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Exploring trade volume dynamics in Sub-Saharan Africa through structural Gravity Theory modeling of international trade: A dynamic econometric analysis

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Abstract:

This study uses the Gravity Theory model to investigate trade volume determinants in Sub-Saharan Africa (SSA). Drawing on a comprehensive dataset spanning multiple years, the analysis examines the influence of economic, geographic, institutional, and cultural factors on regional and bilateral trade flows. The Gravity Theory model serves as the conceptual framework for estimating trade relationships based on the economic sizes of trading partners and the distance between them. This study reveals significant associations between trade volume and several factors, including GDP levels, distance, trade policies, and cultural affinities. The findings contribute to a deeper understanding of trade dynamics in SSA and have important implications for policymakers seeking to promote trade facilitation and economic development in the region. Finally, this research accentuates the relevance of Gravity Theory modeling in explaining trade volume dynamics and offers insights for future empirical and policy-oriented studies in SSA.

Keywords:

Sub-Saharan Africa, trade volume, Gravity Theory, modeling, economic factors

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1. Introduction

Sub-Saharan Africa (SSA) stands at a pivotal juncture in the global economic landscape, characterized by diverse trade dynamics amidst evolving economic, social, and political contexts. With its vast natural resources, burgeoning population, and increasing integration into the global economy, understanding the intricacies of trade within this region has garnered significant scholarly and policy attention.

Sub-Saharan Africa encompasses 46 countries with a combined population exceeding one billion and a wide array of natural resources ranging from oil and minerals to agricultural products. Despite these abundant resources, the region's trade performance has been characterized by a complex interplay of factors. Historically, SSA has relied heavily on primary commodity exports, leading to vulnerability to global commodity price fluctuations and limited diversification of its export base (United Nations Conference on Trade and Development [UNCTAD], 2020). Moreover, intra-regional trade within SSA remains relatively low compared to other regions, accounting for only 16 percent of total trade (African Development Bank Group, 2019).

Analyzing trade volume in Sub-Saharan Africa holds significant importance for several reasons. Firstly, trade volume is a critical indicator of regional economic integration and development. Understanding the patterns and determinants of trade volume provides insights into the extent of market access, competitiveness, and structural transformation (World Bank, 2019). Secondly, trade volume analysis aids in identifying potential barriers to trade, such as tariffs, non-tariff measures, and logistical challenges, which impede the flow of goods and services across borders (International Monetary Fund [IMF], 2021). Thirdly, examining trade volume dynamics can shed light on the effectiveness of regional integration initiatives, trade policies, and infrastructure investments to promote intra-regional trade and enhance global competitiveness (African Development Bank Group [AfDB], 2020).

The Gravity Theory model, first developed in physics, has been widely adopted in economics to explain bilateral trade flows between countries. The model posits that the trade volume between two countries is positively correlated with their economic sizes (measured by GDP) and inversely related to the distance between them (Tinbergen, 1962). Additionally, the model incorporates other factors, such as geographical proximity, cultural similarities, and institutional arrangements, which influence trade patterns (Anderson & van Wincoop, 2003). Similarly, Gravity Theory has been shown to provide a robust framework for analyzing trade volume by

empirically identifying the determinants that shape trade relationships and estimating their respective effects. Hence, this research seeks to explore Sub-Saharan Africa's trade dynamics by employing the structural Gravity Theory model to analyze the determinants of trade volume in Sub-Saharan Africa. Finally, once the model's functional form is determined, appropriate econometric techniques will be used to estimate the parameters and test the model specifications' robustness.

2. Literature review

Trade volume in Sub-Saharan Africa (SSA) has been a subject of significant scholarly interest due to its implications for economic development, regional integration, and poverty reduction. Despite abundant natural resources and a growing consumer market, SSA's trade landscape is complex and challenging. Historically, the region has relied heavily on primary commodity exports, such as oil, minerals, and agricultural products (UNCTAD, 2020). However, this export structure has made SSA vulnerable to external shocks, particularly fluctuations in global commodity prices. In recent years, efforts have been made to diversify SSA's export base and promote intra-regional trade. Regional economic communities such as the Economic Community of West African States (ECOWAS) and the East African Community (EAC) have implemented trade liberalization policies and infrastructure projects to facilitate cross-border trade (African Development Bank Group, 2019). Nevertheless, intra-regional trade within SSA remains relatively low compared to other regions, accounting for only 16 percent of total trade (AfDB, 2020).

The Gravity Theory model is a cornerstone in analyzing international trade patterns. Initially developed in physics, the model was adapted to economics by Jan Tinbergen (1962) and has since been widely applied in trade literature. The Gravity Theory model's core premise is that the trade volume between two countries is positively correlated with their economic sizes (measured by GDP) and inversely related to the distance between them (Anderson & van Wincoop, 2003). The model further incorporates factors influencing trade flows, such as geographic proximity, cultural similarities, and institutional arrangements (Helpman et al., 2008). Gravity Theory provides a robust framework for understanding bilateral trade relationships and has been instrumental in explaining trade patterns across diverse contexts.

Application of Gravity Theory in Sub-Saharan Africa

In the context of Sub-Saharan Africa, Gravity Theory has been applied to analyze trade dynamics and identify determinants of trade flows. Studies have explored the role of geographic factors, economic conditions, institutional quality, and cultural ties in shaping regional trade relationships (Disdier & Head, 2008). Researchers have also investigated the impact of regional integration initiatives on intra-regional trade, finding mixed results regarding the effectiveness of such efforts (Geda & Handa, 2017). Gravity Theory modeling has provided valuable insights into the determinants of trade volume in SSA, contributing to a better understanding of the region's trade dynamics and informing policy interventions to promote economic growth and development.

Determinants of Trade Volume in Sub-Saharan Africa

Several determinants influence trade volume in Sub-Saharan Africa, encompassing economic, geographic, institutional, and cultural factors. Economic factors such as GDP growth, income levels, and trade openness significantly shape regional trade patterns (IMF, 2021). Countries with higher economic development and market access tend to engage in more significant trade volumes.

Geographic factors, including distance, transport costs, and landlocked status, also affect trade flows in SSA (Crespo Cuaresma et al., 2017). Landlocked countries face higher transportation costs and logistical challenges, impeding their participation in international trade.

