

Institutions, Geography, and Intra-African Trade: Evidence from Long-Run Gravity Models

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Abstract

This paper examines how multilateral and regional trade institutions relate to intra-African trade over the long run. Using bilateral trade data for African countries from 1962 to 2020, the analysis combines descriptive evidence, network analysis, and multiple gravity model specifications. Intra-African trade remains sparse and highly concentrated, with many zero trade flows and a small number of dominant exporters. Geographic distance and contiguity consistently explain trade patterns across all models. Joint membership in regional economic communities and the World Trade Organization is positively associated with trade in parsimonious specifications, but these effects weaken in highly saturated fixed-effects models. This sensitivity suggests that institutional indicators primarily capture long-run structural integration rather than short-term policy effects. The findings support AfCFTA's role as a gradual, cumulative framework for continental trade integration.

Keywords: Intra-African trade; Gravity model; AfCFTA; Regional integration; WTO membership; Trade institutions; Africa

Highlights

- Intra-African trade remains limited and uneven, underscoring the structural challenges AfCFTA must address.
- Distance and connectivity factors continue to drive the structure of bilateral trade flows.
- Regional economic community membership is strongly associated with higher intra-African trade.
- WTO co-membership shows positive but modest effects once structural controls are applied.
- Institutional integration reflects long-run structural alignment rather than short-run effects.

1. Introduction

Despite decades of policy attention and repeated integration efforts, intra-African trade remains limited, uneven, and highly concentrated. Africa's external trade expanded strongly after the early 2000s, yet trade among African countries lagged behind other regions. This gap appears both in absolute terms and as a share of total trade. Most bilateral trade relationships within Africa remain weak or entirely absent. A small number of country pairs account for a large share of intra-African trade. These patterns reflect deep structural constraints. They include long distances, weak transport infrastructure, large differences in economic size, and fragmented institutions.

The institutional architecture governing African trade is especially complex. African countries were early adopters of regional integration initiatives. Most Regional Economic Communities, including ECOWAS, SADC, and COMESA, were established before the mid-1990s. Membership in at least one REC is nearly universal across the continent. Multilateral integration through the World Trade Organization followed a different path. Many African countries joined the WTO in 1995 during the initial accession wave. Others joined much later, while some remained outside the system for most of the period studied. As a result, African trade integration evolved through overlapping and partly asynchronous regional and multilateral commitments.

This institutional sequencing raises a fundamental empirical question. To what extent do multilateral and regional trade institutions shape intra-African trade patterns? WTO membership and regional agreements both aim to reduce trade barriers and improve predictability. However, they operate through different mechanisms and affect different margins of trade. Regional agreements may reduce costs through tariff preferences, regulatory alignment, and geographic proximity. WTO membership anchors trade policy within a multilateral rules-based system that strengthens transparency and credibility. In Africa, regional agreements are numerous, overlapping, and heterogeneous. WTO accession also remains incomplete. Disentangling the relative importance of these institutions is therefore empirically difficult and policy relevant.

This challenge is amplified by distinctive features of African trade data. Bilateral trade flows contain many zero and very small observations. These reflect limited diversification, episodic trade relationships, and high entry costs. Trade volumes are extremely skewed, with a long right tail driven by few large economies. Geographic frictions remain substantial across most country pairs. Many countries do not share borders and face long distances, weak logistics, and high transport costs. Historical and institutional ties from the colonial period also persist. These ties interact with modern trade agreements in complex ways. Together, these features complicate standard empirical approaches. They motivate flexible gravity models that accommodate heterogeneity, zero flows, and layered institutions.

In this research, we examine how multilateral and regional institutions shape intra-African trade over the long run. We use a comprehensive panel of bilateral trade flows spanning 1962 to 2020. The analysis is grounded in the gravity model of international trade. This framework links trade flows to economic size, distance, and institutional arrangements. Rather than relying on a single specification, we adopt a comparative approach. We estimate several gravity models that differ in form, normalization, and fixed effects. This strategy allows us to assess robustness across empirical lenses. It also helps clarify the channels through which institutional effects operate.

The empirical analysis proceeds in three integrated stages. We first document stylized facts using descriptive statistics, distributions, and network visualizations. These reveal many zero flows, strong export concentration, and hub-and-spoke trade structures. These patterns motivate gravity

methods and a focus on institutional variables. Building on this foundation, we estimate baseline log-linear gravity models with fixed effects. These relate bilateral trade to distance, contiguity, historical ties, and joint WTO and REC membership. The coefficients admit clear elasticity or semi-elasticity interpretations. To remove mechanical size effects, we also estimated a normalized gravity specification. This scales trade by exporter and importer GDP. The normalization shifts attention from trade volumes to trade intensity. It highlights how institutions and costs shape integration conditional on country size. Finally, we estimate multiplicative gravity models using Pseudo-Maximum Likelihood methods. These retain zero flows and handle heteroskedasticity consistently. Comparing results across models shows that institutional effects depend on zero treatment and fixed effects.

Across all specifications, we emphasize sensitivity to identification strategies. Highly saturated models with exporter-year, importer-year, and pair fixed effects isolate within-pair variation over time. More parsimonious models rely on cross-sectional differences in long-run integration. This comparison is central for interpretation. Differences across models are not treated as contradictions. Instead, they are viewed as informative. They distinguish long-run structural associations from shorter-run changes linked to policy transitions or accessions. Building on the estimated gravity coefficients, we also conduct policy-relevant counterfactual simulations. Using the baseline multiplicative model, we predict trade under alternative institutional scenarios. These include shared WTO membership or shared regional integration. All other determinants are held constant. The simulations are not causal forecasts. They provide model-implied benchmarks under strict *ceteris paribus* assumptions. They translate coefficients into economically meaningful magnitudes. At the same time, they highlight interpretational limits and sensitivity to modeling assumptions.

2. Literature review

The gravity model is the dominant empirical framework for analyzing bilateral trade flows and has been widely applied to African trade. Its foundations were established by (1962) and Anderson (1979), with later advances incorporating multilateral resistance terms to capture relative trade costs (Anderson and van Wincoop, 2003). These developments transformed gravity equations into theory-consistent tools linking trade flows to economic size, geography, and policy barriers (Chaney, 2018; Head and Mayer, 2014). African trade data pose particular challenges for gravity estimation, including many zero trade observations, strong heteroskedasticity, and large disparities across countries. Kareem et al. (2016) show that conventional log-linear estimation performs poorly under such conditions. Santos Silva and Tenreyro (2011; 2006) demonstrate that Poisson Pseudo-Maximum Likelihood estimation yields consistent estimates and naturally accommodates zero trade flows. Recent work further emphasizes the importance of high-dimensional fixed effects to control for unobserved heterogeneity in panel gravity models (Baltagi et al., 2024; Correia et al., 2020)

There is an ongoing discussion whether regional integration initiatives have increased regional trade. However, despite the long-standing presence of Regional Economic Communities, intra-regional trade remains low relative to other regions. Early studies highlight the limited trade impact of Arab and African integration arrangements (Al-Atrash and Yousef, 2000; Bchir et al., 2006) Gravity-based evidence generally finds positive trade effects from regional agreements, but the magnitude and robustness of these effects vary across blocs and countries (Boughanmi, 2008; Dadakas, 2021; Salim et al., 2011). More recent studies emphasize that institutional depth matters. Boughanmi et al. (2016) show that deeper integration generates stronger trade responses than

wider but shallower arrangements, while Boughanmi et al. (2021) highlight the importance of intermediate goods trade and value-chain linkages. African-focused research further stresses the role of logistics performance, regulatory harmonization, and implementation capacity in shaping realized trade gains (Fofack and Mold, 2021; Kpomblekou and Wonyra, 2020).

Recent empirical work has expanded the gravity-based analysis of African trade by explicitly focusing on African Continental Free Trade Area (AfCFTA), trade efficiency, and enabling conditions. Gravity-model evaluations of AfCFTA generally find positive but specification-sensitive trade effects, with outcomes depending on estimator choice, baseline definition, and treatment of general equilibrium adjustments (Fofack et al., 2021; Geda and Yimer, 2023; Letlala and Johnson, 2025). Complementary approaches using stochastic frontier gravity models emphasize that low intra-African trade reflects substantial inefficiency relative to potential, rather than the absence of trade preferences alone. Evidence points to large unexploited export capacity across African economies, shaped by financing constraints, macroeconomic policy settings, and institutional frictions (Bakouan, 2025; Mazorodze, 2024; Njoroge Muriu et al., 2024). Recent structural gravity work further highlights the role of trade facilitation measures, border procedures, and customs performance as quantitatively important determinants of intra-African trade, closely aligned with AfCFTA's implementation agenda (Wassie et al., 2025).

The trade effects of WTO membership remain contested. Rose (2004) finds limited evidence that WTO membership increases trade, whereas Subramanian and Wei (2007) argue that WTO effects are positive but uneven across countries. Later studies suggest that WTO accession may generate stronger trade effects for developing countries and late joiners, particularly when accompanied by domestic reforms (Bekkers and Cariola, 2025). In Africa, identifying WTO effects is empirically challenging due to clustered accessions in the mid-1990s and the coexistence of multiple regional agreements. Recent gravity studies find that joint WTO membership is positively associated with intra-African trade, though estimates are sensitive to estimator choice and fixed-effects structure (Ebaidalla and Ali, 2023; Gulseven et al., 2023b). Evidence from the Middle East and North Africa similarly suggests that WTO membership operates primarily as a long-run institutional anchor rather than an immediate trade shock (Gulseven et al., 2023a; Karam and Zaki, 2013).

