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Bridging the gap: how transport infrastructure reduces bilateral trade costs to fuel GDP growth

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ABSTRACT

Although scholars generally recognize infrastructure development as a pivotal pillar for economic progress, a gap remains in the current literature regarding how transport infrastructure affects GDP growth. This study examines how transport infrastructure impacts GDP growth by reducing trade costs. It confirms that improving the quality of transport infrastructure lowers these costs. Specifically, a 1% improvement in the average transport infrastructure quality between an emerging and a developed economy can reduce bilateral trade costs by up to 0.71%. To estimate the net effect of changes in infrastructure on GDP growth via trade costs, we used the Computational General Equilibrium framework. The results demonstrate significant potential for enhancing GDP growth across different groups of countries based on their level of economic development (i.e. developing countries, emerging countries, and developed countries). The broader implications of transport infrastructure development for the global economy are also examined.

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transport; infrastructure; growth; markets

1. Introduction

The relationship between infrastructure development and economic growth has attracted extensive scholarly attention due to the essential role-efficient infrastructure plays in supporting trade, productivity, and overall economic performance. Numerous theoretical and empirical studies (e.g. Arbués, Baños, and Mayor 2015; Berechman, Ozmen, and Ozbay 2006; Bleaney, Gemmell, and Kneller 2001; Donaldson 2018; Maparu and Mazumder 2017) highlight transport infrastructure as a crucial driver of economic growth and a competitive advantage in a globalised economy. Efficient transport systems not only reduce trade costs but also stimulate international trade flows, supporting economic growth (World Bank 2020). Nevertheless, many studies focus predominantly on infrastructure endowment, using metrics such as roadway length or investment levels

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(Bougheas, Demetriades, and Morgenroth 1999; Calderón and Servén 2010). This focus has limited their ability to capture infrastructure quality's role in affecting trade costs and economic growth, an area of growing importance in the international economic landscape.

Past research yields mixed findings on the economic impacts of infrastructure, often due to variations in methodological approaches, geographical focus, and types of infrastructure assessed. For instance, while Bougheas, Demetriades, and Morgenroth (1999) used roadway length to evaluate infrastructure, this measure does not consider indicators of quality such as maintenance, efficiency, and technological advancements, which are critical to realising sustained economic benefits. Similarly, Felbermayr and Tarasov (2022), with a narrow focus on European countries, generated results that lack generalisability to diverse economies, particularly in developing regions where infrastructure challenges differ considerably. Consequently, these narrow geographical and metric-based scopes limit the applicability of findings to the complex and interconnected global trade environment. Moreover, institutional constraints, particularly in developing countries with limited access to efficient transport and power, further exacerbate the economic development challenges related to poor infrastructure (Woetzel et al. 2017). With a global infrastructure investment gap, particularly stark in regions like the Asia Pacific and Africa, the Asia Pacific region alone requires up to US$1.7 trillion in annual infrastructure investments until 2030 to foster sustainable development (Asian Development Bank 2017).

Prior literature often oversimplifies the relationship between trade costs and infrastructure by using proxies like distance, which fail to capture the range of factors that influence trade costs, including logistics and infrastructure quality. For example, Bougheas, Demetriades, and Morgenroth (1999) measured trade costs through basic distance metrics, overlooking broader trade barriers such as tariffs and transport service quality. This limitation obscures the nuanced role of infrastructure quality in shaping trade costs and can result in biased estimates of economic impacts. Frameworks that incorporate multiple dimensions of trade costs, such as Anderson and Van Wincoop (2004), underscore the need to consider factors beyond simple proxies. Additionally, many studies grapple with endogeneity concerns arising from reverse causality or omitted variable bias, which complicates the identification of a causal relationship between infrastructure quality and economic growth. While some researchers have addressed endogeneity by lagging infrastructure variables (Bougheas, Demetriades, and Morgenroth 1999), these efforts are often insufficient to establish robust causality.

Recent studies have sought to address these limitations by expanding data scope and using advanced econometric techniques. For example, De Soyres, Mulabdic, and Ruta (2020) assessed the Belt and Road Initiative (BRI) across multiple countries, thereby broadening the geographical scope compared to previous studies focused on single regions. Furthermore, many scholars have aimed to capture infrastructure quality more effectively. For instance, Song, Chen, and Hou (2024), Du, Zhang, and Han (2022), and Égert, Kózluk, and Sutherland (2009) found that infrastructure quality improvements were strongly associated with economic growth. Conversely, others, such as Apurv and Uzma (2020), Konno et al. (2021), Su, Song, and Umar (2021), Démurger (2001), and Timilsina, Stern, and Das (2023) observed that returns on infrastructure investments can be marginal, with benefits often unevenly distributed. Cigu et al. (2018) also support these observations, suggesting that methodological approaches, geographical focuses, sector focuses, and variations in the types of infrastructure analyzed contribute to these discrepancies. Holtz-Eakin and Schwartz (1995) provided evidence that the effects of public infrastructure investments on productivity were minimal and statistically insignificant in the U.S. manufacturing sector. Esfahani and Ramírez (2003) suggested that the returns on infrastructure investments vary significantly across countries and are influenced by institutional and policy environments.

Elburz, Nijkamp, and Pels (2017) found that studies using data from the United States are more likely to register a negative impact of public infrastructure on regional growth. They also noted that the type of infrastructure, research methodology, time span, type of infrastructure measure, and geographical scale significantly affect the outcomes of primary studies. Studies considering interregional, interstate, and interprovincial relations often report negative effects, highlighting the potential spillover effects of these investments. Methodological differences are a primary source of conflicting observations. The choice of econometric models, control variables, and data sources can lead to varying results. For instance, cross-sectional analyses may yield different conclusions compared to panel data analyses due to differences in capturing temporal dynamics and controlling for unobserved heterogeneity. The geographical and temporal contexts of studies also contribute to conflicting results. Infrastructure investments in developed countries might not yield the same returns as those in developing countries due to differences in existing infrastructure stock, economic structure, and institutional quality. Additionally, the timing of infrastructure investments can influence their impact, with early-stage investments potentially yielding higher returns than subsequent ones in already well-developed regions. Variations in the type and quality of infrastructure analyzed further complicate the assessment of its economic impact. Different types of infrastructure, such as transportation, energy, and telecommunications, have distinct effects on economic activities. Moreover, the quality of infrastructure, including aspects such as maintenance and technological advancements, plays a crucial role in determining its effectiveness.

The conflicting observations in the literature on the impacts of transportation infrastructure on economic growth underscore the complexity of this relationship. These differences highlight the need for context-specific analyses and careful consideration of methodological approaches when evaluating the economic benefits of infrastructure investments. Understanding these nuances can help policymakers design more effective infrastructure strategies tailored to their specific economic and institutional contexts.

To fill these gaps and address the conflicting observations about transport infrastructure effects, this paper examines the potential impact of improving infrastructure quality on multilateral trade costs and economic growth. The study utilised data from publicly accessible sources, including World Economic Forum data, World Bank country economic data, and CEPII distance data, integrating them into a panel database that covers both developed economies and emerging markets. By deducing insights from the data, we confirm that an improvement of transport infrastructure quality by 1% can significantly reduce trade costs by 0.88%. We then utilise a CGE analysis to estimate the impacts of the resulting trade cost reduction on economic growth and obtain results showing that a one-percentage increase in infrastructure quality can increase GDP by 0.14% to 0.99%. The study further provides deep insights on the net effect of changes in infrastructure on countries' GDP growth via trade costs.

The rest of the paper is organized as follows. Section 2 discusses the theoretical background and related literature. Section 3 presents the database and methodology used to measure the impact of infrastructure quality on trade costs and the estimated results. The measurement of trade costs on economic growth in the CGE model is presented in Section 4. Conclusions and potential practical implications for policymakers follow.

