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Trade-related infrastructure and bilateral trade flows: evidence from Nigeria and its trading partners

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Abstract

This study examines the relative impacts of transport and information and communications technology (ICT) components of trade-related infrastructure on bilateral trade flows between Nigeria and its major trading partners. An augmented standard gravity model that featured variables for the transport infrastructure component and the ICT component was estimated using bilateral trade data on 22 major trading partners of Nigeria for the period 2005–2021. The panel instrumental variables technique, precisely pooled two-stage least squares technique leveraged on fixed and random effects models, was used for the analysis. The findings show that the two components of trade-related infrastructure, transportation and information and communication technology (ICT) have a significant impact on trade flows between Nigeria and its trading partners. In the exports model, the differential impact of the transport infrastructure component is higher than the ICT component, but the differential impact of the ICT component is greater in the imports model. This suggests that the efficient provision of both transport and ICT infrastructure facilitates trade, while the inefficient provision of either or both hinders it. Therefore, greater attention must be placed on improving both components.

Keywords: Trade-related infrastructure, Bilateral trade flows, Gravity model, Panel instrumental variables, Nigeria and trading partners

1 Introduction

Trade is universally agreed in the economic literature to provide an important stimulus to growth and development (Wilson et al., 2003; Todaro and Smith, 2004). International trade involves an element of trade costs, which are partly associated with inefficient infrastructure services. The concept of inefficient infrastructure services refers to the poor state of infrastructure, which creates a gap and increases vulnerability towards high cost and time inefficiencies (Bartle, 2017; Rahman et al., 2020). As established by the structuralists, a country with efficient infrastructure performs better and has a comparative edge, particularly in trade, and can also make a huge difference in the process of development compared to countries with inefficient infrastructure (Portugal-Perez and Wilson, 2012; Ahmad et al., 2015). This implies that efficient infrastructure is critical for trade promotion and global economic integration (Brooks and Menon, 2008; Rim et al., 2019). Studies have also demonstrated that inefficient infrastructure inhibits trade (World Trade Report, 2004; Donaubauer et al., 2018; Zheng and Hongtao, 2022). In the theoretical literature, there is a consensus (or argument) that inefficient and inadequate local infrastructure and trade procedures lead to higher trade costs, thereby making imports more expensive while consumers move away from such imports towards domestic goods (Samuelson, 1952; Krugman, 1979, 1980). On the empirical side, Arvis et al. (2013) found that the poor state of infrastructure and malfunctioning transport systems are sources of trade costs that result in higher transportation costs incurred by exporters and importers. Generally, the cost of production and the level of trade are primarily influenced by the state of the country's available infrastructure. However, traditional trade theories ignored the role of infrastructure because they assumed zero transportation costs, which in reality, does not hold.

Nigeria's contribution to global exports has not been satisfactory (UNCTAD, 2022). Nigeria's share of world exports over the last 2 decades peaked at 0.63% in 2011, with an average of 0.35%.[1] Since then, it has gradually been dropping, recording 0.21% in 2021 (UNCTAD, 2022). This is lower compared with South Africa, whose share of world exports was recorded at 0.55% for the same period. Based on this fact, Nigeria is placed in the 54th position in the International Trade Center (ITC) ranking of world exporting countries, while South Africa, a smaller economy than Nigeria, was ranked 37th in 2021.[2] Also, Nigeria's share of exports to GDP between 2010 and 2021 averaged 17.8%, lower than Ghana and South Africa with 31.7% and 27.9% shares of exports to GDP, respectively (World Development Indicators (WDI), 2022)).

In Nigeria, there is a high deficit of efficient trade-related infrastructure, as the total core infrastructure stock is estimated at 20–25% of GDP. This is against the international benchmark of 70% of GDP. This low rate of infrastructure development has been historically driven by low public and private sector spending on infrastructure (National Planning Commission, 2015). The poor state of infrastructure in Nigeria constrains trading activities and, consequently, pushes up trade costs. Due to a lack of efficient infrastructure services (paved roads, an efficient rail system, an efficient port authority, and better communication networks), Nigeria is being considered one of the places where the cost of trade greatly exceeds the value of the traded commodities (Foster and Pushak, 2011). This is because inefficient infrastructure services reduce the country's connections to distribution networks and global supply chains for producers, thus increasing trade costs, lowering value addition, and reducing profitability potential. Francois and Manchin (2013) found that telecommunications and transport infrastructure played a significant role in determining both export levels and the possibility of exporting. In the 2018–2019 Global Competitiveness Index (GCI), Nigeria received a very poor assessment for its infrastructure and consequently ranked 116 out of 140 countries considered (World Economic Forum, 2019).

This paper's contribution to existing studies is based on the following gaps: first, this study takes into account both the demand and supply sides (i.e., trade flows with

[1] For the period between 1985 and 2011.

[2] See https://en.wikipedia.org/wiki/List_of_countries_by_exports.

consideration to exports and imports to and from its top trading partners). In this study, both the import demand and export supply functions were estimated, unlike previous studies (Korinek and Sourdin, 2009; Nordås and Piermartini, 2004) that looked at either the demand or supply side alone. The rationale for this consideration was to ensure policymaking so that there is a balanced view, as both have implications for the country's balance of payments. As a result, focusing solely on the supply side may result in policy bias. Second, while notable studies have investigated the impact of infrastructure on trade, some of these studies (Deen-Swarray et al., 2012; Limao and Venables, 2001) constructed an infrastructure index without the inclusion of exporter- and importer-specific effects. This makes it difficult to identify the particular infrastructural component with a higher payoff and requires greater attention from policymakers. In addition, Rehman et al. (2020) and (2021) have examined the impact of various indicators of transport and ICT infrastructure on trade without accounting for heterogeneity effects, whereas Ismail and Mahyideen (2015) accounted for heterogeneity effects but estimated the impact of disaggregated components of transport and ICT infrastructure on trade separately. This study is unique in that it considers six trade-related infrastructure indicators disaggregated into two components: transportation infrastructure (ratio of total road network to total population, maritime transport, and air transport) and ICT infrastructure (individuals using the internet as a percentage of the population, fixed broadband internet, and telephone subscriptions). These two components were combined in a model to estimate their respective impacts on bilateral trade flows with the inclusion of exporter- and importer-specific effects. None of the above-mentioned papers looks at the impact ratio of the components of infrastructural services on bilateral trade flows. Third, this study employed an augmented gravity model with the aid of a panel instrumental variables (IVs) estimator, specifically a pooled two-stage least squares (2SLS) technique, leveraging on fixed and random effects models. This differs from previous studies that used panel ordinary least squares (OLS) and Poisson pseudo-maximum likelihood (PPML) model estimations because it helps to solve the problems of heteroscedasticity and endogeneity, while at the same time accounting for heterogeneity. The objective of this study is to evaluate the differential impact ratio of the two components of trade-related infrastructure (transport and ICT infrastructure) on bilateral trade flows between Nigeria and its major trading partners.

After the foregoing introductory section, Sect. 2 presents a stylized fact on the comparative analysis of the components of infrastructural services and trade flows between Nigeria and its trading partners. Section 3 covers a literature review, and Sect. 4 focuses on empirical models and estimation techniques. Section 5 presents the empirical results with a discussion, while Sect. 6 concludes the paper with policy recommendations.

2 Overview of infrastructural services and bilateral trade flows between Nigeria and its trading partners

This section compares the status of infrastructural services between Nigeria and its major trading partners concerning trade-related infrastructure indicators. In addition, the analysis extends to the trade flows of these trading partners, with an emphasis on Nigeria's merchandise exports to and imports from all trading partners.

2.1 Trade-related infrastructure measures in Nigeria and trading partners

Infrastructure inefficiency is unarguably a major challenge in Nigeria. Key infrastructures such as roads, railway networks, ports, and internet facilities are inadequate (WDI, 2022; UNCTAD, 2022). Most of the available ones are also in bad shape. Poor transportation infrastructure tends to constrain businesses. This could also lead to a high cost of transportation, which could have some spillover effects on trade. Therefore, high transport costs and the time of delivery of commodities could affect the competitive position of a country.

2.2 Roads

The total road network[3] (both paved and unpaved) comprises motorways, highways, main or national roads, secondary or regional roads, and all other roads in a country. Figure 1 depicts the ratio of the total road network to the total population of Nigeria and the same for its trading partners. The figure clearly shows that Nigeria's stock of road networks is very low compared with its increasing population. For instance, over the period 2005–2021, Nigeria's total road network only increased from 193,200 km to 195,000 km (about 0.93% increase). However, the population steadily increased from 138 million in 2005 to 211 million in 2021 (about 52.2% increase). By implication, the ratio of the total road network to the total population in Nigeria remains lower, at 0.001 from 2005 through 2021. This is very low relative to most of its trading partners except the UAE and Singapore. Generally, the low ratio of total road networks to the population in Nigeria has created a great burden on the available roads and thus resulted in high transportation and delivery costs for both producers and consumers.

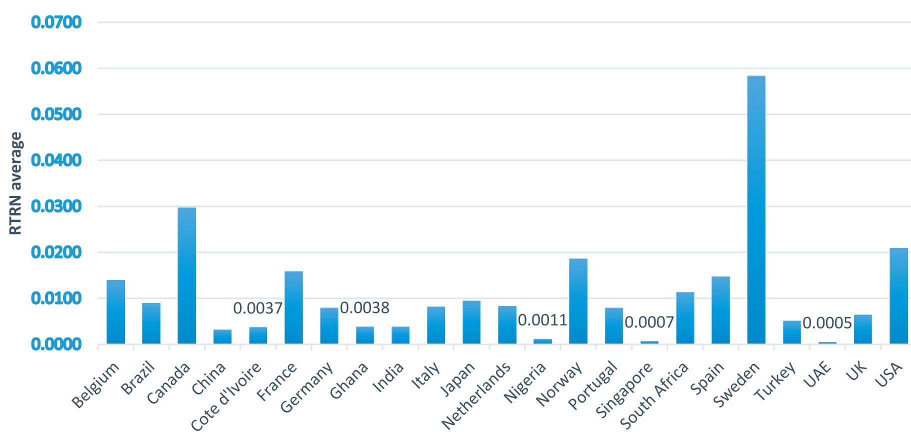

Fig. 1 Ratio of total roads network (RTRN) to total population for Nigeria and major trading partners, average (2005–2021). *Sources:* World Development Indicators, Basic Road Statistics of India (several years), National Planning Commission 2015; and Road Statistics Yearbook, 2022

[3] https://www.cia.gov/the-world-factbook/field/roadways/country-comparison; https://en.wikipedia.org/wiki/List_of_countries_by_road_network_size

