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The effects of trade networks, non-tariff measures and natural disasters on the international beef trade: a gravity approach

This paper aims to investigate the factors influencing the international beef market's trade flows by applying the gravity model. We focus on the effects of trade networks, non-tariff measures, and natural disasters on the beef trade. This is the first study to incorporate network analysis eigenvector scores into the gravity approach with a view to examining the impact of trade network improvements on trade. Eigenvector centrality scores reveal the prominent role played by the European and Southern Common Market countries and show a well-connected beef network. The results of our gravity model show that beef trade increases more when an importer improves its position in the trade network, shedding light on the importance of strategic network engagement. We also show that Sanitary and Phytosanitary measures are more trade-restrictive than tariffs, a finding which emphasises the need for trade policy to pay attention to such measures. Meteorological (hydrological) catastrophes hurt beef imports (exports); this highlights the importance of implementing safeguarding measures on beef farms.

Keywords: network analysis, eigenvector centrality, gravity model, beef trade market, non-tariff measures, natural disasters

JEL classifications: F14, F18, Q17, Q56

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Introduction

Trade flows between countries depict economic exchanges that can reveal vital information about the commodities traded in the international market (De Benedictis *et al.*, 2014). Hence, it is crucial to analyse the respective ties between countries as these can influence policy-related decisions in developing trade partnerships and deliver critical information that is essential for creating new policies. Social network analysis (SNA), such as the eigenvector centrality approach, analyses and visualises social systems and their relations. Regarding international trade flows, it studies the structure of trade linkages, considering all involved countries' interrelationships (De Benedictis *et al.*, 2014). In addition to the SNA, the trade gravity model is an approach that is now widely applied for analysing trade patterns between countries, having advanced sufficiently over the past decades to be regarded as a suitable tool for evaluating global trade (Head and Mayer, 2014).

One of the most protected sectors in international trade is the agricultural sector, with Non-Tariff Measures (NTMs) having a more significant impact on trade than other sectors (Peci and Sanjuán, 2020). NTMs aim to safeguard food safety, animal and plant health, and other quality and technical dimensions of food products. On the one hand, NTMs set the ground rules to deliver food that satisfies minimum quality, safety, and environmental standards, increasing production costs for exporting-producing countries (Peci and Sanjuán, 2020). On the other hand, technical measures may increase welfare by reducing information asymmetries and negative externalities (Xiong and Beghin, 2014). Where the beef trade specifically is concerned, the most prominent issue has been the application by the European Union (EU) in 1989 of Sanitary and Phytosanitary (SPS) measures prohibiting the use of growth-promoting hormones in beef production, which has significantly restricted beef exports from the United States of America (USA) to the EU (Arita *et al.*, 2017; Beckman and Arita, 2016).

The impact of climate change on the agricultural sector is also an emerging subject of discussion (e.g. Lokonon and Egbendewe, 2022; Mounirou and Lokonon, 2022; Mutua and Goda, 2021). Studies have found that natural catastrophes have a considerable detrimental effect on agricultural trade. Tembata and Takeuchi (2019) investigate the impact of climate-related catastrophes on international trade in Southeast Asia, indicating the significant negative effect of natural disasters on agricultural exports. Coulibaly *et al.* (2020) meanwhile investigate African agricultural production and find that natural catastrophes harm production, with poor countries facing the effects more severely than middle and higher-income ones.

The present study considers factors influencing global beef trade flows by applying a gravity approach. In addition, we take endogeneity and multilateral resistance into consideration by using country-pair fixed effects and remoteness indexes, respectively. Besides employing the standard gravity explanatory variables, we believe that we are the first to consider the impacts of network eigenvector centralities, NTMs, and natural disasters. This study makes four important new contributions. First, it visualises the international beef network trade using the eigenvector centrality approach. In SNA, studies for the beef market mainly analyse the logistics aspects at a regional level (e.g. Gandasari *et al.,* 2022; Martino *et al.,* 2013). Second, it incorporates network analysis measures, i.e., the eigenvector centrality score, within the gravity approach to examine the impact of a country's trade network improvement on the international beef bilateral trade flows. Third, it considers the effects of a range of NTMs (i.e., SPS measures, Technical Barriers to Trade -TBT- measures, and other NTMs) on international beef trade. Fourth, it considers the effects of natural disasters on global beef trade.

The paper is organised as follows. Section 2 elaborates on the beef trade gravity model literature. Section 3 shows the methodology. Section 4 discusses the data used. Section 5 presents and discusses the results, while Section 6 discusses the policy implications and conclusions.

Literature review

So far as the beef trade gravity framework is concerned, studies tend to focus on the most significant beef-trading countries or the trading patterns of countries. Specifically, Cao and Johnson (2006) examine New Zealand's exports to its nine major trading countries. Fadeyi *et al.* (2014) meanwhile discuss the trade between the Southern African Development Community and EU first members (EU-15). Darbandi *et al.* (2021) examine the USA exports to its top four importers. Ghazalian (2019) examines the impact of border effects on Canada's beef exports. Tian *et al.* (2021) review China imports based on its top eight importers. However, only Wilson *et al.* (2003) and Webb *et al.* (2018) adopt a worldwide perspective when discussing geographical reach.