Beyond formal trade agreements, African trade is shaped by persistent trade costs and institutional constraints. Distance remains a strong barrier to trade, reflecting weak infrastructure and high transport costs (Brun, 2005). Institutional factors such as legal origin and colonial ties continue to influence bilateral trade patterns and interact with contemporary trade agreements (de Groot et al., 2004; Ngouhouo et al., 2021).

Recent evidence shows that logistics efficiency and border procedures significantly affect African trade performance, especially for landlocked economies (Adjei Tetteh et al., 2025). External shocks also play an important role. Oil price fluctuations affect trade through income effects, transport costs, and macroeconomic conditions. A large literature documents these links (Baumeister and Kilian, 2016; Hamilton, 2009), with recent studies confirming that oil prices influence trade flows in developing economies, including Africa (Moshiri and Kheirandish, 2024; Nanovsky, 2019; Von Below and Vézina, 2016). A parallel strand of the literature broadens the institutional perspective beyond formal trade agreements to encompass financial development and policy space as conditioning factors for African trade integration. Financial sector depth and cross-border financial linkages are shown to support intra-African trade by easing liquidity constraints and reducing transaction costs, particularly for smaller and less diversified economies (Gakpa et al., 2025). Related evidence suggests that trade policy space and Aid for Trade interact with

manufacturing export performance, indicating that institutional capacity and external support mechanisms jointly shape realized trade outcomes within Africa (Gnangnon, 2024). At the same time, institutional quality remains central in structural gravity frameworks, with high-dimensional fixed-effects PPML evidence confirming that institutional variables capture persistent trade-relevant characteristics rather than short-run policy shifts (Alhassan and Payaslioglu, 2020; Olney, 2022).

Against this background, this study contributes to the literature in three ways. First, it provides a long-run, continent-wide gravity analysis of intra-African trade that jointly examines regional and multilateral institutions. Second, it explicitly compares alternative gravity estimators and fixed-effects structures, highlighting how institutional effects depend on identification strategy. Third, by combining descriptive evidence, network analysis, and model-based counterfactuals, it offers a transparent and policy-relevant assessment of African trade integration.

3. Data and variables

The analysis uses the CEPII Gravity dataset (version 2022.11) and focuses on bilateral trade among African countries. African countries are selected to provide a broad and representative setting for identifying the main drivers of intra-continental trade flows. While African countries share certain historical experiences and development challenges, they differ markedly in institutional quality, economic structure, and levels of integration into regional and global markets. There is substantial heterogeneity across countries in terms of economic size, income levels, and stages of development. Some economies rely heavily on oil and mineral exports, while others are dominated by agriculture, manufacturing, or services. Political systems, regulatory frameworks, and trade institutions also vary widely, including among neighboring countries. This combination offers a rich empirical environment to analyze how economic, geographic, and institutional factors jointly shape intra-African trade patterns. Moreover, despite the policy relevance of institutional integration, systematic evidence on the role of multilateral and regional institutions in African trade remains limited.

3.1. Data summary

Two distinct forms of trade integration are considered. Joint membership in the World Trade Organization is captured by a time-varying dummy variable (*WTO_joint*) that equals one when both trading partners are WTO members in a given year and zero otherwise. This variable is constructed directly from the CEPII country-year WTO membership indicators. WTO membership among African countries is uneven and reflects different accession paths and stages of integration into the multilateral trading system. While many African countries joined the WTO during the initial accession wave in the mid-1990s, several acceded later, and some remained outside the WTO for extended periods. This staggered accession process generates meaningful variation over time and across country pairs, allowing the analysis to examine how multilateral institutional alignment is associated with intra-African trade flows. In parallel, regional integration is captured through a joint Regional Economic Community membership indicator. This variable equal one when both countries belong to at least one common African regional agreement in a given year. The measure accounts for the extensive overlap across African Regional Economic Communities, including ECOWAS, SADC, COMESA, the East African Community, and other subregional arrangements. By focusing on joint membership rather than individual agreements, the approach reflects the complex and overlapping nature of African regional integration while avoiding excessive fragmentation of the institutional variables.

Table 1: African Countries Membership in WTO and Regional Agreements

Country	ISO3	WTO (Year)	ECOWAS	SADC	COMESA	EAC
Algeria	DZA	–	–	–	–	–
Angola	AGO	1997	–	1980	–	–
Benin	BEN	1996	1975	–	–	–
Botswana	BWA	1995	–	1980	–	–
Burkina Faso	BFA	1995	1975	–	–	–
Burundi	BDI	1995	–	–	1981	2007
Cameroon	CMR	1995	–	–	–	–
Cabo Verde	CPV	2008	1975	–	–	–
Central African Rep.	CAF	1995	–	–	–	–
Chad	TCD	1996	–	–	–	–
Comoros	COM	1995	–	2005	1981	–
Congo, Rep.	COG	1997	–	–	–	–
Côte d'Ivoire	CIV	1995	1975	–	–	–
DR Congo	COD	1997	–	1997	1981	–
Djibouti	DJI	1995	–	–	1981	–
Egypt	EGY	1995	–	–	1981	–
Equatorial Guinea	GNQ	1995	–	–	–	–
Eritrea	ERI	–	–	–	1994	–
Ethiopia	ETH	–	–	–	1981	–
Gabon	GAB	1995	–	–	–	–
Gambia	GMB	1996	1975	–	–	–
Ghana	GHA	1995	1975	–	–	–
Guinea	GIN	1995	1975	–	–	–
Guinea-Bissau	GNB	1995	1975	–	–	–
Kenya	KEN	1995	–	–	1981	2000
Lesotho	LSO	1995	–	1980	–	–
Liberia	LBR	2016	1975	–	–	–
Libya	LBY	–	–	–	2005	–
Madagascar	MDG	1995	–	2005	1981	–
Malawi	MWI	1995	–	1980	1981	–
Mali	MLI	1995	1975	–	–	–
Mauritania	MRT	1995	–	–	–	–
Mauritius	MUS	1995	–	1995	1981	–
Morocco	MAR	1995	–	–	–	–
Mozambique	MOZ	1995	–	1980	–	–
Namibia	NAM	1995	–	1990	–	–
Niger	NER	1996	1975	–	–	–
Nigeria	NGA	1995	1975	–	–	–
Rwanda	RWA	1996	–	–	1981	2007
São Tomé & Príncipe	STP	1995	–	–	–	–

Senegal	SEN	1995	1975	–	–	–
Seychelles	SYC	2015	–	1997	1981	–
Sierra Leone	SLE	1995	1975	–	–	–
Somalia	SOM	–	–	–	1981	–
South Africa	ZAF	1995	–	1994	–	–
South Sudan	SSD	–	–	–	2011	2016
Sudan	SDN	–	–	–	1981	–
Eswatini	SWZ	1995	–	1980	–	–
Tanzania	TZA	1995	–	1980	–	2000
Togo	TGO	1995	1975	–	–	–
Tunisia	TUN	1995	–	–	1981	–
Uganda	UGA	1995	–	–	1981	2000
Zambia	ZMB	1995	–	1980	1981	–
Zimbabwe	ZWE	1995	–	1980	1981	–

Table 1 documents African countries' participation in the multilateral trading system, through the World Trade Organization (WTO), and in major Regional Economic Communities (RECs), namely ECOWAS, SADC, COMESA, and the EAC. The table highlights three salient features of Africa's trade integration architecture: early multilateral entry, deep but uneven regional integration, and extensive overlap across regional agreements.

WTO membership in Africa is shaped by a strong accession wave in the mid-1990s, when most countries joined following the creation of the WTO. This near-synchronous entry limits cross-sectional variation but generates useful time variation for late and non-members. Countries such as Cabo Verde, Seychelles, and Liberia joined much later, while others, including Ethiopia, Algeria, Libya, Sudan, Somalia, and South Sudan, remained outside the WTO for most or all of the sample period, providing heterogeneity for identification in a long panel.

The variable *REC_joint* captures whether a trading pair shares at least one REC, rather than modeling each agreement separately. Regional integration in Africa predates WTO accession by several decades and remains highly overlapping. ECOWAS, COMESA, and SADC were established between the 1970s and early 1980s, while the EAC represents a more recent and deeper integration effort. Many countries belong to multiple RECs, especially in Eastern and Southern Africa, creating a complex institutional landscape with varying degrees of policy harmonization. This overlap motivates the use of a composite REC indicator capturing shared membership in at least one agreement rather than modeling each bloc separately.

ECOWAS exhibits the earliest and most uniform integration, with consistent membership dating back to the 1970s. SADC displays a mix of early members and later entrants, reflecting its evolution from a coordination conference to a formal trade bloc. COMESA is the most geographically expansive and institutionally heterogeneous, encompassing both coastal and landlocked economies with varying degrees of trade openness. The EAC stands out as the smallest but deepest bloc, often associated with stronger trade effects in empirical studies due to its customs union and common market ambitions.

Table 2 reports descriptive statistics for the variables used in the empirical analysis of intra-African trade over the period 1962–2020. The statistics highlight the pronounced heterogeneity in trade flows, economic size, geography, and institutional characteristics across African country pairs, underscoring the relevance of a gravity-model framework.

Bilateral trade is measured using importer-reported trade flows and expressed in thousands of current US dollars. The distribution of trade flows is highly skewed, with a mean value of USD 7.8 million but a median of zero, reflecting the prevalence of zero trade observations across country pairs and years. Indeed, at least half of the bilateral observations record no trade in a given year, while the upper tail is extremely large, with maximum trade flows exceeding USD 6.8 billion. This pattern is consistent with well-documented features of international trade data and motivates the use of estimation strategies that can properly accommodate zero trade flows.