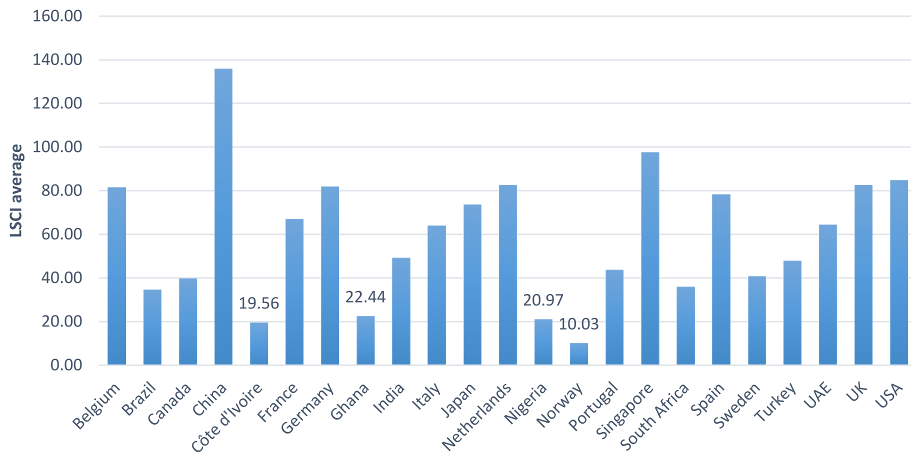

Fig. 2 Liner Shipping Connectivity Index (LSCI) for Nigeria and its top trading partners, average (2005–2021) Source: UNCTADstatistics, 2022

2.3 Maritime transport (liner shipping connectivity index)

Maritime transport is measured by the Liner Shipping Connectivity Index (LSCI). LSCI captures how well countries are connected to global shipping networks and is considered an alternative measure of openness to global trade. LSCI is computed based on five major components of connectivity: maximum vessel size, the total container-carrying capacity of ships, the number of ships, the number of companies that deploy container ships on services from and to a country's ports, and the number of services. A country with a high connectivity index could easily access a high-capacity and high-frequency global maritime transport system, making its effective participation in global trade easier. A look at Nigeria's LSCI and that of its major trading partners shows a low index for Nigeria in terms of maritime shipping connectivity and trade facilitation. Between 2005 and 2021, Nigeria's LSCI values averaged 20.97. This is very low relative to its major trading partners, except Cote d'Ivoire and Norway, as shown in Fig. 2. LSCI values for Nigeria also ranged between 13.02 and 21.71 during the period 2005–2021, which is far below those of its major trading partners, except for Cote d'Ivoire and Norway, with average values of 19.55 and 10.03, respectively. This indicates that Nigeria has very low connectivity values relative to the average values of most of its major trading partners. This is expected to impede trading activities.

2.4 Air transport, freight

Air freight is the total goods transported in bulk by aircraft. It is measured in metric tons multiplied by kilometers traveled. Figure 3 shows that the total amount of goods transported in bulk by aircraft in Nigeria has been extremely low relative to its trading partners, except for Cote d'Ivoire, Ghana, Norway, Portugal, and Sweden. This is an indication that Nigeria is one of the least-performing countries in terms of the quality of its airports.

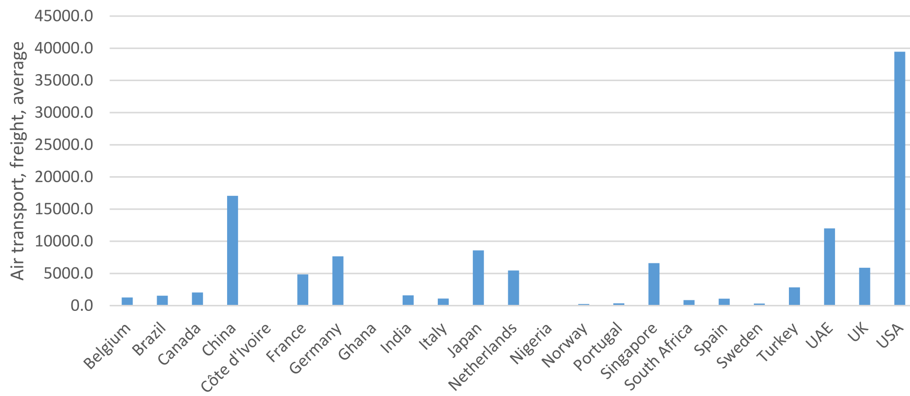

Fig. 3 Air transport, freight (million ton-km) for Nigeria and its top trading partners, average (2005–2021) Source: World Development Indicators, 2022

2.5 ICT infrastructure

Despite the significant role that ICT infrastructure plays in enhancing trade for both exporters and importers, Table 1 clearly shows that Nigeria among its trading partners is very weak, virtually in most of the ICT components. In 2005, Nigeria's internet users (as a percentage of the population), fixed broadband internet, and telephone subscriptions

Table 1 Selected component of ICT infrastructure for Nigeria and its trading partners

Country/year	Individuals using the Internet (% of the population)			Fixed broadband subscriptions (per 100 people)			Fixed telephone subscriptions (per 100 people)		
	2005	2015	2021	2005	2015	2021	2005	2015	2021
Belgium	55.8	85.1	91.5	19.1	36.6	42.4	45.6	39.9	28.4
Brazil	21.0	58.3	81.3	1.7	12.4	19.4	21.3	21.3	13.5
Canada	71.7	90.0	97.0	21.7	36.7	43.1	56.3	43.7	33.9
China	8.5	50.3	70.4	2.9	19.9	37.6	26.9	16.6	12.7
Cote d'Ivoire	1.0	16.7	36.6	0.01	0.5	1.2	1.4	1.2	1.0
France	42.9	78.0	84.8	15.7	42.1	45.3	55.7	61.0	59.6
Germany	68.7	87.6	89.8	13.3	37.4	44.2	67.5	55.3	46.3
Ghana	1.8	23.0	58.0	0.01	0.3	0.4	1.4	1.0	1.0
India	2.4	14.9	43.0	0.1	1.3	2.0	4.3	1.9	1.7
Italy	35.0	58.1	70.5	11.7	24.7	31.5	43.0	33.6	33.8
Japan	66.9	91.1	90.2	18.2	30.5	36.1	45.4	50.1	49.4
Netherlands	81.0	91.7	91.3	25.2	41.2	43.5	46.7	40.8	28.7
Nigeria	3.5	24.5	35.5	0.0004	0.01	0.03	0.9	0.1	0.1
Norway	82.0	96.8	97.0	21.4	39.5	41.9	45.6	18.2	10.8
Portugal	35.0	68.6	78.3	11.1	30.3	41.9	40.2	45.2	51.7
Singapore	61.0	83.2	92.0	15.1	26.3	25.5	42.5	35.7	31.8
South Africa	7.5	51.9	70.0	0.3	2.5	2.9	10.0	7.4	2.5
Spain	47.9	78.7	93.2	11.5	29.2	34.5	44.5	41.7	40.2
Sweden	84.8	90.6	94.5	27.9	35.5	39.9	62.3	36.1	13.2
Turkey	15.5	53.7	77.7	2.3	11.9	21.4	27.6	14.4	14.5
UAE	40.0	90.5	100.0	3.0	13.8	38.2	28.9	25.3	24.0
UK	70.0	92.0	94.8	16.4	37.8	41.2	56.4	50.9	47.8
USA	68.0	74.6	90.9	17.2	31.5	37.7	59.0	38.5	28.8

Source: World Development Indicators, 2022 (per 100 people) were 3.5, 0.0004, and 0.9, respectively. These low figures during this period could be attributed to the insufficient availability of the internet and telephone. In 2015, only internet users increased to 24.5% of the population, and the trend continued steadily until 2021, when it reached 35.5% of the population. The country is completely immature, particularly in the area of broadband internet and telephone subscriptions, as the former could only record a marginal increase (0.03 per 100 people) but a decrease for the latter (0.1 per 100 people) in 2021. Nigeria's figures for internet users, fixed broadband internet, and telephone subscriptions are relatively low, even when compared to other African counterparts like Cote d'Ivoire, Ghana, and South Africa. Consequently, the low stock of ICT infrastructure hinders the adoption of digital trade, making doing business internationally more difficult, slow, and expensive.

2.6 Analysis of Nigeria's trade flows with trading partners

Table 2 shows that both in 2005 and 2010, merchandise exports from Nigeria to the United States exceeded those of other trading partners, recording US$10.42 billion and US$29.75 billion, respectively, in 2005 and 2010. This accounted for about 38.15% and 40.86% of the total merchandise exports to major trading partners. These values were

Table 2 Trade flows indicators of Nigeria and its trading partners

Country/year	Nigeria's merchandize exports to major trading partners (trade value in Million US$)				Nigeria's merchandize imports from major trading partners (trade value in Million US$)			
	2005	2010	2015	2021	2005	2010	2015	2021
Belgium	93.35	2112.66	116.11	333.78	273.07	1706.41	1967.65	3781.88
Brazil	2643.02	6041.97	4633.12	1241.00	953.23	1443.47	688.38	1156.33
Canada	145.93	2544.87	533.73	2143.14	75.03	2.79	251.23	470.64
China	526.88	1440.81	1240.70	1846.03	2303.16	7324.40	13,701.24	12,879.05
Cote d'Ivoire	1438.84	1270.76	1444.16	1325.83	578.15	104.53	363.00	72.61
France	1467.49	3505.96	3266.29	2969.34	1303.27	2587.57	1438.22	1175.65
Germany	882.41	560.79	2185.21	826.10	920.69	205.23	1164.41	1273.38
Ghana	570.69	442.43	519.28	357.75	393.93	6.56	66.19	50.40
India	62.36	9068.48	10,233.80	7732.69	852.10	2377.30	2286.61	4598.98
Italy	753.98	3047.86	878.56	1896.42	703.76	1997.79	798.91	1056.30
Japan	973.75	392.45	2818.09	384.44	518.70	1143.35	358.83	298.86
Netherlands	950.61	3936.55	3724.83	2834.92	1331.84	351.21	3239.71	5351.00
Norway	0.181	34.75	26.45	0.81	47.97	318.46	368.27	1322.71
Portugal	1204.90	1906.88	389.54	1370.34	48.94	108.09	52.17	58.57
Singapore	2.48	215.81	15.34	910.47	165.88	513.76	210.93	353.14
South Africa	653.86	1858.17	4579.05	1558.39	527.69	487.42	644.60	530.20
Spain	3919.35	2830.08	5124.58	5575.74	267.78	305.10	341.54	688.62
Sweden	59.64	55.90	790.13	200.66	255.11	381.06	248.23	127.63
Turkey	234.27	475.41	189.99	985.79	98.56	269.53	313.98	691.43
United Arab Emirates	32.69	53.70	547.43	88.92	6.39	1804.28	505.23	832.43
United Kingdom	276.06	1267.36	2173.27	1120.55	1487.68	1234.67	1620.65	814.46
United States	10,418.33	29,755.94	2003.77	2002.27	1580.79	7936.54	3354.25	3178.64
Average	1241.41	3309.98	2156.07	1713.88	667.90	1482.25	1544.74	1852.86
Maximum	10,418.33	29,755.94	10,233.8	7732.69	2303.16	7936.54	13,701.24	12,879.05

Source: World Integrated Trade Solution (WITS) database, 2022. SITC Revision 2 is reported as it contained data for more years higher than the average merchandise exports to the twenty-two major trading partners during the periods. Conversely, Nigeria's exports to India surpassed those of other major trading partners, particularly in 2015 and 2021. During these periods, merchandise exports to India alone accounted for at least 21.58% and 20.51% of the total merchandise exports to the major trading partners. In addition, these export values were higher than the average exports to the 22 major trading partners with Nigeria for these periods.

