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Spatial Patterns of Cereal Imports and Food Security in Africa: A Gravity Model Approach

Ibtissem Gannoun

Department of Economics and International Trade, Higher Institute of Management

University of Sousse, Sousse, Tunisia

E-mail: ibtissemgannoun@gmail.com

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Abstract

This research analyzes the relationship between international trade fragmentation and food security in Africa, focusing on cereal imports between 2010 and 2021. Using a gravity model, it examines African countries' trade with major global exporters, including France, Germany, the United States, China, Argentina, Brazil, Russia, and Ukraine. The findings reveal that location, economic status, and institutional factors influence the availability and stability of cereal imports. Geographical distance, trade blocs, and economic capacity are significant determinants of trade volumes, while regional integration plays a crucial role in diversifying food supply sources. However, reliance on a limited number of suppliers makes African food systems vulnerable to political and economic crises. The United States, Russia, and Ukraine exert a significant influence on African cereal imports, complicating horizontal trade relations and threatening food security during global disruptions. The study recommends strengthening intra-African cooperation, improving trade infrastructure, and enhancing local production capacities to ensure a stable food supply and mitigate risks associated with an increasingly fragmented and uncertain global trade system.

Keywords: Food security, Cereal Imports, Gravity model, Africa

1. Introduction

Even though food security is universally recognized as a fundamental human right, as of 2021, 828 million people worldwide were still undernourished—representing 9.8% of the global population. This figure marks a significant increase compared to pre-pandemic levels, highlighting the persistent and evolving nature of global hunger (FAO, 2015, 2020; Kerr, 2020). Such regression invites a renewed examination of the global trade system and its ability to support food security. Historically, international trade has played a dual role in

shaping food security outcomes. On the one hand, it has helped bridge regional food deficits by connecting countries with comparative agricultural advantages to net importers (Lamy, 2013; Abis, 2023). On the other hand, trade-distorting policies, such as tariffs and subsidies, have often undermined market integration and created structural vulnerabilities (Jakab et al., 2001). As Gérard (2014) notes, global agricultural crises have exposed the limitations of trade as a stabilizing force, particularly for low-income, food-importing nations.

In Africa, food security remains a pressing issue. Despite local and international efforts, many countries struggle to ensure reliable access to affordable, nutritious food. Recent shocks, including the COVID-19 pandemic and the war in Ukraine, have exposed the fragility of global supply chains. These disruptions underscore how overreliance on a limited number of trade partners can amplify exposure to geopolitical tensions, price volatility, and supply interruptions (Ujunwa et al., 2018; Subramaniam et al., 2023; Jeremy, 2023). Recent data from the World Bank (2024) show that protectionist responses are intensifying. Sixteen countries have introduced 22 export bans on key agricultural commodities, while eight others have implemented 15 export restrictions, exacerbating instability in global food markets. For African countries, which depend heavily on cereal imports due to structural production deficits, this environment poses serious risks (Veeman et al., 1991). While many studies have examined globalization's broad impact on food systems, fewer have explored how fragmentation in trade networks, defined by partner concentration and asymmetric dependencies, affects food security. This study addresses that gap by analyzing the role of excessive dependence on a narrow set of cereal exporters in shaping food vulnerabilities across African nations. Using a gravity model of trade flows from 2010 to 2021, we investigate two hypotheses:

H1: Greater trade integration with key cereal exporters improves food security by stabilizing import flows.

H2: Diversification of trade partners reduces vulnerability to external shocks such as geopolitical conflicts and price volatility.

To ascertain the validity of our hypotheses, the subsequent sections of this paper are structured as follows, section 2 reviews the literature on trade and food security in Africa, with a focus on cereal trade. Section 3 presents a cluster analysis to identify co-exportation patterns. Section 4 outlines the methodology and dataset. Section 5 discusses the gravity model results and derives policy recommendations.

2. Literature Review

The academic literature on international trade has primarily focused on specific issues such as cereal prices (Headey, 2011; Martin, 2012; Kym et al., 2013; Flachsbarth and Garrido, 2014; Turki-Abdelhedi et al., 2014; and Demarest, 2015) and the impact of trade policies on agricultural markets. These studies underscore the fragmented nature of isolated national policies, such as export restrictions or import duty reductions, which can lead to unintended global consequences, including amplified price shocks. This highlights the need for international coordination to enhance the stability of food markets (Martin, 2012).

Huchet-Bourdon et al. (2013) investigated the effects of exchange rate fluctuations on food security in developing countries between 1995 and 2010. Their findings revealed that the least developed countries, which were previously net exporters, have transitioned into net importers of agricultural products, increasing their vulnerability to exchange rate and global food price volatility. Case studies of Gambia and Côte d'Ivoire demonstrated that currency depreciation exacerbated food insecurity in Gambia, while Côte d'Ivoire's net exporter status helped stabilize its food situation. The authors concluded that exchange rates are not the only factor influencing food security, as investments, tariffs, political stability, and economic structure also play crucial roles. They argued that effective exchange rate management and appropriate trade policies can enhance food security in developing countries.

Similarly, Diaz-Bonilla (2015) emphasized the link between macroeconomic policies and food security, advocating for a comprehensive approach. The author demonstrated that protectionist trade policies can sometimes worsen economic conditions if not complemented by appropriate macroeconomic measures (Turki-Abdelhedi et al., 2014).

In contrast, studies directly examining the relationship between trade and food security, especially in Africa, are still scarce (Fellmann et al., 2014; Baldos and Hertel, 2013; Dithmer and Abdulai, 2007; Dorosh and Rashid, 2013; Mary, 2019; Bonuedi, 2020; and Marson et al., 2023).

