ikt}, μ_{jkt} and ϕ_{ijk} represent exporter-time, importer-time and country-pair fixed effects, respectively.

Three data sources are combined for the estimations. Nominal trade flows in agricultural products come from the International Trade and Production Database for Estimation (ITDP-E), described in detail in Borchert et al. (2021, 2022b). For the purposes of this paper, the ITDP-E covers 19 agricultural product/industries, which correspond to International Standard Industrial Classification (ISIC) A-01 division 'Crop and animal production, hunting and related service activities', and contains data on both international and domestic agricultural trade flows. Domestic trade is calculated in this database as the difference between gross production and total exports. The LSCI data are from UNCTAD (2021). The ITDP-E data are available for the period 2000 to 2019, but the LSCI data are available only from 2006 onwards, so this study covers the period 2006 to 2019. LSCI scores are computed for coastal countries, and the country coverage varies significantly across agricultural products and industries in the ITDP-E. The maximum number of countries included in the (pooled) estimations is 156, listed in Table A1 in Appendix S1. Table A2 in Appendix S1 lists the 19 agricultural products covered in this paper and reports basic statistics about trade flows by product. Finally, data on gravity and trade policy variables are taken from the Dynamic Gravity dataset (Gurevich & Herman, 2018). Table A3 in Appendix S1 shows the descriptive statistics for the variables used in the estimations.[6]

4 | EMPIRICAL RESULTS

Table 1 reports PPML estimates of Equations (1) and (2) pooled across agricultural products. The results in Column (1) for Equation (1) show that the coefficient estimates for the gravity regressors are in general in line with the results from previous literature (e.g., Head & Mayer, 2014). Agricultural trade is approximately inversely proportional to distance. $CONTIGUITY_{ij}$ has a positive effect for agricultural trade between countries and sharing a common language also has a positive and statistically significant effect. The coefficient estimate for $COLONY_{ij}$ is negatively signed but not statistically significant. Coefficient estimates for trade policy variables (WTO_{ijt} and PTA_{ijt}) have the expected sign, but only WTO_{ijt} has a statistically significant effect on agricultural trade flows. The estimate of the coefficient on $INTER_{ij}$, the indicator variable for international trade, is negative, large and statistically significant, meaning that domestic trade is significantly more important in agriculture than international trade. More relevant for the purposes of this paper is the estimate of γ (0.90, standard error 0.27). Liner shipping connectivity thus has an economically and statistically significant positive effect on international agricultural trade flows: when the LSCI increases by 1%, international trade relative to domestic trade increases by 0.9%. Liner shipping connectivity does indeed increase agricultural trade between coastal countries.

Column (2) provides the estimation results for Equation (2). The inclusion of exporter-importer-product fixed effects does not change the main result. The estimate for γ is slightly larger (1.17, standard error 0.23), so liner shipping connectivity maintains its economic and statistical significance. The point estimate for WTO_{ijt} drops from 1.06 to 0.16 and loses statistical significance, whereas the coefficient estimate for PTA_{ijt} is very small and remains insignificant. These results are in general in line with the endogeneity analysis of Baier and Bergstrand (2007). With the slight increase in the estimates of the interaction term $\ln LSCI_{it} \times INTER_{ij}$, the upwardly biased effect that reverse causality may generate when estimating the effects of

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[6] The ITDP-E and the Dynamic Gravity dataset are freely available for download on the Gravity Portal of the United States International Trade Commission (https://www.usitc.gov/data/gravity/index.htm; accessed 1 March 2023). LSCI data are also freely available for download on the UNCTADstat platform (https://unctadstat.unctad.org/EN/; accessed 1 March 23).

TABLE 1 PPML gravity estimates with pooled sample.