Table 2 also reveals that Nigeria's merchandise imports are predominantly from China and the US, recording US$2.30 billion, US$7.94 billion, US$13.7 billion, and US$12.88 billion in 2005, 2010, 2015, and 2021, respectively. This constituted about 15.67%, 24.34%, 40.32%, and 31.6% of the total merchandise imports from the major trading partners. For each of these periods, Nigeria's imports from China and the US were greater than the average merchandise imports from the 22 major trading partners.

3 Literature review

Several studies have been undertaken on the crucial role of trade-related infrastructure barriers on trade flows. This sub-section attempts to assess the impact of trade-related infrastructure barriers on trade flows among developed countries. For instance, Bougheas et al. (1999) examined how infrastructure, through its influence on transport costs, could affect trade across European countries over the period 1970–1990. Their findings show that even though the volume of trade is positively affected by infrastructure, their theoretical proposition emphasizes that increasing the volume of infrastructure does not always improve welfare. The results also demonstrate that the benefits of additional investments in high levels of infrastructure in terms of increased trade volume were outweighed by the loss in the final output. Baier and Bergstrand (2001) disentangled the relative contributions of reduced transport costs, tariff liberalization, and income convergence to world trade expansion. The authors considered 16 OECD countries for the period between the late 1950s and the late 1980s. The findings reveal that roughly 67–69% of trade growth could be attributed to growth in real GDP, 23–26% to the decline in tariffs and preferential trade agreements (PTA), and 8–9% to reduced transport costs, but none to income convergence.

The crucial role of trade-related infrastructure barriers is not limited to the level of trade occurring among developed countries but also among developing countries. A series of studies have also assessed its impact on trade flows among developing countries. Limao and Venables (2001), for instance, investigated the transport costs' determinants in geography and infrastructure for a sample of 103 countries during 1990. From the computed estimates, trade flows elasticity with a transport costs factor of around − 3 confirms the importance of infrastructure variables in determining trade. The results show that the deteriorating status of infrastructure from the 50th to 75th percentile increases transport costs by 12% and decreases traded volumes by 28%. In addition, the results show that the poor state of infrastructure in Africa is essentially responsible for its low trade flows. Busse (2003) examined the various forms of transaction costs and their relative levels in developing countries. The findings suggest that an efficient transport and service infrastructure could reduce transaction costs. This was considered a necessity for achieving significant growth and development in the economy. Among developing Asian countries, Brooks (2008) used both hard (physical projects) and soft infrastructure development and services to investigate how trade costs influenced by infrastructure development affect Asia's trade flows and patterns. The findings show that investment in infrastructure could help reduce the costs of doing business, maximize growth, and benefit regional integration in Asia. His findings also show that further infrastructure improvements accompanied by trade expansion would encourage more investment in productive capacity, increase market access and employment opportunities, and widen consumers' choices.

Abe and Wilson (2009), in a regional trade study across developing countries in East Asia, examined the effect of port infrastructure on trade and the role of transport costs in driving trade for the region. The results of their findings reveal that high transport costs from both Japan and the U.S. to East Asia were due to port congestion. The analysis proposes that while port congestion in East Asia could be reduced by 10%, transport costs could also be reduced by about 3%. This, therefore, implies that there was an across-the-board tariff cut of about 0.3 to 0.5%. Brooks and Stone (2010) examined the roles of hard and soft infrastructure in improving trade facilitation among APEC members. Their results indicate trade gains arose from significant reductions, even comparatively modest ones, in trade costs. In addition, the result shows that the increase in the GDP of the region was a result of the diversification of trading patterns. In a panel study involving China and 21 selected Asian economies, Rahman et al. (2021) determined the role of different forms of infrastructure on trade during the 1999–2018 period. According to the analysis, trade flows between exporting and importing nations were significantly increased by the high standards of transportation and ICT infrastructure in place.

As trade relations are not only horizontal but also vertical, studies have, therefore, analyzed the impact of trade costs associated with trade-related infrastructure barriers on trade flows between developing and developed countries. Following the findings of (Limao and Venables, 2001; Wilson et al., 2003; Clark et al., 2004; Freund and Weinhold, 2004; Koczan and Plekhanov, 2013; Donaubauer et al., 2015), infrastructure quality has a significant positive impact on trade. Nordas and Piermartini (2004) evaluated such an impact on the trade performance of 138 countries during the period 1996–2000. Their results also show that infrastructural quality was a major determining factor in trade performance. Among infrastructural indicators, port efficiency was discovered to have had the greatest impact. However, telecommunication accessibility and timeliness determined the competitiveness of the clothing and automotive sectors. In a panel analysis comprising 93 countries, Clarke and Wallsten (2004) analyzed the effect of the internet on export behavior. Their findings suggest that access to the internet does affect firms' export performance in developing countries. Similar findings were reported by Rodriguez-Crespo et al. (2021) for a group of 121 countries. They found a significant positive impact of internet users on bilateral exports for both groups of countries, with a higher impact for bilateral trade flows among high-income countries. Korinek and Sourdin (2009) explored the role of maritime freight costs in determining ocean-shipped imports. The results indicate a strong impact of maritime transport costs on trade. An increase in maritime transport costs of 10% was estimated to result in a 6–8% reduction in trade, ceteris paribus. Generally, maritime transport costs have a great impact, while the magnitude of changes would have a significant impact on trade flows. In addition, in another model using product-level data, the results reveal that an increase in shipping costs of 10% would bring about a reduction in trade by 3%. The overall analysis, therefore, shows that as the impact of distance between trading partners was rising, that of maritime transport costs over time was falling. In a study of trade relationships across the World, Behar and Venables (2011) investigated how the volume and nature of international trade are affected by transport costs. Their findings corroborate those of the World Bank (2009), which emphasized the significance of broader trade facilitation measures as a means of reducing transport costs and improving trade volumes across the World. Seck (2017) based his analysis on 105 countries (with 19 from Africa) to analyze the degree of contribution of different trade cost elements towards shaping African trade patterns both within and outside the continent for the period 2010–2012. His finding reveals the possibility of increasing total trade from 6.8 to 15.1%, provided the average African country could be raised to the world's best-performing country through the provision of trade reforms aimed at physical infrastructure, particularly roads. In a related study, Zheng and Hongtao (2022) used a variant of the Ricardian model to estimate the effect of country-specific infrastructure on both internal and international trade for 243 countries and 170 industries from 2000 to 2016. Their findings indicate that improved infrastructure benefits international trade more than domestic trade and has no negative impact on domestic trade.

In Africa, Deen-Swarray et al. (2012) investigated the magnitude of infrastructure development and its impact on trade and integration among 12 West African countries for the period 1993–2008. Their findings show that infrastructure has a significant and relatively large impact on bilateral trade flows. According to them, this is due to the poor state of infrastructure along main corridors, which adds to the high cost of transportation while also impeding trade. Baita (2020) found that infrastructure development significantly promotes intra-ECOWAS bilateral trade among members, while Tandrayen-Ragoobur et al. (2023) reported similar findings for intra-African trade.

The results of studies on the impact of trade-related infrastructure barriers have found a significant and negative relationship with trade flows. Nevertheless, there was an element of divergence in their conclusions. For instance, some of the studies that used indicators such as transport costs, port efficiency, shipping costs, ICT infrastructure, and physical infrastructure (Baier and Bergstrand, 2001; Limao and Venables, 2001; Busse, 2003; Nordas and Piermartini, 2004; Brooks, 2008; Abe and Wilson, 2009; Brooks and Stone, 2010; Rodriguez-Crespo et al., 2021; among others) concluded on the significant trade potential and welfare gains associated with trade costs reduction. On the contrary, Bougheas et al. (1999) subjected their conclusion to the theoretical proposition that increasing the volume of infrastructure does not always improve welfare. Aggregate trade data within the panel framework was used by these studies across developed countries, developing countries, and even those conducted for both, except Limao and Venables (2001), which employed cross-sectional data. On the methodology adopted, the majority of the studies estimated the gravity model with the aid of different econometric techniques.

In conclusion, the foregoing shows that previous studies in this area have a lot of flaws. The majority of previous studies on the relationship between infrastructure and trade (Korinek and Sourdin, 2009; Nords and Piermartini, 2004; among others) only looked at the demand or supply side, which may result in policy bias. The literature also shows that most of the earlier studies that looked at how infrastructure affected trade constructed an infrastructure index without taking exporter- and importer-specific effects into account. This makes it difficult to identify the specific infrastructural component with a higher payoff and requires greater attention from policymakers. In addition, Ismail and Mahyideen (2015) accounted for heterogeneity effects but estimated the impact of disaggregated components of transport and ICT infrastructure on trade separately. This is in contrast to Rehman et al. (2020) and (2021), who examined the impact of various indicators of transport and ICT infrastructure on trade without taking heterogeneity effects into account. From the overall review, it is shown that there is no study that looks at the differential impact ratio of the two components of infrastructural services on bilateral trade flows. Finally, some of the previous studies employed either a fixed effect or random effect model or two-stage least squares to address either heterogeneity or endogeneity. None of these studies addressed the potential econometric issues of heteroscedasticity, endogeneity, and heterogeneity together.

The present study thus fills (or addresses) the aforementioned gaps (or shortcomings) by evaluating the differential impact ratio of the two components of trade-related infrastructure (transport and ICT infrastructure) on bilateral trade flows between Nigeria and its major trading partners using a fixed effect/random effect model with two-stage least squares to account for heterogeneity, endogeneity, and heteroscedasticity problems.