Fellmann et al. (2014) have demonstrated that export restrictions on cereals can worsen global food crises. While studies by Baldos and Hertel (2015) and Mary (2019) have emphasized the role of international trade in managing food security risks, few have directly examined the impact of trade on food security in developing countries, especially during external shocks. Although studies by Kang (2015), Dithmer and Abdulai (2017), and Marson et al. (2023) have investigated the relationship between trade openness and food security, their findings are nuanced and often contingent on a country's development level and the type of shock. This study stands apart by evaluating the impact of fragmented geographical, geoeconomic, and geopolitical factors on cereal food security across all African countries using a gravity model. Before applying the gravity model, we will first highlight the characteristics of the cereal trade in Africa.

3. Key Features of the Cereal Trade in Africa

Between 2010 and 2021, imports exhibited a 3.8-fold increase. Moreover, imports demonstrated an annual average growth rate of 12.92% over the eleven-year period, escalating from 1030 metric tons in 2010 to 3918 metric tons in 2021, as reported by the FAO. However, imports encountered two substantial shocks during this timeframe. In 2012, a pronounced volatility in cereal prices precipitated a 54% decline in African countries' imports, and in 2021, imports contracted by over 14% in tandem with the Covid-19 pandemic.

The FAO (2022) reports that 20% of the African population is experiencing undernourishment, implying one in five individuals. The prevalence of undernourishment in 2022 was 7.5% in North Africa, 11% in Southern Africa, 15% in West Africa, and around 29% in Central and East Africa. At least one-third of the population in countries such as Lesotho,

Madagascar, the Central African Republic, and Somalia, where rates surpassed 45%, were affected by undernourishment. Regionally, East Africa exhibited the highest incidence of undernourishment with 134.6 million individuals, followed by West Africa with 62.8 million, Central Africa with 57 million, North Africa with 19.5 million, and Southern Africa with 7.6 million.

Recurrent extreme weather events, including droughts, have significantly reduced local cereal production, compelling African countries to augment their cereal imports (Porter, 2014; Baldos and Hertel, 2015). Population growth and subsidy policies promoting high consumption of staple foods have further intensified this dependency.

Motivated by food security imperatives, African countries are actively pursuing diversification and multiplication of their supply chains to mitigate the risks associated with global food price volatility, lessen reliance on a single supplier, and guarantee uninterrupted supply in the face of crises or disruptions in a source country. This is evidenced by Figure 1 of the Herfindahl-Hirschman Index (HHI), which quantifies the concentration of imports from key trading partners for select African countries.

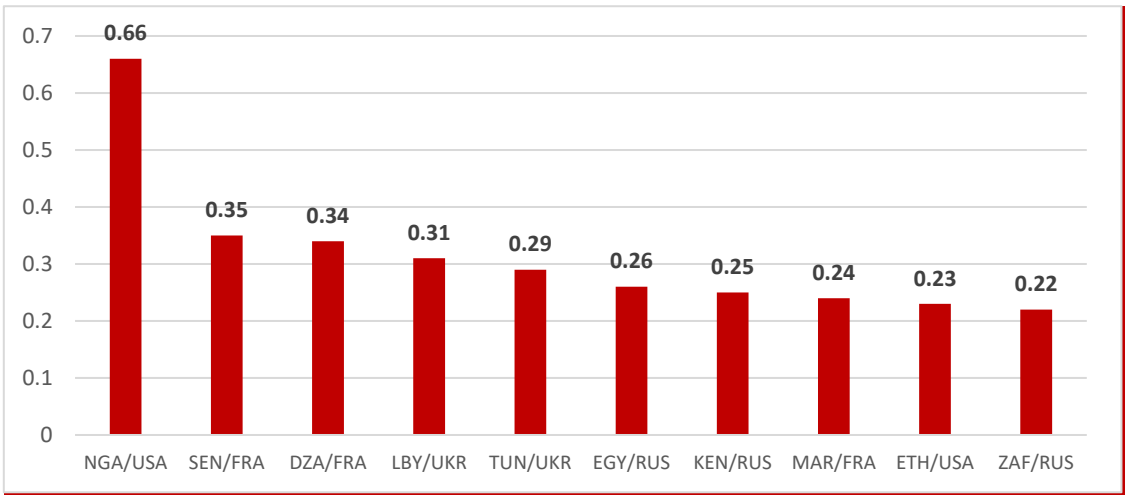

Figure 1. HHI of African Importing Countries

With the exception of Nigeria, which exhibited a high concentration index of 0.66 signifying a substantial reliance on US exports, the remaining countries displayed a diversified supply base. For Ethiopia, while the United States is a significant trading partner with an HHI of 0.23, the index reveals a lower concentration compared to Nigeria. This implies a somewhat more diversified cereal trade for Ethiopia, despite the United States maintaining a pivotal export role.

France has solidified its position as a primary trading partner for numerous African nations, as evidenced by the high HHIs of Senegal (0.35), Algeria (0.34), and Morocco (0.24). This commercial dominance is likely attributed to historical and linguistic ties with former colonies. Conversely, Ukraine has emerged as a crucial cereal exporter to Libya (HHI 0.31) and Tunisia (HHI 0.29), although their reliance, while substantial, is less concentrated

compared to Nigeria's dependence on the United States. Russia is progressively becoming a prominent cereal exporter to Egypt, Kenya, and South Africa, despite relatively moderate HHI values for these countries.

During the analyzed period, the global economic landscape underwent significant transformations, with shifts in political and economic alliances impacting trade patterns. In 2010, the United States was the leading cereal exporter to Africa, followed by France and Argentina. However, by 2021, Russia and South Africa had emerged as the primary suppliers, engaging with 35 African importing nations. Argentina retained its position as the third largest exporter, serving 34 African markets. Russia has proactively expanded its economic ties with numerous African countries through diplomatic efforts, development assistance, and bilateral trade agreements.