	(1)	**(2)**
$\ln DISTANCE_{ij}$	−1.18***	
	(0.12)	
$CONTIGUITY_{ij}$	0.33**	
	(0.15)	
$LANGUAGE_{ij}$	0.54***	
	(0.16)	
$COLONY_{ij}$	−0.2	
	(0.18)	
$INTER_{ij}$	−7.47***	
	(0.96)	
WTO_{ijt}	1.06***	0.16*
	(0.20)	(0.08)
PTA_{ijt}	0.31	0.03
	(0.19)	(0.03)
$\ln LSCI_{it} \times INTER_{ij}$	0.90***	1.17***
	(0.27)	(0.23)
Observations	1,598,207	1,345,780
R^2	0.99	0.99

Note: The dependent variable is X_{ijkt}, the nominal trade of agricultural product k from exporter i to importer j in year t. Both regressions include exporter-product-year and importer-product-year fixed effects. Column (2) also includes country-pair-product fixed effects. The number of observations differs due to the exclusion of singletons groups (see Correia, 2015). The R^2 shows the squared correlation coefficient between the observed dependent variable and the fitted values. Four-way standard errors clustered by exporter, importer, product and year are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

transportation channels (Baier et al., 2018) is not observed. With this benchmark estimate, when the LSCI increases by 1%, international trade relative to domestic trade increases by approximately 1.1%.

Table 2 presents PPML estimates of Equation (3) by agricultural product. Again, the inclusion of exporter-importer fixed effects precludes the identification of time-invariant gravity variables, and the estimates of the trade policy variables are arguably affected by the inclusion of country-pair fixed effects. Joint membership of the WTO is statistically significant for 10 of the 19 agricultural products, although the coefficient estimates are negative in three cases, for Rice, Other Cereals, Other Sweeteners and Other products. The PTA dummy is not statistically significant except in three cases, those of Sugar, Fresh vegetables and Eggs. But the most important result so far is that the coefficient estimates for the interaction term $\ln LSCI_{it} \times I_{ij}$ are positive and statistically significant in 14 of the 19 cases, 12 of them at the 1% significance level and the other 2 at the 5% significance level. The coefficient estimates are larger for some products, especially Other sweeteners (2.23, standard error 0.46), Corn (1.78, 0.65), Other products (1.54, 0.10) and Rice (1.51, 0.27). In five cases, Wheat, Soybeans, Sugar, Cocoa and Tobacco, the PPML estimates of $\ln LSCI_{it} \times I_{ij}$ are not statistically significant. However, the results in Table 2 show that containerisation and liner shipping connectivity are not only important for fresh agricultural products most likely carried in refrigerated containers such as fruit, vegetables, eggs or meat, but also for agricultural produce such as grains that have traditionally been associated with bulk shipping. Liner shipping connectivity appears to be an important factor in boosting international trade relative to internal trade in a wide variety of agricultural products.

TABLE 2 PPML gravity estimates by agricultural product.

	Wheat	Rice	Corn	Other cereals	Soybeans	Other oilseeds	Sugar	Other sweeteners	Pulses and legumes	Fresh fruit
WTO_{ijt}	0.02	−0.62*	1.17**	−0.14***	1.66	0.50**	4.85***	−1.45*	0.40	−0.08
	(0.25)	(0.34)	(0.52)	(0.04)	(1.07)	(0.25)	(0.86)	(0.75)	(0.37)	(0.23)
PTA_{ijt}	−0.06	−0.12	0.30	0.40	−0.11	0.017	1.39**	0.18	−0.10	0.08
	(0.12)	(0.20)	(0.32)	(0.25)	(0.20)	(0.08)	(0.56)	(0.17)	(0.09)	(0.10)
$\ln LSCI_{it} \times INTER_{ij}$	0.17	1.51***	1.78***	0.62***	0.34	1.00***	−0.80	2.23***	1.43***	1.36***
	(0.35)	(0.27)	(0.65)	(0.23)	(1.67)	(0.37)	(1.09)	(0.46)	(0.41)	(0.43)
Observations	41,678	75,064	51,782	49,874	32,812	91,932	6238	50,788	76,978	115,037
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