Most of the studies consider the different categories of beef products in aggregation while reporting the corresponding Standard International Trade Classification and Harmonised System (HS) coding, and only two studies specifically mention the application of disaggregated data, namely Zongo and Larue (2019) and Tian *et al.* (2021). The dependent variable of the gravity models in the literature refers to the value or volume of imports (Webb *et al.,* 2018), the value or volume of exports (Darbandi *et al.,* 2021), or the total volume of bilateral trade flows (Zongo and Larue, 2019).

When referring to beef trade gravity models, we highlight that the effect of NTMs has not been examined thoroughly, as only Zongo and Larue (2019) consider the impact of SPS measures on Canadian bilateral beef trade flows. Nevertheless, there is growing literature on NTMs' effects on agriculture products trade, with available research providing opposing results depending on the non-tariff measure type. For example, Cardamone (2011) indicates that NTMs stimulate trade, Peterson *et al.* (2013) and Dal Bianco *et al.* (2016) that NTMs are a barrier to agricultural trade, whereas Xiong and Beghin (2014) and Beckman and Arita (2016) observe that NTMs have heterogeneous effects on trade; this heterogeneity may be a result of diverse non-tariff measure types, or might be a result of different research methods. In any case, most of the research focuses on specific NTMs (aiming their study on particular products or countries); an exception is the study of Hoekman and Nicita (2011), according to which NTMs hinder overall agri-food product trade.

There needs to be more literature incorporating meteorological and hydrological catastrophes in gravity beef trade models. Nevertheless, weather-related events and catastrophes clearly can affect trade, due to, for example, the loss of transportation infrastructure or changes in production and revenue (Osberghaus, 2019). Hence, our study incorporates data relating to natural disasters, i.e. meteorological and hydrological catastrophes (CRED, 2022), into its empirical framework. A review study by Osberghaus (2019) presents how natural catastrophes affect trade, highlighting that previous literature has yet to focus on a specific economic sector. The study's findings show that exporters' natural catastrophes harmed exports, but the findings are mixed for imports. Mohan (2017) meanwhile investigates how hurricanes affected agricultural product exports in the Caribbean region. According to her findings, exports are significantly negatively affected, making the effect more unfavourable for the smaller islands. Hadri *et al.* (2019) investigate the impact of diverse types of catastrophes on agricultural exports, indicating that earthquakes and floods have a negative effect, temperature changes have an ambiguous effect, and windstorm shocks have no effect.

Methodology

Social network analysis and the eigenvector centrality measure

A graph $G = (V,E)$ presents a social network where V is the set of nodes, and E is the set of edges (see Figure 1). The SNA evaluates a node's connectedness, considering the links with other nodes, i.e., the centrality measurement. In our case, a node represents a country in the international beef trade network, given by their three-code acronym, and an edge represents the connection between two countries.

Bonacich (1972) proposes the eigenvector associated with the largest eigenvalue of an adjacency matrix as a reliable measure of network centrality, which refers to the eigenvector centrality. Let A be the adjacency matrix for graph G that denotes the existence ($L_{hs} = 1$) or not existence ($L_{hs} = 0$) of a connection between nodes h and s by an edge. Therefore, the eigenvector centrality of a country h is defined by the aggregation of the eigenvector centralities of its neighbouring countries n as follows (Bonacich, 1972; De Benedictis *et al.*, 2014):

$$\lambda C_{E_h} = \sum_{s=1\ for\ h\neq s}^{n} \mathcal{L}_{hs}\, C_{E_s} \tag{1}$$

where $\lambda = 1$ is the largest eigenvalue measurement, $\mathcal{L}_{hs}$ shows whether a trade link between the countries h and s exists, and C_{E_h} is the eigenvector centrality score of a neighbouring country s. To calculate the eigenvector centrality for country h (C_{E_h}), we start with an initial estimate for all countries and iteratively update these estimates until they converge.

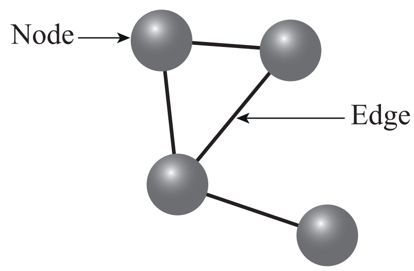

Figure 1: Visual representation of a social network analysis graph G with nodes and edges.
Source: Own composition

A country's eigenvector centrality depends on the number of nearby countries to which it is connected, as well as the centralities of these countries. In our study, a country with a high eigenvector centrality score influences the dynamics of the international beef trade; a high eigenvector centrality suggests that a country is connected to other countries that are themselves essential players in international beef trade, and any changes in their trade policies or practices can have ripple effects throughout the network. Estimating countries' eigenvector centrality can help assess the network's resilience to trade disruptions.