Table 2: Descriptive statistics of variables

Variable	Mean	SD	Min	P25	Median	P75	Max
Trade flow (million USD)	7.8	101.1	0	0	0	30	6,808.8
Distance (km)	3,654	1,963	8	2,122	3,498	4,989	9,671
GDP (in billion USD)	16.6	48.3	0.01	0.86	2.94	10.5	568.5
Population	13.7	22.0	0.04	1.82	6.13	15.4	206.1
Common language	0.54	0.50	0	0	1	1	1
Colonial tie	0.27	0.44	0	0	0	1	1
Contiguity	0.08	0.26	0	0	0	0	1
WTO joint	0.32	0.47	0	0	0	1	1
REC joint	0.28	0.45	0	0	0	1	1
Oil price (USD/bbl)	33.7	29.9	1.2	13.2	23.7	51.2	108.9

Geographic trade costs vary widely across African country pairs. Average bilateral distance is about 3,654 km, ranging from 8 km for neighbors to nearly 9,700 km for the most distant pairs. Only 8 percent of pairs share a common border, implying that most intra-African trade occurs between non-contiguous countries where transport and logistics costs are high. Economic size is highly uneven across countries. Average GDP is about USD 16.6 billion, but values range from below USD 0.1 billion to over USD 568 billion. Population shows similar dispersion, with a mean of 13.7 million and a maximum above 206 million. This concentration implies that a small number of large economies account for most intra-African trade, while many smaller countries trade infrequently. Historical and institutional linkages remain important. More than half of country pairs share a common legal origin, and about 27 percent share colonial ties. These variables proxy for persistent institutional connections that may reduce information and transaction costs, even though geographic contiguity is rare. Trade policy integration also varies substantially. Joint WTO membership is observed for 32 percent of pairs, while 28 percent share membership in at least one Regional Economic Community. Neither form of integration dominates, indicating that multilateral and regional arrangements capture distinct dimensions of African trade integration and that fragmentation remains widespread. Finally, oil prices exhibit strong time variation, with Dubai crude averaging USD 33.7 per barrel and ranging from USD 1.2 to nearly USD 109. This variation captures common external shocks affecting transport costs and macroeconomic conditions across African economies.

3.2. Trade Distribution

Figure 1 exhibits a strong right-skewness, even after log transformation, indicating substantial heterogeneity across country pairs. The distribution of bilateral trade flows in 2020 exhibits a pronounced right skew, even after taking logarithms. Most country pairs are concentrated at relatively low trade values, indicating that the majority of intra-African trading relationships remain weak or limited in scale. Only a small number of country pairs record substantial trade volumes, which generates a long right tail in the distribution.

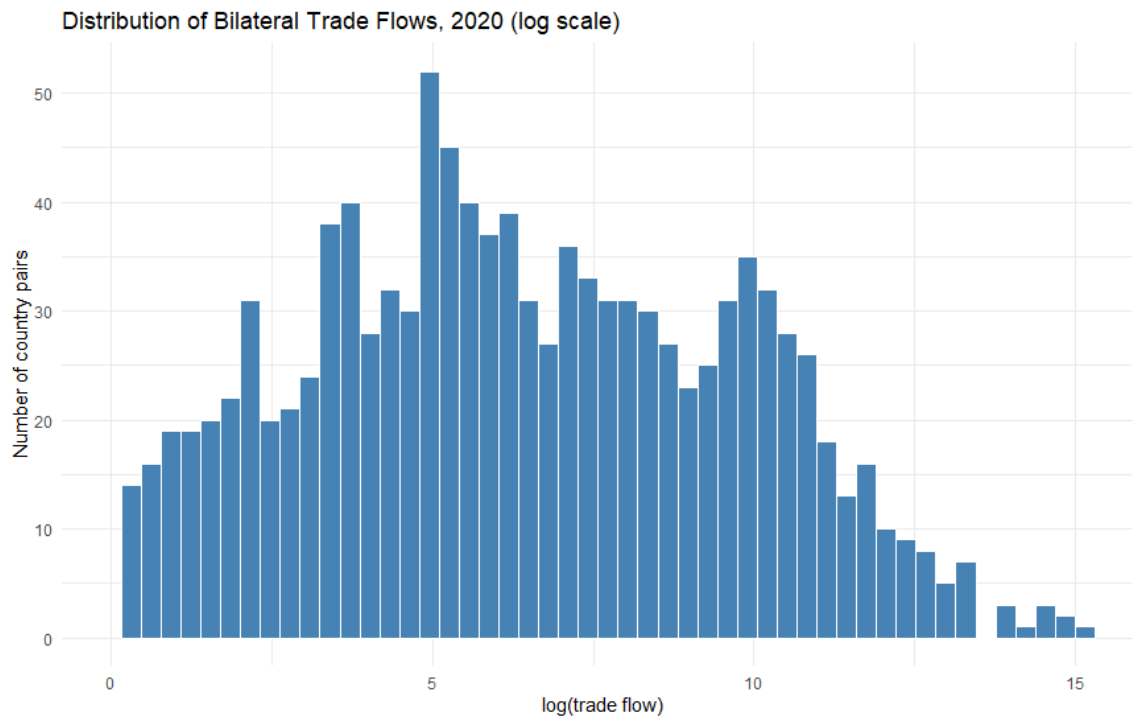


Figure 1. The distribution of bilateral trade flows

This pattern highlights the highly uneven nature of intra-African trade, where a few dominant bilateral relationships account for a disproportionate share of total trade. The prevalence of low and near-zero flows is consistent with substantial trade costs, economic asymmetries, and incomplete integration across African economies, and it provides a strong empirical justification for gravity-based models that can accommodate heterogeneity and zero trade observations. This heterogeneity becomes even more apparent when trade flows are aggregated at the country level. The ranking of total intra-African exports in Figure 2 shows a strong concentration of intra-African exports in 2020, with South Africa overwhelmingly dominating regional trade, exporting far more than any other African country. Nigeria, Zambia, Egypt, and Eswatini follow at a considerable distance, while the remaining exporters in the top twenty exhibit much smaller and relatively similar trade volumes. This pattern underscores the highly uneven structure of intra-African trade, where a small number of relatively diversified and industrialized economies account for the bulk of regional exports, reflecting differences in economic size, production capacity, and integration into regional and continental trade networks.

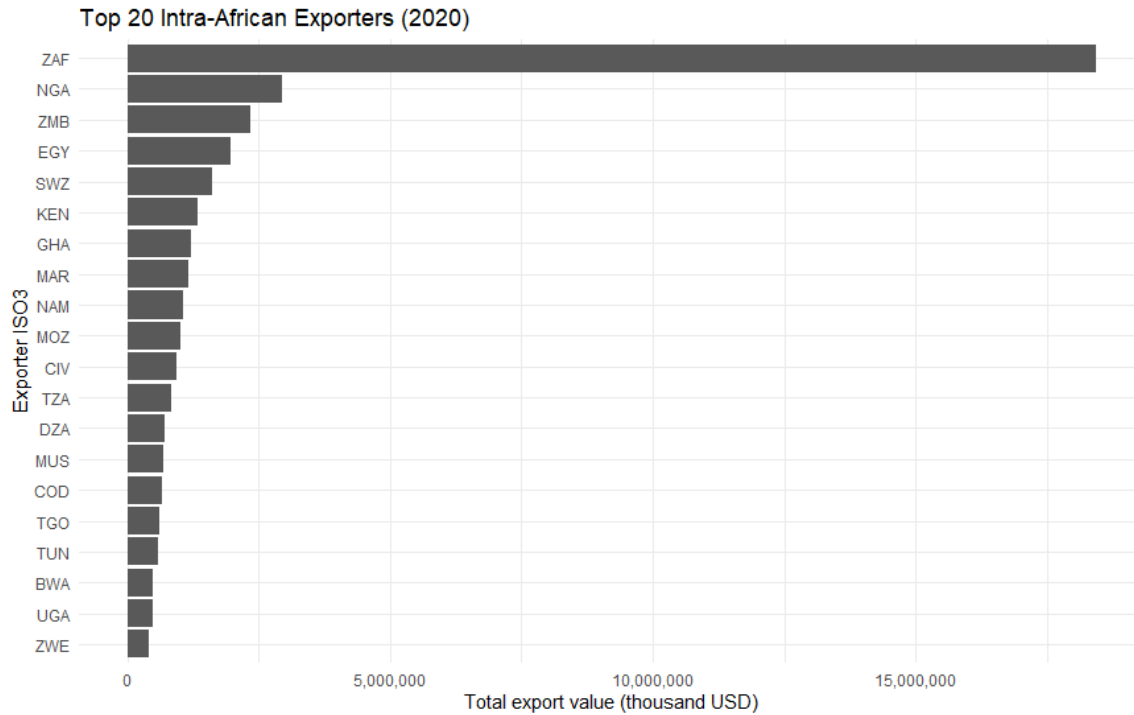


Figure 2. Top 20 Intra-African exports by country

Figure 3 presents the intra-African trade network in 2020, where nodes represent countries and directed links capture bilateral trade relationships. Node size is proportional to GDP, highlighting the central role of larger economies in regional trade. The network is dense but highly uneven, with a small number of economically large countries such as South Africa, Egypt, and Nigeria occupying central positions and maintaining numerous trade connections, while many smaller economies appear on the periphery with fewer and weaker links.