	Fresh vegetables	Nuts	Eggs	Other meats	Cocoa	Beverages	Tobacco	Spices	Other
WTO_{ijt}	0.05	0.19	2.01***	0.84	2.68***	−0.23	0.02	0.71***	−0.58**
	(0.20)	(0.15)	(0.56)	(1.61)	(0.14)	(0.21)	(0.35)	(0.18)	(0.24)
PTA_{ijt}	0.24*	0.12	0.38**	−0.06	−0.00	−0.05	−0.02	0.07	−0.09
	(0.14)	(0.11)	(0.19)	(0.08)	(0.01)	(0.07)	(0.09)	(0.13)	(0.06)
$\ln LSCI_{it} \times INTER_{ij}$	0.89***	1.35***	1.12***	1.06***	0.52	1.39**	0.28	0.96**	1.54***
	(0.24)	(0.46)	(0.19)	(0.35)	(0.98)	(0.69)	(0.41)	(0.37)	(0.10)
Observations	96,334	74,850	36,901	105,283	27,425	106,612	51,273	108,822	146,097
R^2	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.99

Note: Each column in each panel reports the PPML gravity estimates by agricultural product (for full names see Table A2 in Appendix S1). The dependent variable is X_{ijkt}, the nominal trade of agricultural product k from exporter i to importer j in year t. All regressions include exporter-year, importer-year and country-pair fixed effects. The R^2 shows the squared correlation coefficient between the observed dependent variable and the fitted values. Three-way standard errors clustered by exporter, importer and year are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

The international trade effects of liner shipping connectivity are identified through the inclusion of intra-national trade flows. By definition, the importer and the exporter are the same country in intra-national trade flows (X_{ijkt}, $i=j$). For this reason, a drawback of this strategy of identification is that the trade effects of country-specific determinants such as the LSCI are the same on the importer and exporter sides (see the detailed discussion in Beverelli et al., 2018). This means that including the LSCI scores of a country as importer or as exporter yields the same effect, understood as the effect on international trade relative to domestic trade. Nevertheless, it would be worth exploring if the effect is the same for the countries' imports and exports. Furthermore, Figure 1 has already shown that important differences in liner shipping connectivity persist across country income groups. In particular, developing (excluding China) and less developed countries have lower average LSCI scores compared to developed countries. Thus, it would also be interesting to see if the effect of maritime connectivity is maintained across countries, at different stages of development and with different levels of maritime connectivity, where some differential effect is observed.

With these objectives in mind, the income groups of Figure 1 are used here, and countries are classified into the same three bins: developed, developing and less developed countries.[7] Besides, it is also worth exploring whether maritime connectivity has the same effect for the countries that are dependent on food imports. To explore this question, the FAO's list of Low-Income Food-Deficit Countries,[8] developed for analysing food security issues, is used here to define the group of food import-dependent countries in the sample. To gauge the differential effects of liner shipping connectivity on directional trade flows and by country income groups, the following gravity model is estimated:

$$X_{ijkt} = \exp\left[\beta_0 + \beta_5 WTO_{ijt} + \beta_6 PTA_{ijt} + \gamma \ln LSCI_{it} \times INTER_{ij} + \gamma^G \ln LSCI_{it} \times INTER_{ij} \times GROUP_{ij} + \eta_{ikt} + \mu_{jkt} + \phi_{ijk}\right] + \varepsilon_{ijkt} \tag{4}$$

Equation (4) differs from Equation (2) by adding the triple interaction term $\ln LSCI_{it} \times INTER_{ij} \times GROUP_{ij}$, where the indicator variable $GROUP_{ij}$ defines the directional trade flows for the group of countries of interest. Note that, for reasons of perfect multicollinearity, the group of countries of interest cannot be included as both importers and exporters. To give an example, the first interaction term $GROUP_{ij}$ takes the value of 1 when the exporter i is a developed country and the importer j is 'another' country (developing or less developed) and 0 if not. Similarly, the corresponding interaction term will comprise the import trade flows from other countries to developed countries and so on. In the case of food import-dependent countries, only the interaction term with the directional trade flows from other countries (namely developed, developing and less developed ones not included in the FAO's list) to food import-dependent countries is included. For ease of interpretation, the strategy of Beverelli et al. (2018) is followed and the new variable $\ln LSCI_{it} \times INTER_{ij} \times PRODUCT_k$ is subtracted from $\ln LSCI_{it} \times INTER_{ij}$ when estimating Equation (4). Doing so, the point estimates for γ^G and γ can be interpreted independently; while γ^G measures the effect of the LSCI on the directional trade between countries according to $GROUP_{ij}$, γ measures the effect of the LSCI on all the remaining trade flows.

