

Kurmanalieva, Elvira

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## Infrastructure quality, cross-border connectivity, and trade costs

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**ADB Working Paper Series**

**INFRASTRUCTURE QUALITY,  
CROSS-BORDER CONNECTIVITY,  
AND TRADE COSTS**

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Elvira Kurmanalieva

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**Asian Development Bank Institute**

Elvira Kurmanalieva is a leading expert at the Eurasian Development Bank.

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Please contact the authors for information about this paper.

Email: [elvirkas@gmail.com](mailto:elvirkas@gmail.com)

Asian Development Bank Institute  
Kasumigaseki Building, 8th Floor  
3-2-5 Kasumigaseki, Chiyoda-ku  
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500  
Fax: +81-3-3593-5571  
URL: [www.adbi.org](http://www.adbi.org)  
E-mail: [info@adbi.org](mailto:info@adbi.org)

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**Abstract**

Trade costs incorporate the cost of transportation along with tariffs, nontariff measures, insurance, distribution costs, infrastructure quality, and cross-border connectivity. The high costs of trade make the production process slow and costly, which forces international trade flows to concentrate on locations with better infrastructure quality and lower tariffs while abandoning the rest to the periphery. This is how hubs and spokes arise. This evolving process in international trade does not seem to favor geographically disadvantaged remote islands and landlocked countries that are desperately seeking to improve their access to global distribution networks. This paper uses a new approach to measure various indicators of cross-border connectivity by considering so-called “betweenness centrality,” which, broadly interpreted, is the efficiency of networks’ relationships. It then estimates the trade cost function as a function of cross-border connectivity, distance, and infrastructure quality.

**Keywords:** trade cost, infrastructure quality, cross-border connectivity, betweenness centrality

**JEL Classification:** R12, R41, F14

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## 1. INTRODUCTION

Geography is an integral part of international trade theory. Samuelson (1952) first formulated it and introduced it into the trade cost function as an iceberg that “melts” during the process of shipment. The iceberg representation of trade costs is an analytical device that allows researchers to express costs explicitly in geographic terms. It provides a mathematically elegant and tractable way to include distance in a linear function of trade costs.

In practice, a typical trade cost function includes not only true ad-valorem (iceberg) transportation costs (Hummels and Skiba 2004) but also many other additive components that are specific to geographic conditions, country trade policy (specific tariffs, phytosanitary measures, and transportation policy), and nontariff barriers along the route. It also often depends on the presence of cross-border hard and soft infrastructure and connectivity. The improvement of the physical condition of cross-border roads, railways, and other transportation links and the enhancement of IT connection and energy transmission are examples of better hard infrastructure. An improvement of soft infrastructure typically includes better coordination between customs and streamlined processing procedures.

Infrastructure quality is an important part of trade costs. This is why we expect that its improvement would help a country to cut its trade costs and why the governments of many countries have recently increased their investments in domestic and cross-border infrastructure. According to World Bank data, on average, there was a yearly increase of 1.2% of the GDP in domestic public investments between 1995–2009 and 2010–2017. Countries view investments in infrastructure as an important way of improving cross-border connectivity and obtaining better trading relationships with their immediate neighbors and other countries of the world. There is a belief that improved connectivity is a key determinant of the reduction of transportation and other trade costs. Similarly, for the Government of the People’s Republic of China (PRC), access to other countries and “a bid to enhance regional connectivity and embrace a brighter future” were a key reason for its announcement of the Belt and Road Initiative in 2013.<sup>1</sup>

This paper does not aim to become involved in the ongoing debates on the efficiency of public infrastructure investments in terms of their ability to improve the infrastructure quality and ease the cross-border trade relations of a particular country with the rest of the world. Instead, it begins with the belief that, under certain conditions, infrastructure investments along with the application of proper trade policy can improve the quality of infrastructure and offer an important economic motivation for cross-border connectivity. The main research question for this paper is as follows: how can infrastructure quality and cross-border connectivity help to reduce trade costs? In particular, to what extent do infrastructure quality and cross-border connectivity affect trade cost reduction for geographically marginalized landlocked countries or islands?