2. Theoretical background

Trade intensity depends on the 'friction' associated with trade, i.e. the bilateral trade costs (BTCs) between partner countries. Anderson and Van Wincoop's (2004) bottom-up estimate of trade costs includes trade facilitation, transport infrastructure, policy barriers (tariffs and non-tariff barriers), access to trade finance, network infrastructure, information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs in both exporting and importing countries. The drawback of this method is that it may miss relevant cost factors and introduce omitted variable bias. The opposite approach, the top-down approach, includes all observed and unobserved trade costs by implementing an inverse gravity model to calculate trade costs given the observed pattern of trade and production (Novy, 2013). This measure is used in the UNESCAP-World Bank Trade Costs database, where trade costs are expressed in ad valorem equivalent terms as the ratio of international to domestic trade costs and are bilaterally symmetrical. Arvis et al. (2013) used this top-down approach and found that, compared to developed countries, developing countries have much higher trade costs and a slower rate of lowering trade costs, due in large part to logistics and trade facilitation. Their results indicate that the combined effect of trade facilitation and logistics performance has an impact almost as strong as distance on trade costs. Infrastructure services play a major role in trade costs by decreasing distribution margins, reducing prices, and lowering transaction costs (Brooks and Hummels 2009). There are four aspects of infrastructure that affect trade costs: charges for infrastructure services, timeliness, risk of damage, and market access (Nordas and Piermartini 2004).

Previous empirical evidence using both approaches has shown that infrastructure quality is one of the prime determinants of transport costs, with a negative linkage between them. Limão and Venables (2001) constructed an infrastructure measure to assess the costs of shipping in and through a country, which is the average of the density of the road network, the paved road network, the rail network, and the telephone main lines. They showed that the quality of transport and communication infrastructures is qualitatively important in determining transport costs: for coastal countries, own infrastructure accounts for 40% of transport costs, and for landlocked countries, own and transit country infrastructure accounts for 60% of transport costs. Focusing on the Asia-Pacific region, Wilson et al. (2002) observed that improving port and airport efficiency has a considerable and large positive impact on intra-APEC trade. Clark et al. (2004) approximated port efficiency by a general measure of infrastructure and an index of seaport infrastructure. They demonstrated that port efficiency is an important determinant of ocean freight costs, and improvements in port efficiency can significantly lower trade costs. Additionally, Hummels et al. (2001) found that the time cost of a day in transit for United States imports was equivalent to an ad valorem tariff rate of 0.8%. Hence, when improved infrastructure services reduce transport time, it lowers trade costs, which then increases the country's propensity to trade.

While trade costs do not explain economic growth on their own, they are an important factor in understanding why some countries struggle to grow or take advantage of their comparative advantages. In prominent trade models, trade costs can have a significant impact on a country's economic development. High trade costs make exports uncompetitive, raise prices, and limit the products available to households and businesses, which distorts resource allocation. Research from the OECD (2015) shows that richer countries tend to have lower trade costs and that countries that make an effort to lower their trade costs usually grow faster than others. This is mainly due to the burden of high costs, which reduces the gains from trade and limits trade. The literature on trade and economic growth provides overwhelming evidence of a positive statistical correlation between them: Ann Harrison (1996), Frankel and Romer (1999), Alcalá and Ciccone (2004), and Feyrer (2019) are among the many cross-country studies that have estimated the effect of trade flows on standards of living by regressing real GDP levels on trade liberalizations (defined in various ways). Therefore, reducing trade costs through infrastructure development could greatly increase each region's opportunities for trade and boost real income in trading regions. The literature on transport and infrastructure (Berechman, Ozmen, and Ozbay 2006; Donaldson 2018; Januário et al. 2021) provides conflicting findings about the effects of infrastructure quality on multilateral trade costs.

3. Measuring impacts of improving infrastructure quality on trade cost

As previously mentioned, the infrastructure has been evaluated using a variety of broad-based metrics. We incorporate some of these measurements into a regression model to calculate their influence on trade costs. First, we review the existing research on gravity models and explain how to estimate BTC from a reverse gravity model. We then present empirical models with explanations. Finally, we measure the potential trade effects on emerging and developed countries that could result from an improvement in transport infrastructure quality.

3.1. Inferring BTC from inverted gravity model

According to Newton's Law of Universal Gravitation, 'any particle in the universe attracts any other particle as a result of a force that is directly proportional to the product of the particles' masses and inversely proportional to the square of the distance between them' (Lu et al. 2018, 27). Similarly, we believe that in international trade, countries trade in proportion to their market size (e.g. GDP) and proximity (distance between the countries). In this model, consumers have preferences for different goods based on their origin, with a constant elasticity of substitution. The trade costs are proportional to the goods being shipped and reflect the notion that only a fraction of the goods shipped will reach their destination. Some previous studies have focused on exploring the economic foundations underlying gravity equations (see Anderson and van Wincoop 2003; Arkolakis et al. 2012; Eaton and Kortum 2002).

$$X_{ij} = \frac{Y_i Y_j}{Y} \left(\frac{t_{ij}}{K_i P_j} \right)^{(1-\sigma)} \tag{1}$$

$$K_i = \sum_{j=1}^{N} \left(\frac{t_{ij}}{P_j} \right)^{(1-\sigma)} \frac{Y_j}{Y} \tag{2}$$

$$P_j = \sum_{i=1}^{N} \left(\frac{t_{ij}}{K_i} \right)^{(1-\sigma)} \frac{Y_j}{Y} \tag{3}$$

Where X_{ij} refers to exports from country i to country j, Y_i represents the GDP of country i, Y_j is the GDP of country j, Y refers to the world's GDP, σ is the elasticity of substitution between product varieties and t_{ij} is the BTC of sending products from country i to country j. K_i and P_j are outward and inward multilateral trade resistance (MTR) terms. The MTR represents trade barriers which country i and country j face in the trade with all their trading partners (involving internal trade). For example, trade between countries such as Germany and China is predicated on the costs for each of them in trading with all other countries. A decrease in a BTC between China and a third country such as Belgium would reduce China's MTR. Although the BTC between China and Germany remains unchanged, the decline in China's MTR (attributed to reduction of trade cost between China and Belgium) would culminate in a diversion of trade away from China – Germany to trade between China and Belgium (spill-over effect). Failure or inability to account for the multilateral resistance effects would culminate in upward bias in the estimates of gains from improvements.

Because of its multiplicative nature, the gravity equation outlined in (1) can be altered by taking logarithms to a log-linear form demonstrated as follows:

$$lnX_{ij} = lnY_i + lnY_j - lnY + (1-\sigma)\left(lnt_{ij} - lnK_i - lnP_j\right) \tag{4}$$

Owing to the lack of a direct measure of trade cost, t_{ij} is usually specified empirically as a function of observable variables that are seen as directly correlated to trade cost. In past studies, a loglinear specification is often applied as follows (e.g. Mayer and Zignago 2011):

$$lnt_{ij} = \beta_1 ln\left(distance_{ij}\right) + \beta_3 ln\left(contig_{ij}\right) + \beta_4 ln\left(comlang_{ij}\right) + \beta_5 ln\left(colony_{ij}\right) \tag{5}$$

We take distance to denote the geographical distance between countries i and j, contig is a categorical variable equal to one if the countries share a common land border, comlang equals one if the country pairs share the same language and colony is equal to one if countries i and j were in a past colonial association. Accordingly, these aspects reflect the assumptions that transport costs improve with distance and are lower for neighbouring nations. Indicators for common language or colonial history are related to information costs with regard to trade, where search costs are presumably lower for trade between countries whose culture and business practices are familiar to each other.

Lu et al. (2018) proposed a hypothesis that infrastructure quality can change the trade costs t_{ij}, and thus also on the bilateral trade flows. Following the hypothesis from Lu et al.