Intra-African Trade Network (2020)

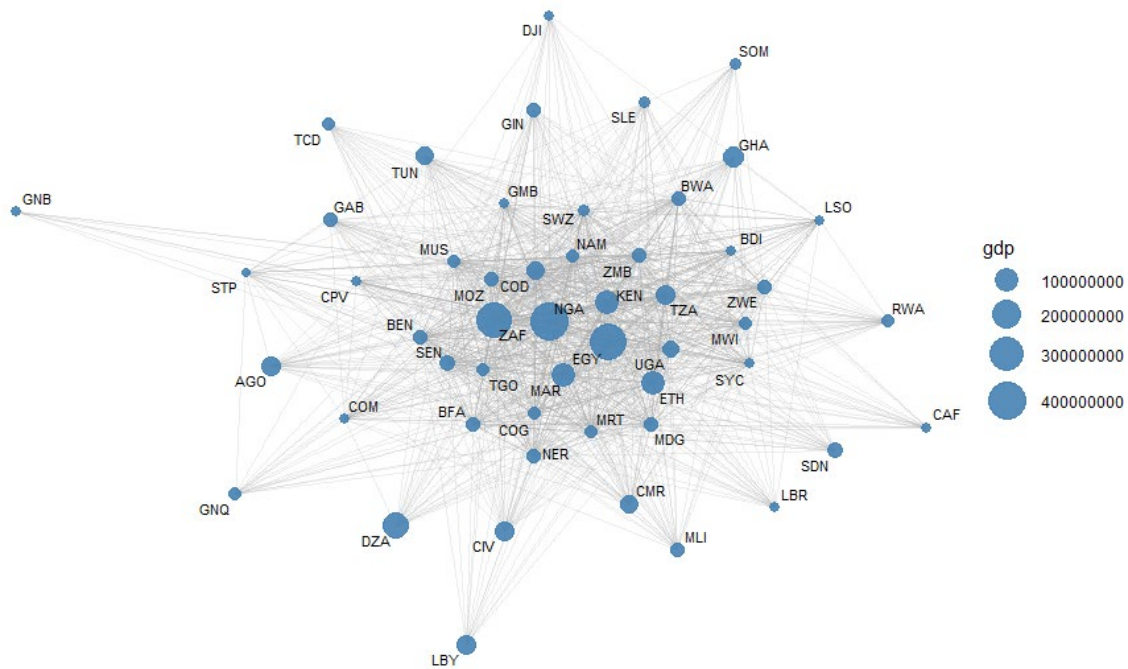


Figure 3. Intra-African Trade Network

The visual structure of the network reveals strong regional clustering, particularly among countries that are geographically proximate or integrated through regional economic communities. Peripheral nodes tend to be smaller economies with limited diversification, often connected indirectly through regional hubs rather than through extensive bilateral links of their own. Overall, the figure illustrates a hub-and-spoke pattern in intra-African trade, emphasizing the importance of economic size and regional integration in shaping trade connectivity across the continent.

3.3. Oil price vs Trade

Figure 4 illustrates the evolution of total intra-African trade alongside Dubai crude oil prices over time, highlighting both long-run trends and short-term co-movements. Intra-African trade remains relatively flat and low until the late 1990s, after which it rises sharply, particularly during the 2000s, reflecting growing economic activity, trade liberalization efforts, and improved connectivity across the continent. This upward trend is punctuated by noticeable slowdowns following major global shocks, including the 2008 financial crisis and the mid-2010s commodity price collapse.

The oil price series displays pronounced volatility, with sharp increases and declines that partially coincide with fluctuations in intra-African trade. Periods of high oil prices, especially during the mid-2000s, align with rapid growth in intra-African trade, suggesting that favorable global commodity conditions may have supported trade expansion through income and demand effects. However, the relationship is not one-to-one, indicating that while oil prices act as an important external influence, structural factors such as regional integration, economic diversification, and institutional reforms play a more dominant role in shaping long-term intra-African trade dynamics.

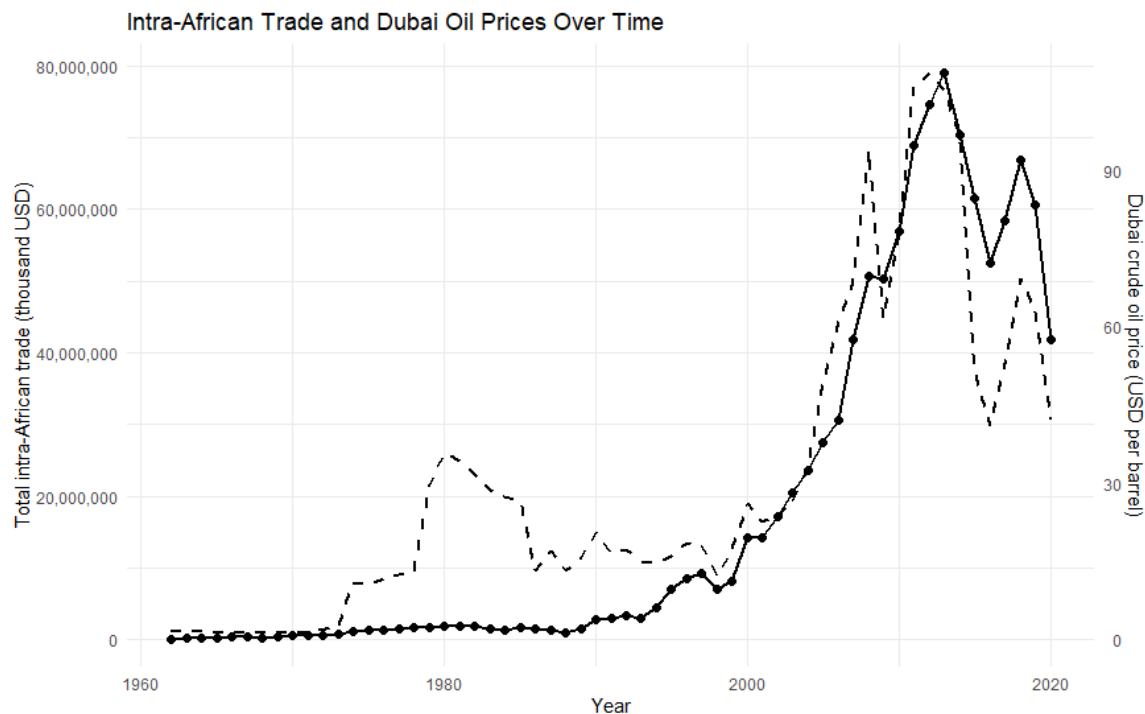


Figure 4. Intra-African trade and Dubai crude oil prices over time

3.4. Correlation Patterns

Correlation matrix in table 3 reports pairwise correlations among the main gravity variables and shows patterns that are consistent with standard trade theory and the African context. Bilateral trade is positively correlated with exporter and importer GDP, although the correlations are modest at 0.28 and 0.11, respectively. This reflects the fact that economic size matters for trade, but alone does not explain the large variation in bilateral flows across African country pairs. Trade is also weakly positively correlated with population, suggesting that market size contributes to trade potential, though its effect is less direct than GDP.

Table 3. Correlation between gravity variables

Variable	Trade	GDP _o	GDP ^d	Pop _o	Pop ^d	Distance	Oil Price
Trade	1.00						
GDP _o	0.28	1.00					
GDP ^d	0.11	0.09	1.00				
Pop _o	0.13	0.69	0.06	1.00			
Pop ^d	0.05	0.06	0.69	0.05	1.00		
Distance	-0.0	0.03	0.03	-0.0	-0.0	1.00	
	8			3	3		
Oil price	0.09	0.27	0.27	0.19	0.19	0.00	1.00

Distance exhibits a negative correlation with trade, as expected, indicating that geographic separation continues to act as a barrier to intra-African trade. The relatively small magnitude of this correlation reflects the presence of many zero or low trade flows even among nearby countries, highlighting the role of non-geographic frictions. GDP and population are strongly correlated within exporter and importer dimensions, confirming that these variables capture related aspects of economic mass. Oil prices show weak but positive correlations with trade and economic size, suggesting that global commodity cycles may influence trade volumes through income and demand effects, while remaining largely orthogonal to geographic distance. Overall, the correlation matrix indicates no problematic multicollinearity and supports the inclusion of these variables in the gravity estimations.

The panels in Figure 3 show clear and intuitive relationships among the logged gravity variables. Bilateral trade flows increase with both exporter and importer GDP, indicating that economically larger countries tend to trade more with each other. These positive associations appear roughly linear in logs, supporting the standard log-linear specification of the gravity model. In contrast, trade flows decline as bilateral distance increases, reflecting the persistent role of geographic separation in raising trade costs even within Africa.

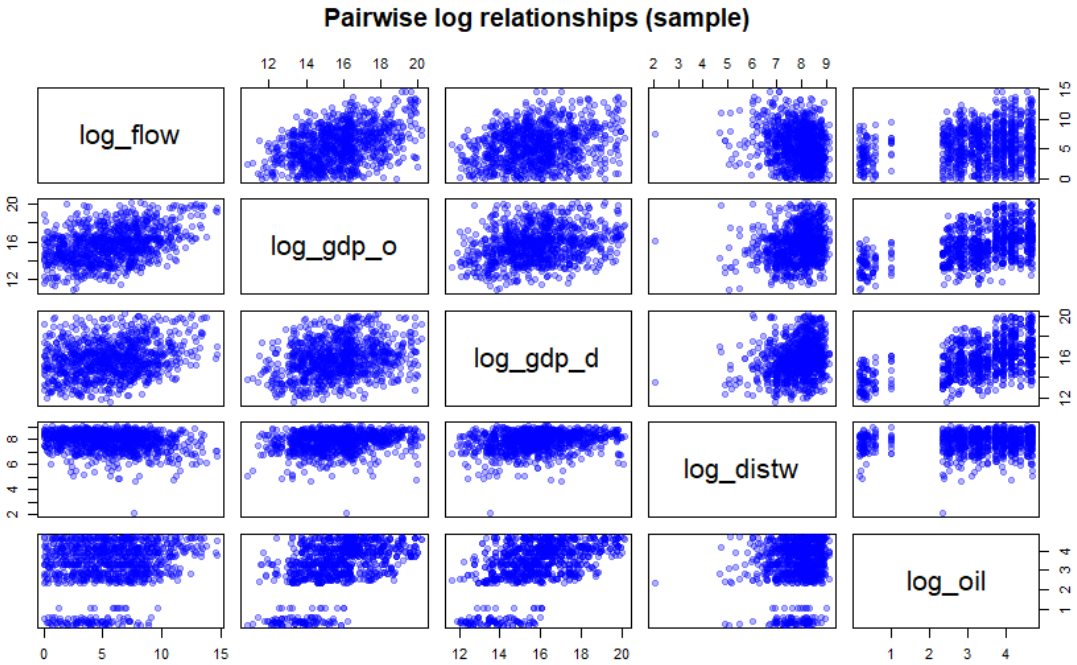


Figure 5. Pairwise log relationships

The plots also reveal substantial dispersion around these average relationships, highlighting the importance of additional factors such as institutional ties, trade agreements, and historical linkages. The relationship between trade and oil prices is positive but weaker, suggesting that global commodity price movements affect trade volumes indirectly rather than being a primary determinant. Overall, the figure illustrates that while core gravity variables explain broad patterns in trade, considerable heterogeneity remains, justifying the inclusion of fixed effects and institutional controls in the empirical analysis.