The paper makes a number of contributions. First, it examines the empirical evidence of a recent increase in infrastructure quality, hypothesizes its relationship with the increase in public capital investments, and investigates its direct inverse relationship with trade costs. The majority of existing analyses have typically focused on only a few countries and a particular type of infrastructure or have concentrated on the improvement of data coverage of infrastructure investments.

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<sup>1</sup> [https://en.wikipedia.org/wiki/Belt\\_and\\_Road\\_Initiative](https://en.wikipedia.org/wiki/Belt_and_Road_Initiative).

Second, we elaborate on earlier applications of network analysis (e.g., Kurmanalieva 2006) to build a new measure of cross-border connectivity for 173 countries. We calculate the index from 1995 to 2018. We compare and analyze this measure across various regions and geographically diverse country groups. We clearly identify the importance of cross-border connectivity for marginalized groups of landlocked countries and islands. Finally, we incorporate it into the trade cost equation and investigate its statistical significance. There are strong indications in the data of the considerable importance of cross-border connectivity to cut transportation and other trade costs.

Third, we use the World Economic Forum's measure of infrastructure quality and our newly created measure of cross-border connectivity to analyze the ways in which they differ for various country groups and especially for geographically marginalized countries, like islands and landlocked states. Among the various country groups that we consider, the infrastructure quality in Europe and cross-border connectivity everywhere else appear to be particularly important.

The next section provides a discussion on the recent increases in infrastructure investments that have improved the quality of infrastructure and are associated with reduced trade costs. Section 3 estimates a proxy for cross-border connectivity using a network analysis. Section 4 contains the empirical model of trade costs, and Section 5 concludes.

## **2. RECENT TRENDS IN INFRASTRUCTURE QUALITY AND TRADE COSTS**

Statistical data document the recent rise in infrastructure quality in the world, especially in the developing countries of Asia, Africa, and the Commonwealth of Independent States (CIS) countries. It is supposed that the improved quality of transport infrastructure as well as the reduced bureaucratic burden along the route of internationally traded goods should help to improve inter-regional, intra-regional, and national connectivity and finally bring a reduction in trade costs.

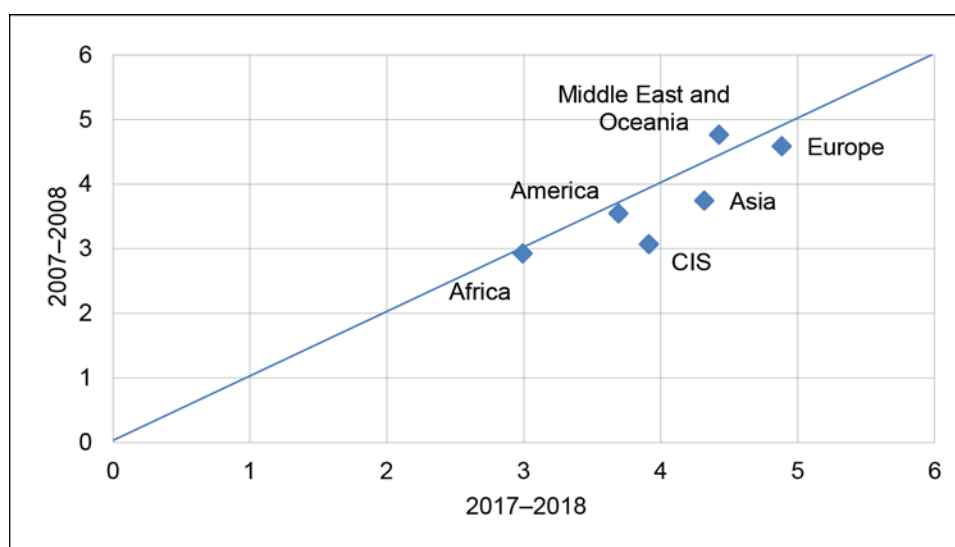
### **2.1 Recent Rise in Infrastructure Quality**

The quality of infrastructure has become much better over the last 11 years. Figure 1 below shows that the biggest improvement within ten years (the 2017–2018 index compared with 2007–2008) happened in countries in the CIS and Asian regions. The World Economic Forum's (WEF) overall infrastructure quality score includes various aspects of different transport infrastructure, like the quality and density of roads, railways, and seaports as well as the quality of services provided. It also includes non-transport infrastructure quality, like electric power transmission, water supply, and irrigation. The airport road connectivity index and linear shipping connectivity index are also components of the infrastructure score calculation. Index scores range between 1 and 7, with the value 7 identifying the best performer.