To gain deeper insights into the dynamics of Africa's cereal trade, we extended our analysis beyond traditional gravity models, focusing on flows from major exporting countries: the United States, Argentina, France, Germany, Russia, Ukraine, and South Africa. To comprehensively understand the interdependencies and trade patterns between African countries and their primary export partners, we employed a co-exportation clustering technique. This approach enables us to map trade flows and identify distinct blocs of economic actors, thereby illuminating the underlying structural relationships governing Africa's cereal trade.

4. Network Analysis of Cereal Trade: A Clustering Approach to Understanding African Import Dependencies

Using clustering techniques, our analysis of co-exportation patterns provides a visual representation of global cereal trade networks and reveals the intricate economic linkages between countries. The analysis identifies distinct trade blocs, highlighting recurring patterns and dependencies among exporting and importing nations. Our study focuses on 32 major cereal exporting countries actively engaged in trade with Africa. The analysis was conducted using Gephi software and the Force Atlas clustering algorithm.

By applying this method, we can identify clusters of exporting countries that exhibit similar trade patterns with African importers. These clusters form the economic backbone of the trade network, and the African countries associated with each cluster highlight their economic dependencies on specific exporting nations.

Figure 2. Mapping Cereal Trade Flows to Africa from Major Suppliers, (Gephi Output)

A study of cereal trade networks in Africa highlights a high degree of heterogeneity in trade relationships, with the formation of two distinct exporter clusters. This market segmentation results in a concentration of African imports on a limited number of partners, increasing the vulnerability of African countries to shocks in the global markets.

The analysis reveals two distinct export clusters supplying the African cereal market. The first cluster comprises major exporters such as Argentina, Belgium, Brazil, China, Germany, Spain, France, India, Italy, Latvia, Poland, Russia, Ukraine, the United States, Lithuania, the Netherlands, Portugal, Cyprus, and Luxembourg. These countries share numerous African import markets for cereals, leading to intense competition among exporters to penetrate African markets. As a result, African importing countries within this cluster often exhibit a high degree of dependence on these major exporting countries.

This cluster includes leading global economies and countries holding strategic positions in agricultural trade, with a particular focus on cereals. The countries within this cluster are recognized for their large-scale export capabilities, facilitated by robust commercial and logistical networks. Notably, Ukraine and Russia are key exporters of wheat, whereas Argentina and Brazil are major players in the global corn export market.

Furthermore, this cluster is characterized by a broad geographic distribution, spanning regions such as South America, Europe, Asia, and North America. This reflects a global presence and dominance in African markets.

The second cluster is represented by Romania (ROU), Croatia (HRV), Finland (FIN), Denmark (DNK), Hungary (HUN), Bulgaria (BGR), Sweden (SWE), Austria (AUT), the Czech Republic (CZE), Estonia (EST), Greece (GRC), Malta (MLT), and Slovakia (SVK). In contrast to the first cluster, this cluster is composed of medium-to-small European countries with a more modest export capacity that are not traditionally considered major powers in the cereal trade, but nevertheless hold some significance in exchanges with African countries.

Although these countries in this cluster do not produce cereals on the same scale as those in the first cluster, they leverage intra-European value chains and trade deals to penetrate African markets. Their geographic proximity to major EU exporters and their location in Central and Eastern Europe position them as significant actors in trade with Mediterranean African countries.

The two clusters reveal varying degrees of trade fragmentation determined by the export capacity and market power of the participating countries. The first cluster encompasses major exporters dominating a significant portion of the African cereal market, whereas the second cluster consists of smaller countries with trade focused on niche markets and often characterized by bilateral dependency and limited trade diversification. This segmentation highlights the fragmented nature of African trade relations, shaped by trading partners and economic opportunities.

For African countries, this fragmentation is evident in their reliance on a restricted group of cereal exporters. This creates distinct economic blocs, isolating some African countries from broader commercial networks. Cluster analysis shows that unequal distribution is a symptom

of fragmentation, reflecting a lack of integration between African and other global markets.

Trade fragmentation, characterized by the dependence of certain African countries on a limited group of exporting nations, exacerbates their vulnerability to external shocks such as price fluctuations and export restrictions. This is particularly critical for food security in African countries. In this context, the surge in prices and export restrictions imposed by dominant exporting countries (like Russia or Ukraine) have weakened the food security of African countries reliant on these exports. As a result, any changes in supply conditions (logistical issues, conflicts, economic crises) can disrupt access to cereal supplies.

This fragmentation limits the ability of African countries to diversify their import sources, and this lack of diversification makes them more vulnerable to global market disruptions. Furthermore, cluster analysis reveals the existence of 'trade blocs' that do not allow for optimal flexibility in times of crisis.

We note that several factors contribute to the fragmentation of trade relations among African countries, including tariff and non-tariff barriers, inadequate trade infrastructure limiting their integration into global trade networks. Political crises and conflicts can also play a role in fragmentation, disrupting established trade relations and forcing countries to turn to a restricted pool of trading partners.

A co-exportation analysis highlights patterns of dependency and isolation within African trade, indicating fragmentation. To address these risks, regional integration, aligned with hypothesis H1, is crucial. Initiatives like the African Continental Free Trade Area (AfCFTA) can stimulate intra-African trade and reduce reliance on non-African exporters. Furthermore, enhancing infrastructure and diversifying trade partners, as suggested by hypothesis H2, is essential for fostering balanced and resilient trade relationships.