Institutional factors such as trade policies, regulatory frameworks, and infrastructure development considerably influence trade volume in SSA (African Union, 2012). Weak institutional capacity and governance issues can hinder trade facilitation efforts and undermine the competitiveness of SSA economies. Cultural factors, such as language, colonial ties, and historical linkages, contribute to trade relationships within SSA (Nunn, 2007). Shared cultural backgrounds and historical connections often facilitate trade between countries, while linguistic barriers and colonial legacies may act as impediments. While existing studies have contributed valuable insights into the determinants of trade volume in Sub-Saharan Africa, several limitations and areas for further research exist. Firstly, there is a need for more comprehensive data and rigorous econometric techniques to accurately estimate the parameters of Gravity Theory models in SSA contexts (Keller & Shiue, 2008). Secondly, many studies focus primarily on aggregate trade flows, overlooking the heterogeneity and sectoral composition of trade within the region (Ogundipe et al., 2018). Future research could explore sector-specific trade dynamics and the role of value chains in driving SSA trade volume.

Furthermore, the impact of non-tariff barriers, informal trade, and illicit financial flows on trade volume still needs to be studied in the SSA context (UNCTAD, 2020). Addressing these gaps would provide a more nuanced understanding of the factors shaping regional trade relationships and inform policy interventions to enhance trade facilitation and promote inclusive growth.

Theoretical framework

Gravity Theory, initially developed in physics and later adapted to economics by Jan Tinbergen (1962), provides a conceptual framework for understanding bilateral trade flows between countries (Tinbergen, 1962). The theory posits that the trade volume between two countries is positively correlated with their economic sizes (measured by GDP) and inversely related to the distance between them (Anderson & van Wincoop, 2003). Additionally, Gravity Theory incorporates other factors, such as geographic proximity, cultural similarities, and institutional arrangements, influencing trade patterns (Helpman et al., 2008). The model's intuitive appeal lies in its ability to capture the gravitational pull between trading partners, with larger economies exerting a more substantial influence on trade flows.

Adaptation of Gravity Theory to Sub-Saharan Africa

Adapting Gravity Theory to Sub-Saharan Africa involves recognizing the region's unique economic, geographic, institutional, and cultural characteristics. While the core principles of Gravity Theory remain applicable, several adjustments are necessary to account for specific factors shaping trade dynamics in SSA. For instance, the distance variable may need to be disaggregated to reflect the region's diverse transportation networks and infrastructure challenges (African Development Bank Group, 2019). Moreover, institutional factors such as trade policies, regulatory frameworks, and governance structures vary widely across SSA countries and require careful consideration in Gravity Theory modeling (AfDB, 2020). Cultural factors, including linguistic diversity, historical ties, and social networks, also significantly shape trade relationships within SSA (Nunn, 2007). Therefore, adapting Gravity Theory to SSA involves incorporating these contextual nuances into the modeling framework to enhance its explanatory power and predictive accuracy.

Hypotheses development

Geographic Factors: Hypothesis 1: Geographic proximity positively influences trade volume between countries in Sub-Saharan Africa. Countries that share borders or are in close

geographic proximity are expected to engage in higher levels of trade due to lower transportation costs and greater accessibility.

Economic Factors: Hypothesis 2: Economic size positively affects trade volume in Sub-Saharan Africa. Larger economies with higher GDPs are expected to trade more with regional and global partners, reflecting their more significant market potential and purchasing power.

Institutional Factors: Hypothesis 3: Institutional quality positively influences trade volume in Sub-Saharan Africa. Countries with more transparent, efficient, and predictable institutional frameworks are expected to attract higher levels of trade and investment, fostering greater economic integration and growth.

Cultural Factors: Hypothesis 4: Cultural affinity positively influences trade volume in Sub-Saharan Africa. Shared linguistic ties, historical legacies, and cultural similarities are expected to facilitate trade relationships between countries, enhancing trust and reducing transaction costs.

Consequently, the theoretical framework based on Gravity Theory provides a robust foundation for analyzing trade volume in Sub-Saharan Africa. Developing these hypotheses aims to clarify the complex determinants shaping regional trade dynamics by incorporating geographic, economic, institutional, and cultural factors.

3. Methodology

The econometric method for this gravity trade model has become a foundation in international trade research, providing robust frameworks for analyzing trade flows between countries. This approach leverages regression techniques to quantify the effects of economic size and distance on bilateral trade, incorporating variables such as GDP, population, and trade barriers. Thus, the study explores advanced econometric strategies to address common challenges in gravity trade analysis and improve the accuracy of trade flow predictions.

Data sources

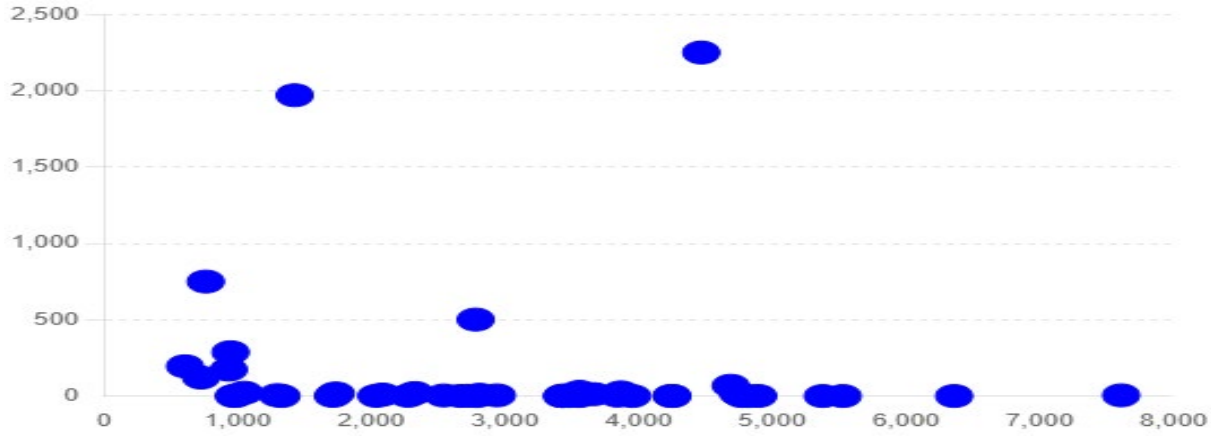
Trade data for Sub-Saharan Africa (SSA) were sourced from the World Bank (2019), the International Monetary Fund (2021), and the United Nations Conference on Trade and Development (2020). The dataset spans 1990–2022 and is structured as a panel dataset with annual observations across 46 SSA countries. These sources provide comprehensive and

reliable datasets on bilateral trade flows, including merchandise trade, services trade, and trade in intermediate goods. The study covers a period typically spanning multiple years to capture long-term trade dynamics and trends.