According to WEF data, Europe has a historically high quality of infrastructure. However, its recent improvement is marginal and mostly refers to emerging European states like Albania, Bosnia and Herzegovina, Bulgaria, Poland, Serbia, and Turkey, while the high-income part of Europe demonstrates a decrease in infrastructure quality. The Middle East and Oceania also have a high score since high-income countries like Australia, Bahrain, the United Arab Emirates, and Kuwait represent them. This is the only regional group that shows a decrease in infrastructure quality over 10 years (located above a 45-degree line). The American region demonstrates a slight improvement in infrastructure

quality, which Ecuador and Nicaragua mostly drive. The drivers of better infrastructure in Africa are Ethiopia, Kenya, Morocco, and Zambia. Two of the best African performers are landlocked. Similarly, landlocked countries in the CIS and Asia, like Armenia, Azerbaijan, Tajikistan, and Mongolia, have significantly improved the quality of their infrastructure and become drivers of infrastructure improvement in their respective regions.

**Figure 1: Quality of Overall Infrastructure (Index, 1–7)**



Source: Global competitiveness data, World Economic Forum.

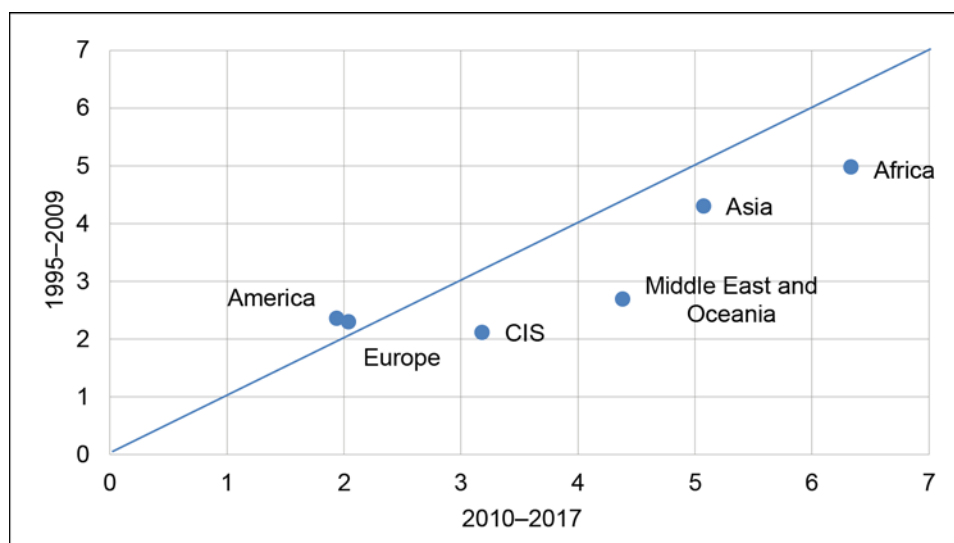
The increased volume of infrastructure investment is the main reason for such improvement in infrastructure quality. Research has recognized that world infrastructure investments have broadly increased over the last 15 years (Gurara, Mwase, and Presbitero 2018). However, the only available data on the infrastructure investments of the 48 OECD countries, most of which are high-income European countries, do not show any significant change in infrastructure investment patterns. Only a few developing and emerging countries demonstrate an increase. The biggest increase in this dataset occurred in the PRC, where the investments in physical infrastructure grew from 2.8% to 4.9% of its GDP. CIS countries, like Georgia and Azerbaijan, also increased their investments in infrastructure from 2% of their GDP to almost 3% of their GDP.