5. Data and Methodology

5.1 Data

The empirical analysis is based on data sourced from reputable institutions such as CEPII and FAO. This dataset encompasses 121,276 observations of bilateral cereal imports between African countries and the global community during the period 2010-2021. To identify the determinants of these import flows, we utilize a gravity model, which incorporates a comprehensive array of geographic, economic, historical, and institutional factors.

The gravity model's conventional variables, including economic scale, geographic distance, shared borders, linguistic commonalities, trade pacts, and international organizational affiliations, enable us to analyze the fragmentation effects on cross-country economic and social interactions. By employing these variables, we delve deeper into how political, economic, and geographic fragmentation shape cereal trade flows across the African continent and evaluate their implications for regional food security. Furthermore, we incorporate binary variables to capture the cereal trade dynamics between African countries and significant global cereal exporters.

Table 1. Operational Definitions of Variables and Data Origin

Variables	Definitions	Sources
M_{ijt}	Overall cereal import (wheat + rice + maize), the proxy for food security in tonnes, since African countries are large importers of cereals and their food supply is dependent on imports.	FAO
DIS_{ij}	Geodesic distance between most populated cities (km)	CEPII
$Contig_{ij}$	Dummy equal to 1 if countries are contiguous	CEPII
$Lang_{i}$	1 if countries share common official or primary language	CEPII
$Colo_{i}$	1 if countries share a common colonizer post 1945	CEPII
$GATT_{i}$	1 if country currently is a GATT member	CEPII
$GATT_{j}$	1 if country currently is a GATT member	CEPII
WTO_{ij}	1 if country currently is a WTO member	CEPII
EU_{j}	1 if country currently is a EU member	CEPII
$FTAs_{ij}$	fta_wto : 1 if pair currently engaged in a regional trade agreement (source: WTO supplemented by Thierry Mayer)	CEPII
FTA_{ij}	fta_wto_raw: 1 if pair currently engaged in a regional trade agreement (source: WTO)	CEPII
GDP_{it}	GDP (current thousands US$)	CEPII
GDP_{jt}	GDP (current thousands US$)	CEPII
POP_{it}	Population (in thousands)	CEPII
POP_{ij}	Population (in thousands)	CEPII
V.dummy	USA, ARG, FRA, DEU, RUS, UKR et ZAF	Author's Choice

We have selected imports as a proxy variable for food security, given that cereal products form the basis of consumption in African countries and constitute a culinary identity. Furthermore, with the impacts of climate change on cereal production in Africa and geopolitical tensions at the regional and international levels, the stability of cereal import flows is a determining factor in ensuring the stability of food security within the African continent. Table 2 presents a comprehensive summary of descriptive statistics for the variables under consideration, emphasizing their key features.

Table 2. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
M_{ijt}	163,296	0,221	1,432166	0	16,03592
Spatial variables					
DIS_{ij}	157,685	8,733545	0,7363731	2,079442	9,895808
$Contig_{ij}$	157,685	0,0170086	0,1293035	0	1
Linguistic and historical variables					
$Lang_i$	150,975	0,2512535	0,4337354	0	1
$Colo_i$	150,975	0,1561053	0,3629564	0	1
Trade agreements and international organizations					
$GATT_i$	163,053	0,7511177	0,4323668	0	1
$GATT_j$	157,92	0,5404255	0,4983647	0	1
WTO_{ij}	157,92	0,6794326	0,4666962	0	1
EU_j	157,92	0,1173759	0,3218687	0	1
$FTAs_{ij}$	157,685	0,0604877	0,2383889	0	1
FTA_{ij}	157,685	0,0674446	0,2507912	0	1
Economic Variables					
GDP_{it}	153,576	16,37414	1,587626	12,21125	20,15851
GDP_{it}	131,096	17,27544	2,395265	10,368	23,85859
POP_{it}	157,221	9,077027	1,577696	4,470964	12,26151
POP_{it}	140,392	8,391173	2,36936	2,285134	14,16077
Country-specific variables					
ARG	163,296	0,0041152	0,0640181	0	1
DEU	163,296	0,0041152	0,0640181	0	1
FRA	163,296	0,0041152	0,0640181	0	1
RUS	163,296	0,0041152	0,0640181	0	1
UKR	163,296	0,0041152	0,0640181	0	1
USA	163,296	0,0041152	0,0640181	0	1
ZAF	163,296	0,0041152	0,0640181	0	1

Source: Author, Stata output.

Table 2. highlights the heterogeneity of geographic, economic, and institutional features across the sample countries, coupled with substantial variation in bilateral trade flows. The average bilateral trade flow (M_{ij}) is 0.22, exhibiting a high degree of dispersion (standard deviation of 1.43) and values spanning from 0 to 16.03. The average logarithmic distance between countries is 8.73, indicating a relatively low level of dispersion.

Geographic contiguity is a rare occurrence, with an average of 0.017, suggesting that few pairs of countries share a common border. In terms of linguistic and historical variables, shared languages have an average of 0.25, while former colonial relationships are less common, with an average of 0.16. Participation in trade agreements under the GATT and WTO is relatively high, with averages ranging from 0.5 to 0.7. Nevertheless, agreements with EU countries are less prevalent, with an average of 0.12. The GDPs and populations of countries exhibit a wide dispersion, reflecting underlying economic and demographic differences. Dummy variables for major trading partners (ARG, DEU, FRA, RUS, UKR, USA, ZAF) indicate very low frequencies (average of 0.004), suggesting concentrated interaction on a limited number of bilateral relationships.