Analysis of Export/Import Values and Distance with Nigeria as the Center of Gravity

The scatter plot presented in Figure 1 illustrates the relationship between export values and the distance from Nigeria to its trading partners. The analysis focuses on Nigeria as the center of gravity, depicting the export values in millions of USD against the distance in kilometers. The plot reveals that South Africa, despite being one of the farthest trading partners, has the highest export value of 2250 million USD. Conversely, Côte d'Ivoire and Togo, which are relatively closer, also show significant export values of 1970 million USD and 750 million USD, respectively. This distribution indicates that trade volume does not solely depend on geographic proximity but also on other economic and strategic factors.

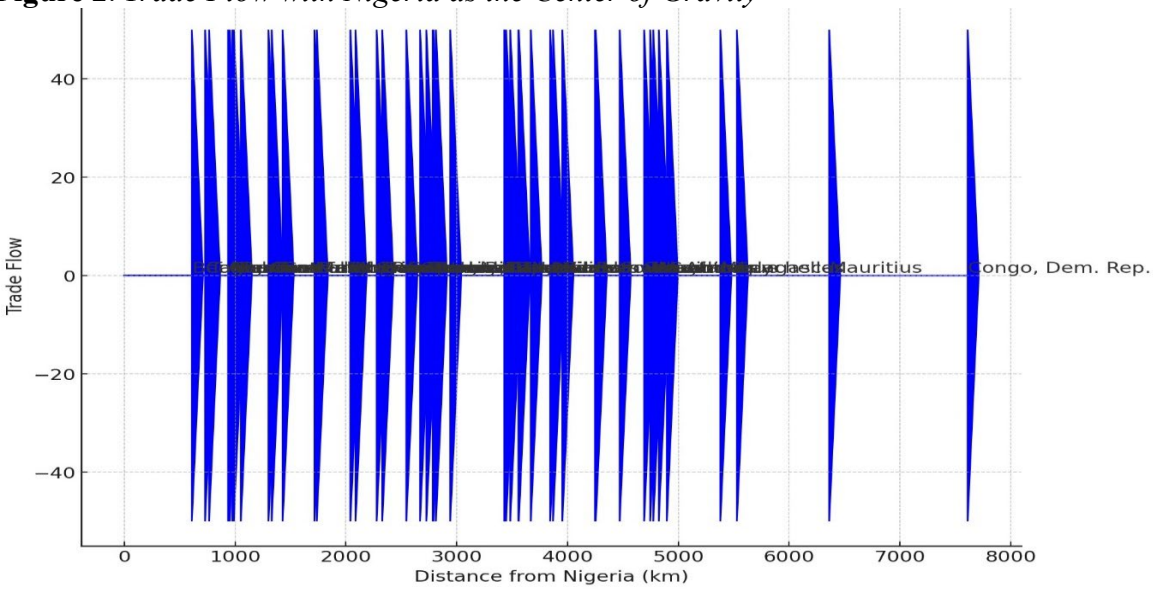
Figure 1. Export Value vs Distance for Nigeria



Source: UNCTAD (2022) data and Author's estimation using SPSS

The trade connectivity diagram illustrates Nigeria as the central hub of trade relations with various countries in Sub-Saharan Africa for 2022, as shown in Figure 2. This highlights Nigeria's extensive trade links, underscoring its pivotal role in the regional economy. The thickness of the edges represents the volume of exports, reflecting the intensity of trade activities between Nigeria and its partners. Countries like Angola, Benin, and Burkina Faso emerged as significant trading partners, with considerable export volumes directed toward Nigeria. It shows Nigeria's economic integration within Sub-Saharan Africa, emphasizing its strategic importance in trade dynamics.

Figure 2. *Trade Flow with Nigeria as the Center of Gravity*



Source: UNCTAD (2022) data and Author's estimation using SPSS

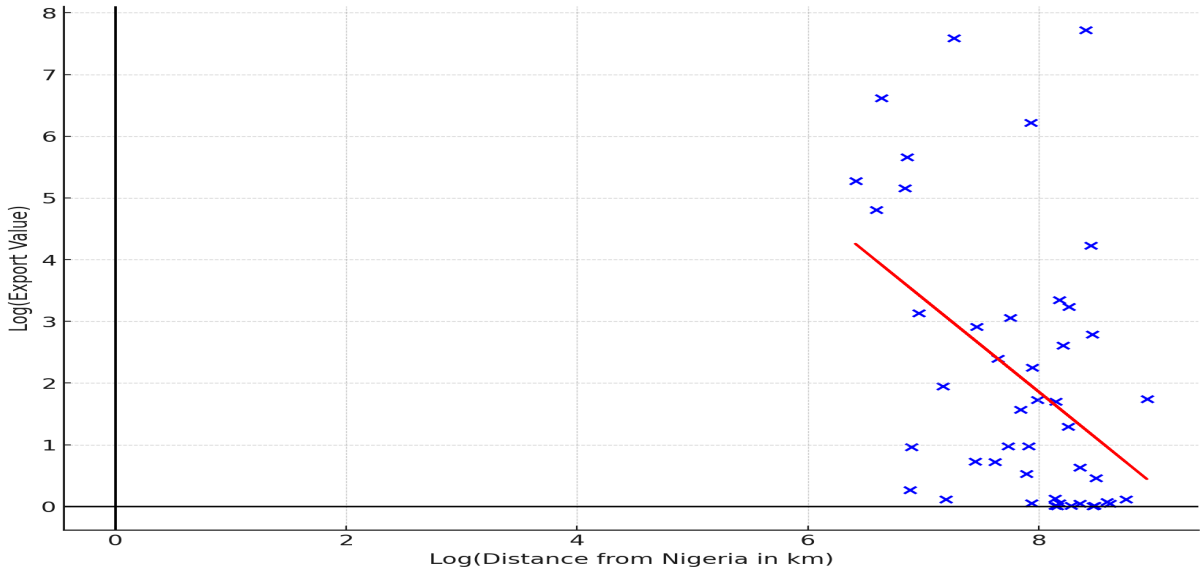
Furthermore, log-transformed export values were used against the log-transformed distances from Nigeria, with Nigeria serving as the central node in the trade network, as shown in Figure 3. The plot reveals a negative correlation between the distance and the export values, indicating that the export value tends to decrease as the distance from Nigeria increases. This analysis underscores the importance of regional proximity in shaping Nigeria's trade network and offers a quantitative foundation for policymakers and economists to develop strategies that leverage geographic advantages.