A broader set of internationally comparable data on infrastructure investments in developing and emerging countries is lacking. However, many countries have conducted their infrastructure investments through fully or partly publicly financed projects. This is why it is possible to analyze data on public capital investments and public–private partnership (PPP) projects instead. Gurara, Mwase, and Presbitero (2018) mentioned that transport infrastructure development accounts for nearly half of public investments within developing countries. The World Bank’s World Development Indicators (WDI) dataset of more than 200 countries demonstrates that the average share of public spending increased from 3.1% of the GDP in 1995–2009 to 3.8% of the GDP in 2010–2017 (Figure 2). Meanwhile, for America and Europe, there has not been much change in the capital expenditure shares. For other regions, like the CIS, the Middle East and Oceania, Asia, and Africa, the average share of public spending increased by at least 1 GDP percentage point. The biggest increase in public investment happened in landlocked countries in Africa (Rwanda, Lesotho, Uganda, and the Central African Republic), Asia (Nepal, Afghanistan, Cambodia, Mongolia,



and Myanmar), and the CIS (Azerbaijan, Kazakhstan, the Kyrgyz Republic, and Uzbekistan).

**Figure 2: Public Capital Investments (Percentage of GDP)**



Source: World Development Indicators data, World Bank.

Private sector participation can also channel infrastructure investments. The World Bank's Private Participation in Infrastructure (PPI) dataset provides information about such transport infrastructure projects in some countries. On average, the annual PPI infrastructure investments do not exceed 1% of the GDP and vary from country to country. Asian countries have received more than half and sub-Saharan Africa one-third of the USD43 billion PPP investments since 2010. The PRC, India, and the Association of Southeast Asian Nations (ASEAN) countries are the largest recipients of private infrastructure investments. In Europe, Turkey, Serbia, and Romania are the largest beneficiaries. Among the CIS countries, there are some notable projects in the Russian Federation, Ukraine, and Kazakhstan.

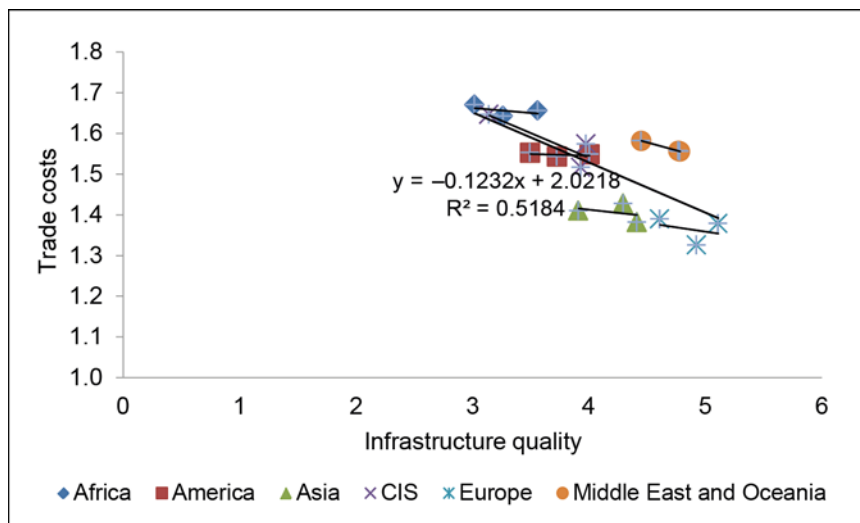
It is important to mention that a single country's large-scale initiative can also provide a big push. The Chinese government announced the pan-Asian One Belt, One Road initiative in 2013. This initiative aimed to create an economic zone covering Asia, Europe, and Africa and facilitated a sharp multicountry and multiregion increase in infrastructure investments in emerging and developing markets. In 2014, the initiative's investments in infrastructure and energy increased to USD100.2 billion, which accounted for about 60% of the PRC's overall investments in East Asia (Yu 2017).