(2018), we suggest one hypothesis that infrastructure quality can change the trade costs t_{ij} that could contribute to economic growth. This leads to the specification of trade costs:

$$\begin{aligned} Trade\ cost = {} & \beta_1(infrasquality_i) + \beta_2 ln(distance_{ij}) + \beta_3(contig_{ij}) + \beta_4(comlang_{ij}) \\ & + \beta_5(colony_{ij}) \end{aligned} \tag{6}$$

Infrastructure can be decomposed into the quantity and the quality of infrastructure. In our study, we use the density, length, connectivity, or efficiency of transport infrastructure to represent the quality of infrastructure index. Additionally, we use the overall infrastructure score provided by the World Bank to represent the quality of infrastructure. After quantifying the impact of transport infrastructure on BTC, we will use it as a critical input for the CGE analysis in the next stage.

3.2. Measurement of trade costs

We employ the measurement of BTCs, T_{ij}, in manufactured and agricultural goods from 178 countries in the world. It is estimated by reversing the gravity model and inferring BTCs from the observed productions and trade flows across countries (Arvis et al. 2016; Novy 2013;). In our regression, we take the natural log of T_{ij} to alleviate the concern from outliers and measurement errors. This measurement is available from the database of the ESCAP-World Bank. Following the same method, we compute another measurement of BTCs by excluding the tariffs between countries, $T_{ij\_}extariff$. We conduct robustness tests to use this alternative measure of the BTCs.

3.3. Measurement of transport infrastructure

To measure the transport infrastructure of each country-pair in a given year, we follow Arvis et al. (2013) to calculate the geometric average of country i's and j's scores on the overall infrastructural quality ($Infras_{ij}$), while the annual infrastructural quality score of each country is available from World Bank's World Development Indicators. In our regression, we take the natural log of $Infras_{ij}$ to alleviate the concern from outliers and measurement errors. $Infras_{ij}$ is an integrated measure which comprehensively considers the quality of the infrastructure in terms of transportation and communication. According to Francois and Manchin (2013), using integrated overall infrastructural proxy is superior to incorporating several dimensional factors into the gravity model, since these dimensional factors are highly correlated.

To confirm that our inferences are not sensitive to the measurement of transport infrastructure, we employ two sources of alternative measurements. First, we select the other three integrated infrastructure proxies from World Bank's World Development Indicators: LPT_{ij} is the geometric average of country i's and j's scores on the logistic performance index; $LSCI_{ij}$ is the geometric average of country i's and j's scores on the linear shipping connectivity index; $Port_{ij}$ is the geometric average of country i's and j's scores on the quality of port infrastructure. These three measures are all related to the quality of traffic infrastructure across countries.

Second, while the integrated proxies are advocated by some scholars, other literature reports also promote individual measurements of traffic connectivity (Lu et al. 2018), because the improvement of the ports, airports, and trainlines will significantly reduce the cost and time of the transportation. Specifically, we select the following proxies to represent the overall connectivity in terms of aviation, railway, roadway, and maritime transportation: $Aird_{ij}$ is the geometric average of country i's and j's number of airports scaled by the area of each country, i.e. average of airport density of each country pair i and j; $Raild_{ij}$ is the geometric average of country i's and j's length of railway scaled by the area of each country; $Roadd_{ij}$ is the geometric average of country i's and j's length of roads scaled by the area of each country; $Containerd_{ij}$ is the geometric average of country i's and j's flows of containers from land to sea (or vice versa), scaled by the area of each country. Number of airports, and the length of roads are obtained from CIA's World Factbook by each year. The container flows are obtained from the World Bank's World Development Indicators. The source of the length of the railway is twofold. We first obtain the railway data from the World Bank's World Development Indicators, and then, we complement the missing values from CIA's World Factbook.

3.4. Determinants of trade costs

To examine the determinants of BTCs, our model takes the following form:

$$\begin{aligned}\mathrm{Ln}\left(T_{ij}\right) = \mathrm{a}_0 + \mathrm{a}_1\,\mathrm{Ln}\left(Infras_{ij}\right) + \mathrm{a}_2\,\mathrm{Ln}\left(Dist_{ij}\right) + \mathrm{a}_3\,Common\ border_{ij} + \mathrm{a}_4\,Comlang\_off_{ij} \\ + \mathrm{a}_5\,Comlang\_ethno_{ij} + \mathrm{a}_6\,Colony_{ij} + \mathrm{a}_7\,Colonizer_{ij} + \mathrm{a}_8\,Same\ country_{ij} \\ + \mathrm{a}_9\,Landlocked_{ij} + \mathrm{a}_{10}\,RTA_{ij} + \mathrm{a}_{11}\,Ln\left(Entry\ cost_{ij}\right) + e_{ij};\end{aligned} \tag{7}$$

Since the BTCs are symmetric, in our estimations we drop half country pairs (i.e. U.S. exports to China and China exports to the U.S. are regarded as repetitive country pairs since the BTCs will be the same for each pair) to avoid the potentially under-estimated standard errors due to the duplicate country pairs. In unreported tests, we confirm that our inferences are robust without removing the duplicate country-pairs. In the baseline model, we employ the OLS model to run the regression. However, considering omitted variables which may bias our inferences, we consider two forms of the estimations to address the model specification. First, we control for the imported, exported, and year-fixed effects to control the omitted determinants of BTCs at the country level that are time-invariant. Second, we also choose the Poisson Maximum Likelihood Estimation (PPML), which has been advocated in the literature (Lu et al. 2018).[1]

The dependent variable (BTCs) and the main independent variable (traffic infrastructure) have been introduced in Sections 1.1 and 1.2. Prior literature argues that there are also other determinants that affect the BTCs, which could be either 'policy' or 'natural'. Following the literature (e.g. Arvis et al. 2013; Novy and Chen 2011; Limão and Venables 2001), we select the following control variables: $Dist_{ij}$ is the geodesic distance between the exporting and importing countries, using the largest (by population) city in each; $Common\ border_{ij}$ is a dummy = 1 if both countries are geographically contiguous; $Comlang\_off_{ij}$ and $Comlang\_ethno_{ij}$ are dummy variables equal to 1 if both countries have common official or ethnographic language; $Colony_{ij}$ is a dummy = 1 if one country used to be a colony of another; $Colonizer_{ij}$ is a dummy = 1 if both countries used to be colonized by another country; $Same\ country_{ij}$ is a dummy = 1 if the two countries used to be part of the same country; $Landlocked_{ij}$ is a dummy = 1 if both countries are landlocked; RTA_{ij} is a dummy = 1 if both the importer and exported benefit from the same regional trade agreement; $Entry\ cost_{ij}$ are the cost of starting a business. Following the logic of creating infrastructure measures for each country pair, we take the geometric average for the country i's and j's entry cost and use the log form to avoid outliers.

3.5. Data and sources

The definition and data source of our variables are summarized in Table 1 as below.

Our sample stems from 2010 to 2015, which allows us to cover a maximum range of data availability across various databases. Our sample covers 143 countries, including both developed and developing countries.

Table 1. Data and sources.