Variable Selection

The dependent variable of interest is trade volume, representing the total value of goods and services exchanged between countries within Sub-Saharan Africa. Trade volume data was measured regarding imports, exports, or total trade (sum of imports and exports). They were adjusted for inflation and currency fluctuations to ensure comparability. The independent variables include a range of factors that influence trade volume in Sub-Saharan Africa. These variables are categorized into: A. Geographic Factors – distance between trading partners, contiguity (sharing a border), and landlocked status; B. Economic Factors – GDP of trading partners, trade openness (measured as the ratio of trade to GDP), and income levels; C. Institutional Factors – trade policies (tariff and non-tariff barriers), ease of doing business index,

and infrastructure quality (e.g., transport and logistics infrastructure); D. Cultural Factors – language similarity, colonial ties, and historical trade relationships.

Figure 3. *Export Value vs Distance for Nigeria*



Source: UNCTAD (2022) data and Author's estimation using SPSS

Model Specification

The gravity model of trade, widely used in international economics, posits that bilateral trade flows between two countries are positively related to their economic sizes and inversely related to the geographic distance between them. This analogy to Newton's law of gravitation intuitively encapsulates the effects of economic mass (GDP) and distance on trade and effectively incorporates various other resistances to trade.

Mathematically, the gravity equation for trade between two countries, i and j, can be expressed as follows:

$$T_{ij} = G\frac{Y_i Y_j}{D_{ij}^{\alpha}} \quad \text{..... (1)}$$

Here, T_{ij} represents the trade flow from country i to country j, Y_i and Y_j are the GDPs of countries i and j, respectively, D_{ij} is the distance between the two countries, α is a parameter typically more significant than zero that indicates the elasticity of trade flow to distance, and G is a constant encapsulating all other factors affecting trade such as trade agreements and transportation costs. To estimate the parameters of this model, a logarithmic transformation is commonly applied, simplifying the empirical estimation:

$$\ln(T_{ij}) = \ln(G) + \ln(Y_i) + \ln(Y_j) - \alpha \ln(D_{ij}) + \epsilon_{ij} \quad \text{..... (2)}$$

$$\ln(T_{ij}) = \ln(G) + \beta_1 \ln(GDP_i) + \beta_2 \ln(GDP_j) - \beta_3 \ln(D_{ij}) + \epsilon_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where T_{ij} represents the trade volume between country i and country j, GDP_i and GDP_j denote the GDP of the respective countries, D_{ij} is the distance between them, α is the intercept term, β_1 and β_2 are the coefficients measuring the elasticity of trade volume with respect to GDP, β_3 represents the coefficient measuring the elasticity of trade volume with respect to distance, and ϵ_{ij} is the error term capturing unobserved factors affecting trade volume. Where ϵ_{ij} is an error term capturing unobserved factors, this linear form is conducive to regression analysis, allowing researchers to empirically test the significance and size of the hypothesized effects of GDP and distance on bilateral trade flows.

Researchers commonly employ multiple dummy variables to represent bilateral trade participation. Empirical investigations often substitute trade costs with bilateral distance. However, customary practice also involves integrating supplementary variables. These country dummies, binary variables (0,1), encompass all nations within an Economic Group like the World Trade Organization (WTO), facilitating control over a country's comprehensive import/export activities.

$$\ln(T_{ij}) = \ln(G) + \beta_1 \ln(GDP_i) + \beta_2 \ln(GDP_j) - \beta_3 \ln(Distance_{ij}) + \beta_4 Onein + \beta_5 Bothin + \beta_6 Nonein + \epsilon_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The gravity equation was estimated using panel data regression techniques, such as the fixed effects model or the random effects model, depending on the nature of the data and the presence of time and country-specific effects. Robust standard errors accounted for heteroscedasticity and serial correlation in the data.

Estimation Techniques

The gravity equation was estimated using ordinary least squares (OLS) regression analysis, controlling for relevant covariates and potential confounding variables. Panel data techniques, such as the Hausman test for endogeneity, were used to address potential biases and model specification issues. The robustness of the estimated results was assessed through various sensitivity analyses and robustness checks. Additionally, diagnostic tests such as the Breusch-Pagan test for heteroscedasticity and the Durbin-Watson test for autocorrelation were performed

to ensure the validity of the regression results. Thus, the research methodology outlined above provides a systematic approach for analyzing the determinants of trade volume in Sub-Saharan Africa using the gravity model framework. By collecting relevant data, selecting appropriate variables, specifying the model, and employing robust estimation techniques, the study aims to generate empirical insights into the factors driving regional trade dynamics.

One common approach is to assume that the variance of the error terms is a function of the predictors. A simple model might assume that the variance is proportional to one of the critical variables, such as the GDPs.

$$\epsilon_{ij} \sim N(0, \sigma^2 \times f(\text{variables})) \quad \ldots\ldots (5)$$

where f(variables) could be:

$$f(\text{variables}) = \exp[\gamma_1 \ln(GDP_i) + \gamma_2 \ln(GDP_j)] \quad \ldots\ldots (6)$$

The mean equation:

$$\ln(T_{ij}) = \ln(G) + \beta_1 \ln(GDP_i) + \beta_2 \ln(GDP_j) - \beta_3 \ln(Distance_{ij}) + \beta_4 Onein + \beta_5 Bothin + \beta_6 Nonein + \epsilon_{ij} \quad \ldots\ldots (7)$$

while the variance equation:

$$\text{Var}(\epsilon_{ij}) = \exp[(\gamma_1 \ln(GDP_i) + \gamma_2 \ln(GDP_j)] \quad \ldots\ldots (8)$$

The model is estimated using specialized econometrics and maximum likelihood estimation methods, where you simultaneously estimate the parameters of the mean and variance equations.

Thus, by explicitly modeling the variance of the error terms, this approach helps address heteroscedasticity, improving the efficiency of the parameter estimates and the reliability of the inference drawn from the model.

In the log-linear regression models (Models 3 and 4), the following variables were log-transformed to allow for elasticity interpretation and to linearize multiplicative relationships: GDP of exporter countries**,** GDP of importer countries**,** and geographical distanc**e**. These transformations were applied to reduce heteroscedasticity and align with the gravity model's theoretical structure.

4. Results and Discussion

The descriptive statistical analysis in Table 1 includes data on several variables relevant to economic and geographic factors affecting 46 countries. The variables analyzed are export volume (export), Gross Domestic Product (GDP) of exporter countries (GDP exporter), GDP of importer countries (GDP importer), and the distance between trading partners (distance).