4. Model

The empirical analysis builds on the standard gravity framework of international trade, which predicts that bilateral trade flows increase with the economic size of trading partners and decrease with trade-related frictions (Baltagi et al., 2024). This framework is particularly well suited to the African context, where large disparities in economic size, geography, and institutional integration shape trade outcomes. The choice of estimators and fixed-effects structures follows current best practice in panel gravity modeling, consistent with recent econometric guidance. The framework is applied to intra-African trade flows using a set of complementary estimators commonly employed in applied gravity analysis. In all specifications, the dependent variable is bilateral exports from country i to country j in year t , denoted $Trade_{ijt}$.

4.1. Baseline fixed-effects gravity model

As a starting point, the analysis estimates log-linear gravity equations as baseline specifications. Let $Trade_{ijt}$ denote exports from exporter i to importer j in year t , and let $Dist_{ij}$ measure bilateral distance using the CEPII population-weighted harmonic metric. The baseline fixed-effects gravity model relates the logarithm of bilateral trade to the logarithm of distance and a vector of additional covariates capturing geography, historical ties, and institutional integration:

$$\ln(Trade_{ijt}) = \beta_1 \ln(Dist_{ij}) + \gamma' X_{ijt} + \alpha_i + \delta_j + \varepsilon_{ijt} \quad (1)$$

where X_{ijt} includes contiguity, common legal origin, common colonial history, joint WTO membership, and joint membership in a Regional Economic Community (REC). Exporter and importer fixed effects, α_i and δ_j , capture multilateral resistance terms and time-invariant country characteristics. Heteroskedasticity-robust standard errors are used throughout.

The underlying gravity specification can be written more explicitly as:

$$\begin{aligned} \ln(Trade_{ijt}) = & \alpha + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(GDP_{jt}) + \beta_3 \ln(POP_{it}) \\ & + \beta_4 \ln(POP_{jt}) + \beta_5 \ln(Dist_{ij}) + \beta_6 \ln(OIL_t) + \beta_7 WTO_{ij,t} \\ & + \beta_8 REC_{ij,t} + \beta_9 ComLeg_{ij} + \beta_{10} ComCol_{ij} + \beta_{11} Contig_{ij} \\ & + \varepsilon_{ijt} \end{aligned} \quad (2)$$

where GDP and population proxy economic mass, distance and contiguity capture geographic trade costs, and institutional variables reflect multilateral and regional trade integration. Oil prices are included to capture global commodity-cycle effects that may influence trade volumes across African economies.

To account for unobserved bilateral heterogeneity, the analysis also relies on specifications that absorb exporter-year, importer-year, and pair fixed effects. These transformations ensure that identification comes from within-pair variation over time, abstracting from time-invariant bilateral characteristics and persistent country-specific factors.

Let \tilde{y}_{ij} denote the within-transformed trade variable:

$$\tilde{y}_{ij} = y_{ij} - \bar{y}_{i \cdot} - \bar{y}_{\cdot j} + \bar{y} \quad (3)$$

and the regression is estimated (without an intercept) on the transformed variables:

$$\ln(\widehat{Trade}_{ij}) = \beta_1 \ln(\widehat{Dist}_{ij}) + \gamma' \tilde{X}_{ij} + \tilde{\varepsilon}_{ij}. \quad (4)$$

This approach ensures that estimation exploits deviations from average exporter and importer behavior within the African sample.

4.2. Trade volumes vs trade intensity (BVU normalization)

To shift the focus from trade volumes to trade intensity, the analysis implements the Bonus Vetus Unilateral (BVU) normalization, which scales bilateral trade by the product of exporter and importer GDP. This normalization removes the mechanical influence of economic size and highlights the role of trade costs and institutional factors in shaping relative trade integration:

$$\ln\left(\frac{Trade_{ijt}}{GDP_{it} GDP_{jt}}\right) = \beta_1 \ln(Dist_{ij}) + \gamma' X_{ijt} + u_{ijt} \quad (5)$$

In the African context, this specification provides a complementary perspective by emphasizing how geography, history, and institutions affect trade conditional on country size.

4.3. Multiplicative gravity in levels (PPML)

To address heteroskedasticity and retain zero trade observations, multiplicative gravity models are estimated using Pseudo-Maximum Likelihood methods. The conditional mean of bilateral trade is specified as:

$$E[Trade_{ijt} | \cdot] = \exp(\beta_1 \ln(Dist_{ij}) + \gamma' X_{ijt} + \alpha_i + \delta_j) \quad (6)$$

The Poisson Pseudo-Maximum Likelihood (PPML) estimator is particularly well suited for intra-African trade data, as it yields consistent estimates under heteroskedasticity and naturally accommodates zero flows. As a robustness check, a Gamma Pseudo-Maximum Likelihood estimator with a log link is also estimated for strictly positive trade flows, mirroring the PPML specification.

4.4. Policy Simulation

The estimated gravity coefficients are used to conduct policy-relevant counterfactual simulations. Using the baseline PPML estimates, predicted bilateral trade flows are computed under observed institutional arrangements and under counterfactual scenarios in which joint WTO membership or joint REC membership is imposed, holding all other determinants constant. For binary institutional variables, coefficients are interpreted as semi-elasticities. The percentage change in predicted trade associated with switching a dummy variable from zero to one is given by:

$$\% \Delta Trade = 100(e^{\beta_D} - 1) \quad (7)$$

where β_D is the estimated coefficient of the institutional dummy. This transformation follows directly from the log-link structure of the PPML model and provides an intuitive measure of the trade effects associated with deeper multilateral or regional integration in Africa.

5. Results

5.1. Baseline gravity estimates: FE log-linear models

Results in Table 4 show that the baseline fixed-effects log-linear gravity specification for intra-African trade performs in line with theoretical expectations. In the model with exporter, importer, and year fixed effects, the core gravity variables behave as “workhorses” of the framework. Bilateral distance is strongly trade-reducing and highly precisely estimated, with an elasticity of -1.046 . This implies that a 1 percent increase in distance between two African countries is associated with approximately a 1 percent reduction in bilateral trade, highlighting the continued importance of geographic frictions within the continent.

Geographic proximity and historical linkages play an economically meaningful role. Contiguity enters with a large positive coefficient, indicating that neighboring African countries trade substantially more than non-contiguous pairs. Colonial ties and common legal origin are also positive and statistically significant, reflecting the persistence of historical and institutional linkages in shaping African trade patterns. These effects suggest that legacy institutions continue to lower informational and transaction costs, even decades after independence.

Table 4. Baseline Gravity Estimates: Fixed-Effects Log-Linear Models

Variable	FE: exporter importer year	FE: exporter×year importer×year pair
log(distance)	-1.046^{***} (0.025)	—
Contiguity	1.130^{***} (0.041)	—
Colonial tie	0.941^{***} (0.032)	—
Common legal origin	0.191^{***} (0.028)	—
REC joint	1.119^{***} (0.036)	—
WTO joint	0.446^{***} (0.054)	0.488^* (0.212)
Observations	45,782	45,604
Within R ²	0.304	0.000

*, **, *** denote significance at 10%, 5%, and 1%. Robust std errors in parenthesis.

Institutional integration variables display strong associations with trade levels. Joint membership in a Regional Economic Community (REC) is associated with an increase in bilateral trade of roughly 1.12 log points, corresponding to a large and economically significant effect. Joint WTO membership is also positive and significant, with a coefficient of about 0.45 log points, indicating

that African country pairs that are jointly integrated into the multilateral trading system trade more with each other, conditional on country fixed effects and common time shocks.

The structural fixed-effects specification, which absorbs exporter-year, importer-year, and bilateral pair fixed effects, yields a more conservative picture of institutional effects. In this design, identification relies exclusively on within-pair changes over time. As a result, only joint WTO membership remains marginally significant, while the REC indicator is absorbed due to limited within-pair variation. This contrast is informative rather than problematic. It indicates that much of the explanatory power of regional integration operates through time-invariant bilateral characteristics and long-run country fundamentals rather than short-run within-pair changes.

5.2. Trade volumes vs trade intensity

The “trade volumes” classic OLS regression results is shown in Table 5, where log bilateral trade is regressed on exporter and importer GDP, population, distance, and standard bilateral controls with exporter, importer, and year fixed effects. The estimates clearly highlight scale effects. Exporter and importer GDP enter positively and are highly significant, confirming that larger African economies both export and import more. Distance remains strongly trade reducing, with an elasticity slightly above -1 , while contiguity, common colonial ties, and a shared legal tradition are all positive and precisely estimated. Joint WTO membership also remains positive and significant in this richer specification, indicating that WTO co-membership is associated with higher bilateral trade volumes within Africa, even after controlling for geography, historical ties, and multilateral resistance.