Variable	Definition	Source
T_{ij}	BTC between importing and exporting countries	ESCAP-World Bank
T_{ij}_extariff	BTC between importing and exporting countries, excluding tariff	ESCAP-World Bank
$Infras_{ij}$	Geometric average of country i's and j's scores on the overall infrastructural quality	World Economic Forum
LPT_{ij}	Geometric average of country i's and j's scores on the overall logistic performance index	World Bank
$LSCI_{ij}$	Geometric average of country i's and j's scores on the linear shipping connectivity index	World Bank
$Port_{ij}$	Geometric average of country i's and j's scores on the port quality index	World Bank
$Aird_{ij}$	Geometric average of country i's and j's number of airports scaled by the area of each country i.e. average of airport density of each country pair i and j	CIA World Factbook. We obtain the legacy data by years from 2010 to 2015
$Raild_{ij}$	Geometric average of country i's and j's length of railway scaled by the area of each country	World Bank; CIA World Factbook
$Roadd_{ij}$	Geometric average of country i's and j's length of roads scaled by the area of each country	CIA World Factbook
$Containerd_{ij}$	Geometric average of country i's and j's flows of containers from land to sea (or vice versa), scaled by the area of each country	World Bank
$Dist_{ij}$	Geodesic distance between the exporting and importing countries, using the largest (by population) city in each	CEPII
$Common\ border_{ij}$	Dummy = 1 if both countries share a common land border	CEPII
$Comlang\_off_{ij}$	Dummy = 1 if both countries share the same official language	CEPII
$Comlang\_ethno_{ij}$	Dummy = 1 if both countries share the same ethnographic language	CEPII
$Colony_{ij}$	Dummy = 1 if one country used to be a colony of another	CEPII
$Colonizer_{ij}$	Dummy = 1 if both countries used to be colonized by another country	CEPII
$Same\ country_{ij}$	Dummy = 1 if the two countries used to be part of the same country	CEPII
$Landlocked_{ij}$	Dummy = 1 if both countries are landlocked	CEPII
RTA_{ij}	Dummy = 1 if both the importer and exported benefit from the same regional trade agreement	Personal website of Prof. De Sousa
$Entry\ cost_{ij}$	Geometric average for the country i's and j's entry cost	Doing Business (via World Bank)

3.6. Empirical findings

3.6.1. Baseline results

Table 2 presents the baseline results. Column 1 employs the OLS model where the dependent variable is T_{ij}. The benefits of improving transport infrastructure quality are statistically and economically significant: 1% increase of the overall infrastructure quality for a country pair will on average reduce the BTC by 0.88% ceteris paribus. The coefficient signs of the control variables within our regression model are generally in line with the expectation from the prior literature. In Column 2 we control the exporter, importer, and year fixed effect to alleviate the effect of omitted variables to our inferences, and in Column 3 we employ the PPML model.[2] The results from Columns 2 and 3 confirm the negative relationship between improved traffic infrastructure and BTCs, albeit with smaller elasticities. Columns 4 to 6 repeat the estimations from Columns 1 to 3 by employing the BTCs excluding tariffs. Again, our inferences are robust.

Our model may be subject to endogeneity issues in several areas, and we address these in Appendix 3. Specifically, reverse causality could be a concern since improving transportation infrastructure quality may reduce trade costs, while lower trade costs could also encourage infrastructure improvement. In Panel A of Appendix 3, we use a one-year lag for the independent and control variables to mitigate this concern, as lagged infrastructure quality is expected to influence bilateral costs without reciprocal causation; our results remain robust, showing a negative relationship between transportation infrastructure improvements and bilateral trade costs. Additionally, in untabulated tests, we confirm the robustness of our findings when using a two-year lag for the independent and control variables.

Another potential source of endogeneity is omitted variable bias, which may correlate with both the dependent and independent variables. We address this in Panel B of Appendix 3 by adding control variables that capture differences in the institutional environment, human capital, and technology levels between exporting and importing countries. To account for institutional differences, we follow Ghoul, Guedhami, and Kim (2017) by including variables for disparities in public institutions, civil society, capital markets, and labour markets, drawing on institutional indexes from the Institutional Profiles Database (IPD) provided by CEPII: Institutional Profiles Database (cepii.fr).

Moreover, human capital has been shown to significantly influence a country's competitive advantage and trade costs. We use the difference in educational attainment (Blanchard and Olney 2017), measured as the percentage of the population aged 25 and above whom have completed secondary school, with data obtained from the World Bank. Finally, to control for technological variations, we incorporate the difference in R&D expenditure as a percentage of GDP between exporting and importing countries, a factor identified as critical in determining bilateral trade costs (Xiong 2024). Country-level R&D expenditure data was also sourced from the World Bank. The results in Panel B of Appendix 3 confirm the negative relationship between improvements in transport infrastructure quality and bilateral trade costs, further supporting our conclusions after accounting for endogeneity.

Table 2. Impacts of improving transport infrastructure on BTCs.

Estimation Method	(1) OLS	(2) FE	(3) PPML	(4) OLS	(5) FE	(6) PPML
Dependent Vars	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij}_Extariff)	Ln (T_{ij}_Extariff)	Ln (T_{ij}_Extariff)
Ln (Infras$_{ij}$)	**−0.8843*****	**−0.2005*****	**−0.2001*****	**−0.8218*****	**−0.2241*****	**−0.1862*****
	(−53.23)	**(−4.64)**	**(−45.79)**	**(−48.06)**	**(−5.01)**	**(−41.48)**
Ln (Dist$_{ij}$)	0.1922***	0.3281***	0.1606***	0.1924***	0.3357***	0.1643***
	(46.96)	(94.15)	(35.10)	(45.87)	(92.10)	(35.15)
Common border$_{ij}$	−0.5736***	−0.2773***	−0.6272***	−0.5889***	−0.2745***	−0.6483***
	(−33.14)	(−16.84)	(−32.36)	(−33.57)	(−16.16)	(−34.08)
Comlang_off$_{ij}$	0.0679***	−0.0583***	0.0765***	0.0703***	−0.0502***	0.0759***
	(5.76)	(−6.55)	(5.48)	(5.82)	(−5.46)	(5.35)
Comlang_ethno$_{ij}$	−0.0987***	−0.0414***	−0.0879***	−0.1102***	−0.0403***	−0.0993***
	(−8.51)	(−4.64)	(−6.42)	(−9.24)	(−4.36)	(−7.08)
Colony$_{ij}$	−0.3920***	−0.2248***	−0.4889***	−0.3887***	−0.2400***	−0.4784***
	(−24.13)	(−15.65)	(−24.62)	(−23.11)	(−16.52)	(−23.47)
Colonizer$_{ij}$	0.1806***	−0.0672***	0.2036***	0.1636***	−0.0789***	0.1905***
	(14.44)	(−6.57)	(14.07)	(12.72)	(−7.49)	(12.92)
Same country$_{ij}$	−0.1525***	−0.1237***	−0.1758***	−0.1465***	−0.1247***	−0.1725***
	(−15.32)	(−15.97)	(−14.40)	(−14.36)	(−15.67)	(−13.88)
Landlocked$_{ij}$	0.2687***	−0.2082***	0.2651***	0.2892***	−0.2057***	0.2778***
	(18.01)	(−15.52)	(16.54)	(19.16)	(−15.04)	(17.45)
RTA$_{ij}$	−0.2559***	−0.1497***	−0.2568***	−0.1989***	−0.0986***	−0.2023***
	(−34.18)	(−27.81)	(−28.90)	(−26.13)	(−17.93)	(−22.45)
Entry cost$_{ij}$	0.0634***	0.0083	0.0598***	0.0502***	0.0113	0.0466***
	(23.56)	(1.21)	(19.33)	(18.16)	(1.61)	(14.71)
Constant	5.0149***	2.9269***	5.0023***	4.8356***	2.8029***	4.8281***
	(112.34)	(32.71)	(106.47)	(105.68)	(30.86)	(100.05)
Fixed Effect	No	Exporter, Importer, year	No	No	Exporter, Importer, year	No
Obs	36047	36047	36047	35701	35701	35701
Adj R2 (Pseudo R2)	0.3840	0.7630	0.4488	0.3387	0.7425	0.4184

t-statistics are in the parentheses; ***, **, and * represents statistical significance at 1%, 5%, and 10% level, respectively (two-tailed test).