4 Theoretical framework and methodology

4.1 Theoretical framework

The main argument in the theoretical literature is that infrastructure development may either promote or inhibit trade (Limao and Venables, 2001; Portugal-Perez and Wilson, 2012; Ahmad et al., 2015). This study follows the same strand of literature and, as stated earlier in the concluding part of the previous section, employs a gravity model that is derived from the "Law of Universal Gravitation". The law proposes that the force of attraction, V_{ij}, between two separate entities i and j is a positive function of the entities' respective masses, M_i and M_j, and inversely related to the squared distance, D_{ij}^2, between the objects.

Specifically, gravity modeling in economics involves the application of Newton's Law of Gravity to provide an empirically tractable framework for demonstrating a linear relationship between trade volumes, trading distances, and the GDP of importing and exporting countries. The basic gravity model formulation is used in this work, which is then modified to reflect theoretical refinement. This law is formalized as

$$V_{ij} = G * \frac{M_i^{\beta_1} * M_j^{\beta_2}}{D_{ij}^{\beta_3}} * u_{ij} \tag{1}$$

where V_{ij} is the force of attraction (trade value between countries i and j), M_i and M_j are the respective two entities' masses (the GDPs of countries i and j), D_{ij} is the distance between the two entities (objects), G is a gravitational constant depending on the units of measurement for mass and force, u_{ij} is a normal random error term, and $\beta_1, \beta_2, \beta_3$ are parameters. An intuitive gravity model of trade is, therefore, derived from this law since trade flow between two countries is equivalent to the economic mass of each country, commonly measured by GDP. This is divided by the distance, D_{ij} between the countries, in order to account for all possible factors that might create trade resistance (Christie, 2002; Krugman and Obstfeld, 2009; Azam, 2016).

According to Frankel and Wei (1993), the degree of specialization and trade is determined by the partner economies' levels of development (as measured by GDP per capita). As a result, they argued that when countries grow in size, they appear to specialize and trade more. Following McCallum's (1995) findings, Anderson and van Wincoop (2003) propose a theoretical modification by including multilateral trade resistance variables. McCallum (1995) estimated a traditional version of the gravity equation for bilateral trade between the United States and Canadian provinces using two variables (i.e., bilateral distance and a dummy variable that is equal to one if the two regions are in the same country and equal to zero if otherwise). After controlling for distance and size, he discovers that trade between provinces is twenty-two times greater than trade between states and provinces. This shows that significant trade costs were incurred in cross-border trading. Several ways of augmenting the gravity equation have been proposed, including the use of common border or contiguity dummy variables as well as exporter and importer fixed effects, which result in the stochastic theory-based gravity equation (McCallum, 1995; Anderson and van Wincoop, 2003; Feenstra, 2004; Baier and Bergstrand, 2007; Birun et al., 2005). Another significant contribution to the literature on the analysis of drivers of trade flows between countries using the gravity equation was in terms of the augmentation of the equation with other factors that are considered significant drivers of trade costs and volumes. These drivers include a variety of country characteristics such as language, logistics, and the strength of government institutions, among others (Anderson and Marcouiller, 2000; Wu et al., 2012).

Incorporating other determinants of trade, including trade-related infrastructure variables of both trading partners, in Eq. 1 produces the following:

$$V_{ij} = G_{ij}\frac{M_i^{\beta_1}M_j^{\beta_2}}{D_{ij}^{\beta_3}} * TRANif_i^{\beta_4} * TRANif_j^{\beta_5} * ICTif_i^{\beta_6} * ICTif_j^{\beta_7} * OTF_i^{\beta_8} * OTF_j^{\beta_9} \tag{2}$$

where $TRANif_i$ and $TRANif_j$ represent transport infrastructure component in countries i and j, $ICTif_i$ and $ICTif_j$ stand for information and communications technology (ICT) components of trade-related infrastructure in countries i and j. OTF_i and OTF_j represent other determinants in the model for both trading partners. Following Nordas & Piermartini (2004), Ismail and Mahyideen (2015), Rahman et al. (2021), and Tandrayen-Ragoobur et al. (2023), this study specifies a standard multiplicative form of the modified gravity model as follows:

$$\begin{aligned} \exp_{ijt} = G * \beta_1 M_{it} * \beta_2 M_{jt} * \beta_3 D_{ijt} * \beta_4 TRANif_{it} * \beta_5 TRANif_{jt} \\ * \beta_6 ICTif_{it} * \beta_7 ICTif_{jt} * \beta_8 OTF_{it} * \beta_9 OTF_{jt} \end{aligned} \tag{3}$$

$$\begin{aligned} imp_{ijt} = G * \beta_1 M_{it} * \beta_2 M_{jt} * \beta_3 D_{ijt} * \beta_4 TRANif_{it} * \beta_5 TRANif_{jt} \\ * \beta_6 ICTif_{it} * \beta_7 ICTif_{jt} * \beta_8 OTF_{it} * \beta_9 OTF_{jt} \end{aligned} \tag{4}$$

where $\exp_{ijt}$ represents export of country i to country j, while imp_{ijt} signifies import of country i from country j at time t.

4.2 Methodology

4.2.1 Model specification

Following the above theoretical framework, this paper specifies a modified standard gravity model in its multiplicative form, in which the variable 'distance' is replaced by the cost of transporting goods from country *i to j,* which is equivalent to one plus the tariff rate applied to the goods as given by Eqs. (5) and (6):

$$\begin{aligned} \ln \exp_{ijzt} = \beta_0 + \beta_1 \ln M_{it} * M_{jt} + \beta_2 trf_{ijt} + \beta_3 rot_{it} + \beta_4 mat_{it} + \beta_5 nitu_{it} \\ + \beta_6 latfr_{it} + \beta_7 lfbi_{it} + \beta_8 fts_{it} + \beta_9 inst_{it} + \varepsilon_t \end{aligned} \tag{5}$$

$$\begin{aligned} \ln imp_{ijzt} = \beta_0 + \beta_1 \ln M_{it} * M_{jt} + \beta_2 trf_{ijt} + \beta_3 rot_{jt} + \beta_4 mat_{jt} + \beta_5 nitu_{jt} \\ + \beta_6 latfr_{jt} + \beta_7 lfbi_{jt} + \beta_8 fts_{jt} + \beta_9 inst_{jt} + \varepsilon_t \end{aligned} \tag{6}$$

Anderson and van Wincoop (2003) suggested that bilateral countries should include exporter- and importer-specific effects in a gravity specification to control multilateral resistance to trade. This method accounts for the country-specific nature of export and import transaction costs (Baier and Bergstrand, 2001). As a result, Eqs. 5 and 6 are re-specified in a log-linear form after taking the natural logs and with consideration to both multilateral trade resistance and heterogeneity effects:

$$\begin{aligned} \ln \exp_{ijzt} = \beta_0 + \beta_1 \ln M_{it} + \beta_2 \ln M_{jt} + \beta_3 trf_{ijt} + \beta_4 rot_{it} + \\ \beta_5 rot_{jt} + \beta_6 mat_{it} + \beta_7 mat_{jt} + \beta_8 nitu_{it} + \beta_9 nitu_{jt} + \\ \beta_{10} latfr_{it} + \beta_{11} latfr_{jt} + \beta_{12} lfbi_{it} + \beta_{13} lfbi_{jt} + \beta_{14} fts_{it} \\ + \beta_{15} fts_{jt} + \beta_{16} inst_{it} + \beta_{17} inst_{jt} + \varepsilon_t \end{aligned} \tag{7}$$

$$\begin{aligned} \ln imp_{ijzt} = \beta_0 + \beta_1 \ln M_{jt} + \beta_2 \ln M_{it} + \beta_3 trf_{ijt} + \beta_4 rot_{jt} \\ + \beta_5 rot_{it} + \beta_6 mat_{jt} + \beta_7 mat_{it} + \beta_8 nitu_{jt} \\ + \beta_9 nitu_{it} + \beta_{10} latfr_{jt} + \beta_{11} latfr_{it} + \beta_{12} lfbi_{jt} \\ + \beta_{13} lfbi_{it} + \beta_{14} fts_{jt} + \beta_{15} fts_{it} + \beta_{16} inst_{jt} + \beta_{17} inst_{it} + \varepsilon_t \end{aligned} \tag{8}$$

where z equals total trade, i indexes countries and t denotes time. The dependent variable $\left(\exp_{ijztd}\right)$ in Eq. (7) represents exports of commodity z from country i (Nigeria) to country j (each of the trading partners) at year t on a one-digit division d. The dependent variable (imp_{ijztd}) in Eq. (8) is imports of country i (Nigeria) of commodity z from country j (each of its trading partners). The one-digit division separates both export and import flows into 10 categories such as "0—Food and live animals"; "1—Beverages and tobacco"; "2—Crude materials, inedible, except fuels"; "3—Mineral fuels, lubricants, and related materials"; "4—Animal and vegetable oils, fats and waxes"; "5—Chemicals and related products"; "6—Manufactured goods classified chiefly by material"; "7—Machinery and transport equipment"; "8—Miscellaneous manufactured articles"; "9—Commodities and transactions not elsewhere classified". The export volumes of both exporting and importing countries are explained by their respective GDP, which is represented as:

M_{it} is Nigeria's GDP at market prices (constant 2015 US$) at time t,

M_{jt} represents the GDP at market prices for each of Nigeria's major trading partners (constant 2015 US$).

$\exp_{ijt}$ represents Nigeria's real exports value to each of its major trading partners at time t.

imp_{ijt} represents Nigeria's real imports value from each of its major trading partners at time t.

trf_{ijt} is bilateral weighted average level applied MFN tariffs rates at time t.

rot_{it} and rot_{jt} denote ratio of total roads network to total population for both exporting and importing countries at time t.

mat_{it} and mat_{jt} denote liner shipping connectivity index for both exporting and importing countries at time t.

$atfr_{it}$ and $atfr_{jt}$ represent air transport, freight (million ton-km) for both exporting and importing countries at time t.

$nitu_{it}$ and $nitu_{jt}$ represent individuals using the internet (% of population) for both exporting and importing countries at time t.

fbi_{it} and fbi_{jt} denote fixed broadband subscriptions (per 100 people) for both exporting and importing countries at time t.

fts_{it} and fts_{jt} represent fixed telephone subscriptions (per 100 people) for both exporting and importing countries at time t.

inq_{it} and inq_{jt} denote institutional quality for both exporting and importing countries at time t.