## 2.2 Link between Infrastructure Quality and Trade Costs

The main components of trade costs include the cost of transportation, tariff measures, insurance, other fees, and various nontariff barriers. The cost of shipment in international trade is the main part of all expenses, which involves the shipping process of internationally traded goods from their origin to their destination. Large shipping expenses make trade costs high. The general measure that includes transportation costs together with other monetary costs is the CIF/FOB ratio. CIF stands for cost-insurance-freight and includes the cost of production, shipping cost, and insurance payments. This is the cost of a good at the importer's border. FOB stands for "free on

board.” It is the price of a good at the exporter’s border. Despite criticism, the CIF/FOB ratio often acts as a proxy for trade costs. Hummels and Lugovsky (2006) concluded that the ratio can contain useful information on cross-country variations.

**Figure 3: Trade Cost and Infrastructure Quality**



Source: Global Competitiveness data, World Economic Forum, and Directions of Trade Statistics, IMF.

Figure 3 displays a correlation between trade costs and infrastructure quality. The trend line and equation show a negative causality relationship between the two variables; lower trade costs are associated with better quality of infrastructure. It shows that European countries have better infrastructure quality and lower trade costs, while the African region suffers from high trade costs and lower overall quality of infrastructure. Small trend lines indicate the magnitude of the correlation for particular regions. The steep line for the CIS region indicates that even a small improvement in infrastructure quality means a large decrease in trade costs. In contrast, for the American region, a large improvement in infrastructure quality is necessary for a relatively small reduction in trade costs. Thus, countries should not disregard the importance of infrastructure quality for trade cost reduction. It plays a vital role by increasing the efficiency of distribution, reducing prices, and increasing the welfare of final consumers (Brooks 2008). Infrastructure quality can deepen and broaden shipment methods. Improved infrastructure can also help a country to introduce new products and new destinations.

### 3. NEW ESTIMATE OF CONNECTIVITY

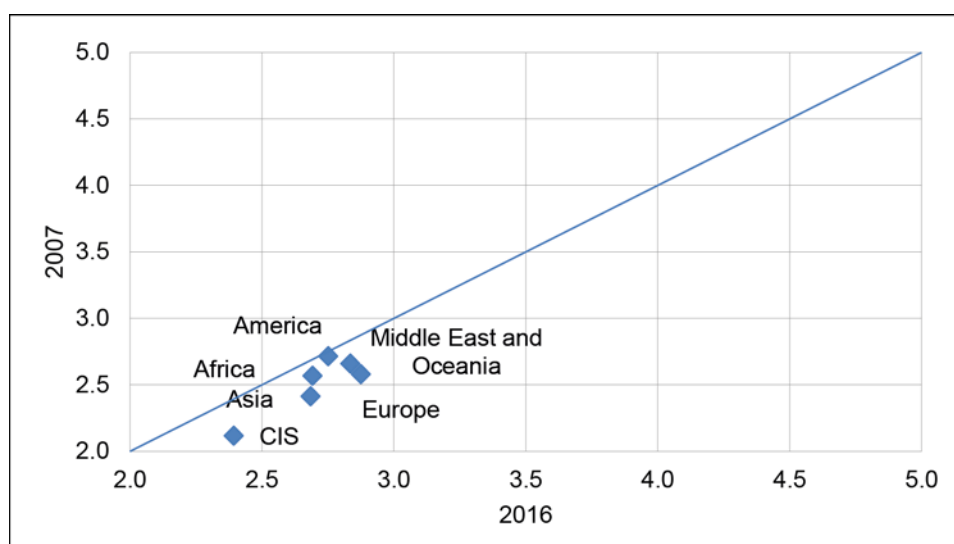
#### 3.1 Concept of Cross-Border Connectivity

Improved infrastructure, together with a rapid reduction in transportation and other trade costs, indicates that countries are becoming more connected and interdependent. Better transport facilities and better infrastructure quality lead to a faster production process at a lower cost. This motivates international trading companies to move to places with good transport access and better infrastructure. As Brooks (2016) stated, the “competitiveness of each country’s production depends on the other countries in the production network as well as on the efficiency of the trading links among them. Therefore, there is a strong

incentive to cooperate with each other, particularly on improving physical and soft infrastructure to reduce the costs of trading between them.”

What is connectivity? An implied meaning of connectivity associates it with a network, in which nodes interconnect with each other directly or through other nodes. A node can be any spatial entity, like a person, city, or country. Connectivity is therefore a measure of how well any node connects to all the other nodes in the network (World Bank, 2019). Like infrastructure, connectivity has hard and soft dimensions. The hard dimension relates to the physical infrastructure, while the soft dimension includes the skills, knowledge, and other comparative advantages of a node.