5.2 Methodology

The gravity model, as conceptualized by Bergstrand (1989), enables us to understand and analyze the complex dynamics of international trade. It is grounded in a theoretical framework that incorporates elements of classical gravity models in economics, while also integrating additional factors such as trade policies (including trade agreements, tariffs, and non-tariff barriers), exchange rate effects, transaction costs, and the impact of regional integration (economic unions and common markets). Moreover, the gravity model equation takes the following form:

$$X_{ijt} = A \,.\, Y_{it}^{\alpha} . Y_{jt}^{\beta} . Z_{it}^{\gamma} . Z_{jt}^{\delta} . d_{ij}^{-\theta} . \varepsilon_{ijt}. \quad (1)$$

Where:

- X_{ijt} represents the volume of trade between country i and country j over the period considered.
- A is a constant of proportionality
- $Y_{it}^{\alpha} . Y_{jt}^{\beta}$. are the GDPs or economic sizes of countries i and j, respectively.
- $Z_{it}^{\gamma} . Z_{jt}^{\delta}$ are vectors of additional country-specific variables, such as development indicators, infrastructure, trade policies, or other socioeconomic factors.
- $d_{ij}^{-\theta}$ represents the distance between countries i and j, which can be measured in terms of geographic distance or economic costs (such as tariffs or non-tariff barriers).
- $\alpha,\beta,\gamma,\delta,\theta$ are the respective elasticities of the associated variables, measuring the relative impact of each factor on trade flows.
- ε_{ijt} is the error term, capturing unexplained or stochastic variations in trade flows.

By taking the natural logarithm of both sides, the equation can be linearized for the purpose of statistical estimation.

$$\ln(X_{ijt})=\ln(A)+\alpha\ln(Y_{it}) + \beta\ln(Y_{jt})+\gamma\ln(Z_{it})+\delta\ln(Z_{jt})-\theta\ln(d_{ij})+\ln(\varepsilon_{ijt}). \quad (2)$$

Considering the variables included in this analysis, our gravity model can be expressed as follows:

$$\begin{aligned}\ln(M_{ijt})=\ln(A)+\alpha_1\ln(DIS_{ij})+\alpha_2(Contig_{ij})+\alpha_3(Lang_i)+\alpha_4(Colo_i)+\alpha_5(GATT_i)+\alpha_6(GATT_j)\\ +\alpha_7(WTO_{ij})+\alpha_8(EU_j)+)+\alpha_9(FTAs_{ij})+)+\alpha_{10}(FTA_{ij})+\alpha_{11}\ln(GDP_{it})+\alpha_{12}\ln(GDP_{jt})+\\ \alpha_{13}\ln(POP_{it})+\alpha_{14}\ln(POP_{jt})+\alpha_{15}(USA_{it})+\alpha_{16}(ARG_{it})+\alpha_{17}(RUS_{it})+\alpha_{18}(UKR_{it})\\ +\alpha_{19}(FRA_{it})+\alpha_{20}(DEU_{it})+\alpha_{21}(ZAF_{it})+\ln(\varepsilon_{ijt}). \quad (3)\end{aligned}$$

The application of the Bergstrand (1989) model can be carried out through econometric analyses using multiple regression techniques to estimate the effects of different variables on trade volumes and determine the coefficients α, β, γ, and δ. Following the recommendations of Yotov et al. (2016), we chose to use panel data to estimate our gravity equation, using the Poisson Pseudo Maximum Likelihood (PPML) estimator. Our choice was driven by several

arguments, including the PPML model's ability to account for the frequent heteroscedasticity of trade data (Fontagne et al., 2002; De Benedictis and Vicarelli, 2005; Baldwin and Taglioni, 2006; Silva and Tenreyro, 2006; Laoute and Ali, 2023), and its ability to exploit information contained in zero trade flows, unlike traditional panel data methods such as fixed effects (FE) and random effects (RE) models.

Gravity models typically assume a multiplicative specification of trade flows, implying that trade between two countries is proportional to a combination of their characteristics. The PPML estimator maintains this multiplicative structure, unlike traditional methods, which may introduce biases due to heteroscedasticity or logarithmic transformations. Additionally, we performed a preliminary multicollinearity test among the model's variables, with the results reported in Table 3.

Table 3. Multicollinearity test

Variables	VIF	1/VIF
POP_{it}	4.19	0.238599
POP_{jt}	3.73	0.268392
GDP_{it}	2.93	0.340972
GDP_{jt}	2.76	0.362355
$FTAs_{ij}$	2.68	0.373675
FTA_{ij}	2.65	0.376653
$GATT_i$	1.90	0.525290
WTO_{ij}	1.88	0.532201
EU_j	1.52	0.657540
DIS_{ij}	1.48	0.674432
$Lang_i$	1.38	0.726858
$Colo_i$	1.35	0.741284
$Contig_{ij}$	1.24	0.809671
$GATT_i$	1.13	0.881386
USA	1.06	0.940253
FRA	1.05	0.951751
RUS	1.05	0.955429
DEU	1.05	0.955847
UKR	1.04	0.965653
ZAF	1.02	0.980490
ARG	1.02	0.983782
Mean VIF	1.81	

Source: Author, Stata output.

Our analysis reveals no severe multicollinearity issues. All variables exhibit a VIF below 5, indicating low collinearity among the model's variables. The average VIF of 1.81 further supports that the model is well-specified and free from major multicollinearity problems. The minor correlations observed between certain variables, such as GDP and population, align with expected economic relationships and are unlikely to substantially impact the coefficient estimates.

6. Findings and Recommendations

We used the Poisson Pseudo Maximum Likelihood (PPML) method to estimate the gravity model of trade (3) in order to analyze the determinants of international trade flows. Table 4 reports the estimation results. The estimated coefficients for the different variables shed light on the main determinants of bilateral trade and emphasize the role of geographic, linguistic, historical, and institutional factors in promoting or hindering cereal imports in African countries.