4.2.2 Definition and measurement of variables

Bilateral trade flows (exports and imports): following the work of Deen-Swarray et al. (2012), this study employs bilateral exports and imports as dependent variables. The rationale for using both exports and imports was to ensure policymaking so that there is a balanced view, as both have implications for the country's balance of payments. The bilateral exports and imports data in Thousands of US dollars are obtained from the World Integrated Trade Solution (WITS).

Gross domestic product (gdp): The production and consumption capacity of trading partners, which determines the trade flows between them, is largely reflected in their GDPs. In a gravity model, GDP is commonly used to measure a country's economic size, and it is anticipated to have a significant impact on bilateral trade between the trading partners. Hence, both importers' and exporters' GDPs are predicted to have a positive impact on trade flows. The series for GDP are obtained from the World Development Indicators (WDI).

Tariff (trf): This is a trade policy barrier that is usually imposed by importing countries. Tariffs act as trade barriers, representing trade costs. The variable 'distance' in the standard gravity model is replaced in this study with the cost of transporting goods from country i to country j, which is equivalent to one plus the tariff rate applied to the goods (Sadikov, 2007). High tariffs have a negative impact on trade, production, and consumption patterns, as well as worsening the welfare of both the citizens of the countries that impose them and their trading partners. Thus, a negative coefficient is predicted for it. Data on tariffs are taken from the World Bank database.

Road networks to total population (rot): This is used to measure both the adequacy and quality of road infrastructure. The low ratio of the country's total road networks to its population tends to create a great burden on the available roads in the country and thus have some spillover effects on trade. In addition, a country's competitive position in the global market may be impaired due to limited stock and the unimproved status of the available road network. The ratio of road networks to the total population of both exporters and importers is expected to have either a positive or negative impact on trade.

Air transport, freight (atfr): This measures a country's air transport capacity in terms of the volume of freight, express, and diplomatic bags carried on each flight stage (the operation of an aircraft from takeoff to its next landing). It is measured in metric tons times kilometers traveled. A low amount of goods transported by aircraft is an indication of inefficient transport services, which are reflected in higher freight costs and longer delivery times (high trade costs) and vice versa. In addition, the efficiency of a country's logistics may be falling, with transportation costs accounting for a high proportion of the final price of goods, thus affecting a country's competitiveness in international trade. Based on the status of airport infrastructure, the coefficients for both exporters and importers are anticipated to have either a positive or negative impact on trade. Its series are obtained from WDI.

Maritime transport (mat): This study uses liner shipping connectivity index because it is a good proxy for maritime transport. It measures how well countries are connected to global shipping networks and how accessible they are to global trade. Countries with a high connectivity index, as reflected in their improved and efficient port infrastructure quality, could easily access a high capacity and frequency global maritime transport system, resulting in the effective participation of such countries in global trade and vice versa. Improved maritime transportation reduces trade costs associated with port congestion, which leads to the imposition of demurrage charges, thus promoting trade flows. Based on the status of maritime transport of trading partners, its coefficients for exporters and importers are anticipated to have either a positive or negative impact on trade flows. Its series are obtained from the United Nations Conference on Trade and Development (UNCTAD) statistics database.

With respect to ICT infrastructure indicators, individuals using the internet (% of population), fixed broadband subscriptions (per 100 people), and fixed telephone subscriptions (per 100 people) were used in this study. According to Nipo et al. (2018), the use of ICT stimulates the growth of trade activity through the establishment of the electronic commerce (e-commerce) sector, as well as the rise of ICT-producing and-using industries. ICT use in trade is driven by its ability to dramatically lower the cost of doing business, allowing firms to market their goods and services at competitively cheaper prices. In addition, ICT development makes it possible for importers and exporters to obtain information across national borders at a relatively low cost since searching costs and the cost of entering a new market become lower. As a result, countries with greater ICT development and use are likely to have higher trade flows, and vice versa. Thus, the coefficients for both exporters and importers with respect to the three ICT infrastructure indicators are expected to have either a positive or negative impact. The data for these three ICT indicators are sourced from WDI.

Number of internet users (nitu): This is used to measure the number of people who have access to the Internet. The Internet can be used through a computer, mobile phone, personal digital assistant, gaming machine, digital television, and other devices (World Development Indicators, 2023). There is a general consensus in the literature that access to the Internet promotes the adoption of digital trade, making doing business internationally easier, faster, and less expensive.

Fixed broadband internet (fbi): This is used to measure the total number of subscriptions per 100 people and in total number of subscriptions to broadband technologies such as DSL, cable modem, fiber-to-the-home and other fixed technologies (such as broadband over power lines and leased lines) with download speeds of 256 kbit/s or greater. According to the literature, broadband internet expansion may directly promote trade by lowering fixed and marginal trade costs.

Fixed telephone subscriptions (fts): This measures the proportion of the population that have access to active number of analogue fixed telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents and fixed public payphones.

Institutional quality (inq): This measures the mechanisms by which the effectiveness of institutions affects trade. Poor institutional quality, like tariffs, comes at a cost. In the study, the average of four measures of governance related to trade is used as a proxy for institutional quality. These include control of corruption, regulatory quality, political stability and absence of violence or terrorism, and rule of law, all of which are derived from the World Bank Governance Indicators (Kaufmann, Kraay, and Mastruzzi, 2011). The estimates of each of these indicators give the country's score on the aggregate indicator at approximately − 2.5 (weak) to 2.5 (strong) institutions. According to the World Trade Organization (WTO, 2004), these four indicators are suitable to be used as institutional quality indicators in the context of trade. They are likely to have a significant impact on the level of uncertainty in trade and, thus, transaction costs. The coefficients for both exporters and importers are expected to be positive or negative, based on the assumption that sound or weak institutional arrangements among trading partners result in higher or lower bilateral trade flows.

A summary of the variables discussed above and their respective sources is presented in Table 3. The period considered for the econometric analysis of this study ranges from 2005 to 2021. The choice of this period is due to data availability and also to bring the bilateral trade data closer to the year in which the liner shipping connectivity index was constructed (i.e., 2004). The 22 top trading partners of Nigeria represent the sample for the study. These countries have consistently maintained a significant bilateral trade relationship with Nigeria during the last decade. The volume of trade between Nigeria and its partners forms the total volume of trade used for this study. These countries were also cited from the trade database, and they include India, Canada, Spain, Turkey, Ghana, Japan, Netherlands, France, Portugal, South Africa, Italy, UAE, Belgium, UK, USA, Sweden, Norway, Singapore, China, Cote d'Ivoire, Germany, and Brazil.

4.3 Estimation issues and techniques

Equations (7) and (8) could be estimated using the ordinary least squares (OLS) technique. However, the use of OLS tends to present a number of issues as it could not

Table 3 Definition, measurement, and A'priori expectation of the variables used in Eqs. (7) and (8)

Abbreviation of variables	Explanation of variables	Measurement	Expected relationship (sign)	Data source
EXP	Export	Trade value of export in 1000 USD		WITS
IMP	Import	Trade value of import in 1000 USD		WITS
GDP	Gross Domestic Product	GDP at market prices (constant 2015 US$)	+	WDI
TRF	Tariff	Bilateral weighted average level applied MFN tariffs rates (%)	–	WDI, World bank database. https://data.worldbank.org/indicator/TM.TAX.TCOM.SM.AR.ZS
ROT	Roads transport	Ratio of total roads network to total population	±	Computed from WDI; National Planning Commission and Road Statistics Yearbook; https://www.cia.gov/library/publications/the-world-factbook/fields/2085.html
MAT	Maritime Transport	Liner shipping connectivity index (LSCI)	±	UNCTADstat
ATFR	Air transport	Air transport, freight (million ton-km)	±	WDI
NITU	Number of internet users	Individuals using the internet (% of population)	±	WDI
FBI	Fixed broadband internet	Fixed broadband subscriptions (per 100 people)	±	WDI
FTS	Fixed telephone subscriptions	Fixed telephone subscriptions (per 100 people)	±	WDI
INQ	Institutional quality	The average value of the four elements (control of corruption, regulatory quality, political stability and absence of violence/terrorism, and rule of law) in the Worldwide Governance Indicators	±	Computed from data available in WGI

account for the potential endogeneity of the explanatory variables (possible reverse causality) between exports/imports value and real gross domestic product (RGDP). To address the issue of endogeneity, any of the generalized method of moments (GMM), seemingly unrelated regressions (SUR), and generalized least squares (GLS) estimators are appropriate if the available data contains longer time series with a longer cross-section.

To estimate Eqs. (7 and 8) above, a panel instrumental variables (IVs) estimator, precisely pooled 2SLS technique was used. A rationale for this technique is that it is designed for a few time periods and longer cross-sections. To achieve this objective, two different methods were applied. As a starting exercise, the study established the need to estimate IV-2SLS by first using the standard OLS method and then testing for endogeneity. If this is suspected, it implies that the OLS assumption has been violated. This, therefore, requires estimating pooled 2SLS and then testing for heterogeneity using the F-test while performing the Hausman test to determine the most suitable between the fixed effect model and the random effect model.

According to Hsiao (1986), since there is a possibility of bi-directional causality between the endogenous and right-hand side variables, there may be a correlation between regressors and error term. Based on this, OLS estimates become biased and inconsistent as the underlying assumptions are violated. In a cross-country analysis, endogeneity is a common issue that could be traced to variable omissions and measurement errors other than reverse causality (i.e., simultaneity). Omitted variables occur as a result of the non-inclusion of some relevant variables in the model. If an omitted variable is correlated with the other regressors, then the subsequent estimated parameters will be inconsistent and biased. Even if an omitted variable is not correlated with other regressors, the intercept term will be biased and the parameter estimates will be inefficient. Measurement errors, on the other hand, occur mainly due to wrong measures of explanatory variables in the model. Theoretically, there is a potential endogeneity problem between exports and imports and GDP, which relates to measurement error.