The gravity model for trade

The gravity framework (Pöyhönen, 1963; Tinbergen, 1962) models trade flow heterogeneities on a regional and global scale. The model explores bilateral trade flows, considering the size of the countries' economies and the physical distance between them (Head and Mayer, 2014). The gravity model for international beef trade at time t is given as:

$$X_{ijt} = cM_{it}^{\alpha_{11}} M_{jt}^{\alpha_{21}} D_{ij}^{\delta} \tag{2}$$

where X_{ijt} denotes beef exports of country i to destination j, M_{it} represents the exporter's (i) beef production, M_{jt} is the importer's (j) GDP per capita, and D_{ij} measures the distance between countries i and j.

We also wish to examine the effects of the eigenvector centrality score, tariff quotas, NTMs, and natural disasters, on the exports of country i to destination j, meaning that Eq. (2) becomes:

$$X_{ijt} = cM_{it}^{\alpha_{11}} M_{jt}^{\alpha_{21}} D_{ij}^{\delta} C_{E_{it}}^{\beta_1} C_{E_{jt}}^{\beta_2} tr_{jt}^{\gamma_1} sps_{jt}^{\gamma_{21}} tbt_{jt}^{\gamma_{22}} ontm_{jt}^{\gamma_{23}} meteo_{it}^{\zeta_1} meteo_{jt}^{\zeta_{21}} hydro_{it}^{\zeta_3} hydro_{jt}^{\zeta_4} \tag{3}$$

where $C_{E_{it}}$ ($C_{E_{jt}}$) is the eigenvector centrality score of the exporter (importer) derived from Eq. (1), tr_j is the *ad valorem* tariff enforced by country j to the exports of country i, sps_{jt}, tbt_{jt} and $ontm_{jt}$ represent SPS measures, TBT measures, and other NTMs enforced by the importer, respectively, $meteo_{it}$ ($meteo_{jt}$) denotes meteorological catastrophes in the exporter (importer), and $hydro_{it}$ ($hydro_{jt}$) denotes hydrological catastrophes in the exporter (importer).

We incorporate time-fixed effects to consider macro-shocks and country-pair fixed effects to absorb all time-invariant gravity covariates along with any other time-invariant bilateral determinants of trade costs that are not observable. As a result, our specification omits bilateral (ij) variables since these variables are perfectly collinear with the country-pair fixed effects. Moreover, the country-pair fixed effects address endogeneity issues (Yotov *et al.,* 2016).

The straightforward gravity model encounters challenges when we delve into advanced trade concepts in the literature, such as trade creation and diversion. Anderson and Van Wincoop (2003) propose an outward (inwards) multilateral resistance term that captures the fact that exports (imports) from (into) country i to (from) country j depend on trade costs across all export markets (suppliers). Therefore, we use and estimate remoteness indexes for the exporter and importer as a proxy of multilateral resistance terms given by (Yotov *et al.,* 2016):

$$RI_{it} = \sum_j D_{ij} / (M_{jt} / maxM_{jt}) \tag{4}$$

and

$$RI_{jt} = \sum_i D_{ij} / (M_{jt} / maxM_{it}) \tag{5}$$

where Σ is the sum operator, RI_{it} (RI_{jt}) is the remoteness index for the exporter (importer), and $maxM_{it}$ ($maxM_{jt}$) is the maximum value of the aggregated $M_{it}(M_{jt})$ for the country i (j) at time t.

We use the Poisson pseudo-likelihood (PPML) regression with multiple levels of fixed effects (Correia *et al.,* 2020) to obtain the coefficient estimates of our model. Silva and Tenreyro (2006) suggest that the gravity model should be estimated by a PPML regression instead of an Ordinary Least Squares log-log regression since it is more consistent in the presence of heteroskedasticity and provides robust estimates. Based on the above, we build the following PPML gravity regression for international beef trade:

$$\begin{aligned} X_{ijt} = {} & \exp [c + \alpha_{11} lnM_{it} + \alpha_{12} lnM_{it-1} + a_{21} lnM_{jt} + \\ & + a_{22} lnM_{jt-1} + \beta_1 lnC_{E_{it}} + \beta_2 lnC_{E_{jt}} + \gamma_1 \ln(1 + tr_{jt}) + \\ & + \gamma_{21} ln(1 + sps_{jt}) + \gamma_{22} ln(1 + tbt_{jt}) + \\ & + \gamma_{23} ln(1 + ontm_{jt}) + \zeta_1 ln(1 + meteo_{it}) + \\ & + \zeta_{21} ln(1 + meteo_{jt}) + \zeta_{22} lnM_{jt} ln(1 + meteo_{jt}) + \\ & + \zeta_3 ln(1 + hydro_{it}) + \zeta_4 ln(1 + hydro_{jt}) + fe_{ij} + \\ & + \tau_{ijt} + \eta_{11} lnRI_{it} + \eta_{12} lnRI_{it-1} + \eta_{21} lnRI_{jt} + \\ & + \eta_{12} lnRI_{it-1} + \varepsilon_{ijt}] + \eta_{22} lnRI_{jt-1} + \varepsilon_{ijt} \end{aligned} \tag{6}$$