Table 4. Gravity Model Estimation Results: PPML Approach

	Coef,	Std, Err,	z	P>z
Log DIS_{ij}	-0,4373319	0,0226908	-19,27	0a
$Contig_{ij}$	1,380657	0,0669875	20,61	0
$Lang_i$	0,4674241	0,0396852	11,78	0
$Colo_i$	0,4194871	0,0552432	7,59	0
$GATT_i$	0,3388588	0,0423662	8	0
$GATT_j$	-1,05951	0,0552461	-19,18	0
WTO_{ij}	2,360694	0,1773071	13,31	0
EU_j	2,879047	0,0881016	32,68	0
$FTAs_{ij}$	-0,0243884	0,0718661	-0,34	0,734
FTA_{ij}	0,8472027	0,0715063	11,85	0
logGDP_{it}	0,1733714	0,0151195	11,47	0
logGDP_{jt}	-0,242119	0,0227981	-10,62	0
logPOP_{it}	0,199317	0,0182438	10,93	0
logPOP_{jt}	0,887618	0,0287635	30,86	0
ARG	4,961819	0,0757013	65,54	0
DEU	0,8817178	0,0726392	12,14	0
FRA	1,038225	0,0621097	16,72	0
RUS	3,149864	0,0722036	43,62	0
UKR	2,987771	0,0684083	43,68	0
USA	3,562439	0,1028564	34,64	0
ZAF	2,39344	0,0843066	28,39	0
cons	-10,37823	0,3532024	-29,38	0

Source: Auteur, Stata output.

Using the PPML estimation method, all variables are found to be significant at the 1% level. The results of the Poisson Pseudo Maximum Likelihood (PPML) estimation model reveal the importance of geo-historical variables and trade agreements in shaping global trade relations, particularly cereal trade between major African importing countries and their partners.

In the gravity model for analyzing the determinants of international trade, geographic variables traditionally play a crucial role in explaining trade flows. The effects of distance and proximity between countries are particularly revealing of the costs and opportunities associated with trade. The coefficient associated with the distance variable is negative (-0.437), which is an expected relationship, consistent with the gravity theory of trade, highlighting an inversely proportional relationship between the distance between countries and cereal imports. Conversely, the contiguity coefficient is positive (1.381), indicating that having a common border increases cereal imports, likely due to proximity and historical trade relations.

Cultural and historical factors also reveal relationships consistent with expectations. With positive effects, countries sharing an official language tend to trade more. Similarly, former colonial ties still influence trade flows, particularly cereal imports in African countries.

International trade agreements and membership in economic organizations strongly influence trade flows between countries. These agreements aim to facilitate trade by reducing tariff and non-tariff barriers, although their effects may vary across contexts and countries involved (Martey et al., 2024). The coefficient associated with the GATT membership variable (GATT_o) reveals a positive effect (0.39), confirming that countries that are members of the GATT facilitate trade through reduced trade barriers, encouraging African countries to import more. Our results align with Ayuda et al. (2024), who argues that trade agreements played a key role in the agro-food export boom experienced by Latin American countries between 1994 and 2019.

In contrast to the negative coefficient (-1.060) of the variable gatt_d (Partner countries members of GATT), which reveals that adherence to international trade agreements such as the GATT may be associated with regulations or trade policies that, while aiming to harmonize and facilitate trade, can also reduce import volumes in certain cases due to stricter standards or protectionist policies.

Countries that are signatories to the GATT or members of the WTO must comply with certain rules and trade regulations, such as quality standards, sanitary and phytosanitary requirements, and other non-tariff barriers. These can be more stringent trade rules that make trade more complex or costly, especially if exporters must comply with rigorous standards to access partner country markets. Such regulations can hinder trade and impact imports in African countries, which are seeking alternative trade partners. Complex regulations that negatively impact cereal imports may also explain the formation of the second cluster of small-scale exporting countries.

GATT and WTO members often implement more structured trade regimes, characterized by trade policies such as tariffs, quotas, and restrictions on specific goods, particularly to safeguard sensitive domestic industries. These policies can curtail import volumes and discourage trade. The adoption of protectionist policies by some member countries, aimed at shielding domestic agriculture from international competition, can have adverse effects on trade. In the realm of cereal imports, the application of protectionist measures can negatively impact trade flows. While these policies are frequently justified to support domestic agricultural development, they can also limit access to international cereal markets, especially during periods of high demand. Moreover, during food crises or periods of cereal price volatility, protectionist policies can exacerbate the situation by restricting the supply of imported cereals, thereby driving up domestic prices and compromising food security. This is particularly problematic for countries that are reliant on cereal imports to meet their domestic needs.

The negative correlation between African cereal imports and partner countries that are GATT members also points to a selection effect. Non-GATT member countries may have more open or less regulated markets, potentially leading to larger or less restricted trade flows. In contrast,

GATT member countries might be more selective in their trade partners and impose stricter market access requirements.

The positive coefficients on variables (wto_d) and (eu_d) support the theory of economic integration, indicating that bilateral or multilateral agreements reduce trade barriers, promote trade among member countries, and can indirectly boost trade with non-member countries by fostering a more stable and predictable trading environment. These findings underscore the significance of regional and international integration for enhancing the resilience of trade flows and improving food security in African countries.

Economic variables also play a key role in explaining cereal trade flows between countries, directly influencing nations' capacity to trade based on their economic size and population. These factors determine not only production and consumption but also the demand for imported cereal products.