Table 5. Classic OLS vs Normalized Gravity Estimates

Variable	Classic OLS (FE)	Normalized Gravity BVU (FE)
log(GDP exporter)	0.513*** (0.031)	—
log(GDP importer)	0.595*** (0.037)	—
log(Pop exporter)	-1.231*** (0.109)	-1.469*** (0.109)
log(Pop importer)	0.398*** (0.113)	0.412*** (0.114)
log(distance)	-1.064*** (0.025)	-1.073*** (0.025)
Contiguity	1.122*** (0.041)	1.124*** (0.041)
Colonial tie	0.947*** (0.032)	0.952*** (0.032)
Common legal origin	0.186*** (0.028)	0.182*** (0.028)

REC joint	1.105*** (0.036)	1.100*** (0.036)
WTO joint	0.489*** (0.054)	0.522*** (0.054)
Observations	45,782	45,782
R ²	0.518	0.530

*, **, *** denote significance at 10%, 5%, and 1%. Robust std errors in parenthesis.

The BVU-normalized specification reframes the analysis from trade volumes to trade intensity by netting out exporter and importer GDP from log trade. In this setting, distance and bilateral cost proxies retain their expected signs and statistical strength, showing that trade costs shape not only the size of flows but also their intensity relative to economic scale. Joint WTO membership continues to enter positively and significantly, suggesting that multilateral integration is associated with higher conditional trade intensity among African country pairs. Joint REC membership also remains positive in the normalized model, indicating that regional integration contributes to stronger trade relationships even after accounting for country size. Taken together, the results in Table 5 show that both multilateral and regional institutions matter for African trade, and that their influence extends beyond scale effects to affect the depth of bilateral trade integration.

5.3. PPML results and the role of oil prices

The multiplicative gravity estimates in levels using PPML shown in Table 6 reinforce the core gravity mechanisms while exploiting the key advantages of PPML for trade data with heteroskedasticity and zero flows. In the parsimonious PPML baseline specification, bilateral distance enters with a strong and statistically significant negative coefficient, while contiguity is positive and economically large, indicating that neighboring African countries trade substantially more than non-neighbors. Joint WTO membership is strongly positive, and joint REC membership also enters with a large and significant coefficient, suggesting that both multilateral and regional integration are associated with higher intra-African trade levels in the baseline multiplicative framework. In contrast to the log-linear models, common colonial ties enter with a negative sign in the baseline PPML specification, while common legal origin is positive and significant. This sign reversal for colonial ties is substantive rather than mechanical, indicating that once trade is modeled in levels with an appropriate treatment of heteroskedasticity, colonial linkages are no longer associated with higher trade and may even correlate with lower bilateral trade volumes.

Table 6. Multiplicative Gravity Models (PPML vs GPML)

Variable	PPML Baseline	PPML + GDPs	FE PPML
log(distance)	-0.219*** (0.032)	-0.415*** (0.032)	—
Contiguity	1.747*** (0.092)	1.148*** (0.074)	—
Colonial tie	-1.305*** (0.073)	-0.043 (0.058)	—
Common legal origin	1.095*** (0.073)	0.734*** (0.059)	—
REC joint	1.087*** (0.065)	1.219*** (0.053)	—
WTO joint	1.709*** (0.068)	1.313*** (0.053)	0.701 (0.479)
log(GDP exporter)	—	1.206*** (0.026)	—

log(GDP importer)	—	0.687*** (0.025)	—
log(Pop exporter)	—	-0.315*** (0.033)	—
log(Pop importer)	—	-0.156*** (0.022)	—
log(oil price)	1.001*** (0.045)	-0.205*** (0.043)	—
Observations	136,100	136,100	76,512
R2	0.437	0.755	

*, **, *** denote significance at 10%, 5%, and 1%. Robust std errors in parenthesis.

When GDP and population variables are added, the PPML model with economic size behaves as expected. Exporter and importer GDP enter positively and with large magnitudes, confirming the dominant role of economic mass in shaping trade flows. Population effects are asymmetric, with importer population positive and significant and exporter population negative, reflecting differences in market absorption versus production scale across African economies. Distance remains strongly trade reducing. Institutional variables attenuate relative to the parsimonious specification but remain economically meaningful: joint WTO membership and joint REC membership stay positive and significant, while the contiguity effect weakens once size controls are included, suggesting that part of the contiguity effect in simpler models was capturing correlated scale effects or omitted bilateral characteristics.

The structural PPML specification with exporter-year, importer-year, and pair fixed effects yields a markedly different picture for institutional variables. In this design, identification relies entirely on within-pair changes over time. Joint REC membership is absorbed due to limited within-pair variation, while joint WTO membership enters with a smaller and statistically weak coefficient. As in the log-linear case, this contrast is informative rather than contradictory. It highlights that institutional indicators largely capture long-run cross-sectional differences in trade integration, and that once highly saturated fixed effects are imposed, the remaining within-pair variation may reflect contemporaneous shocks or policy transitions rather than clean institutional treatment effects. Together, the PPML results confirm the robustness of gravity fundamentals in African trade while emphasizing the sensitivity of institutional coefficients to estimator choice and fixed-effects structure.

5.4. Policy simulation as model-implied counterfactuals

The counterfactual exercise translates the baseline PPML estimates into model-implied predictions of bilateral trade under alternative institutional configurations, holding all other covariates at their observed values. Using the Ethiopia–Algeria pair in the final year of the sample, the baseline scenario yields a predicted bilateral trade flow of about USD 1.9 billion. Setting joint WTO membership equal to one increases the predicted trade flow to roughly USD 10.6 billion, corresponding to an increase of about 453 percent relative to the baseline. Imposing joint REC membership raises predicted trade to approximately USD 5.7 billion, implying a 197 percent increase. These large proportional changes mechanically reflect the sizable positive semi-elasticities associated with WTO and REC joint membership in the baseline PPML specification and illustrate how strongly institutional indicators influence predicted trade when estimated effects are large.

Table 7. Policy Simulation

Scenario	Predicted trade (USD '000)	Change vs baseline
Baseline: no WTO, no REC	1,909.6	—
WTO membership	10,551.8	+452.6%
REC membership	5,661.4	+196.5%

Substantively, these simulations should be interpreted as model-implied counterfactual associations rather than literal policy forecasts. The exercise assumes strict *ceteris paribus* conditions, namely that institutional alignment changes while all other determinants of trade remain fixed, and it inherits any identification limitations present in the baseline PPML model. Framed appropriately, the Ethiopia–Algeria (no WTO or joint regional economic block) example provides an intuitive magnitude benchmark: if multilateral or regional integration operated through the same channels captured by the PPML estimates, the implied gains in bilateral trade could be substantial, even for geographically distant country pairs. At the same time, the sensitivity of institutional coefficients to alternative fixed-effects structures cautions against a causal reading. The counterfactual results are therefore best presented as illustrative, upper-bound estimates that highlight the potential importance of institutional integration in shaping intra-African trade.

6. Conclusion

In this research we examined the relationship between trade institutions and intra-African trade over the long run. The results offer empirically grounded insights that align closely with the policy objectives and implementation challenges of the African Continental Free Trade Area. The descriptive evidence confirms that intra-African trade remains limited and unevenly distributed. Trade relationships are sparse, with many country pairs recording no trade, while a small group of economies account for a large share of continental exports. Network structures reveal strong concentration around a few regional hubs. These features underscore the structural constraints that policymakers need to address, including fragmentation, high trade costs, and limited connectivity.

Across all empirical specifications, geographic trade costs remain central. Distance continues to exert a strong negative effect on trade, while contiguity significantly increases bilateral flows. These findings are consistent with AfCFTA policy assessments that emphasize the importance of transport infrastructure, corridor development, and trade facilitation. Institutional integration alone is unlikely to deliver meaningful gains without parallel progress in these enabling areas. Institutional variables display positive and economically meaningful associations with trade in most models. Joint membership in regional economic communities is associated with higher trade volumes and stronger trade intensity. Joint WTO membership also correlates positively with trade, suggesting that multilateral disciplines complement regional integration efforts. This evidence supports incremental approach, which builds on existing regional arrangements rather than attempting to bypass them.

At the same time, the results highlight an important message for AfCFTA expectations. In highly saturated fixed-effects specifications, institutional coefficients weaken or lose significance. This pattern suggests that institutional indicators mainly reflect long-run structural integration rather than immediate policy effects. Trade responses appear gradual and cumulative, consistent with AfCFTA policy documents that frame the agreement as a medium- to long-term integration project. The PPML results reinforce this interpretation. Gravity fundamentals remain robust once zero trade flows and heteroskedasticity are addressed. Institutional effects remain positive in

parsimonious models but attenuate under strict identification. Model-implied counterfactual simulations suggest potentially large gains from institutional alignment, but these should be interpreted as indicative benchmarks rather than short-term forecasts.

Taken together, the findings point to a realistic understanding of AfCFTA's role. It is best viewed as a continental coordination framework that reduces uncertainty, aligns rules, and supports gradual integration. Its effectiveness will depend on sustained implementation, policy coherence, and complementary investments in productive capacity and logistics. From a policy perspective, the results reinforce emphasis on implementation depth rather than formal membership. Progress on non-tariff barriers, customs cooperation, and regulatory alignment will be critical. Regional economic communities remain essential building blocks in this process, providing institutional experience and practical pathways for deeper continental integration.