where exp(ln) is the exponential (natural logarithm) operator, fe_{ij} denotes country-pair fixed effects, τ_{ijt} denotes time-fixed effects and ε_{ijt} is the error term, assuming that it is independent and identically distributed. We use natural logarithms to capture the elasticities of each corresponding independent variable, given by the estimated coefficient parameters α_{11}, α_{21}, β_1, β_2, γ_1, γ_{21}, γ_{22}, γ_{23}, ζ_1, ζ_{21}, ζ_3 and ζ_4.[1] We cluster standard errors (ε_{ijt}) based on trading pairs to address potential intra-cluster correlations at the trading pair level (Yotov *et al.*, 2016).

Note that in Eq. (6), we add the log economic size lag variables (M_{it-1} and M_{jt-1}). For the case of the exporter, there could be a delay in the impact of beef production on the international beef market due to the beef production cycle, given by α_{12}. For the case of the importer, we examine whether economic growth can have long-lasting effects on imports, given by α_{22}. We also add the log remoteness index lag variables for the exporter and importer (RI_{it-1} and RI_{jt-1}) to examine whether there are dynamics that affect trade flows and are not captured by the lagged economic size variables, given by η_{12} and η_{22}. Finally, we also estimate the interaction term between real GDP per capita and meteorological catastrophes for the

[1] For computational efficiency, we add a constant point in variables with zero values to include cases where the data point is zero (logarithms cannot transform zero values).

importer (i.e., $M_{jt}meteo_{jt}$) to capture the effect of the size of the economy during excessive atmospheric and weather conditions, given by ζ_{22}.

To assess the robustness of our model given by Eq. (6) in terms of the inclusion of lagged variables and interaction terms, we estimate three variations, i.e., model A, B, and C. Model A represents the baseline version of Eq. (6) and excludes lagged variables and interaction terms, i.e., $\alpha_{12}=a_{22}=\zeta_{22}=\eta_{12}=\eta_{22}=0$. Model B extends Model A by incorporating the lagged values of economic size (M_{it-1} and M_{jt-1}) and remoteness index (RI_{it-1} and RI_{jt-1}), i.e., $\zeta_{22}=0$. Model C is the most comprehensive one as it extends model B by incorporating the interaction term between real GDP per capita and meteorological catastrophes for the importer.

Based on Pregibon (1980), we employ the specification link test to assess if the three models are correctly specified. The link test refits the dependent variable with the predicted variable of a model and the predicted squared variable and assesses their significance. The predictive variable term should be significant since it incorporates the expected value. However, the predictive squared variable term should be statistically insignificant if our model is specified correctly.

Data

The BACI database of the Centre d' Études Prospectives et d' Informations Internationales (CEPII) provides the bilateral trade flows for 193 United Nations (UN) members and 34 areas with various degrees of sovereign statuses, totalling 227 UN members and other areas (hereafter mentioned as "countries").[2]

For our gravity models, we extract trade flow data of beef products (X_{ijt}) from CEPII's gravity database (CEPII, 2021), covering the period from 2009 to 2019. We gather our independent variables from various databases and sources. We use the CEPII's gravity database (CEPII, 2021) to extract data on the GDP per capita of the importer (M_{jt}). In addition, we use the World Integrated Trade Solution of the World Bank (WITS, 2021) to attain *ad valorem* tariff rates enforced by the importer (tr_{jt}), while we obtain the number of beef livestock representing the production of the exporter (M_{it}) from the UN Food and Agriculture Organization (FAO, 2022).

Beef trade flows comprise the sum of the four-digit HS codes 0201-0202, containing all categories of bovine animals in aggregate (fresh, chilled, and frozen carcasses, half-carcasses, boneless cuts, and other cuts with bone in). According to this classification, we have acquired data on NTMs in use on beef products from the Integrated Trade Intelligence Portal (I-TIP) of the World Trade Organization (WTO, 2021). We use three separate variables that describe the number of NTMs in effect. One variable includes the SPS measures (sps_{jt}), which are classed into a subcategory by the UN Conference on Trade and Development (UNCTAD, 2019). Another variable represents the TBT measures (tbt_{jt}), ordered into subcategory B; a third variable includes all other NTMs in effect ($ontm_{jt}$), organised into subcategories C to O (UNCTAD, 2019).[3]

Where natural disaster variables for the exporters and the importers are concerned, we use the CRED (2022) database to obtain data on meteorological catastrophes ($meteo_{it}$ and $meteo_{jt}$) and hydrological catastrophes ($hydro_{it}$ and $hydro_{jt}$). Table 1 illustrates the gravity model's descriptive statistics.