Export Volume: The export volume data exhibits a broad range, with a minimum of 0 and a maximum of 2,250 units, suggesting a significant disparity in export capabilities among the countries. The mean export volume is relatively low at 141.49 units, with a standard deviation of 65.97 units, indicating moderate variability in the data. The skewness is positively high (4.064), reflecting that the distribution is heavily right-skewed, with most countries having lower export volumes and a few outliers with very high exports. This is further supported by a high kurtosis value of 16.501, indicating a peak distribution.

GDP of Exporter Countries: Exporter countries show no variation, as all values are recorded at 477 units. This could suggest a placeholder or an error in data recording, as it is implausible for all observed countries to have identical GDP values.

GDP of Importer Countries: The GDP of importer countries ranges from 0.51 to 406 units, with a mean of 33.84 units and a standard deviation of 9.47 units, reflecting less variability compared to export volumes. The high skewness (4.635) and kurtosis (25.673) indicate a distribution similar to that of export volumes, with most countries having low GDP values and a few outliers with higher GDP values.

Distance Between Trading Partners: The distances between trading partners range from 609.28 to 7,610.68 km, with a mean of 3,055.22 km and a significant standard deviation of 1,639.18 km. This suggests a wide variation in the geographical distances across trading relationships. The distribution has a skewness close to zero (-.074), indicating a reasonably symmetrical distribution around the mean. The negative kurtosis (-.074) suggests a flatter distribution compared to a standard normal distribution.

Table 1. *Descriptive statistics*

	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Export	2250	0	2250	141.49 (65.97)	447.43	200194	4.064 (0.35)	16.501 (0.688)
GDP Importer	405.49	0.51	406	33.838 (9.469)	64.224	4124.7	4.635 (0.35)	25.673 (0.688)
Distance	7001.4	609.28	7610.7	3055.2 (241.7)	1639.2	3E+06	0.457 (0.35)	-0.074 (0.688)

Note: *Numbers in parentheses are Std. Error.*

Source: Author's calculation based on IMF/World Bank data (2022) using SPSS

The descriptive statistics indicate significant variability in export volumes and geographical distances, with economic characteristics like GDP showing unusual consistency or high variability patterns. The analysis underscores the economic disparities and diverse geographical dynamics among the countries studied. Further investigation may be required to understand the implications of these variables on trade and economic relationships more thoroughly. The key findings of Table 1 present a comprehensive understanding of the data's implications in the context of economic and geographic analyses. Based on the descriptive analysis in Table 1, the findings provide insight into the relationships among various economic and geographic variables across 46 countries.

Correlational matrix

The correlational analysis under Table 2 examined several relationships between export volume, Gross Domestic Product (GDP) of exporter and importer countries, geographical distances, and other dummy variables. Onein, Bothin, and Nonein capture the WTO agreement. The correlation coefficient between export volume and GDP of importer countries is significantly positive ($r = .683$, $p < .001$, $N = 46$), suggesting a strong and significant positive relationship.

Table 2. *Correlation matrix*

	export	GDP exporter	GDP importer	Distance	Onein	Bothin	Nonein
export	1	.[a]	.683[**] (<.001)	-0.106 (0.482)	.[a]	0.134 (0.374)	.[a]
GDP exporter	.[a]	. 1	.[a]	.[a]	.[a]	.[a]	.[a]
GDP importer	.683[**] (<.001)	.[a]	1	0.074 (0.625)	.[a]	0.16 (0.288	.[a]
Distance	-0.106 (0.482)	.[a]	0.074 (0.625)	1	.[a]	-0.123 (0.416)	.[a]
Onein	.[a]	.[a]	.[a]	.[a]	1	.[a]	.[a]
Bothin	0.134 (0.374)	.[a]	0.16 (0.288)	-0.123 (0.416)	.[a]	1	.[a]
Nonein	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	1

** *Correlation is significant at the 0.01 level (2-tailed).*
a. *Cannot be computed because at least one of the variables is constant.*

Source: Author's calculation based on UNCTAD (2022) data using SPSS

This indicates that the higher GDP of importing countries is associated with increased export volumes, which could reflect greater economic capacity to import goods. However, the correlation between export volume and geographical distance is slightly negative (r = -.106, p = .482, N = 46), though not statistically significant. This suggests that distance might have a minor inhibitory effect on exports, but the effect is not robust enough to be statistically meaningful. The relationship between the GDP of importing countries and distance shows a slight positive correlation (r = .074, p = .625, N = 46), but this is also not statistically significant, indicating that the geographical distance has little to no effect on the economic size of importing countries. The variables Onein, Bothin, and Onein WTO agreement do not correlate significantly with the other studied variables.

Hence, the most notable result from this correlational analysis is the strong and significant positive correlation between the export volumes and the GDP of importing countries. This relationship underscores the economic interdependence between nations, where more prosperous nations tend to import more goods. The other correlations, particularly those

involving geographical distance and Onein, Bothin, and Nonein, do not show significant or strong relationships, suggesting that factors other than distance might play more critical roles in influencing economic activities like exports. These findings contribute to understanding the factors affecting trade and economic exchanges between countries, highlighting the importance of economic capacity over geographical proximity in driving trade volumes.

Model 1: Analysis of Regression without Log Transformation and No Dummy Variables

The regression analysis outlined in Table 3 investigates the influence of geographical distance and the GDP of importer countries on export volumes, using data from 46 countries. The regression model provides insights into how these factors quantitatively affect exports. This narrative dissects the vital statistical outputs and their implications, as presented in Table 3. The regression model demonstrates a moderately strong relationship between the predictors (distance and GDP of importer countries) and the dependent variable (export volume), with an R^2 value of .701. The ANOVA results show that the regression model is statistically significant ($F(2, 43) = 20.814$, $p < .001$). This significant F-test indicates that the model is a good fit for the data and that at least one of the predictors significantly affects the export volumes.

Table 3. *Regression coefficients without log transformation and no dummy variables*

Predictor	Coefficients	Std. Error	Beta	t	Sig.
(Constant)	109.259	104.365		1.047	0.301
GDP Importer	4.843	0.759	0.695	6.377	<.001
Distance	-0.043	0.03	-0.158	-1.448	0.155
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Regression	4431322	2	2215661	20.814	<.001
Residual	4577401	43	106451		
Total	9008723	45			

Breusch-Pagan test ($\chi^2 = 3.55$, $p = .616$), and Durbin-Watson 2.18

Source: Author's calculation based on UNCTAD (2022) data using SPSS

Diagnostic Tests

The GDP of the exporter country and membership in trade agreements were not statistically significant predictors of trade value. Diagnostic tests indicated no significant heteroscedasticity, as evidenced by a Breusch-Pagan test ($\chi^2 = 3.55$, $p = .616$), and the Durbin-Watson statistic was 2.18, suggesting no substantial autocorrelation in the residuals. These results indicate that the

GDP of the importer is a strong predictor of trade value, while distance and the other variables appear to have less impact.