Finally, this study highlights a methodological lesson that is also relevant for policy evaluation. Estimated institutional effects depend strongly on model choice and identification strategy. This sensitivity should inform cautious interpretation rather than undermine confidence in integration efforts. Trade institutions shape long-run trajectories more than short-run outcomes. Future research could focus on effects at the product or firm level, where adjustment mechanisms may be more visible. Linking trade integration to diversification, resilience, and food security would further strengthen the evidence base. Such work would help align empirical analysis more closely with AfCFTA's broader development agenda.

Declaration of competing interests

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

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Data availability statement

The data used in this study are publicly available. Bilateral trade and gravity variables are obtained from the CEPII Gravity database (version 2022.11), which can be accessed at <https://www.cepii.fr>. Any additional data processing scripts are available from the corresponding author upon reasonable request.

CRedit author statement

[JA]: Conceptualization; Methodology; Data curation; Formal analysis; Writing – original draft; Writing – review & editing.

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Declaration of generative AI and AI-assisted technologies

During the preparation of this manuscript, generative AI tools were used to assist with language editing and clarity of expression. The author(s) reviewed and edited all content generated using these tools and take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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Appendix: R Code

```
#####  
## Intra-AFRICAN Trade Gravity Pipeline (UPDATED)  
## Uses CEPII Gravity built-in WTO variables (wto)  
## REC_joint (ECOWAS, SADC, COMESA, EAC)  
## Outputs, in order:  
## 1) Descriptive statistics table (copy paste ready)  
## 2) Trade network (latest year)  
## 3) Distribution of latest intra-African tradeflow  
## 4) Correlation matrix (continuous variables)  
## 5) Pairwise log relationships  
## 6) log(trade) vs log(distance)  
## 7) Baseline gravity (fixed effects log-linear models)  
## 8) Classic OLS vs Normalized Gravity (BVU)  
## 9) Multiplicative gravity: PPML baseline, PPML with GDPs, FE PPML (pair & time FE)  
## 10) Predicted trade scenarios for an example pair: WTO_joint, REC_joint  
#####  
  
if (!requireNamespace("pacman")) install.packages("pacman")  
rm(list = ls()); pacman::p_unload(); while (!is.null(dev.list())) dev.off(); cat("\014")  
  
pacman::p_load(tidyverse, fixest, modelsummary, sandwich, skimr, scales, igraph, ggraph,  
tidygraph)  
options(scipen = 999)  
  
#####  
## PRINT TABLES TO CONSOLE + HTML  
#####  
print_both <- function(x) {  
  print(x) # console output  
  cat("\n\n") # spacing  
  invisible(x)  
}  
  
#####  
## 0) USER SETTINGS  
#####  
start_year <- 1962  
end_year <- 2020  
data_path <- "C:/Users/o.golseven/Downloads/Gravity_rds_V202211/Gravity_V202211.rds"  
  
#####  
## 1) LOAD + FILTER AFRICA SAMPLE  
#####  
data <- readRDS(data_path)
```

```

africa_iso <- c(
  "DZA","AGO","BEN","BWA","BFA","BDI","CMR","CPV","CAF","TCD",
  "COM","COG","CIV","COD","DJI","EGY","GNQ","ERI","ETH","GAB",
  "GMB","GHA","GIN","GNB","KEN","LSO","LBR","LBY","MDG","MWI",
  "MLI","MRT","MUS","MAR","MOZ","NAM","NER","NGA","RWA","STP",
  "SEN","SYC","SLE","SOM","ZAF","SSD","SDN","SWZ","TZA","TGO",
  "TUN","UGA","ZMB","ZWE"
)

```

```

Africa <- data %>%
  filter(iso3_o %in% africa_iso, iso3_d %in% africa_iso) %>%
  select(
    year, iso3_o, iso3_d,
    tradeflow_comtrade_d,
    gdp_o, gdp_d,
    pop_o, pop_d,
    dist,
    comleg_posttrans, comcol, contig,
    wto_o, wto_d
  ) %>%
  filter(year >= start_year, year <= end_year)

```

```

#####
## 2) BUILD PPML DATASET (keep zeros) + WTO_joint
#####

```

```

df_ppml <- Africa %>%
  filter(iso3_o != iso3_d) %>%
  mutate(
    flow = replace_na(tradeflow_comtrade_d, 0),
    wto_o = replace_na(wto_o, 0),
    wto_d = replace_na(wto_d, 0),
    WTO_joint = as.integer(wto_o == 1 & wto_d == 1)
  ) %>%
  transmute(
    year,
    iso_o = iso3_o,
    iso_d = iso3_d,
    pair_id = paste0(iso3_o, "_", iso3_d),
    flow,
    gdp_o, gdp_d,
    pop_o, pop_d,
    distw = dist,
    comleg = comleg_posttrans,
    comcol,
    contig,
    WTO_joint
  )

```

```

) %>%
drop_na()

cat("Rows in df_ppml:", nrow(df_ppml), "\n")

#####
## 3) ADD DUBAI OIL PRICE + log_oil
#####
oil_prices <- tibble(
  year = 1960:2024,
  oil_price = c(1.63,1.57,1.52,1.50,1.45,1.42,1.36,1.33,1.32,1.27,
    1.21,1.69,1.82,2.81,10.97,10.43,11.63,12.57,12.92,29.82,
    35.85,34.29,31.76,28.73,27.49,26.46,13.20,16.94,13.22,15.70,
    20.46,16.56,17.19,14.94,14.67,16.12,18.54,18.10,12.13,17.17,
    26.08,22.71,23.72,26.74,33.46,49.29,61.43,68.37,93.78,61.75,
    78.06,106.03,108.90,105.43,96.66,51.18,41.20,53.12,69.15,63.18,
    42.17,68.81,97.05,81.98,79.66)
)

df_ppml <- df_ppml %>%
left_join(oil_prices, by = "year") %>%
mutate(log_oil = log(oil_price))

if (any(is.na(df_ppml$oil_price))) {
  stop("Missing oil prices after join. Fix oil_prices coverage or year filter.")
}

#####
## 4) REGIONAL ECONOMIC COMMUNITIES (REC_joint)
#####

# ECOWAS (15)
ecowas <- c(
  "BEN", "BFA", "CIV", "CPV", "GHA", "GIN", "GNB",
  "LBR", "MLI", "NER", "NGA", "SEN", "SLE", "TGO", "GMB"
)

# SADC (16)
sadc <- c(
  "AGO", "BWA", "COM", "COD", "LSO", "MDG", "MWI", "MUS",
  "MOZ", "NAM", "SYC", "ZAF", "SWZ", "TZA", "ZMB", "ZWE"
)

# COMESA (21)
comesa <- c(
  "BDI", "COM", "COD", "DJI", "EGY", "ERI", "ETH", "KEN",

```

```

    "LBY", "MDG", "MWI", "MUS", "RWA", "SYC", "SDN", "SOM",
    "SSD", "TUN", "UGA", "ZMB", "ZWE"
)

# EAC (6)
eac <- c("BDI", "KEN", "RWA", "SSD", "TZA", "UGA")

# Construct REC_joint (binary, no double counting)
df_ppml <- df_ppml %>%
  mutate(
    REC_joint = as.integer(
      (iso_o %in% ecowas & iso_d %in% ecowas) |
      (iso_o %in% sadc & iso_d %in% sadc) |
      (iso_o %in% comesa & iso_d %in% comesa) |
      (iso_o %in% eac & iso_d %in% eac)
    )
  )

#####
## 5) OLS DATASET (drop zeros) + logs
#####
df_ols <- df_ppml %>%
  filter(flow >= 1) %>%
  mutate(
    lflow = log(flow),
    lgdp_o = log(gdp_o),
    lgdp_d = log(gdp_d),
    lpop_o = log(pop_o),
    lpop_d = log(pop_d),
    ldistw = log(distw)
  )

cat("Rows in df_ols:", nrow(df_ols), "\n")

#####
## 6) DESCRIPTIVE STATISTICS TABLE (console + html)
#####
desc_vars <- df_ppml %>%
  transmute(
    flow,
    gdp_o, gdp_d,
    pop_o, pop_d,
    distw,
    oil_price,
    REC_joint, WTO_joint,
    comleg, comcol, contig
  )

```

```

)

desc_table <- desc_vars %>%
  pivot_longer(everything(), names_to = "variable", values_to = "value") %>%
  group_by(variable) %>%
  summarise(
    N = sum(!is.na(value)),
    Mean = mean(value, na.rm = TRUE),
    SD = sd(value, na.rm = TRUE),
    Min = min(value, na.rm = TRUE),
    P25 = quantile(value, 0.25, na.rm = TRUE),
    Med = median(value, na.rm = TRUE),
    P75 = quantile(value, 0.75, na.rm = TRUE),
    Max = max(value, na.rm = TRUE),
    .groups = "drop"
  )

print_both(modelsummary::datasummary_df(desc_table, output = "markdown"))
print_both(modelsummary::datasummary_df(desc_table, output = "html"))

#####
## 7) TRADE NETWORK (latest year)
#####
latest_year <- max(df_ppml$year, na.rm = TRUE)

edges <- df_ppml %>%
  filter(year == latest_year, flow > 0) %>%
  group_by(iso_o, iso_d) %>%
  summarise(flow = sum(flow, na.rm = TRUE), .groups = "drop")

nodes <- df_ppml %>%
  filter(year == latest_year) %>%
  group_by(iso_o) %>%
  summarise(gdp = mean(gdp_o, na.rm = TRUE), .groups = "drop") %>%
  rename(name = iso_o)

g <- graph_from_data_frame(d = edges, vertices = nodes, directed = TRUE)
g_tbl <- as_tbl_graph(g)

ggraph(g_tbl, layout = "fr") +
  geom_edge_link(aes(width = flow), alpha = 0.2, color = "darkgray", show.legend = FALSE) +
  geom_node_point(aes(size = gdp), color = "steelblue", alpha = 0.9) +
  geom_node_text(aes(label = name), repel = TRUE, size = 3) +
  scale_size_continuous(range = c(2, 10)) +
  scale_edge_width(range = c(0.1, 2)) +
  theme_void() +