Table 1: Descriptive statistics.

Variables	Variable Description	Descriptive Statistics	Data Source
X_{ijt}	Value of trade flow in thousands of current United States Dollars (USD).	Mean: 14901.7 Min: 0.001 Max: 2682461 St. dev.: 88225.88 Obs.: 31068	CEPII
M_{it}	Number of beef livestock.	Mean: 4.15e+09 Min: 2628 Max: 8.79e+11 St. dev.: 3.92e+10 Obs.: 28731	FAO
M_{jt}	GDP per capita in thousands of current USD.	Mean: 22.980 Min: 0.195 Max: 119.173 St. dev.: 23.510 Obs.: 29428	CEPII
$C_{E_{it}}$	Measures how influential an exporter is in the international network of beef trade.	Mean: 0.546 Min: 0.001 Max: 1 St. dev.: 0.266 Obs.: 31068	Own estimation

[2] CEPII provides this categorisation.

[3] SPS and TBT measures are the most used NTMs for beef products, accounting for 47.8% and 67.9% of all NTMs in 2009 and 2019, respectively.

Variables	Variable Description	Descriptive Statistics	Data Source
$C_{E_{jt}}$	Measures how influential an importer is in the international network of beef trade.	Mean: 0.357 Min: 0.001 Max: 1 St. dev.: 0.266 Obs.: 31068	Own estimation
tr_{jt}	*Ad valorem* (on value) tariff rate.	Mean: 195.78 Min: 0 Max: 1587.57 St. dev.: 242.13 Obs.: 31068	WITS
sps_{jt}	Number of SPS measures in force.	Mean: 1.2 Min: 0 Max: 67 St. dev.: 4.95 Obs.: 31068	I-TIP
tbt_{jt}	Number of TBT measures in force.	Mean: 0.379 Min: 0 Max: 45 St. dev.: 3.278 Obs.: 31068	I-TIP
$ontm_{jt}$	Number of other NTMs in force.	Mean: 1.228 Min: 0 Max: 31 St. dev.: 4.141 Obs.: 31068	I-TIP
$meteo_{it}$	Number of people in the exporter impacted by risks of excessive atmospheric and weather conditions (e.g., wave action, floods, and landslides).	Mean: 601932.5 Min: 0 Max: 8.50e+07 St. Dev.: 5848021 Obs.: 31068	CRED
$meteo_{jt}$	Number of people in the importer impacted by risks of excessive atmospheric and weather conditions.	Mean: 275373.3 Min: 0 Max: 8.50e+07 St. Dev.: 3117229 Obs.: 31068	CRED
$hydro_{it}$	Number of people in the exporter impacted by risks of terrestrial or sub-terrestrial freshwater and saltwater.	Mean: 795219.9 Min: 0 Max: 1.42e+08 St. Dev.: 6828135 Obs.: 31068	CRED
$hydro_{jt}$	Number of people in the importer impacted by risks of terrestrial or sub-terrestrial freshwater and saltwater.	Mean: 444715.2 Min: 0 Max: 1.42e+08 St. Dev.: 5080759 Obs.: 31068	CRED

Source: Own composition

Results

Figure 2 presents the beef network trade regarding eigenvector centrality for 2019, using the BACI database and applying the eigenvector centrality method to the data with a lower threshold of 100 million USD in trade flow values. The beef network is well organised, with Europe taking the lead. Specifically, Germany, the Netherlands, France, and Italy are significant players in exports (their nodes are displayed in darker red) and have strong flows with numerous countries across Europe, Asia, and the Middle East. Mercado Común del Sur (MERCOSUR) countries have the second most prominent role, mainly due to Brazil, Argentina, and Uruguay (their nodes are displayed in dark orange). Other important players are the USA, China, and Japan since they appear to have strong trade flows with several EU countries and countries from different continents.