Table 3 provides PPML estimates of Equation (4), that is, including the interaction term for country groups, using the full pooled sample. The headings of the columns of Table 3 identify the group and directional trade defined by $GROUP_{ij}$. The first thing to note is

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[7] The sample comprises 53 developed countries, 44 developing countries and 57 less developed countries. See Table A1 in Appendix S1. Income data for two small and dependent states (the Cook Islands and Niue) included in the full sample are not available, so these countries are not included in any particular income group but appear as partners.

[8] See https://www.fao.org/countryprofiles/lifdc/en/ (accessed 1 March 2023). This list comprises 47 less developed countries, 28 of which are included in the sample. See Table A1 in Appendix S1.

TABLE 3 PPML gravity estimates with country groups interactions.

Exporter Importer	Developed Other	Other Developed	Developing Other	Other Developing	Less developed Other	Other Less developed	Other Import dependent
WTO_{ijt}	0.16*	0.15*	0.16*	0.16**	0.14*	0.15*	0.16*
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)
PTA_{ijt}	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
$\ln LSCI_{it} \times INTERit$	1.16***	1.14***	1.12***	1.12***	1.06***	1.14***	1.16***
	(0.23)	(0.24)	(0.23)	(0.22)	(0.21)	(0.22)	(0.23)
$\ln LSCI_{it} \times INTER_{ij} \times GROUP_{ij}$	1.25***	1.27***	1.40***	1.36***	1.63***	1.47***	1.34***
	(0.40)	(0.24)	(0.28)	(0.35)	(0.30)	(0.39)	(0.20)
Observations	1,345,780	1,345,780	1,345,780	1,345,780	1,345,780	1,345,780	1,345,780
R^2	0.98	0.99	0.99	0.98	0.99	0.99	0.99
Wald test p-value (H_0: $\gamma^k = \gamma$)	0.76	0.40	0.26	0.41	0.01	0.14	0.07

Note: The dependent variable is X_{ijkt}, the nominal trade of agricultural product k from exporter i to importer j in year t. All regressions include exporter-product-year, importer-product-year and country-pair-product fixed effects. For country groups, see footnotes 6 and 7 and Table A1 in Appendix S1. The R^2 shows the squared correlation coefficient between the observed dependent variable and the fitted values. p-values for the Wald test of equality of coefficients on $\ln LSCI_{it} \times INTER_{ij}$ and $\ln LSCI_{it} \times INTER_{ij} \times GROUP_{ij}$ are shown at the bottom of the table. Four-way standard errors clustered by exporter, importer, product and year are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels respectively.

that the estimates of γ, the effect of the LSCI on the 'group of control' (the remaining trade flows in each case), are quite similar across regressions. Moreover, all the columns in Table 3 show positive, large and statistically significant estimates of γ^G, the effect of the LSCI on trade between countries as defined by $GROUP_{ij}$ in each case. Overall, the LSCI keeps its economic and statistical significance across country groups and directional trade flows. Despite the marked differences in LSCI scores shown in Figure 1, estimation results reported in Table 3 show that liner shipping connectivity is an international agricultural trade driver for coastal countries at any level of development, and for both import and export trade flows. The coefficient estimates are somewhat larger for the trade flows of developing countries, and even larger for less developed countries' import and export flows. The larger estimate of γ^G (1.63, SE = 0.30) is for less developing countries' export flows. Interestingly, the estimate of γ^G for the imports of import-dependent countries is also large and especially more precise (1.34, SE = 0.20). The bottom of Table 3 gives the probability values for a Wald test of the equality of the parameters of interest (H_0: $\gamma^G = \gamma$). There is clear evidence favouring the null hypothesis that γ^G and γ are equal in most cases, although there is some evidence against the null in the cases of less development countries' exports and import-dependent countries' imports, especially for the former. So the results in Table 3 seem to suggest that the effect of maritime connectivity on agricultural trade flows could be somewhat more significant for less developed countries, although the evidence is not conclusive. Nonetheless, the results for both developing and less developed countries are remarkable in the light of their lower scores on the LSCI. On balance, the bottom line of these results is that the effect of liner shipping connectivity in boosting international agricultural trade relative to domestic trade is robust across levels of development.