The coefficient for GDP of importer countries is 4.843, with a standard error of .759. This positive coefficient is significant (t = 6.377, p < .001), suggesting that as the GDP of importer countries increases, so does the export volume from the exporting country. The standardized coefficient Beta = .695 indicates that the GDP of importer countries strongly predicts export volume, having a substantial positive effect. The coefficient for distance is -.043, with a standard error of .030. This negative coefficient, though not statistically significant (t = -1.448, p = .155), suggests a minor decrease in export volumes as the distance between trading partners increases. The intercept of the model is 109.259 with a standard error of 104.365, which is not statistically significant (t = 1.047, p = .301). This suggests that when the importer's GDP and distance are zero, the expected export volume would be around 109.259. However, this scenario is practically implausible and thus of limited interpretative value. The regression analysis highlights that the GDP of importer countries is a significant and robust predictor of export volumes, confirming economic intuition that countries with larger economies tend to import more due to greater demand. In contrast, the effect of geographical distance, while intuitively expected to be an inhibitor of trade, does not significantly impact this model, suggesting that other factors such as trade agreements, logistical capabilities, or political relationships might mitigate the effect of physical distance on trade.

Model 2: Analysis of regression without log transformation with dummy variables

The regression analysis in Table 4 enhances the previous model by including dummy variables to account for additional categorical factors. This model examines the impact of the GDP of importer countries, geographical distance, and the presence of both countries in a specific economic group (represented by the dummy variable Bothin) on export volumes. The analysis is based on data from 46 countries. Table 4 achieves an R^2 value of .701, indicating that about 70.1percent of the variability in export volumes can be explained through the predictors used in the model. The standard error of the estimate is 330.13, which measures the typical distance that the observed values fall from the regression line. The ANOVA for this regression model indicates a significant fit (F(3, 42) = 13.554, p < .001), confirming that the model significantly predicts the dependent variable and that the included predictors collectively affect export volumes. The coefficient for the GDP of importer countries remains significant and robust (B = 4.838, SE = .780, t = 6.204, p < .001). This suggests a strong positive relationship between

the GDP of importing countries and export volumes, consistent with the first model, and underscores the economic capability of importing countries to purchase more goods.

Table 4. *Regression coefficients without log transformation with dummy variables*

Predictor	Coefficients	Std. Error	Beta	t	Sig.
(Constant)	105.082	164.155		.640	.526
GDP Importer	4.838	.780	.695	6.204	<.001
Distance	-.043	.030	-.157	-1.413	.165
BothinWTO	4.605	138.582	.004	.033	.974
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Regression	4431322	2	1477147.428	13.554	<.001
Residual	4577401	43	108982.879		
Total	9008723	45			

Source: Author's calculation based on UNCTAD (2022) data using SPSS

Similarly, the coefficient for distance is negative (B = -.043, SE = .030), indicating that greater distances might slightly reduce export volumes. However, this effect is not statistically significant (t = -1.413, p = .165), suggesting that distance may not be a solid deterrent to exporting under the conditions and variables studied. The coefficient for the dummy variable Bothin WTO agreement is 4.605, with a standard error of 138.582. The effect of this variable is not significant (t = .033, p = .974), indicating that the membership of both countries in a specific economic group does not have a statistically significant impact on export volumes in this model.

The intercept is 105.082 with a standard error of 164.155, which is not statistically significant (t = .640, p = .526). This value suggests the expected export volume when all predictor variables are at zero, which serves as a baseline in the regression equation. Model 2 reaffirms the significant influence of the GDP of importing countries on export volumes and continues to show that geographical distance has a minimal, non-significant negative impact on exports. They have contributed little to the model, including the dummy variable for economic group membership (both in), indicating that such membership does not play a critical role in determining export volumes for this data set. Future analyses could consider different categorical factors or interactions between variables to better understand the nuances of trade dynamics.

In Models 3 and 4, logarithmic transformations were applied to GDP (exporter and importer) and distance. This approach enables the interpretation of the coefficients as elasticities, which is consistent with the multiplicative form of the gravity equation.

Model 3: Analysis of regression with log transformation and with dummy variables

Model 3 was estimated without a constant to align with the multiplicative nature of the gravity model, where trade flows are assumed to arise solely from the interaction of GDP, distance, and institutional factors. This specification ensures that the regression equation reflects the core theoretical formulation of the gravity model, assuming that trade volume is zero when the determinants are absent. It allows for a purer interpretation of the elasticities and avoids overparameterization in the log-log framework. Table 5 introduces logarithmic transformations to the variables and includes dummy variables in the regression analysis to examine their impact on the log of export volumes. The analysis uses log transformations for the GDP of importer countries and distance, alongside the dummy variable for both countries being in an economic group (both in). Model 3 achieves an R^2 value of .714, and the standard error of the estimate is 1.091, indicating the average distance the data points fall from the regression line.

Table 5. *Regression coefficients with log transformation and with dummy variables*

Predictor	Coefficients	Std. Error	Beta	t	Sig.
(Constant)	5.742	5.742		2.716	.010
Log GDP Importer	1.047	1.047	.459	3.935	<.001
Log Distance	-2.083	-2.083	-.387	-3.541	<.001
BothinWTO	.735	.735	.177	1.514	.138
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Regression	52.014	3	17.338	14.566	<.001
Residual	49.993	42	1.190		
Total	102.006	45			

Source: Author's calculation based on UNCTAD (2022) data using SPSS

The ANOVA table shows a significant regression model fit ($F(3, 42) = 14.566$, $p < .001$), confirming that the model significantly predicts the dependent variable and that the relationships modeled are statistically meaningful. The coefficient for importer countries' GDP logarithm is significantly positive (B = 1.047, SE = .266, $t = 3.935$, $p < .001$). This indicates a strong positive effect, meaning that as the economic size of importer countries increases (in logarithmic terms), so does the logarithm of export volumes. This relationship is the strongest

among the predictors, with a standardized coefficient (Beta) of .459. The coefficient for the logarithm of distance is significantly negative (B = -2.083, SE = .588, t = -3.541, p < .001). This significant finding suggests that greater distances negatively impact export volumes when considered on a logarithmic scale. The substantial relationship, with a standardized coefficient of -.387, indicates that distance is crucial in decreasing export volumes.