The positive coefficients of the variables $logGDP_{it}$ and $logGDP_{jt}$ (GDP of the African country and its partner, respectively) highlight that the economic size of African countries has a positive effect on imports, consistent with the gravity model of trade. This positive relationship translates into a greater capacity to supply and a greater ability to diversify sources of cereal supply. The effect of the partner country's GDP is, however, negative (-0.242). The negative coefficient for the variable $logGDP_{jt}$, in the context of cereal imports, highlights an unexpected effect that reveals complex dynamics linked to the domestic demand of the partner country. Such a negative relationship raises several effects, varying from one country to another, including the diversification effect. Indeed, economic growth can lead to a policy of diversifying partners and developing the nature of exported products, as well as developing trade agreements with partners other than African countries whose needs remain basic and with very low added value for exporting countries.

Rising GDP in partner countries can be linked to a shift in consumer preferences toward higher value-added goods, which may be produced domestically or imported from other regions. This shift in import composition can reduce imports of cereal products, which are perceived as inferior goods. Notably, trade barriers play a prominent role among countries with stronger economies, or partner countries. To protect their agricultural sectors, these countries have imposed stricter trade barriers to limit their export volumes. This phenomenon has been particularly evident following the Russia-Ukraine conflict among major cereal exporters.

As for the standard gravity model variables, $logPOP_{it}$ and $logPOP_{jt}$ (population of African countries and their partners), the positive coefficients on both suggest that larger populations are linked to higher levels of cereal trade. Our results are consistent with Ma et al. (2025), who argue that trade networks are strongly influenced by internal network effects, such as historical or geopolitical relations between countries, as well as the economic structure of the countries involved.

Beyond the classic gravity model variables, we introduced dummy variables for certain key trading partners, including the United States, Argentina, Russia, Ukraine, South Africa,

France, and Germany. Cereal trade with partners such as Ukraine, Russia, the United States, and European countries has a direct impact on food security. Fixed effects for these partner countries have highlighted specificities in bilateral relationships that influence cereal trade flows between African countries and these partners. Fixed effects for trading partners are represented by significant coefficients associated with the dummy variables for the selected partner countries in the PPML model. These coefficients capture specific differences for each partner that influence African countries' cereal imports, taking into account unobserved characteristics that may affect trade flows. The selection of these countries was based on the historical record of their cereal trade with African countries.

The dummy variable coefficients for partner countries indicate varying levels of import intensity across different partners, with larger economies and cereal exporters being more prominent. These findings underscore the significance of bilateral relations, specific resources traded, and trade policies in shaping import flows. These fixed effects offer a perspective on the asymmetry of trade relationships and potential dependencies among countries. Three distinct clusters of coefficients were identified.

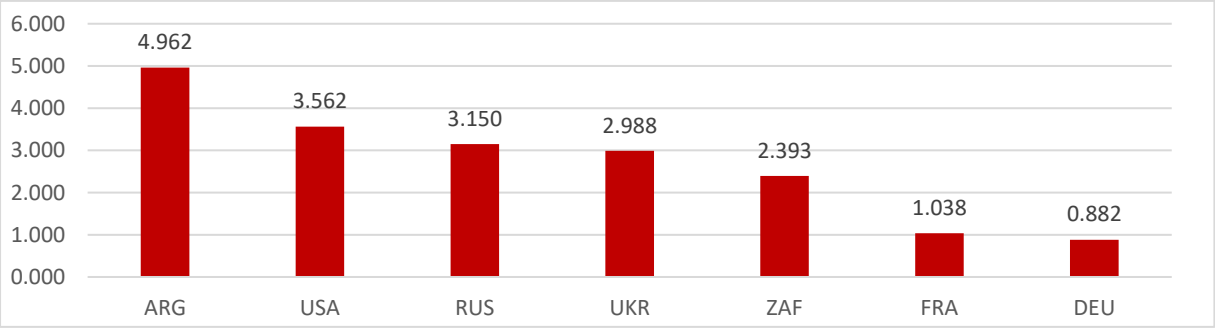

Figure 3. Coefficients of dummy variables

The first cluster, the "Large Exporters," comprises countries with the highest coefficients, particularly the United States and Argentina (USA and ARG), which are often exporters of cereals and other strategic commodities (oil, gas, etc.). This increases the intensity of trade flows. These trade relations are also influenced by bilateral or multilateral agreements facilitating exchanges. The United States, as a major exporter of corn and wheat, plays a prominent role in stabilizing global supply, especially during crises. Moreover, the impact on food security depends on US trade policies, agricultural subsidies, and fluctuations in global cereal prices.

The second cluster, "Major Crisis Exporters," includes RUS, UKR, and ZAF, with lower but still notable coefficients. South Africa's prominence as a trading partner for other African countries can be attributed to its favorable geographic location and economic development, making it a hub for trade in Southern Africa. Notably, Ukraine (UKR) and Russia (RUS), with high coefficients of 2.988 and 3.150 respectively, reflect the significance of these two countries as major suppliers of cereals, especially wheat, in global cereal supply chains, particularly for the African region heavily dependent on imports for food needs (Antras and

De Gortari, 2020). Furthermore, any disruption in cereal exports from these countries, as witnessed during the Russia-Ukraine war, can significantly impact food prices and access to cereals in importing countries. Such conflicts can jeopardize the availability and access to cereals and aggravate food insecurity in vulnerable African countries, especially in North Africa (Ujunwa et al., 2018; Subramaniam et al., 2023).

The third cluster, "Traditional European Exporters," consists of DEU and FRA. Although their coefficients are lower and the weakest compared to those of major cereal-exporting powers, France and Germany remain important cereal trading partners due to their central role in global value chains, geographic proximity, and historical ties with African countries. The significant coefficients for France (1.038) and Germany (0.882) show that they are also important partners for cereal trade with African countries. As exporters of wheat, corn, and other agricultural products, they emerge as alternative suppliers when flows from Ukraine or Russia are disrupted. However, the capacity of these countries to compensate for deficits depends on cereal availability and global market conditions. Transportation costs and price competitiveness can also influence the accessibility of imported cereals.