4.1 | Further results and robustness checks

Regression results shown in Tables 1–3 offer clear evidence about the positive effect of liner shipping connectivity on agricultural trade. This effect is found for the majority of the agricultural products analysed, and also occurs across countries at different levels of development. This subsection briefly comments on other regressions results, several robustness checks and a general equilibrium simulation that are available in the Supplementary Material (online).

The main results are robust to: (i) specifying the dependent variable as trade shares and the inclusion of the LSCI in levels; (ii) the inclusion of tariffs and the use of more nuanced indicator variables for preferential trade agreements; (iii) the inclusion of different proxies for non-tariff measures, being defined as country-level covariates or bilateral regressors; and (iv) the inclusion of different kinds of potentially related covariates such as institutional quality, time to export, trade sanctions and logistic indicators.

Very similar results at the product level are obtained using product dummies and interactions such as those utilised in Equation (4) for country groups. In addition, the positive effect of maritime connectivity on agricultural trade shown in Tables 1–3 is confirmed using the UNCTAD's Liner Shipping Bilateral Connectivity Index (LSBCI). The LSBCI coefficient estimates are in general more imprecise, but lead to similar conclusions and back up the main results.

Finally, the identified positive impact of the LSCI is a partial equilibrium effect that shows the average effect that liner shipping connectivity has on international agricultural trade relative to domestic trade for all countries in the sample. A general equilibrium simulation, carried out at the aggregate agricultural sector level for a subsample of 89 countries, shows a heterogeneous response across countries, with a positive general equilibrium effect of the LSCI on trade averaging between 55% and 67% of the partial equilibrium effect, depending on the type of general equilibrium effect considered. The general equilibrium analysis also suggests that the effect could be larger for those countries with lower participation in international agricultural trade.

5 | DISCUSSION AND POLICY IMPLICATIONS

Previous literature found a positive effect of liner shipping connectivity on total or manufactured trade flows (Fugazza & Hoffmann, 2017; Del Rosal & Moura, 2022). There is also empirical evidence that links liner shipping connectivity to reductions in agricultural trade costs (Arvis et al., 2013). The empirical results shown in the previous section confirm that liner shipping connectivity, proxied by the LSCI, has an economically and statistically positive effect on international trade in agricultural products for coastal countries.

The empirical results of estimating Equation (1) reported in Table 1 show that international trade is significantly less important in agriculture than domestic trade. This result is always obtained when domestic trade flows are available (e.g., Beverelli et al., 2018 and Heid et al., 2021), and is maintained at the disaggregated level across industries (Borchert et al., 2022a). This fact may be related to the existence of substantial home bias and border effects (Yotov et al., 2016), which in turn may be the consequence of a large variety of trade frictions including geographical barriers, cultural differences, home bias in preferences, national regulations and trade policy measures.

Inspection of the sample used in the previous section shows that, for the whole agriculture sector, domestic trade exceeds international trade by a factor of approximately five, although there are differences across agricultural products. ITPD-E data for other goods sectors such as manufacturing and mining and energy show that domestic and international trade flows are more balanced, the former being approximately 1.5 times the latter in global terms. Furthermore, for the period 2006 to 2019 covered in the database used here, the share of agricultural products in world trade in goods is around 3%. In more recent years, the share of agricultural and food products in world trade has declined somewhat (Poonyth, 2021).