3.6.2. Baseline results by developed and emerging countries

We further examine the baseline results by looking at the subsamples where (1) both importing and exporting countries are developed countries (DLC), (2) the bilateral trades occur between developed and emerging countries and (3) the bilateral trades occur within emerging countries (EGC). For brevity, we only report the results employing the OLS model where the dependent variable is Tij.[3] We define a country as a developed one if it simultaneously satisfies the criteria of developed countries criteria set by the following organizations: United Nations, World Bank, International Monetary Foundation (IMF), and CIA. There are 31 developed countries within our sample. The results are presented in Table 3 as follows: we document that the negative relationship between infrastructure quality and BTCs is consistent within the subsample of DLCs, the subsample of EGCs, and the subsample where bilateral trades occur between DLCs and EGCs. Specifically, 1% increase of the average overall infrastructure quality for a pair of DLCs will on average reduce the BTC by 0.25% ceteris paribus (Column 1), while 1% increase of the average overall infrastructure quality for a pair of EGCs will on average reduce the BTC by 0.46% ceteris paribus (Column 3). The difference between the coefficients of Ln (Infrasij) is statistically significant in the seemingly unrelated estimation (SUEST) which is used to compare the coefficients of the same variable across subsamples (Chi 2 = 5.87, p-value = 0.0152). Therefore, compared with the bilateral trades within the pair of developed countries, the impact of infrastructure improvement on BTC is more pronounced within the pair of emerging countries.

3.6.3. Alternative measures of traffic infrastructure

To verify whether our findings are sensitive to the choice of traffic infrastructure measures, we conduct several robustness tests by employing seven alternative measures specified in Section 3.3. The results are reported in Table 4. Column 1 shows that, ceteris paribus, an improvement of 1% in the logistical performance index is associated with a reduction of the BTC by 2.40%. This is in line with the findings of Arvis et al. (2016) who documented an elasticity of −1.61 between LPT and BTCs. Columns 2 and 3 show that our findings remain robust when employing two other integrated infrastructure proxies.

In Columns 4 to 7, we use single traffic connectivity measures for aviation, railway, roadway, and maritime transportation. On average, an increase of 1% in the airport density for the country pair is associated with a 0.15% reduction in BTCs. Similarly, increasing 1% of the railway density, roadway density, and container flow capacity is associated with a reduction of BTCs by 0.13%, 0.04%, and 0.24%, respectively. Finally, we look at the impacts of the alternative traffic infrastructure measures on BTCs by considering the developed and emerging countries separately and interactively. The results are presented in Table 5. Again, the negative relationship between alternative traffic infrastructure measures and the BTCs is robust within each subsample.

3.6.4. Summary

Based on the literature discussing the determinants of BTCs, we conduct a regression study to reveal the impact of improving traffic infrastructure on BTCs. Our results confirm that improving infrastructure (either proxied by integrated traffic quality or single traffic connectivity) is significantly associated with lower BTCs, and this finding is robust within developed and emerging countries.

Table 3. Impacts of improved infrastructure on BTCs: developed (DLC) and emerging (EGC) countries.

	(1)	(2)	(3)
Estimation Method	OLS	OLS	OLS
Dependent Vars	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})
Subsample	B	Cross DLC-EGC	Within EGC
Ln (Infras$_{ij}$)	**−0.2528*** **	**−0.7142*** **	**−0.4622*** **
	(−2.78)	**(−23.96)**	**(−19.60)**
Ln (Dist$_{ij}$)	0.3209***	0.2195***	0.1576***
	(23.94)	(34.03)	(27.50)
Common border$_{ij}$	−0.3394***	−0.5936***	−0.5911***
	(−8.69)	(−6.70)	(−31.60)
Comlang_off$_{ij}$	0.0551	0.1219***	0.0024
	(1.60)	(7.30)	(0.14)
Comlang_ethno$_{ij}$	−0.3768***	−0.1333***	−0.0162
	(−14.18)	(−8.43)	(−0.93)
Colony$_{ij}$	−0.0662**	−0.3689***	−0.3388***
	(−2.19)	(−18.27)	(−7.14)
Colonizer$_{ij}$	0.2832***	0.3099***	0.1458***
	(4.39)	(14.17)	(9.01)
Same country$_{ij}$	0.1476***	−0.0756***	−0.2490***
	(4.47)	(−5.11)	(−17.27)
Landlocked$_{ij}$	0.2673***	0.2719***	0.3845***
	(5.69)	(13.63)	(18.14)
RTA$_{ij}$	0.1090***	−0.1472***	−0.3130***
	(4.12)	(−14.44)	(−26.60)
Entry cost$_{ij}$	−0.0216***	0.0228***	0.0762***
	(−2.62)	(5.65)	(19.34)
Constant	2.4279***	4.5004***	4.7917***
	(10.69)	(59.65)	(78.87)
Obs	1895	14768	19384
Adj R^2	0.6060	0.2519	0.3383

t-statistics are in the parentheses; ***, **, and * represents statistical significance at 1%, 5%, and 10% level, respectively (two-tailed test).

Table 4. Impacts of improving transport infrastructure on BTCs: alternative infrastructure measures.

Estimation Method	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS
Dependent Vars	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})
Integrated indicators							
Ln (LPT_{ij})	**−2.4040*** (−108.64)**						
Ln ($LSCI_{ij}$)		**−0.4381*** (−87.84)**					
Ln ($Port_{ij}$)			**−0.9201*** (−63.44)**				
Single traffic connectivity							
Ln ($Aird_{ij}$)				**−0.1507*** (−42.71)**			
Ln ($Raild_{ij}$)					**−0.1263*** (−40.59)**		
Ln ($Roadd_{ij}$)						**−0.0401*** (−13.67)**	
Ln ($Containerd_{ij}$)							**−0.2433*** (−109.23)**
Other Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.2038*** (149.13)	4.1890*** (104.65)	4.8145*** (119.28)	3.6225*** (86.71)	3.6359*** (100.75)	3.3245*** (74.37)	5.8984*** (125.64)
Obs	33537	26402	36774	26874	38832	38832	26223
Adj R^2	0.5148	0.5331	0.4050	0.4214	0.3636	0.3386	0.5791

t-statistics are in the parentheses; ***, **, and * represents statistical significance at 1%, 5%, and 10% level, respectively (two-tailed test).

Table 5. Impacts of improving transport infrastructure on BTCs: alternative infrastructure measures: developed (DLC) and emerging countries (EGC).

	Panel A: Within DLC				Panel B: Cross DLC and EGC				Panel C: Within EGC			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Single traffic connectivity												
Ln (*Aird*$_{ij}$)	**−0.1209***** **(−7.74)**				**−0.1284***** **(−21.64)**				**−0.0511***** **(−9.98)**			
Ln (*Raild*$_{ij}$)		**−0.0248**** **(−2.02)**				**−0.0843***** **(−16.23)**				**−0.0369***** **(−7.88)**		
Ln (*Roadd*$_{ij}$)			**0.0246**** **(2.29)**				**−0.0220***** **(−4.84)**				**0.0175***** **(4.29)**	
Ln (*Containerd*$_{ij}$)				**−0.1596***** **(−23.88)**				**−0.2244***** **(−69.15)**				**−0.2414***** **(−74.16)**
Other Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.7817***	2.0009***	2.1361***	4.1994***	3.6460***	3.4013***	3.1696***	5.6006***	4.2129***	4.1015***	4.3029***	6.0952***
	(15.66)	(17.23)	(15.77)	(31.09)	(55.97)	(60.10)	(46.48)	(78.64)	(68.84)	(81.31)	(66.57)	(85.63)
Obs	1610	2049	2049	1752	11151	16107	16107	10981	14113	20676	20676	13490
Adj R2	0.6736	0.6036	0.6039	0.7106	0.2637	0.2334	0.2221	0.4971	0.3594	0.3240	0.3226	0.5277

We examine the impacts of improving traffic infrastructure on BTCs within the subsample of developed countries (Panel A), the subsample between developed and emerging countries (Panel B) and within the subsample of emerging countries (Panel C). We use the OLS model where the dependent variable is the natural log of T_{ij}. We present the results of the individual traffic connectivity proxies in terms of aviation, railway, roadway, and maritime transportation. We do not tabulate the results using other integrated infrastructure proxies such as LPI, LSCI, and port quality. They are available upon request. The *t*-statistics are in the parentheses; ***, **, and * represents statistical significance at 1%, 5%, and 10% levels, respectively (two-tailed test).