**Figure 4: Logistics Performance Index**



Source: World Development Indicators data, World Bank.

The World Bank compiles the logistics performance index and reports it every two years. It reports information from more than 200 countries regarding their performance on trade logistics. The index is a weighted average based on six dimensions related to logistical services in international trade. This measure indicates the relative quality and efficiency with which goods transportation can take place into and within each country and thus can serve as a proxy for cross-border connectivity. The index scores range between 1 and 5, with the value 5 identifying the best performer. Figure 4 above shows that the logistic performance improved for all regions between 2007 and 2016 (the average index for all regions is below the 45-degree line), with the greatest improvement happening in Europe, Asia, and the CIS.

### **3.2 Application of Graph and Network Analysis to Measure Cross-Border Connectivity**

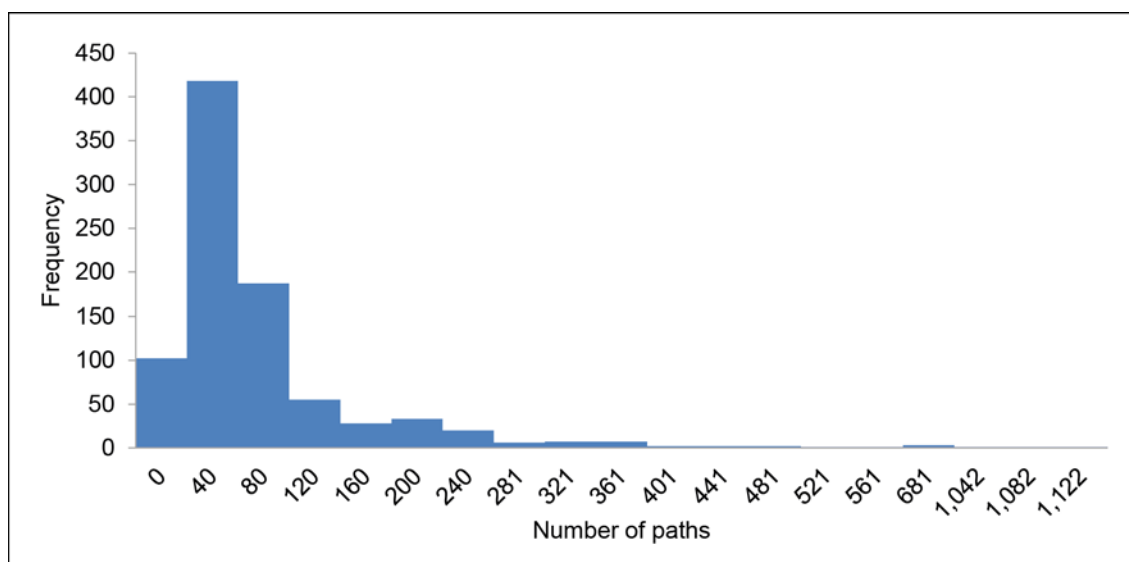
As defined above, cross-border connectivity relates to a network and can measure how well a node connects to all the other nodes in the network. The role that a node and its hinterland play in a network identifies with the significance of connectivity. The cost of accessing that node and the reliability of connecting to the node also factor into the value of connectivity. This paper associates cross-border connectivity with interaction between countries along international trade links or in the nodes that a trade network connects.

When the cost of accessing the node is low, it is likely to achieve complete connectivity, whereas limited connectivity is possible when the cost is high.