The results obtained in this study confirm Hypothesis H2 and underscore the critical importance of diversifying supply sources to mitigate dependency on a limited number of suppliers. This conclusion is particularly relevant in light of the trade disruptions caused by the Russia-Ukraine war, which has significantly affected international grain trade, especially wheat and corn. Marson and Saccone (2023) highlighted that this crisis has led to a significant increase in the number of undernourished individuals in developing countries, particularly those heavily reliant on a few trading partners. The Black Sea blockade and the protectionist policies implemented in response to the war have further exacerbated the disruptions and heightened the vulnerability of countries dependent on a small number of key suppliers (Adams, 2013; Nana and Ouedraogo, 2023). In this context, the diversification of import sources emerges as a crucial strategy to mitigate risks associated with trade disruptions, whether geopolitical, natural, or related to export restrictions. Therefore, food security management should adopt a proactive approach that promotes supply diversification, reduces vulnerability to external shocks, and strengthens local agricultural production capacities. Enhancing agricultural production, implementing appropriate food security policies, and securing trade agreements with multiple suppliers are essential levers to strengthen national cereal reserves and ensure a stable supply of essential foodstuffs for African countries (Kotchoni et al., 2019). Thus, our results confirm the importance of diversification and resilience in food supply chains, which are essential elements in reducing the vulnerability of developing countries to global crises. This diversification is also crucial for African countries, which are unable to ensure cereal self-sufficiency through local production, especially given the frequency of climatic and geopolitical shocks in the region. In this regard, Larson et al. (2014) highlighted the importance of strategic cereal storage strategies, particularly for wheat, to ensure food security. Unlike procyclical policies, such as those implemented by the EU with targeted subsidies, strategic storage policies are counter-cyclical, allowing for the smoothing of external crisis impacts. However, this approach requires higher investments than direct subsidies, but it represents a sustainable

solution to address food security challenges in unstable contexts.

In this context, we note that the diversification of supply sources appears as a key strategic lever to maximize the effectiveness of storage policies, enabling the creation of more robust and resilient reserves, thus contributing to the stabilization of food security in Africa.

Our findings also indicate that international cooperation is necessary for agricultural trade to be universally beneficial. Initial efforts, exemplified by the establishment of the GATT in 1947, were unsuccessful in incorporating agricultural matters into trade agreements, a shortcoming that was only addressed 50 years later with the successful conclusion of the Uruguay Round.

However, two major events of the early 21st century highlighted the shortcomings of international cooperation. The Doha Round (2001), initiated to cover a wide range of issues (agriculture, industry, services), has yet to be concluded after more than 20 years of negotiations due to a lack of inter-state cooperation. On the other hand, we note the potential benefits of implementing the Doha Round projects, which could lead to increased global food production, improved trade infrastructure, and better integration of developing countries. Economic simulations show that the conclusion of the Doha Round could generate annual global revenue gains between 93 and 163 billion dollars (Laborde and Martin, 2015; Laborde et al., 2017).

Furthermore, the 2007-2008 food price crisis, marked by soaring prices and the implementation of interventionist trade policies including export restrictions and export tax hikes, negatively affected agricultural trade. These ill-suited instruments underscored the need for more direct approaches, such as investments in agricultural supply and support programs for vulnerable households. Additionally, reforming export taxation practices, which create an asymmetry between importers and exporters, exploring agreements on consolidating existing taxes and establishing a Pigovian tax on distortive subsidies and destabilizing export policies to fund an international support fund or tax consolidation agreements to harmonize fiscal practices between importers and exporters, reducing market distortions and improving the predictability of agricultural trade, could offer solutions. Moreover, encouraging governments to prioritize monetary transfers over costly food stocks would assist households without disrupting market prices.

7. Conclusion

Our findings demonstrate that trade fragmentation, driven by geographic, economic, and political factors, directly affects food security in Africa. Regional integration and diversifying import sources are crucial for mitigating risks and enhancing the stability of food supplies across the continent. This analysis confirms that traditional factors of trade integration theory, such as geographic proximity, shared languages, free trade agreements, and membership in international organizations like the WTO or EU, are instrumental in facilitating trade. These elements promote economic integration by reducing transaction costs, harmonizing regulations, and fostering regional and global economic cooperation. The alignment of our results with economic theory deepens our understanding of how trade policies can be

optimized to foster integration and economic growth. Our findings provide clear guidance for developing trade strategies that promote deeper integration, strengthen the resilience of African economies, and stimulate sustainable growth.

This study reveals that overdependence on a limited number of major cereal exporters (e.g., the United States, Russia, or Ukraine) renders African countries vulnerable to supply disruptions and price volatility. By illuminating these asymmetrical trade relationships, our research highlights the need to diversify supply sources to mitigate the impact of external shocks (such as geopolitical or climatic crises). This necessitates the implementation of policies that facilitate the development of new trade partnerships with alternative producers and underutilized regions. In this context, strengthening regional integration is essential. Furthermore, the establishment of trade agreements within the African Continental Free Trade Area (AfCFTA) could be a pivotal factor in enhancing food security. By promoting regional cooperation and eliminating barriers to intra-African trade, countries can improve their capacity to supply food products and stabilize domestic markets (Ndao, 2024).

Historically, international trade has been instrumental in ensuring food security. However, its full potential can only be realized through enhanced multilateral cooperation. In a world grappling with climate change, geopolitical, and economic challenges, managing agricultural risks requires integrated and transparent policies. Revitalizing multilateral trade negotiations, regulating tax practices, and developing economic solutions that meet the needs of both consumers and producers are essential steps toward a stable and resilient global food supply.

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Data sharing statement

No additional data are available.

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