4. Measuring the impact of trade cost shock on economic growth

Above, we have estimated the effects of enhancing transport infrastructure on trade costs. To model the relationship between the alteration of trade costs and economic growth, we first analyze the theoretical basis of a CGE model, then utilize the estimated results from the prior section as suppositions for trade cost change in the CGE model. We provide an estimation of the trade cost impacts on GDP growth across various economic regions.

4.1. Baseline CGE model

Our projections are based on version 10 of the standard Global Trade Analysis Project (GTAP) computable general equilibrium (CGE) model featuring imperfect competition. Generally, the CGE model consists of the production side and consumption side described by production functions, income functions, price equations, payment functions, and macro-closure equations. The first four groups of functions represent the characteristics of the economic system described by the CGE model, while the macro-closed functions are the reflection of the CGE model's theoretical basis-Walras general equilibrium theory. Production generates income for the regional households, and then this income is distributed across three broad categories of expenditure: private consumptions, investment, and government spending. Each category of expenditure comprises both domestic and imported goods and services, thereby generating both domestic and export sales by firms.

4.2. Data source

The GTAP 10 database features 2014 reference years as well as 141 regions and countries for all 65 GTAP sectors. This paper, based on the Global Trade Analysis Project 10 (GTAP 10) database, uses the standard GTAP CGE model to estimate the impact of improving transport infrastructure to a total of 141 countries/regions in the world. This paper aggregates these data into three countries in terms of country classification including developed country, emerging country, and developing country (Appendix 1). Also, our model covers 32 sectors and these sector details can be seen at the aggregation level of the CGE structure (Appendix 2).

4.3. Assumptions in CGE model

In this study, we have provided robust evidence about the impacts of improving transport infrastructure on trade cost. In this section, we further explore the impacts of reduction of trade cost on economic growth. We regard trade cost as an exogenous shock to simulate the cost changes and trace the impact on key economic variables, including real GDP and nominal GDP growth. Specifically, the model simulation needs to identify and quantify the initial shocks in exogenous variables. In the case of trade facilitation as an initial shock to a CGE model, researchers can use the so-called iceberg specification as a standard approach. In the latest GTAP model, the parameter (ams), import-augmenting technical change, is adopted as the exogenous shock variable for the simulation of the importing cost reduction, particularly that from trade facilitation measures (Walmsley and Minor 2016). Kleitz and Directorate, O.E.C.D (2002), also indicate that the benefits of trade facilitation can typically be viewed as equivalent to trade costs that can be saved.

Shocks to ams (i,r,s) refer to the negative of the rate of decay on imports of commodity or service i from region r imported by region s (the arguments in the parentheses represent as follows: i; commodity, r: exporting region, and s: importing region). Take an example, when one percent increase in ams (i,r,s) takes places for all exporters, then the price of the imported goods in the region declines by 1%. We use a scenario analysis, and each scenario puts forward a separate assumption to reflect the impacts of trade facilitation (or trade cost) on economic growth (see Table 6). Indeed, in scenario 1, based on the estimator, 1% increase of the overall infrastructure quality for a country pair will on average reduce the BTC by 0.88% ceteris paribus. Therefore, we estimate the impacts of a decrease of 0.88% of the BTC on GDP growth by employing a CGE model. Given the fixed effect estimator in scenario 2, 1% growth of the overall infrastructure quality for a country pair could averagely reduce the BTC by 0.2% ceteris paribus. So, we test the impacts of a 0.2% decrease of trade cost on GDP Growth. Also, we employ estimations of the PPML model as our assumption in scenario 3. Specifically, 1% growth of the overall infrastructure quality for a country pair could averagely reduce the BTC by 0.2% ceteris paribus. Scenarios 4 to 6 repeat the estimations from scenarios 1 to 3 by employing the BTC excluding tariff.

4.4. Model estimations

The estimations based on the GTAP CGE model provide evidence on the impacts of improving transport infrastructure on economic growth. Our findings show that reducing trade costs contributes to a rise in real GDP across all economies. Specifically, in Scenario 1, the developing country could gain the most, with a 0.99% increase in real GDP growth. Developed countries would enjoy a 0.86% increase in real GDP growth. Emerging countries could gain 0.66% in GDP growth (See Table 7). In Scenario 2, our findings show that developing countries could still enjoy the most significant economic growth, with a 0.22% rise in real GDP growth. Developed countries could experience a 0.19% increase in real GDP growth. In Scenario 3, our estimations show that the developing country could gain the most, with a 0.92% increase in economic growth. Additionally, developed countries could gain 0.18% in GDP growth. Emerging economies could enjoy a 0.14% rise in GDP growth. Similarly, Scenarios 4 to 6 show that the developing country would gain the most, followed by developed countries and emerging countries.

Table 6. The impacts of trade facilitation on economic growth.

Scenario	Assumptions
scenario 1	Based on the estimations of OLS model, a country pair could averagely reduce the BTC by 0.88%
scenario 2	Based on the fixed-effect estimator, a country pair could averagely reduce the BTC by 0.20%
scenario 3	Based on the estimations of PPML model, a country pair could averagely reduce the BTC by 0.20%
scenario 4	Based on the estimations of OLS model, a country pair could averagely reduce the BTC by 0.82% (excluding tariff)
scenario 5	Based on the fixed-effect estimator, a country pair could averagely reduce the BTC by 0.22% (excluding tariff)
scenario 6	Based on the estimations of PPML model, a country pair could averagely reduce the BTC by 0.19% (excluding tariff)

Table 7. Changes in the percentage of real GDP of the world in the long term.

Scenario	Developed country (Real GDP percent)	Emerging country (Real GDP percent)	Developing country (Real GDP percent)
scenario 1	0.86	0.66	0.99
scenario 2	0.19	0.15	0.22
scenario 3	0.19	0.15	0.22
scenario 4	0.80	0.16	0.92
scenario 5	0.21	0.16	0.25
scenario 6	0.18	0.14	0.21

5. Discussion and conclusions

The current scholarly literature has paid limited attention to the relationship between infrastructure quality, GDP growth, and trade costs. This study advances our understanding of this important issue by examining the impact of infrastructure quality on trade costs for both developed and emerging markets. Using a computable general equilibrium (CGE) analysis, we demonstrate the potential benefits of improving infrastructure quality on GDP growth through the trade-cost channel across different economies.

Our key findings indicate that enhancing transport infrastructure quality can significantly reduce trade costs: by 0.46% between emerging economies, 0.25% between developed economies, and 0.71% between emerging and developed economies for every 1% increase in infrastructure quality. Furthermore, our estimations provide evidence of the impacts of improving overall infrastructure quality on trade costs and economic growth through the trade-cost reduction channel. We observe that reducing trade costs leads to an increase in real GDP across all economies, with the greatest gains in developing countries (0.21–0.99%). Developed and emerging countries can also expect GDP growth of 0.16–0.86% and 0.14–0.66%, respectively. These findings suggest that improved transport infrastructure quality plays a crucial role in economic success, indicating that fiscal policies aimed at enhancing transport infrastructure can significantly promote economic growth. Moreover, investments in East Asia and the Pacific may yield even higher growth payoffs than initially anticipated. These results support initiatives such as the Belt and Road Initiative and the expansion of 5 G networks. By enabling goods to move faster and more efficiently through markets, the positive spillovers from the BRI may be greater than initially thought. However, further investigation into this topic is warranted.