There are approaches to working around the endogeneity issue. A better approach involves choosing a set of instrumental variables (IV) for each potentially endogenous variable. However, finding instruments that perform well is difficult, as weak instruments tend to generate other problems (Wooldridge, 2012). More importantly, when there is a simultaneity problem (i.e., reverse causality) in a model in which choosing a good instrument is difficult, an alternative solution to such an issue is to use a time-lagged version of the potentially endogenous variable (Bacchetta et al., 2012). This serves as a natural source of instruments in terms of predetermined variables (Wooldridge, 2012). However, it is worth noting that lagging a variable reduces the number of years for which such a variable is included in the series. Given this scenario, Eqs. (7) and (8) can be rewritten as

$$\begin{aligned}\ln \exp_{ijzt} = {} & \beta_0 + \beta_1 \ln \exp_{ijz,t-1} + \beta_2 \ln M_{it} + \beta_3 \ln M_{jt} + \beta_4 trf_{ijt} \\ & + \beta_5 rot_{it} + \beta_6 rot_{jt} + \beta_7 mat_{it} + \beta_8 mat_{jt} + \beta_9 nitu_{it} \\ & + \beta_{10} nitu_{jt} + \beta_{11} latfr_{it} + \beta_{12} latfr_{jt} + \beta_{13} lfbi_{it} \\ & + \beta_{14} lfbi_{jt} + \beta_{15} fts_{it} + \beta_{16} fts_{jt} + \beta_{17} inst_{it} + \beta_{18} inst_{jt} + \varepsilon_t\end{aligned} \tag{9}$$

$$\begin{aligned}\ln imp_{ijzt} = {} & \beta_0 + \beta_1 \ln imp_{ijz,t-1} + \beta_2 \ln M_{jt} + \beta_3 \ln M_{it} + \beta_4 trf_{ijt} \\ & + \beta_5 rot_{jt} + \beta_6 rot_{it} + \beta_7 mat_{jt} + \beta_8 mat_{it} + \beta_9 nitu_{jt} \\ & + \beta_{10} nitu_{it} + \beta_{11} latfr_{jt} + \beta_{12} latfr_{it} + \beta_{13} lfbi_{jt} + \beta_{14} lfbi_{it} \\ & + \beta_{15} fts_{jt} + \beta_{16} fts_{it} + \beta_{17} inst_{jt} + \beta_{18} inst_{it} + \varepsilon_t\end{aligned} \tag{10}$$

5 Empirical results and discussion

5.1 Descriptive statistics

Table 4 shows the descriptive statistics of the variables used in the analysis. The values of aggregate exports and imports range from US$0.008 billion to US$34.7 billion and from US$2.78 billion to US$15.95 billion, respectively. The average values of the components of trade-related infrastructure, particularly transport infrastructure (roads transport, maritime transport, and air transport), are 0.001, 20.49, and 12.46 for the exporter (Nigeria), while 0.012, 60.17, and 5487.5, respectively, for the importers (trading partners).

Table 4 Descriptive statistics

Variable	Obs	Mean	Std. D	Min	Max
Aggr_exp	374	2607.3	4281.6	0.008	34,758
Aggr_imp	374	1380.9	2146.2	2.786	15,947.4
Aggrgdp_x	374	418.38	80.43	270.51	511.93
Aggrgdp_m	374	2391.9	4028.2	25.65	20,338
trf_partner	374	4.501	2.626	0.03	17.94
trf_nig	374	9.86	0.941	8.33	12.38
rot_x	374	0.0011	0.0001	0.001	0.001
rot_m	374	0.012	0.011	0.0004	0.061
mat_x	374	20.49	2.73	12.79	23.5
mat_m	374	60.17	29.73	7.623	168.5
nitu_x	374	19.37	10.74	3.549	35.5
nitu_m	374	64.809	27.78	1.039	100
inst_x	374	− 1.23	0.045	− 1.32	− 1.15
inst_m	374	0.77	0.83	− 1.5	1.938
fbi_x	374	0.03	0.02	0.0003	0.062
fbi_m	374	22.58	14.33	0.007	47.49
fts_x	374	0.41	0.40	0.05	1.17
fts_m	374	32.16	18.82	0.59	67.47
atfr_x	374	12.46	6.67	0.74	24.80
atfr_m	374	5487.5	8735.8	0.26	42,985.3

Also, the average values of the Information and communications technology (ICT) component of trade-related infrastructure constituted by the number of internet users, fixed broadband internet, and fixed telephone subscriptions are 19.37, 0.03, and 0.41 for the exporter (Nigeria), while 64.81, 22.58, and 32.16, respectively, for the importers (trading partners). In addition, the result of the correlation analysis presented in Appendix 1 shows that some of the explanatory variables had strong relationships but that these relationships could not result in econometric problems in the model, except for rot_x and lfts_x (0.966). The mean–variance inflation factors (VIF) score is also 43.8, which is greater than the acceptable 10.0 threshold. Given this, we conclude that multicollinearity does exist (Hsiao, 2003).

5.2 Trade-related infrastructure and Nigeria's aggregate exports

This section presents the regression results of the panel analysis to show the impact of trade-related infrastructure on Nigeria's aggregate exports for the period 2005–2021. The gravity model was estimated for aggregate exports and imports using three estimators (pooled 2SLS, fixed effects, and random effects models). During the estimation process, endogeneity and multicollinearity issues were observed. The latter was detected among the explanatory variables using correlation analysis. To avoid both multicollinearity and an insufficient degree of freedom, which may be caused by including too many variables in a single model, the model was partitioned into two (i.e., models 1 and 2)[4] Also, an endogeneity test was conducted by estimating separate OLS for each of the

[4] Because of the short period, limited observation, and too many variables in a model, there is a low degree of freedom. As a result, some of the variables in the model are omitted from the analysis, prompting the model to be divided into two parts.

partitioned models, from which the OLS residual was generated. Then, in each partitioned model, a Durbin-Wu test was performed to identify the potentially endogenous variable(s). This is accomplished by correlating the OLS residual with each model's respective explanatory variables. In each of the models estimated, the F-test conducted reveals the presence of heterogeneity, as shown in Table 5. This implies that the pooled 2SLS model cannot be chosen. Therefore, the Hausman test is used as a model selection criteria to choose between fixed effect (FE) and random effect (RE) models. In the case of the aggregate exports model presented in Table 5, the FE model is preferred for both models 1 and 2, based on the Hausman test statistics. All of the significant explanatory variables in the aggregate exports model exhibit the expected signs, according to the estimated results of the two models in Table 5. However, in model 1, the number of internet users of trading partners, Nigeria's fixed broadband subscription per 100 people, and the ratio of the total roads network to the total population are not statistically significant, while in model 2, the aggregate GDP of trading partners, trading partners' air transport freight, and Nigeria's fixed broadband internet subscription per 100 people are statistically insignificant.

From Table 5, the preliminary econometric checks for each of the models show that there is no serial autocorrelation, as evidenced by autocorrelation test results of 0.302 and 0.300 for models 1 and 2. The heteroskedasticity test for each model reveals a value of 476.976 and 481.234, respectively, with probability values of 0.000 and 0.000. This indicates the presence of heteroscedasticity in the series of each model. In addition, the normality test is statistically significant, indicating that the null hypothesis of normality can be rejected for all series. These econometric issues can be addressed with the aid of the 2SLS technique. Similar results were also observed for the import model.

Based on the gravity model literature (such as Abe and Wilson, 2009; Deen-Swarray et al., 2012; Ismail and Mahyideen, 2015; Baita, 2020), improvement in transport infrastructure (maritime transport, ratio of roads network to population, and air transport) and improvement in ICT infrastructure (number of internet users, fixed broadband internet subscription, fixed telephone subscription, and other ICT indicators) tend to reduce trade costs associated with trade-related infrastructure while otherwise increasing it. The model 1 estimates in Table 5 reveal that aggregate GDP, measured by the economic size of both Nigeria and its trading partners, exerts a positive and significant impact on its aggregate exports. This implies that the productive capacity of Nigeria (GDP) and the market size of its trading partners (GDP) significantly promote Nigeria's exports. From the estimated results, the differing impact is clearly shown, as the coefficient of GDP of Nigeria exerts a higher impact than that of the importer on aggregate exports. This finding is consistent with previous studies (Ismail and Mahyideen, 2015; Rodriguez-Crespo et al., 2021; Rahman et al., 2021) that economic size (i.e., GDP of both exporters and importers) is one of the key determinants of bilateral trade. In model 2, however, the estimates show that only the GDP of Nigeria has a significant impact on its aggregate exports. The estimates of both models in Table 5 also indicate the impact of tariffs as a deterrent to bilateral exports, as the tariff rate imposed by the trading partners on Nigeria's exports is found to have a significant negative impact. These results are in line with the findings of Koczan and Plekhanov (2013), who also found a significant negative effect of tariffs on trade.

Table 5 Impact of trade-related infrastructure on Nigeria's aggregate exports

Dependent variable: aggregate exports	Model 1			Model 2		
	Pooled 2SLS	Fixed effects model	Random effects model	Pooled 2SLS	Fixed effects model	Random effects model
Aggregate GDP Nigeria (log)	20.339*** (4.504)	23.562*** (3.678)	25.173*** (3.754)	14.006** (6.644)	15.297*** (4.507)	15.879*** (4.774)
Aggregate GDP partners (log)	0.818*** (0.122)	1.516* (0.885)	0.572* (0.295)	0.643*** (0.116)	0.129 (0.891)	0.777*** (0.258)
Tariff	− 0.076 (0.061)	− 0.126** (0.063)	− 0.114* (0.064)	− 0.028 (0.061)	− 0.138** (0.063)	− 0.125** (0.063)
Maritime transport (Nigeria)	− 0.522*** (0.175)	− 0.617*** (0.144)	− 0.67*** (0.147)	− 0.646*** (0.211)	− 0.626*** (0.149)	− 0.621*** (0.156)
Maritime transport (Partners)	− 0.001 (0.005)	0.044** (0.018)	0.027** (0.012)	− 0.004 (0.005)	0.053*** (0.017)	0.017* (0.01)
Ratio of road transport to population (Nigeria)	− 0.204 (1.023)	1.181 (0.814)	1.174 (0.826)			
Ratio of road transport to population (Partners)	0.00003 (0.001)	0.021*** (0.005)	0.006** (0.003)			
Air transport Nigeria (log)	− 0.519*** (0.138)	− 0.554*** (0.105)	− 0.573*** (0.109)	− 0.54*** (0.147)	− 0.489*** (0.106)	− 0.513*** (0.111)
Air transport Partners (log)	− 0.048 (0.084)	0.291** (0.148)	0.087 (0.126)	0.05 (0.081)	0.152 (0.148)	0.02 (0.122)
Number of internet users (Nigeria)	− 0.271** (0.11)	− 0.175** (0.085)	− 0.179** (0.086)	− 0.222*** (0.065)	− 0.317*** (0.046)	− 0.289*** (0.048)
Number of internet users (Partners)	− 0.024** (0.01)	0.002 (0.012)	− 0.004 (0.011)	− 0.031*** (0.01)	0.024* (0.013)	0.009 (0.011)
Fixed broad-band internet Nigeria (log)	0.028 (0.095)	0.06 (0.071)	0.068 (0.073)	0.143 (0.094)	0.076 (0.069)	0.086 (0.071)
Fixed broad-band internet Partners (log)	− 0.436*** (0.156)	− 1.109*** (0.367)	− 0.916*** (0.291)	− 0.572*** (0.156)	− 0.668* (0.369)	− 0.76*** (0.273)
Fixed telephone subscriptions (Nigeria)				− 3.551** (1.542)	− 2.492** (1.064)	− 2.478** (1.105)
Fixed telephone subscriptions (Partners)				0.042*** (0.009)	-0.063*** (0.016)	− 0.039*** (0.014)
Institutional quality (Nigeria)	7.863** (3.599)	10.492*** (2.763)	10.743*** (2.859)	8.169** (3.669)	7.604*** (2.605)	7.956*** (2.74)
Institutional quality (Part-ners)	0.307 (0.247)	1.386* (0.709)	0.163 (0.456)	0.07 (0.244)	1.618** (0.708)	0.463 (0.41)
Constant	− 520.194*** (120.421)	− 646.178*** (98.037)	− 656.631*** (100.701)	− 345.496** (170.916)	− 370.826*** (118.48)	− 399.891*** (123.238)