Higher trade costs constitute a key reason for explaining lower volumes of international trade in agricultural products (Eum et al., 2017; Xu, 2015). Overall estimates of agricultural trade costs show that they are higher than those for manufactured goods (Arvis et al., 2013). Every component of trade costs is greater for agricultural products, including trade policy barriers and transport costs in the broader sense. Tariffs are higher and non-tariff measures are more prevalent in agriculture (Gourdon et al., 2020), although there have been substantial reductions in applied tariffs through multilateral, regional and unilateral tariff concessions (Bureau et al., 2019). Trade friction costs related to border and custom procedures have greater impact in agriculture, especially in poor countries (Liapis, 2015; Tombe, 2015). For instance, custom clearance delays are particularly costly for perishable agricultural products. In general, the bulky and/or perishable nature of agricultural and food goods increases transport costs (Beghin & Schweizer, 2021). In a study of maritime freight costs for agricultural products, Korinek and Sourdin (2010) estimated an average cost of shipping of 10% of import value, although this cost may reach 20%–30% of import value for some products and some importing countries.

Virtually all papers that analyse agricultural trade costs in terms of country conclude that they are considerably higher for less developed countries. Therefore, reducing trade costs and increasing participation in world agricultural and food markets is a key challenge for these countries. Agricultural trade costs themselves have important negative productivity effects in poor countries as they protect inefficient producers and increase agricultural employment to meet subsistence consumption (Tombe, 2015). Trade barriers also limit participation in the increasingly important global agricultural value chains and limit the associated productivity gains (Greenville et al., 2017; OECD, 2019). In addition, abundant literature relates international trade with food security, especially in a scenario increasingly dominated by climate change (e.g., Smith & Glauber, 2020). Domestic production in many less developed countries is especially vulnerable to the effects of climate change.

The evidence documented in this paper shows that liner shipping connectivity does foster international agricultural trade. An increase in the LSCI increases international trade with respect to domestic trade. Disaggregated PPML results show that this positive effect occurs across many agricultural products. The results for country group and directional trade interactions reported in Table 3 show that liner shipping connectivity is also relevant for developing and less developed countries, despite these countries' lower levels of connectivity. In particular, the results for the FAO's Low-Income Food-Deficit Countries included in the sample point to the relevance that maritime connectivity may have for securing food provision to these countries. In sum, maritime connectivity is an agricultural trade driver for any coastal country, including developing and poor countries. This conclusion is underlined by the fact that less developed countries rely on maritime shipping more frequently than others (UNCTAD, 2021, p. 71).

However, improving maritime connectivity may be challenging for national policymakers, especially those from small and remote countries such as the small island states (UNCTAD, 2021). The key actors in shipping networks are shipping companies, so it is necessary to attract their services with potential business opportunities. In general, the recommendations for improving maritime connectivity highlight the fact that maritime connectivity is closely linked to port efficiency and connectivity with the inland markets that maritime gateways serve (Arvis et al., 2019; OECD/WTO, 2017; UNCTAD, 2017). All of this require investment (ports, intermodal infrastructure) and reforms (port management, trade facilitation), and may be not suitable for every country. A possible strategy may be to attract trans-shipment traffic, as has been the case of the Bahamas, Jamaica and Mauritius (UNCTAD, 2021). The resulting improvement in connectivity may benefit inland trade. Another viable strategy may be to attract vertically integrated shipping companies, who would be involved in port and inland logistics development (Arvis et al., 2019).

Finally, landlocked countries are not included in the sample used in the paper. For instance, 18 of the 47 Low-Income Food-Deficit Countries are landlocked. The lack of direct access to the sea is a serious geographical constraint, especially for landlocked poor and food import-dependent countries. It makes these countries completely dependent on their transit coastal neighbours (World Bank, 2014). At the same time, landlocked countries may benefit indirectly from better maritime connectivity of their coastal neighbours. Analysing these possible indirect effects is a topic also left for future research.

6 | CONCLUSION

The purpose of this article was to analyse the effects of liner shipping connectivity on international trade in agriculture products. A motivation for the paper was the fact that containerisation is increasingly used for shipping of all types of agricultural products. Therefore, the network of regular services established by shipping companies is also becoming increasingly important in the development of global agricultural trade.

Gravity equation results confirm a positive, economically and statistically significant effect of liner shipping connectivity on international agricultural trade flows, a result that also holds at the disaggregated level for the majority of the agricultural products analysed. Furthermore, the effect is robust across countries at any level of development, including less developed countries with low levels of maritime connectivity. These results are relevant in terms of the general objectives of both increasing less developed countries' participation in global value chains and improving food security through international trade.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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