This study addresses critical gaps left by prior literature by utilizing newly available data from the World Bank and other credible sources, specifically tackling limitations in data quality, coverage, and scope. Unlike earlier studies that relied on outdated datasets, our research includes enhanced metrics such as infrastructure quality assessments, reducing measurement errors and allowing for more precise estimates of infrastructure impacts on trade costs and GDP growth. This dataset offers extensive temporal coverage, capturing recent trends and developments in transportation infrastructure, particularly in the context of initiatives like the Belt and Road Initiative (BRI). The up-to-date information enables our study to reflect the current economic environment and the modern-day effects of infrastructure, which previous studies could not achieve.

Furthermore, the comprehensive dataset allows for granular analysis across regions and sectors, helping to avoid the broad generalizations found in earlier research. This level of detail facilitates the exploration of variations between developed and emerging markets, providing insights into how infrastructure impacts trade costs and economic growth differently across diverse economic contexts. By including variables such as institutional quality and governance, we can account for broader economic and social factors influencing the effectiveness of infrastructure investments – elements often overlooked in the past research due to limited data.

The availability of consistent data across multiple countries supports the application of advanced econometric techniques, including regression models, neural network analysis, and CGE models. These methodologies enable a robust and nuanced analysis of the relationship between infrastructure quality and economic outcomes on both macro and global scales, addressing both the immediate and long-term effects of infrastructure investments. By overcoming limitations in data quality, scope, and methodology, our study provides a more comprehensive and reliable assessment of the impact of transportation infrastructure on trade costs and economic growth, marking a meaningful contribution to the literature.

5.1. Theoretical and practical implications

From a theoretical standpoint, this paper contributes to the existing literature by quantifying the impact of infrastructure investment on Bilateral Trade Costs (BTCs). While Arvis et al. (2013) discussed the influence of infrastructure on BTCs within developing countries, this study updates their research by employing a sample period following the onset of the Belt and Road Initiative (BRI). Additionally, it extends the examination of infrastructure-trade costs to bilateral partnerships between emerging and developed economies. Although previous literature established the theoretical relationship between infrastructure and GDP growth and suggested trade costs as a connecting mechanism, this study is the first to quantify the impact of this channel.

Moreover, by utilizing newly available data from the World Bank database and other sources, this research addresses several limitations of prior studies. The updated data offer comprehensive and current temporal coverage, capturing recent trends and developments in transportation infrastructure and their impact on economic growth. This granularity facilitates nuanced analyses across various regions and sectors, thus addressing generalizations often found in earlier studies. Enhanced metrics in the new data, such as infrastructure quality assessments, mitigate measurement errors and provide a more precise understanding of infrastructure effectiveness. Real-time data also facilitate the examination of immediate and short-term effects of infrastructure investments, aspects frequently neglected in previous research.

The availability of consistent data across multiple countries and regions supports comparative analysis and the application of advanced econometric techniques, enhancing the robustness and reliability of the findings. The inclusion of additional variables, such as institutional quality and governance, allows for a comprehensive analysis that considers broader economic and social contexts influencing infrastructure's impact. These improvements enable this study to offer a more detailed and accurate assessment of the relationship between transportation infrastructure and economic growth, thereby filling gaps left by previous research. By combining regression models, neural network analysis, and computable general equilibrium models to estimate the impacts of improving transport infrastructure on trade costs and economic growth, this study traces the effects of infrastructure enhancements on macro and global scales.

5.2. Limitations and directions for further research

By comparing the cost of improving infrastructure quality with our estimated benefits, we identify a vast scope for future research. However, our study is limited by its specific focus on transport infrastructure, which restricts generalizability to other industrial settings. This limitation presents a promising new area for future exploration. Additionally, it is worth examining the relationship between transport infrastructure improvements, due to major transport infrastructure projects, and the economic performance of the participating economies, such as those associated with the Belt and Road Initiative (BRI). This evidence is essential not only for the development of future projects but also because BRI can serve as an example for other infrastructure investments that can boost economic links.

Notes

1. PPML can naturally accept a large number of zero trade values in the dependent variable, which particularly fits into the gravity model since there are massive zeroes for the bilateral trade costs within our sample (Silva and Tenreyro, 2006). We appreciate one reviewer for pointing this out. Additionally, compared with OLS, PPML has at least two advantages: (1) it provides consistent estimates of the original nonlinear model when incorporating fixed effects ((Silva and Tenreyro 2006), and (2) interpretation of the coefficients from the PPML model is straightforward and still be interpreted as elasticities. Empirically, PPML has been dominantly employed, including the latest articles (e.g. Lateef and Riaz 2022; Nguyen and Wu 2023).
2. Because the dependent variable cannot be negative in the PPML model, in Column 3 and 6 we do not take the natural log of the BTCs.
3. The results are robust when we use alternative regression models. These results are available upon requested.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The raw data necessary for constructing the variables in our study were obtained from publicly available datasets specified in the article. The data supporting this article are accessible in both the article itself and its online supplementary material.

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Appendix 1. Sectorial aggregation

Sector aggregation	Previous sector	Code in modelling
Automotive	Motor vehicles and parts	mvh
Beef	Bovine meat products	cmt
BeverTobac	Beverages and tobacco	b_t
BusiServs	Business services nec	obs
CerealGrns	Paddy rice, Wheat, Cereal grains nec, Processed rice	pdr, wht, gro, pcr
CheRubPlas	Chemical, rubber, plastic products	crp
Communicat	Communication	cmn
Construct	Construction	cns
Dairy	Raw Milk, Dairy products	rmk, mil
ElectronEq	Electronic equipment	ele
Ferrous	Ferrous metals	i_s
FinanServs	Financial services nec, Insurance	ofi, isr
Fishing	Fishing	fsh
FoodProd	Food products nec	ofd
ForestWood	Forestry, Wood products, Paper products, publishing	frs, lum, ppp
FossilFuel	Coal, Oil, Gas, Petroleum, coal products	coa, oil, gas,p_c
FruitVege	Vegetables, Fruits, Nuts	v_f
MachinEq	Machinery and equipment nec	ome
MetalProd	Metal products	fmp
MinralProd	Minerals nec, Mineral products nec	omn, nmm
NonFerrous	Metals nec	nfm
OilSVegOil	Oil seeds, Vegetable oils and fats	osd, vol
OthFarming	Plant-based fibers, Crops nec, Bovine cattle, Sheep and goats, Horses, Animal products, Wool, Silk-worm cocoons	pfb, ocr, cti, oap, wol
OthManufac	Manufactures nec	omf
OthServs	Public Administration, Defense, Education, Health, Dwellings	osg, dew
PorkPoul	Meat products nec	omt
Recreation	Recreational and other services	ros
Sugar	Sugar cane, Sugar beet, Sugar	c_b, sgr
TextApparl	Textiles, Wearing apparel, Leather products	tex, wap, lea
Trade	Trade	trd
TranspEq	Transport equipment nec	otn
Transport	Transport nec, Water transport, Air transport	otp, wtp, atp