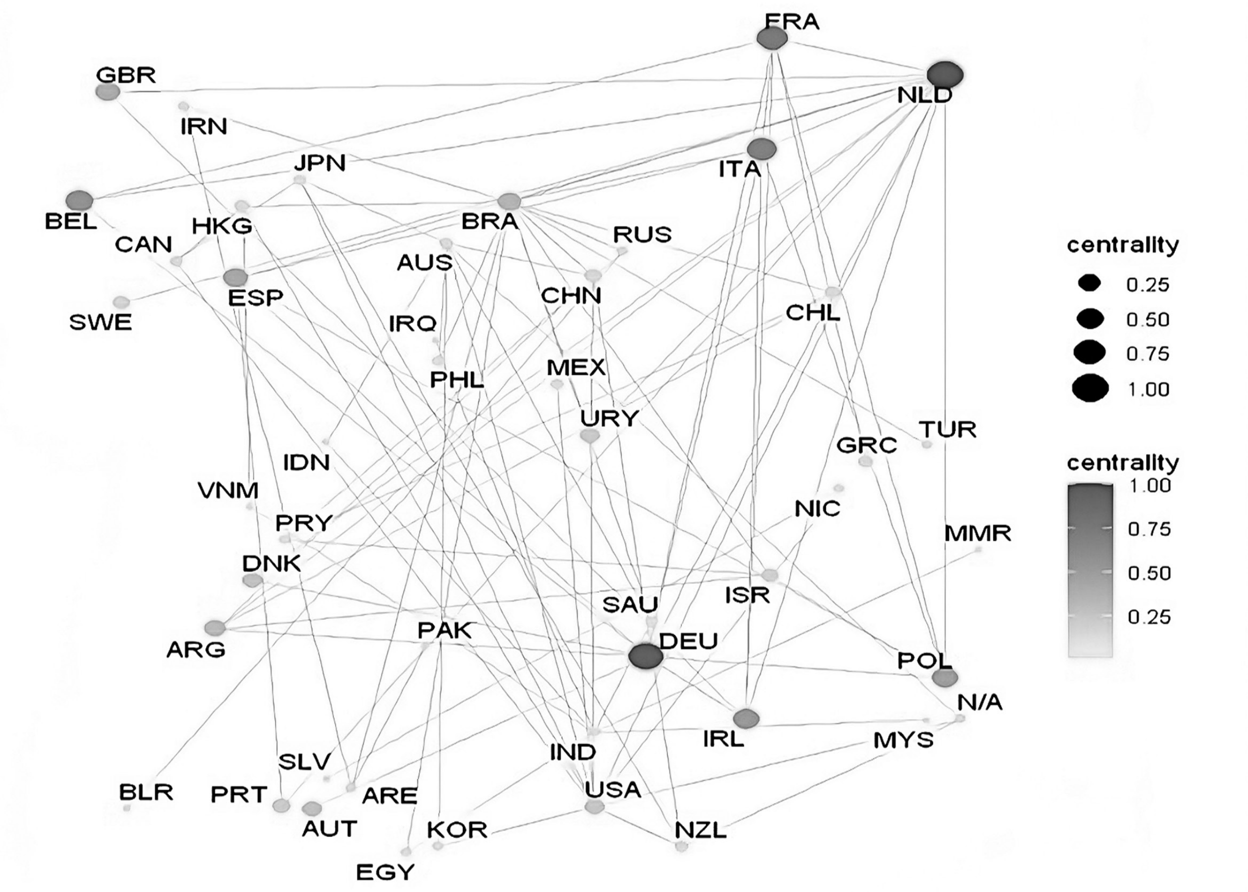

Figure 2: Social network analysis of the beef market using eigenvector centrality for 2019.
Source: Own composition

Table 2: Specification link test results.

	Model A	Model B	Model C
Constant	–2.596 [0.236] (2.191)	–2.571 [0.314] (2.553)	–2.224 [0.362] (2.440)
Predicted variable ($\widehat{X_{ijt}}$)	1.490 [0.000] (0.337)	1.478 [0.000] (0.391)	1.418 [0.000] (0.374)
Squared predicted variable ($\widehat{X_{ijt}}^2$)	–0.022 [0.095] (0.013)	–0.022 [0.161] (0.015)	–0.019 [0.200] (0.015)

Notes: Values in brackets (parentheses) denote p-value (robust standard error) estimates.
Source: own composition

Table 2 presents the specification link test by Pregibon (1980) for our three models, i.e., A, B and C. All models pass the specification link test as it fails to reject the null hypothesis that no misspecification errors exist. Specifically, the predicted values of international bilateral beef trade flows ($\widehat{X_{ijt}}$) are statistically significant. In contrast, the squared predicted value of international bilateral beef trade flows is statistically significant at the 10% significance level for model A and statistically insignificant at any conventional level of significance for models B and C.[4] Based on the above and the fact that the coefficients and the statistical significance of our fundamental variables do not change much among our models, we choose model C (the most comprehensive model) as the most appropriate for explaining international beef trade flows. Table 3 presents the estimation results of our three models.

Based on the results of model C, we observe that a 1% increase in the exporter's past beef production (M_{it-1}) increases the international beef trade flows by 0.269%. Beef production has a complex production cycle since cattle require considerable time to mature and prepare for slaughter (Wachenheim and Singley, 1999). This suggests that changes in beef production may take time to impact the market as there can be a delay between changes in production and the availability of beef exports. Importer's GDP per capita (M_{jt}) also positively affects beef trade by 1.223%. We also find that the importer's GDP per capita of the previous year

[4] Our analysis refers to 5% as a significant level unless stated otherwise.

Table 3: Estimation results of the gravity model.