Both countries in an economic group (BothinWTO)

The dummy variable BothinWTO agreement has a coefficient of .735 with a standard error of .485. This result is not statistically significant (t = 1.514, p = .138), suggesting that being in the same economic group does not significantly affect the log of export volumes under the conditions of this model. The Beta value of .177 shows a minor positive contribution when significant. The intercept of the model is 5.742 with a standard error of 2.114, which is significant (t = 2.716, p = .010). This value represents the expected log of export volume when all predictor variables are zero.

Model 3, incorporating logarithmic transformations and the dummy variable for economic group membership, provides a nuanced understanding of how the economic size and distance influence export volumes on a logarithmic scale. The significant negative effect of distance highlights the challenges that geographical barriers pose in trade. In contrast, the substantial positive impact of GDP underscores the importance of economic capacity in driving exports. Although not significant, the dummy variable suggests that other factors associated with economic group membership might require further exploration to understand their impact on trade. This model offers valuable insights for policymakers and businesses looking to optimize trade strategies in a global context.

Comparison with previous studies

These results align with findings from Disdier and Head (2008), who highlighted the persistent influence of distance on trade flows, even after accounting for institutional and economic similarities. Similar to their study, our Model 3 confirms that distance remains a statistically significant barrier to export volume in Sub-Saharan Africa, despite regional integration efforts. Furthermore, Geda and Handa (2017) emphasized the limited success of trade agreements like COMESA and ECOWAS in significantly boosting intra-African trade. Our analysis corroborates this finding, as WTO membership and economic group dummies BothinWTO did

not yield statistically significant impacts on trade volume in our models. This underlines the critical role of non-tariff barriers and implementation gaps, rather than membership alone.

Conversely, the finding that the GDP of importing countries has a robust, positive influence on export volume builds on insights by Helpman, Melitz, and Rubinstein (2008), who stressed the gravity model's sensitivity to market size and heterogeneity. Our study extends this insight into the SSA context, providing contemporary empirical support using a panel data framework from 1990 to 2022.

Model 4: Log-log regression with dummy variables and no constant

Table 6 presents the results of a log-log regression model estimated without a constant term, incorporating both economic and institutional predictors. This specification allows for a direct interpretation of the elasticity of trade volume for each explanatory variable, aligning closely with the multiplicative form of the structural gravity model. The coefficient for log GDP of exporter countries is statistically significant ($\beta = 1.886$, $t = 2.716$, $p = 0.01$), suggesting that a 1 percent increase in the economic size of the exporting country is associated with approximately a 1.89 percent increase in trade volume, holding other variables constant. Similarly, the log GDP of importer countries remains a robust and highly significant predictor ($\beta = 1.046$, $t = 3.93$, $p < 0.001$), reinforcing that larger markets drive greater trade flows in the region.

In contrast, log distance carries a statistically significant negative coefficient ($\beta = -2.087$, $t = -3.537$, $p = 0.001$), indicating that a 1 per cent increase in distance between trading partners reduces trade volume by approximately 2.09 percent. This finding confirms the persistent friction of distance in Sub-Saharan Africa's trade relationships, despite technological and logistical advancements. Among the institutional variables, the OneinWTO dummy (where at least one of the trading partners is a WTO member) is significant ($\beta = 0.704$, $t = 2.716$, $p = 0.01$), implying that partial WTO participation may enhance trade volume. However, BothinWTO (both countries being WTO members) is not statistically significant ($\beta = 0.734$, $t = 1.511$, $p = 0.138$), suggesting that mutual membership does not necessarily lead to a measurable increase in trade volume under current trade conditions. As expected, the NoneinWTO category served as the reference group and shows zero effect due to the model's construction.

Table 6. *Regression coefficients with log transformation, dummy variables without a constant*

Predictor	Beta	Std. Error	t	Sig.
Log GDP Exporter	1.886	0.695	2.716	0.01
Log GDP Importer	1.046	0.266	3.93	<0.001
Log Distance	-2.087	0.59	-3.537	0.001
OneinWTO	0.704	0.259	2.716	0.01
BothinWTO	0.734	0.486	1.511	0.138
NoneinWTO	0	0	-	-

Source: Author's calculation based on UNCTAD (2022) data using SPSS

Diagnostic tests

Heteroscedasticity was assessed using the Breusch-Pagan test, which did not indicate significant heteroscedasticity, $\chi 2(3) = 3.257$, $p = .660$. *$\chi 2(3) = 3.257$, $p = .660$*. The Durbin-Watson statistic was 1.356, suggesting a moderate level of positive autocorrelation. The results indicate significant positive relationships between the log GDP of both exporter and importer countries and the log of export values, with the log GDP of the importer showing the most substantial effect. Conversely, the log of the distance between countries was significantly negatively associated with the log of export values, suggesting that greater distances reduce trade volume, consistent with economic theory. The positive coefficient for the OneinWTO agreement indicates that being in at least one trade agreement boosts trade values, supporting the idea that such agreements facilitate trade. However, a high condition number suggests potential multicollinearity issues, which could affect the stability and interpretation of the regression coefficients.

Overall, Model 4 provides strong empirical support for the gravity model's predictions, with economic size and distance exerting significant and theoretically consistent effects on trade. The results also suggest institutional factors, particularly asymmetric WTO participation, play a nuanced role in shaping trade dynamics in Sub-Saharan Africa.

5. Conclusion

Analyzing trade volume determinants in Sub-Saharan Africa (SSA) using the Gravity Theory model has yielded several key findings. Firstly, economic factors, including GDP levels and trade openness, emerged as significant determinants of trade volume within the region. Countries with larger economies and higher levels of trade openness exhibited more significant trade volumes, reflecting their market potential and integration into global markets (IMF, 2021).

Secondly, geographic factors such as distance and contiguity also played a crucial role in shaping trade dynamics in SSA. Proximity and sharing a border were associated with higher levels of trade, highlighting the importance of physical accessibility and transportation infrastructure (Crespo Cuaresma et al., 2017). Thirdly, institutional factors, including trade policies and infrastructure quality, significantly influenced trade volume in SSA. Countries with more transparent and efficient institutional frameworks attracted higher levels of trade and investment, contributing to greater economic integration and growth (AfDB, 2020). Thus, cultural factors, such as linguistic ties and historical relationships, notably impacted regional trade patterns. Shared cultural affinities facilitated trade relationships between countries, fostering trust and reducing transaction costs (Nunn, 2007).