Appendix 2. Regional/national code & aggregation

Regions/countries	Code in modelling
China, Hong Kong, Taiwan. Russian Federation.India	chn, hkg, twn, rus. Ind,
United States of America	usa,kaz, kgz, arm, aze, geo, irn,
Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Georgia, Iran Islamic Republic of Iran	
Japan, Korea, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia, Mongolia	Jpn, kor, brn, khm, idn, lao, mys, phl, sgp, tha, vnm, xse, mng
Bangladesh, Nepal, Pakistan, Sri Lanka, Rest of South Asia,	bgd, npl, pak, lka, xsa,
Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Albania, Bulgaria, Belarus, Croatia, Ukraine, Rest of Eastern Europe, Bahrain, Israel, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Egypt	cze, est, grc, hun, lva, ltu, pol, svk, svn, alb, bgr, blr, hrv, ukr, xee,
Kenya, Tanzania	bhr, isr, omn, qat, sau, tur, are, egy ken, tza,
Australia, New Zealand, Rest of Oceania, Rest of East Asia, Canada, Mexico, Rest of North America, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean, Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain, Sweden, United Kingdom, Switzerland, Norway, Rest of EFTA, Romania, Rest of Europe, Rest of Former Soviet Union, Jordan, Kuwait, Rest of Western Asia, Morocco, Tunisia, Rest of North Africa, Rest of North Africa, Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, South Central Africa, Ethiopia,	aus, nzl, xoc, xea, can, mex, xna, arg, bol, bra, chl, col, ecu, pry, per, ury, ven, xsm, cri, gtm, hnd, nic, pan, slv, xca, jam, pri, tto, xcb, aut, bel, cyp, dnk, fin, fra, deu, irl, ita, lux, mlt, nld, prt, esp, swe, gbr, che, nor, xef, rou, xer, xsu, jor, kwt, xws, mar, tun, xnf, ben, bfa, cmr, civ, gha, gin, nga, sen, tgo, xwf, xcf, xac, eth, mdg, mwi, mus, moz, rwa, uga, zmb,
Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Uganda, Zambia,	zwe, xec, bwa, nam, zaf, xsc, xtw
Zimbabwe, Rest of Eastern Africa, Botswana, Namibia, South Africa, Rest of South African, Customs, Rest of the World	

No.	Code	Description	Old regions
1	ddc	developed economies	aus nzl hkg jpn kor can usa aut bel cyp dnk fin fra deu grc irl ita ltu lux nld prt esp swe gbr
2	ems	emerging economies	chn twn idn mys phl sgp tha vnm ind pak lka mex xna arg bra chl col ecu per ury ven cze est hun lva mlt pol svk svn xef bgr hrv rou rus ukr xee xer kaz arm aze geo bhr irn isr kwt omn qat sau tur are egy mar tun nga sen ken zaf
3	dpc	developing economies	xoc mng xea khm lao xse bgd npl xsa bol pry xsm cri gtm hnd nic pan slv xca xcb che nor alb blr kgz xsu xws xnf ben bfa cmr civ gha gin tgo xwf xcf xac eth mdg mwi mus moz rwa tza uga zmb zwe xec bwa nam xsc xtw

Appendix 3. Robustness Tests of Table 2: Impacts of Improving Transport Infrastructure on BTCs

	Panel A: Control variables with one-year lag			Panel B: Extra control variables		
Estimation Method	(1) OLS	(2) FE	(3) PPML	(4) OLS	(5) FE	(6) PPML
Dependent Vars	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})	Ln (T_{ij})
Ln (Infras$_{ij}$)	**−0.8752*** (−47.08)**	**−0.1995*** (−3.83)**	**−0.1612*** (−47.00)**	**−1.0656*** (−44.84)**	**−0.1132* (−1.76)**	**−0.1997*** (−44.94)**
Ln (Dist$_{ij}$)	0.1909*** (42.09)	0.3259*** (84.71)	0.0361*** (41.68)	0.1625*** (27.05)	0.2946*** (58.63)	0.0316*** (26.91)
Common border$_{ij}$	−0.5800*** (−30.13)	−0.2986*** (−16.02)	−0.1245*** (−30.55)	−0.5418*** (−20.97)	−0.3050*** (−12.67)	−0.1187*** (−22.13)
Comlang_off$_{ij}$	0.0642*** (4.92)	−0.0664*** (−6.94)	0.0120*** (4.93)	0.0300* (1.76)	−0.1073*** (−9.00)	0.0057* (1.74)
Comlang_ethno$_{ij}$	−0.0874*** (−6.81)	−0.0392*** (−4.10)	−0.0163*** (−6.80)	−0.0469*** (−2.71)	−0.0127 (−1.07)	−0.0093*** (−2.80)
Colony$_{ij}$	−0.3971*** (−22.59)	−0.2149*** (−13.85)	−0.0803*** (−22.29)	−0.3692*** (−17.31)	−0.1855*** (−10.16)	−0.0762*** (−17.11)
Colonizer$_{ij}$	0.1840*** (13.24)	−0.0685*** (−6.07)	0.0356*** (13.87)	0.1367*** (6.88)	−0.0511*** (−3.27)	0.0275*** (7.41)
Same country$_{ij}$	−0.1538*** (−13.88)	−0.1240*** (−14.72)	−0.0286*** (−13.55)	−0.1719*** (−12.01)	−0.1456*** (−13.71)	−0.0319*** (−11.42)
Landlocked$_{ij}$	0.2661*** (16.07)	−0.2136*** (−14.47)	0.0487*** (16.57)	0.2152*** (8.72)	−0.1460*** (−6.46)	0.0387*** (8.78)
RTA$_{ij}$	−0.2645*** (−31.46)	−0.1570*** (−26.52)	−0.0510*** (−31.34)	−0.3248*** (−31.22)	−0.1426*** (−18.51)	−0.0643*** (−31.19)
Entry cost$_{ij}$	0.0618*** (20.33)	−0.0110 (−1.32)	0.0114*** (20.20)	0.0464*** (12.36)	−0.0095 (−0.92)	0.0086*** (12.27)
ΔIPD_Public$_{ij}$				−0.0033 (−0.11)	−0.0245 (−0.66)	−0.0006 (−0.09)
ΔIPD_G&S$_{ij}$				−0.0207 (−0.87)	0.0079 (0.33)	−0.0039 (−0.86)
ΔIPD_Capital$_{ij}$				−0.0060 (−0.31)	0.0050 (0.21)	−0.0010 (−0.27)
ΔIPD_Labour$_{ij}$				0.0391* (1.75)	0.0101 (0.39)	0.0070* (1.67)
ΔHuman_capital$_{ij}$				0.0048 (0.88)	0.1570*** (2.75)	0.0009 (0.90)
ΔTech_intensity$_{ij}$				−0.0033 (−1.32)	−0.0147 (−0.51)	−0.0006 (−1.33)
Constant	5.0150*** (100.58)	3.5615*** (46.40)	1.6060*** (171.85)	5.5124*** (82.27)	3.7509*** (40.89)	1.6961*** (132.68)
Fixed Effect	No	Exporter, Importer, year	No	No	Exporter, Importer, year	No
Obs	30015	30015	30015	17102	17102	17102
Adj R2 (Pseudo R2)	0.3778	0.7605	0.3751	0.4411	0.8008	0.4405

t-statistics are in parentheses; ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively (two-tailed test). We perform robustness tests in Table 2 to account for potential endogeneity. Specifically, in Panel A, we use a one-year lag for the independent and control variables to address concerns of reverse causality. In Panel B, to mitigate concerns of omitted variable bias, we add extra variables to the model: *ΔIPD_Public*, *ΔIPD_G&S*, *ΔIPD_Capital*, and *ΔIPD_Labour* represent the differences in institutional characteristics between exporting and importing countries across four dimensions: public institutions, civil society, capital markets, and labour markets. Additionally, *ΔHuman_capital$_{ij}$* is the difference in the educational attainment of adults who completed secondary school in exporting and importing countries, used in the literature as a proxy for country-level human capital; *ΔTech_intensity$_{ij}$* represents the difference in R&D expenditure relative to GDP in exporting and importing countries.