```

```

labs(title = paste0("Intra-African Trade Network (", latest_year, ")"))

#####
## 7B) TOTAL INTRA-AFRICAN EXPORTS BY COUNTRY (latest year)
#####
df_ppml %>%
  filter(year == latest_year) %>%
  group_by(iso_o) %>%
  summarise(total_export = sum(flow, na.rm = TRUE), .groups = "drop") %>%
  slice_max(order_by = total_export, n = 20) %>%
  ggplot(aes(x = reorder(iso_o, total_export), y = total_export)) +
  geom_col() +
  labs(
    title = paste0("Top 20 Intra-African Exporters (", latest_year, ")"),
    x = "Exporter ISO3",
    y = "Total export value (thousand USD)"
  ) +
  coord_flip() +
  scale_y_continuous(labels = scales::comma) +
  theme_minimal()

#####
## 8) DISTRIBUTION OF LATEST INTRA-AFRICAN TRADEFLOW
#####
df_latest <- df_ppml %>% filter(year == latest_year)

ggplot(df_latest %>% filter(flow >= 1), aes(x = log(flow))) +
  geom_histogram(bins = 50, fill = "steelblue", color = "white") +
  scale_x_continuous(limits = c(0, NA)) +
  labs(
    title = paste0("Distribution of Bilateral Trade Flows, ", latest_year, " (log scale)"),
    x = "log(trade flow)",
    y = "Number of country pairs"
  ) +
  theme_minimal()

#####
## 9a) CORRELATION MATRIX (console + html)
#####
cont_vars <- df_ppml %>%
  select(flow, gdp_o, gdp_d, pop_o, pop_d, distw, oil_price)

corr_mat <- cor(cont_vars, use = "pairwise.complete.obs")
corr_df <- as.data.frame(round(corr_mat, 3)) %>%
  tibble::rownames_to_column(var = "variable")

```

```
print_both(modelsummary::datasummary_df(corr_df, output = "markdown"))
print_both(modelsummary::datasummary_df(corr_df, output = "html"))
```

```
#####
```

```
## 9b) PAIRWISE LOG RELATIONSHIPS (sample)
```

```
#####
```

```
df_pairs <- df_ols %>%
```

```
  transmute(
    log_flow = lflow,
    log_gdp_o = lgdp_o,
    log_gdp_d = lgdp_d,
    log_distw = ldistw,
    log_oil = log_oil
  ) %>%
  drop_na()
```

```
set.seed(123)
```

```
pairs_sample <- df_pairs %>% sample_n(size = min(1000, nrow(df_pairs)))
```

```
pairs(
```

```
  ~ log_flow + log_gdp_o + log_gdp_d + log_distw + log_oil,
  data = pairs_sample,
  main = "Pairwise log relationships (sample)",
  pch = 19, col = rgb(0, 0, 1, 0.3)
```

```
)
```

```
#####
```

```
## 10) Oil and Trade
```

```
#####
```

```
trade_oil_ts <- df_ppml %>%
```

```
  group_by(year) %>%
  summarise(
    total_trade = sum(flow, na.rm = TRUE),
    oil_price = mean(oil_price, na.rm = TRUE),
    .groups = "drop"
  )
```

```
scale_factor <- max(trade_oil_ts$total_trade, na.rm = TRUE) /
```

```
  max(trade_oil_ts$oil_price, na.rm = TRUE)
```

```
ggplot(trade_oil_ts, aes(x = year)) +
```

```
  geom_line(aes(y = total_trade), linewidth = 1) +
  geom_point(aes(y = total_trade), size = 2) +
  geom_line(aes(y = oil_price * scale_factor), linewidth = 1, linetype = "dashed") +
  scale_y_continuous(
    name = "Total intra-African trade (thousand USD)",
    labels = scales::comma,
```

```

    sec.axis = sec_axis(~ . / scale_factor,
                        name = "Dubai crude oil price (USD per barrel)")
) +
labs(
  title = "Intra-African Trade and Dubai Oil Prices Over Time",
  x = "Year"
) +
theme_minimal()

#####
## 11) BASELINE GRAVITY (fixed effects log-linear) (console + html)
#####
m_fe_baseline <- feols(
  lflow ~ ldistw + contig + comcol + comleg + REC_joint + WTO_joint + log_oil |
  iso_o + iso_d + year,
  data = df_ols,
  vcov = "HCl"
)

m_fe_structural <- feols(
  lflow ~ REC_joint + WTO_joint + log_oil |
  iso_o^year + iso_d^year + pair_id,
  data = df_ols,
  vcov = "HCl"
)

print_both(modelsummary(
  list(
    "FE log linear: o i year FE" = m_fe_baseline,
    "FE log linear: oy dy pair FE" = m_fe_structural
  ),
  output = "markdown",
  stars = TRUE
))

print_both(modelsummary(
  list(
    "FE log linear: o i year FE" = m_fe_baseline,
    "FE log linear: oy dy pair FE" = m_fe_structural
  ),
  output = "html",
  stars = TRUE
))

#####
## 13) CLASSIC OLS vs NORMALIZED GRAVITY (BVU) (console + html)

```

```

#####
df_ols <- df_ols %>%
  mutate(bvu = lflow - lgdp_o - lgdp_d)

m_classic_ols <- feols(
  lflow ~ lgdp_o + lgdp_d + lpop_o + lpop_d + ldistw +
    contig + comcol + comleg + REC_joint + WTO_joint + log_oil |
  iso_o + iso_d + year,
  data = df_ols,
  vcov = "HCl"
)

m_bvu <- feols(
  bv_u ~ lpop_o + lpop_d + ldistw +
    contig + comcol + comleg + REC_joint + WTO_joint + log_oil |
  iso_o + iso_d + year,
  data = df_ols,
  vcov = "HCl"
)

print_both(modelsummary(
  list(
    "Classic OLS (FE)" = m_classic_ols,
    "Normalized Gravity BVU (FE)" = m_bvu
  ),
  output = "markdown",
  stars = TRUE
))

print_both(modelsummary(
  list(
    "Classic OLS (FE)" = m_classic_ols,
    "Normalized Gravity BVU (FE)" = m_bvu
  ),
  output = "html",
  stars = TRUE
))

#####
## 14) MULTIPLICATIVE GRAVITY MODELS IN LEVELS (console + html)
#####
ppml_baseline <- fepois(
  flow ~ log(distw) + contig + comcol + comleg + REC_joint + WTO_joint + log_oil,
  data = df_ppml,
  vcov = "HCl"
)

```

```
ppml_gdps <- fepois(
  flow ~ log(gdp_o) + log(gdp_d) + log(pop_o) + log(pop_d) + log(distw) +
  contig + comcol + comleg + REC_joint + WTO_joint + log_oil,
  data = df_ppml,
  vcov = "HCl"
)
```

```
gpml_fe <- fepois(
  flow ~ REC_joint + WTO_joint + log_oil |
  iso_o^year + iso_d^year + pair_id,
  data = df_ppml,
  vcov = "HCl"
)
```

```
print_both(modelsummary(
  list(
    "PPML baseline" = ppml_baseline,
    "PPML with GDPs" = ppml_gdps,
    "FE PPML (oy dy pair)" = gpml_fe
  ),
  output = "markdown",
  stars = TRUE
))
```

```
print_both(modelsummary(
  list(
    "PPML baseline" = ppml_baseline,
    "PPML with GDPs" = ppml_gdps,
    "FE PPML (oy dy pair)" = gpml_fe
  ),
  output = "html",
  stars = TRUE
))
```

```
#####
## 15) PREDICTED TRADE SCENARIOS (example: Nigeria -> Ghana)
#####
#####
## 15) PREDICTED TRADE SCENARIOS (counterfactual baseline)
#####
```

```
pair_o <- "ETH" # not in WTO until 2020, not same REC as importer
pair_d <- "DZA" # WTO member, different REC
```

```
pair_hist <- df_ppml %>%
```

```

filter(iso_o == pair_o, iso_d == pair_d)

if (nrow(pair_hist) == 0) {
  stop("No observations found for selected pair.")
}

yr_use <- max(pair_hist$year, na.rm = TRUE)

# Baseline: force NO institutional integration
base_row <- df_ppml %>%
  filter(iso_o == pair_o, iso_d == pair_d, year == yr_use) %>%
  slice(1) %>%
  mutate(
    WTO_joint = 0,
    REC_joint = 0
  )

base_pred <- predict(ppml_baseline, newdata = base_row, type = "response")

# WTO counterfactual
wto_row <- base_row %>%
  mutate(WTO_joint = 1)

wto_pred <- predict(ppml_baseline, newdata = wto_row, type = "response")

# REC counterfactual
rec_row <- base_row %>%
  mutate(REC_joint = 1)

rec_pred <- predict(ppml_baseline, newdata = rec_row, type = "response")

pred_table <- tibble(
  exporter = pair_o,
  importer = pair_d,
  year = yr_use,
  scenario = c(
    "Baseline: no WTO, no REC",
    "Counterfactual: WTO_joint = 1",
    "Counterfactual: REC_joint = 1"
  ),
  predicted_trade = round(c(base_pred, wto_pred, rec_pred), 2),
  percent_change_vs_baseline = c(
    "0%",
    paste0(round(100 * (wto_pred / base_pred - 1), 1), "%"),
    paste0(round(100 * (rec_pred / base_pred - 1), 1), "%")
  )
)

```

)

```
print_both(modelsummary::datasummary_df(pred_table, output = "markdown"))  
print_both(modelsummary::datasummary_df(pred_table, output = "html"))
```