Table 5 (continued)

Dependent variable: aggregate exports	Model 1			Model 2		
	Pooled 2SLS	Fixed effects model	Random effects model	Pooled 2SLS	Fixed effects model	Random effects model
Over identification test (*p*-value)	3.55 (0.6154)			2.79 (0.8349)		
F-test		16.33 (0.0000)			14.72 (0.0000)	
Hausman test		30.27 (0.0110)			36.63 (0.0014)	
No. of cross-sections	22	22	22	22	22	22
No. of observations	352	352	352	352	352	352
R-square	0.344	0.289	0.248	0.380	0.306	0.279
Normality test						
Sktest residuals	7.32(0.0257)			15.42(0.0004)		
Swilk residuals	4.452(0.0000)			4.300(0.0000)		
Autocorrelation test	0.302			0.300		
Heteroscedasticity test	476.976(0.0000)			481.234(0.0000)		

The measure of aggregate exports includes the summation of agriculture, manufacturing, and extractive sectors' exports. While the summation of industry and agriculture, value added (constant 2015 US$) gives rise to aggregate GDP across the trading partners. Standard errors are in parentheses while ***, **, and *, respectively, represent $p < 0.01$, $p < 0.05$, and $p < 0.1$

Concerning the transport infrastructure component, the FE estimates of models 1 and 2 in Table 5 show that Nigeria's maritime transport[5] had a negative and significant impact, while that of trading partners exerted a significant positive impact on trade. These estimates demonstrate that the improved status of maritime transport of trading partners reduced trade costs associated with port congestion leading to the imposition of demurrage charges, thus promoting Nigeria's aggregate exports by 0.04% and 0.05%, respectively. The unimproved status of Nigeria's maritime transport could otherwise reduce its exports by 0.62% and 0.63% if such improvements could not be replicated in Nigeria. A comparison of the estimates of the two indicators shows that the unimproved status of Nigeria's maritime transport could significantly reduce its aggregate exports, than further improvement in the status of maritime transport of the trading partners. A similar result was reported by Baita (2020), who found that improved infrastructural quality in the importing country could potentially reduce market access constraints, lower opportunity costs, and increase the likelihood of exporters capturing trade benefits. The FE estimates of model 1 in Table 5 show a significant positive coefficient of the ratio of the total road network to the total population of trading partners. By implication, a one-point increase in the ratio of the quality of the available road network to the total

[5] Which measures how well countries are connected to global shipping networks and access to global trade.

population of trading partners could reduce the trade costs associated with higher transportation and delivery costs, thus increasing Nigeria's aggregate exports. Air freight, which measures the total number of goods transported in bulk by aircraft, is used as a proxy for airport infrastructure. From the estimates, the two models show that Nigeria's airport infrastructure is found to be significantly negative, while that of trading partners in model 1 exerts a significant positive impact on trade. The estimates demonstrate that a 1% fall in the status of airport infrastructure associated with a decrease in the number of bulky goods transported by aircraft could reduce Nigeria's aggregate exports by 0.55% and 0.49%. Although an improvement in the status of the airport infrastructure of the trading partners could increase aggregate exports by 0.29%.

For the ICT infrastructure, the estimates of the two models in Table 5 show that the low proportion of internet users to the total population in Nigeria significantly reduced aggregate exports, while in model 2, improvement in the ratio of internet users of the trading partners significantly increased it. This implies that a low proportion of internet users in Nigeria could significantly hamper its exports (0.18% and 0.32%) more than the improved ratio of internet users of the trading partners (0.02%). These results are contrary to the previous findings in Asia and other developed and developing countries (Ismail and Mahyideen, 2015; Rodriguez-Crespo et al., 2021), who found a significant positive impact of internet users on bilateral exports for both groups of countries, with a higher impact for bilateral trade flows among high-income countries. In the case of fixed broadband internet subscriptions, the estimates of the two models show positive coefficients for Nigeria but are insignificant. However, the trading partners' fixed broadband internet subscriptions is negative and significant, implying that a 1% decrease in the number of fixed internet subscribers for importers (trading partners) hinders Nigeria's exports by 1.1% and 0.7%, respectively. According to the FE estimates of model 2 in Table 5, the impact of a unit decrease in the number of fixed telephone subscribers in Nigeria hinders its exports by 2.5%, while the impact of a unit decrease in the number of fixed telephone subscribers of the trading partners hinders Nigeria's exports by 0.06%. These results do not agree with the findings of Ismail and Mahyideen (2015), who found a significant positive impact of fixed telephone lines on exports for both groups of countries. Generally, these results underscore the importance of ICT in international trade and confirm that the lack of a two-way communications network between exporters and importers with inefficient ICT facilities could affect the competitiveness and reduce the trade gains of both trading partners. A very strong institutional setup tends to promote trade flows. In effect, low levels of corruption, efficient governance and implementation of the rule of law, and the consistency of the regulatory environment in a country all contribute to generating a positive impact on trade. The estimates of the two models in Table 5 show a significant positive impact of both Nigeria's and its trading partners' institutional quality. This reflects the fact that the existence of well-structured institutions both in the exporting and importing countries could improve trade flows. For instance, a 1% improvement in the quality of the institutional setup of the two trading countries could significantly increase aggregate exports by 10.49% and 7.6%, respectively.

From the overall analysis, both transport and ICT infrastructure are important determinants of Nigeria's aggregate exports to its major trading partners. The component of transport infrastructure in the two models constitutes 71.4% and 37.5%, while the ICT component constitutes 28.6% and 62.5%. From the estimates, the component of transport infrastructure exerts a greater impact on average (54.5%) than the ICT component (45.5%).

5.3 Trade-related infrastructure and Nigeria's aggregate imports

To have a better understanding of the trade dynamics between Nigeria and its major trading partners, the same analysis was carried out on Nigeria's aggregate imports from the trading partners. Table 6 shows the estimated results of the impact of trade-related infrastructure on Nigeria's aggregate imports from its major trading partners. Based on Hausman test statistics, the RE model is chosen for each of the two models. From the estimated results in Table 6, all the significant explanatory variables in model 1 are correctly signed except tariff, while none of the significant variables in model 2 turned out to have the wrong signs. In model 1, the ratio of the total road network to the total population of trading partners, the airport infrastructure of both Nigeria and trading partners, Nigeria's fixed broadband internet subscriptions, and the quality of its institutions are not statistically significant. In model 2, however, the GDP of both trading partners, tariff, Nigeria's maritime transport, Nigeria's fixed broadband internet and telephone subscriptions, and institutional quality of both trading partners are statistically insignificant.

Estimates of model 1 in Table 6 indicate that the GDP of both Nigeria and the trading partners were found to have a significant positive impact on Nigeria's aggregate imports, with the GDP of Nigeria having a greater impact than that of the trading partners, thereby predicting the differing impacts on bilateral imports. This result agrees with the findings of Nordås and Piermartini (2004). However, the GDP of both trading partners had no impact in model 2. The significant positive coefficient of tariffs, as shown in model 1, contradicts the findings of Nordås and Piermartini (2004) and Francois and Manchin (2013). The argument could either be due to the low production capacity of Nigeria to produce certain commodities or that if the substitution effect for importing such commodities is high enough that Nigeria's consumers create more preferences for its importation, imposing a high tariff might not hinder the importation of such commodities.

For the transport infrastructure component, low connectivity to maritime shipping networks could hinder a country's effective participation in global trade. This is supported by the unimproved status of Nigeria's maritime transport, which shows a significant negative impact on Nigeria's aggregate imports. The analysis further suggests that the failure of Nigeria to develop its maritime shipping networks has a greater impact of reducing its aggregate imports (0.18%) more than the increase that the improved status of its trading partners could yield (0.01% and 0.06%). A significant improvement in the ratio of the total road network to the total population of Nigeria could stimulate