Variable name	Variable	Coef.	Model A	Model B	Model C
Constant term		c	4.380 [0.001] (1.355)	–0.378 [0.873] (2.370)	–0.509 [0.830] (2.366)
Economic Size					
Exporter's production	$ln(Mit)$	a_{11}	0.033 [0.551] (0.206)	–0.012 [0.767] (0.041)	–0.013 [0.741] (0.039)
Exporter's past production	$ln(M_{it-1})$	a_{12}	–	0.254 [0.019] (0.108)	0.269 [0.013] (0.108)
Importer's GDP per capita	$ln(M_{jt})$	a_{21}	1.838 [0.000] (0.206)	1.228 [0.000] (0.217)	1.223 [0.000] (0.219)
Importer's past GDP per capita	$ln(M_{jt-1})$	a_{22}	–	0.641 [0.001] (0.193)	0.599 [0.001] (0.187)
Eigenvector score					
Exporter's eigenvector score	$ln(C_{Eit})$	β_1	0.167 [0.212] (0.134)	0.079 [0.555] (0.134)	0.065 [0.626] (0.134)
Importer's eigenvector score	$ln(C_{Ejt})$	β_2	0.325 [0.005] (0.117)	0.344 [0.002] (0.113)	0.368 [0.002] (0.117)
Importer's Tariffs and NTMs					
Ad valorem tariff rate	$ln(1+tr_{jt})$	γ_1	0.022 [0.202] (0.018)	0.019 [0.253] (0.016)	0.022 [0.181] (0.016)
SPS measures	$ln(1+sps_{jt})$	γ_{21}	–0.223 [0.000] (0.063)	–0.302 [0.000] (0.070)	–0.297 [0.000] (0.069)
TBT measures	$ln(1+tbt_{jt})$	γ_{22}	0.101 [0.299] (0.097)	0.081 [0.359] (0.088)	0.083 [0.335] (0.087)
Other NTMs	$ln(1+ontm_{jt})$	γ_{23}	0.216 [0.000] (0.067)	0.217 [0.000] (0.061)	0.198 [0.001] (0.059)
Natural disasters					
Exporter's meteorological catastrophes	$ln(1+meteo_{it})$	ζ_1	–0.004 [0.230] (0.003)	–0.003 [0.289] (0.003)	–0.003 [0.317] (0.003)
Importer's meteorological catastrophes	$ln(1+meteo_{jt})$	ζ_{21}	–0.009 [0.034] (0.004)	–0.008 [0.031] (0.004)	–0.040 [0.035] (0.019)
Importer's interaction between meteorological catastrophes and GDP per capita	$ln(M_{jt})$ $ln(1+meteo_{jt})$	ζ_{22}	–	–	0.011 [0.065] (0.006)
Exporter's hydrological catastrophes	$ln(1+hydro_{it})$	ζ_3	–0.008 [0.041] (0.004)	–0.010 [0.019] (0.004)	–0.011 [0.012] (0.004)
Importer's hydrological catastrophes	$ln(1+hydro_{jt})$	ζ_4	–0.006 [0.146] (0.004)	–0.002 [0.557] (0.004)	–0.002 [0.557] (0.004)
Remoteness indexes					
Exporter's remoteness index	$ln(RI_{it})$	η_{11}	0.061 [0.054] (0.032)	0.071 [0.027] (0.032)	0.076 [0.016] (0.032)
Exporter's past remoteness index	$ln(RI_{it-1})$	η_{12}	–	0.040 [0.076] (0.022)	0.042 [0.055] (0.022)
Importer's remoteness index	$ln(RI_{jt})$	η_{21}	0.028 [0.034] (0.013)	0.031 [0.031] (0.013)	0.028 [0.060] (0.015)
Importer's past remoteness index	$ln(RI_{jt-1})$	η_{22}	–	–0.002 [0.896] (0.015)	–0.003 [0.867] (0.015)
Country-pair effects			Yes	Yes	Yes
Time fixed effects			Yes	Yes	Yes
Number of observations			25,636	18,582	18,582
Pseudo R^2			97.03%	97.35%	97.36%
Wald X^2			192.77	371.44	206.33

Notes: Values in brackets (parentheses) denote p-value (robust standard error) estimates.
Source: Own composition

(M_{jt-1}) positively impacts the trade flows by 0.599%, suggesting that GDP per capita continues to affect trade flows over an extended period, i.e., there is evidence of a persistent effect.

The results on the eigenvector centrality score highlight that the importer impacts trade flows as their involvement in the trade network, i.e., centrality score, increases. Specifically, the importer's eigenvector centrality score (C_{Ejt}) increases beef imports by 0.608%, while there is no evidence that the exporter's eigenvector centrality score (C_{Eit}) affects beef exports. The above suggests that network centrality and connectivity can be critical drivers of import growth. *Ad valorem* equivalent tariffs (tr_{jt}) are also statistically insignificant. A possible explanation is that tariffs remained relatively stable during the examined period, meaning that tariffs in the key importers did not differ substantially to have a notable impact on beef trade. However, we find SPS measures to affect beef trade negatively; an increase in SPS measures (sps_{jt}) will lead to a trade flow decrease of 0.297%.[5] Even though SPS measures establish rules that ensure the safety of food products and prevent the spread of diseases, they can increase production costs for exporting-producing countries. The respective analysis highlights that SPS measures are more trade-restrictive than tariffs. However, other NTMs positively affect beef trade by 0.198%. A possible explanation is that other NTMs establish confidence among importers regarding the beef products' quality and safety, which may increase consumers' confidence in beef.