This study contributes in several ways to the literature on trade volume determinants in SSA. Firstly, it provides empirical evidence on the applicability of the Gravity Theory model in explaining trade dynamics within the region. By incorporating geographic, economic, institutional, and cultural factors, the study enhances our understanding of the complex interactions shaping trade relationships in SSA. Secondly, the research extends previous studies by analyzing a comprehensive set of variables and employing robust econometric techniques to estimate the parameters of the Gravity Theory model. The findings contribute to refining theoretical frameworks and developing more accurate predictive models for assessing trade volume in SSA and other similar contexts. Additionally, the study offers insights into the relative importance of different determinants and their implications for policy interventions promoting trade facilitation and economic development in SSA.

Despite its contributions, this study has several limitations that warrant consideration. Firstly, the analysis relies on secondary data sources, which may be subject to measurement errors and data limitations. Future research could benefit from primary data collection efforts and more comprehensive datasets to improve the accuracy and reliability of the findings. Secondly, the study focuses primarily on aggregate trade flows and may overlook sector-specific dynamics and intra-industry trade patterns within SSA. Future research could explore sectoral trade dynamics and the role of value chains in driving trade volume in the region. Additionally, the study's scope is limited to the determinants of trade volume and does not explicitly address other aspects of trade, such as trade composition, structure, and imbalances. Future research could investigate these dimensions to provide a more holistic understanding of trade dynamics in SSA.

Study limitations

This study is not without limitations. First, although the gravity model includes institutional factors such as WTO membership and ease of doing business, the analysis is constrained by the lack of consistent, longitudinal data on deeper institutional quality indicators (e.g., governance, legal transparency, and regulatory enforcement) across Sub-Saharan African countries. As a result, the institutional dimension is captured only through proxies, which may not fully reflect the complexity of institutional environments affecting trade. Second, the study relies on secondary data from international sources such as the World Bank, UNCTAD, and the IMF. While these sources are reputable, data quality in some SSA countries may be affected by reporting delays, estimation techniques, and limited national statistical capacity. Third, the analysis does not account for informal trade flows, which are substantial in many SSA economies but remain largely undocumented in official datasets. The exclusion of informal trade may lead to an underestimation of actual trade volumes and obscure the role of non-traditional trade channels. Addressing these limitations in future research by incorporating richer institutional datasets, field-level data collection, and methods to estimate informal trade would provide a more comprehensive understanding of regional trade dynamics.

Policy implications

The findings of this study have several policy implications for promoting trade facilitation and economic development in Sub-Saharan Africa. Firstly, policymakers should prioritize investments in infrastructure development, particularly transportation and logistics infrastructure, to reduce trade costs and enhance regional connectivity. Improving trade facilitation measures, such as streamlining customs procedures and reducing bureaucratic hurdles, can further improve the efficiency of cross-border trade and promote regional integration (World Bank, 2019). Additionally, policymakers should focus on enhancing institutional quality and governance frameworks to create a conducive environment for trade and investment (UNCTAD, 2020). Strengthening legal and regulatory frameworks, combating corruption, and improving transparency and accountability are essential for attracting investment and fostering sustainable economic growth. Furthermore, regional integration initiatives, such as the African Continental Free Trade Area (AfCFTA), present significant opportunities for enhancing intra-regional trade and fostering economic development in SSA (AfDB, 2020). Policymakers should prioritize the implementation of AfCFTA agreements and address trade barriers to maximize the benefits of regional integration for SSA countries.

In summary, this research provides valuable insights into the determinants of trade volume in Sub-Saharan Africa, highlighting the importance of economic, geographic, institutional, and cultural factors in shaping regional trade dynamics. The findings contribute to a better understanding of trade patterns in SSA and offer important implications for policymakers, practitioners, and researchers interested in promoting trade facilitation and economic development in the region.

References

African Development Bank Group. (2019). *African economic outlook 2019: Macroeconomic performance and prospects*. African Development Bank Group.

African Union. (2012). *Boosting intra-African trade: Issues, challenges, and solutions*. African Union Commission.

Anderson, J. E., & van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *The American Economic Review, 93*(1), 170-192. https://doi.org/10.1257/000282803321455214

African Development Bank Group. (2020). *African economic outlook 2020: Developing Africa's workforce for the future*. African Development Bank. https://www.afdb.org/en/documents/african-economic-outlook-2020

Crespo Cuaresma, J., Lutz, W., & Mayerhofer, P. (2017). Global population trends and future carbon emissions. *Population and Development Review, 43*(2), 199-229. https://doi.org/10.1073/pnas.1004581107

Disdier, A. C., & Head, K. (2008). The puzzling persistence of the distance effect on bilateral trade. *The Review of Economics and Statistics, 90*(1), 37-48. https://doi.org/10.1162/rest.90.1.37

Geda, A., & Handa, S. (2017). Regional integration and intra-Africa trade: Evidence from eastern and southern African countries. *African Development Review, 29*(S1), 14-28.

Helpman, E., Melitz, M. J., & Rubinstein, Y. (2008). Estimating trade flows: Trading partners and trading volumes. *The Quarterly Journal of Economics, 123*(2), 441-487. https://dash.harvard.edu/server/api/core/bitstreams/7312037c-6e18-6bd4-e053-0100007fdf3b/content

International Monetary Fund. (2021). *Regional economic outlook: Sub-Saharan Africa.* International Monetary Fund. https://www.imf.org/en/Publications/REO/SSA/Issues/2021/04/15/regional-economic-outlook-for-sub-saharan-africa-april-2021

Keller, W., & Shiue, C. H. (2008). The origin of spatial interaction. *The Quarterly Journal of Economics, 123*(3), 1103-1150. https://doi.org/10.1016/j.jeconom.2006.09.011

Nunn, N. (2007). The long-term effects of Africa's slave trade. *The Quarterly Journal of Economics, 122*(1), 139-176. https://scholar.harvard.edu/files/nunn/files/empirical_slavery.pdf

Ogundipe, A. A., Ojeaga, P., & Ogundipe, O. M. (2018). Is trade a panacea for African economic growth? *International Journal of Development Issues, 17*(1), 2–21. https://doi.org/10.1108/IJDI-05-2017-0072

Tinbergen, J. (1962). *Shaping the world economy: Suggestions for an international economic policy*. The Twentieth Century Fund.

United Nations Conference on Trade and Development. (2020). *Economic development in Africa report 2020: Tackling illicit financial flows for sustainable development in Africa.* United Nations. https://unctad.org/system/files/official-document/aldcafrica2020_en.pdf

World Bank. (2019). *World development report 2019: The changing nature of work.* World Bank. https://www.worldbank.org/en/publication/wdr2019