Table 6 Impact of trade-related infrastructure on Nigeria's aggregate imports

	Model 1			**Model 2**		
Dependent variable: aggregate imports	**Pooled 2SLS**	**Fixed effects model**	**Random effects model**	**Pooled 2SLS**	**Fixed effects model**	**Random effects model**
Aggregate GDP Nigeria (log)	10.773*** (2.515)	7.066*** (1.826)	7.245*** (1.801)	2.118 (2.609)	1.196 (2.031)	1.76 (2.095)
Aggregate GDP Partners (log)	0.519*** (0.066)	− 0.552 (0.492)	0.403*** (0.141)	0.568*** (0.06)	− 1.477** (0.646)	0.063 (0.255)
Tariff	0.334*** (0.093)	0.181*** (0.067)	0.209*** (0.066)	0.078 (0.073)	0.011 (0.061)	0.03 (0.063)
Maritime transport (Nigeria)	− 0.239** (0.093)	− 0.185*** (0.067)	− 0.176*** (0.066)	− 0.07 (0.08)	− 0.11* (0.062)	− 0.103 (0.065)
Maritime transport (Partners)	0.015*** (0.003)	0.027*** (0.01)	0.014** (0.006)	0.018*** (0.002)	0.062*** (0.021)	0.063*** (0.024)
Ratio of road transport to population (Nigeria)	3.019*** (0.708)	1.474*** (0.527)	1.523*** (0.521)			
Ratio of road transport to population (Partners)	0.0001 (0.001)	− 0.005* (0.003)	− 0.001 (0.001)			
Air transport Nigeria (log)	0−0.006 (0.083)	− 0.067 (0.058)	− 0.062 (0.058)	− 0.081 (0.078)	− 0.103* (0.06)	− 0.112* (0.063)
Air transport partners (log)	0.166*** (0.048)	− 0.057 (0.08)	0.003 (0.064)	0.084* (0.045)	− 0.179* (0.094)	− 0.184* (0.108)
Number of internet users (Nigeria)	0.23*** (0.072)	0.1* (0.053)	0.105** (0.052)	− 0.058** (0.026)	− 0.051** (0.021)	− 0.061*** (0.023)
Number of internet users (Partners)	0.016** (0.007)	− 0.02*** (0.007)	− 0.017*** (0.006)	0.012** (0.006)	− 0.013 (0.008)	− 0.015** (0.007)
Fixed broad-band internet Nigeria (log)	0.07 (0.055)	0.035 (0.039)	0.033 (0.039)	− 0.017 (0.051)	0.008 (0.04)	0.002 (0.041)
Fixed broad-band internet Partners (log)	− 0.523*** (0.11)	0.65*** (0.201)	0.309** (0.145)	-0.2** (0.1)	0.726*** (0.219)	0.359** (0.168)
Fixed telephone subscriptions (Nigeria)				− 0.563 (0.743)	− 0.861 (0.578)	− 0.77 (0.601)
Fixed telephone subscriptions (Partners)				− 0.028*** (0.005)	− 0.029*** (0.009)	− 0.026*** (0.008)
Institutional quality (Nigeria)	6.286*** (2.431)	2.674 (1.735)	3.156* (1.728)	− 0.24 (1.914)	− 1.18 (1.505)	− 0.949 (1.565)
Institutional quality (Part-ners)	0−0.088 (0.136)	− 0.209 (0.388)	− 0.138 (0.225)	0.036 (0.132)	0.243 (0.411)	0.022 (0.261)
Constant	− 320.173*** (69.656)	− 174.41*** (52.019)	− 205.512*** (50.357)	− 58.24 (67.566)	21.599 (57.618)	− 34.661 (55.22)

Table 6 (continued)

	Model 1			Model 2		
Dependent variable: aggregate imports	**Pooled 2SLS**	**Fixed effects model**	**Random effects model**	**Pooled 2SLS**	**Fixed effects model**	**Random effects model**
Over identification test (*p*-value)	2.67 (0.6149)			14.29 (0.2171)		
F-test		17.92 (0.0000)			15.46 (0.0000)	
Hausman test		16.90 (0.3250)			8.64 (0.8957)	
No. of cross-sections	22	22	22	22	22	22
No. of observations	352	352	352	352	352	352
R-square	0.594	0.176	0.672	0.629	0.102	0.470
Normality test						
Sktest residuals	15.38(0.0005)			25.83(0.0000)		
wilk residuals	3.583(0.0001)			5.089(0.0000)		
Autocorrelation test	0.299			0.293		
Heteroscedasticity test	512.307(0.0000)			494.010(0.0000)		

The measure of aggregate imports includes the summation of agriculture, manufacturing, and extractive sectors' exports. While the summation of industry and agriculture, value added (constant 2015 US$) gives rise to Aggregate GDP across the trading partners. Standard errors are in parentheses while ***, **, and *, respectively represent $p < 0.01$, $p < 0.05$, and $p < 0.1$

its aggregate imports by 1.5%, as it leads to a reduction in transportation and delivery costs associated with moving imported goods from Nigerian seaport through the road to the final users. Conversely, the RE estimates of model 2 show that the low stock of airport infrastructure of both Nigeria and its trading partners significantly reduces Nigeria's aggregate imports, with the low stock of airport infrastructure of trading partners (0.18%) having a greater impact than that of Nigeria (0.11%). This is contrary to the findings of Nordås and Piermartini (2004), who found a significant positive impact of airport infrastructure on trade.

In the case of the ICT component, the estimated results in model 2 suggest that a low proportion of internet users both in Nigeria and in trading partners could hinder Nigeria's aggregate imports. However, in model 1, an increasing proportion of internet users in Nigeria (0.11%) has a greater impact of boosting its aggregate imports than a low percentage of the population of the trading partners (0.02%) having access to the internet. Under the two models, the estimates show that increasing the number of fixed internet subscribers of trading partners could stimulate Nigeria's aggregate imports, but the number of fixed internet subscribers in Nigeria does not matter. A low number of fixed telephone subscribers of trading partners could hinder Nigeria's aggregate imports, as shown in model 2. The existence of a sound institutional setup in Nigeria tends to reduce trade costs associated with corruption taxes and thus improve its importation, irrespective of the nature of the institutions of the trading partners. This is confirmed by the estimates of model 1 in Table 6.

Similarly, it is important to analyze the differential impact ratio of transport and ICT infrastructure components on Nigeria's aggregate imports. From the estimates of the two models, while the former accounted for 50% and 42.9%, the latter accounted for 50% and 57.1%, respectively. By implication, the impact ratio of the ICT component is higher, constituting 53.5%, while the transport infrastructure component constitutes 46.5% on average.

This study is essentially driven by traditional trade theory, specifically the H–O model, which assumes unrestricted trade and the absence of trade impediments. This is only true if a country can operate in autarky, such that it has a comparative advantage in every good. Based on the findings of this study, the results are contrary to the basic assumptions of the H–O model. This is due to the fact that a country cannot have a comparative advantage in all goods. Thus, there are costs associated with inefficient infrastructure services that are incurred both locally and globally for a country to engage in international trade. These costs are referred to as trade costs, and they tend to inhibit trade flows between or among the trading partners. Finally, the overall analyses demonstrate that infrastructure services in Nigeria are inefficient due to the poor condition of both transportation and ICT infrastructure components.

6 Conclusion and policy recommendations

This study specifically explored the impact of both transport and ICT components of trade-related infrastructure and then compared their differential impacts on bilateral trade flows between Nigeria and its trading partners. The key findings show that both the transport component (maritime transport, ratio of total roads network to total population, and airport infrastructure) and the ICT component (number of internet users, fixed broadband internet, and telephone subscribers) had a significant impact on reducing or increasing the volume of trade flows between Nigeria and its trading partners. In the exports model, the transport infrastructure component has a higher impact (54.5%) than the ICT components (45.5%). However, in the imports model, the ICT component has a greater impact, constituting 53.5%, than the transport infrastructure component (46.5%). In addition, it is clear from the analysis of the export model that the impact of increasing the stock of the transport infrastructure component could yield a higher payoff than further improvement in the ICT component. In the imports model, however, the impact of increased investment in ICT infrastructure could yield a higher payoff than further expansion of the component of transport infrastructure.

Moreover, the results show that unilateral actions by both exporting and importing countries are required to prioritize trade policies that could promote bilateral trade relations. This is because the benefits of trade facilitation or trade cost reduction can only be realized to their full potential if each trading partner makes a complementary effort. Improving the degree of infrastructural development in the exporting country, for example, should be complemented by similar efforts in the importing country.

Based on the findings, significant efforts are required to improve the status of both transport and ICT infrastructure to lower trade costs associated with inefficient infrastructure services, thereby improving the country's trade performance. To accomplish this, the government should commit to long-term and consistent infrastructure development support from developed countries. Since investment in transport and ICT infrastructure is an economically viable long-term initiative, efforts should be made to involve private-sector participation in financing such projects through public–private partnerships (PPP). Such an arrangement will allow private-sector groups to use their skills and knowledge to develop trade-related infrastructure while also raising the necessary funds for such investments. In addition, government should introduce user charges as a way of raising funds in financing such project. More so, Government should ensure that infrastructure maintenance is prioritized as part of an infrastructure development strategy. Finally, the findings confirm that efficient infrastructure services are critical as markets become more integrated. To facilitate doing business and enhance bilateral trade relations, economies with poor transportation infrastructure should supplement their efforts by increasing expenditures on port, air, and road infrastructure. It is also critical to develop ICT infrastructure, such as telephone lines, broadband internet access, and telephone subscriptions, among other things, for communication benefits and to simplify financial transactions between trading partners. These efforts are necessary to complement the efforts of trading partners.

6.1 Areas of future research

Future studies are required to explore the relationship between infrastructure and bilateral trade flows, which could be expanded to include more trading partners. In addition, such studies could look into the impact of infrastructure on intra-Africa trade, with a focus on regional blocs such as the Economic Community of West African States (ECOWAS), East African Community (EAC), and Southern African Development Community (SADC), among others.

Appendix 1

See Table 7.

Table 7 Results of correlation analysis

	rot_x3	rot_m3	trf	inst_x	inst_m	mat_x	mat_m	nitu_x	nitu_m	lagrgdp_x	lagregdp_m	latfr_x	latfr_m	lfbi_x	lfbi_m	lfts_x	lfts_m
rot_x	1																
rot_m	− 0.005	1															
trf	− 0.061	− 0.201	1														
inst_x	− 0.44	− 0.012	0.039	1													
inst_m	− 0.005	0.444	− 0.680	− 0.006	1												
mat_x	− 0.78	0.011	− 0.009	0.229	0.007	1											
mat_m	− 0.194	− 0.216	− 0.455	0.093	0.203	0.157	1										
nitu_x	− 0.993	0.001	0.071	0.438	0.002	0.730	0.197	1									
nitu_m	− 0.419	0.390	− 0.559	0.173	0.801	0.338	0.332	0.415	1								
lagregdp_x	− 0.951	0.009	0.046	0.270	0.006	0.890	0.187	0.928	0.404	1							
lagregdp_m	− 0.077	0.111	− 0.249	0.034	0.195	0.062	0.619	0.079	0.333	0.077	1						
latfr_x	0.179	0.003	− 0.036	− 0.112	0.004	− 0.044	− 0.041	− 0.205	− 0.085	− 0.049	− 0.008	**1**					
latfr_m	− 0.002	− 0.045	− 0.498	− 0.001	0.369	− 0.002	0.706	0.002	0.452	0.003	0.792	0.005	**1**				
lfbi_x	− 0.507	0.005	0.008	0.403	− 0.001	0.660	0.105	0.439	0.224	0.529	0.041	− 0.081	0.010	**1**			
lfbi_m	− 0.231	0.330	− 0.682	0.078	0.738	0.221	0.484	0.221	0.857	0.235	0.560	− 0.024	0.650	0.151	**1**		
lfts_x	0.966	− 0.002	− 0.068	− 0.355	− 0.003	− 0.731	− 0.188	− 0.974	− 0.403	− 0.940	− 0.077	0.115	− 0.001	− 0.352	− 0.215	**1**	
lfts_m	0.125	0.292	− 0.718	− 0.065	0.722	− 0.092	0.450	− 0.129	0.693	− 0.116	0.545	0.038	0.685	− 0.060	0.881	0.123	**1**

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Declarations

Competing interests
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