Regarding natural disasters, meteorological catastrophes in the importer ($meteo_{jt}$) slightly decrease beef imports by 0.4% for a 10% increase. A possible explanation is that risks triggered by excessive atmospheric and weather conditions affect the importer's trade supply chain as they can cause infrastructural damage and higher transportation costs. As for the exporters, hydrological catastrophes ($hydro_{it}$) slightly decrease beef exports by 0.107% for a 10% increase. The relevant decrease is mainly attributed to physical damages caused to livestock production and indirect effects regarding the destruction of pertinent infrastructure that may lead to harvest failures, machinery and equipment damages, and other damages. Therefore, countries with significant exporting capability should increase their safeguard measures to protect their livestock production and all the relevant factors that can affect beef output, i.e., nutrition, transportation, infrastructure, power and utilities, environment, and wildlife.

Moreover, the positive estimate of the interaction between M_{jt} and $meteo_{jt}$ variables, i.e., $\iota_1 = 0.011\%$, indicates that excessive atmospheric and weather conditions in a wealthier country will have a lower effect on imports than in a less rich country. This could be attributed to wealthier countries' better infrastructure and resources to withstand and recover from wave actions, floods, and/or landslides. They might have more robust transportation systems, communication networks, and emergency response capabilities, which allows them to resume import activities quicker after a meteorological catastrophe, minimising disruptions.

[5] We follow Wooldridge (2012, p. 192), where he explains that the $log(1+x)$ transformation may retain the interpretation of $log(x)$.

Discussion and Conclusions

The current paper utilises the gravity modelling framework to analyse bilateral trade flows in the international beef market from 2009 to 2019. It focuses on the effects of trade networks, NTMs, and natural disasters. This is the first study incorporating results from the SNA, i.e., the eigenvector or centrality score, into the gravity approach to examine the impact of trade network improvements on beef trade flows.

In our network analysis, eigenvector centrality results for 2019 show the prominent role of the EU and MERCOSUR countries. We also find a well-connected beef network, with Germany, the Netherlands, France, and Italy taking the lead. MERCOSUR countries Brazil, Argentina, and Uruguay have the second most prominent role, while the USA and China appear to have strong trade flows with several countries worldwide.

In our gravity model, we show that increases in past values of exporter's beef production positively affect beef trade flows, suggesting that beef production may not immediately impact the market due to the delay between changes in production and beef export availability. We also observe that the positive effect of real GDP per capita has a persistent impact on beef trade flows. The positive influence of both current and lagged GDP per capita suggests that economic conditions have a lasting impact on trade relationships, signifying that policymakers should recognise the importance of stable and growing economies in bolstering beef trade; efforts to support economic growth in importers can be expected to have a positive impact on beef imports, even in the medium term. Moreover, when an importer enhances its position within this network, it experiences a boost in beef imports. This suggests that network centrality and connectivity can be critical drivers of trade growth. Therefore, importers should seek to establish and strengthen trade agreements and partnerships within the beef trade network. These agreements can lead to increased access to suppliers, reduced trade barriers, and improved market conditions, ultimately fostering more significant beef imports.

As for NTMs, we observed an adverse effect of the SPS measures, TBT measures were statistically insignificant, and we found other NTMs to impact the beef market positively. Policymakers should encourage international harmonisation of SPS measures to align regulations across countries. A global consensus on SPS measures may provide compliance for beef-exporting nations and foster trust among beef-importing countries in the safety and quality of the product. Furthermore, technical assistance and capacity-building programmes (such as training in food safety practices, improving inspection and certification processes, and upgrading infrastructure) must be provided to exporters to meet the stringent SPS requirements of importers. Assisting importers to manage and enforce other NTMs effectively can facilitate beef trade while ensuring that safety and quality standards are met.

In the case of natural disasters, wave action, floods, and landslides in the importer slightly yet negatively impact beef imports, but the effect is less pronounced for wealthier countries. Importers vulnerable to such catastrophes should prioritise risk mitigation strategies, such as improving disaster preparedness, investing in resilient infrastructure, and enhancing early warning systems. Moreover, wealthier countries can be seen as more reliable beef suppliers during a meteorological crisis. Finally, risks that result from the existence and motion of terrestrial or sub-terrestrial freshwater and saltwater in the exporters slightly yet negatively impact beef exports. Therefore, exporters should work on building resilience within their supply chains. Diversifying transportation routes, storage facilities, and distribution networks can help ensure the continued availability of beef products during and after such catastrophes.

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