Research has proposed the concept of centrality, which comes from graph and network analysis, to measure cross-border connectivity. It is possible to use centrality to measure the efficiency of a transportation network and infrastructure and to identify the most important edges within a graph or network. Urban and transportation network analysis usually applies betweenness centrality to find key infrastructure nodes. Betweenness centrality uses the concept of a “shortest-path problem” (SPP), which simply represents the minimization of the distance between countries. Researchers have applied the shortest-path method in various fields. It is a part of a network and graph analysis, and Kurose and Ross (2000) used it in transportation engineering and Newman (2001) in scientific collaboration networks. Oyama and Taguchi (1991) and Oyama and Morohosi (2004) applied this method to automobile road networks to evaluate the magnitude of traffic congestion in Japan. The graph theory, instead of distance, finds the shortest path on the base of the weights that it assigns to each segment. Similarly to distance, it minimizes the weights of the segments to find the optimal solution. In this paper, nodes represent capital cities, edges represent automobiles, railroads, or other transportation modes between countries, and weights are the transportation cost or distance of the route. Within such a setup, regarding the costs of transporting a good from one city to another, the optimal solution represents the shortest path with the lowest cost of transportation.

The number of shortest paths for each country is a betweenness centrality score, which we use as an approximation for the cross-border connectivity measure with respect to global markets. Suppose a transportation route on which the distance between two countries is short. Ignoring for a while an economic rationale for international trade, like a comparative advantage, many shippers will have the motivation to use this route. This creates an additional stimulus for infrastructure development and better conditions for trade along the way. However, the absence of a direct link to global trade centers and the various natural and artificial barriers, such as bad climatic conditions, mountainous terrain, poor infrastructure, complicated border procedures, corruption, and low legal enforcement, result in the dispersion of economic activity even between conveniently located economies. It is possible to calculate two measures: potential cross-border connectivity, which is the number of shortest paths passing through a country, and actual connectivity, which is the number of cheapest paths using (CIF/FOB) cost data. The difference between the actual and the potential connectivity indicators could provide an understanding of the magnitude of artificial barriers to international trade. Kurmanalieva (2006) applied betweenness centrality as an indicator of the existing barriers in the global trade network.

The histogram plot (Figure 5) shows the distribution of the actual cross-border connectivity scores across all 173 countries and looks like a smoothed histogram. A few countries have a high betweenness centrality score, but most are located between 40 and 79 cheapest paths. The pattern is consistent with a hub-and-spoke concept in which only a few countries with high scores act as global trade hubs, while the majority of countries act as peripheral spokes. About 100 countries suffer from their disadvantaged geographic location and various barriers to trade.

**Figure 5: Histogram of the Cross-Border Connectivity Measure**

Source: Author's calculations.

**Table 1: Cross-Border Connectivity Estimates**

	Betweenness Centrality				
	Distance	1995–2000	2001–2008	2009–2014	2015–2018
<b>All</b>	<b>44.05</b>	<b>65.19</b>	<b>62.14</b>	<b>66.11</b>	<b>63.81</b>
Africa	59.60	65.63	69.38	64.92	63.64
America	26.54	37.05	38.01	41.65	42.81
Asia	64.09	98.64	93.58	91.69	92.27
CIS	44.67	50.68	64.18	156.42	127.54
Europe	43.65	89.43	67.13	58.43	53.65
Middle East and Oceania	30.79	40.51	37.81	33.78	36.12
<b>All</b>	<b>44.05</b>	<b>65.19</b>	<b>62.14</b>	<b>66.11</b>	<b>63.81</b>
Coastal	65.89	95.10	88.74	86.79	84.31
Island	16.57	26.54	26.41	31.15	31.87
Landlocked	7.49	8.95	13.52	35.68	30.87

Source: Author's calculations.

Table 1 represents the regional and geographic distribution of the derived results. It is immediately apparent that the world average of the number of cheapest paths is higher than the potential number of shortest paths. The demonstrated fact that the actual connectivity is greater than the potential level leads to the conclusion that global international trade, in general, helps to improve connectivity among countries. CIS and Asian countries seem to be the main drivers of international trade since their connectivity scores are always above the world average, while the American region and countries in the Middle East and Oceania have steadily been below the global average. All regions, albeit to various degrees, could overcome their potential level of cross-border connectivity. Europe, as well as the Middle East and Oceania, could reap the benefits of their geographic location during the period 1995–2000 by maximizing the number of cheapest paths. However, after this period, it gradually drifted downward, closer to the potential level. For countries in Africa, which are geographically located between America and Asia, the average actual connectivity score does not change much

over different time periods and always stays close to the potential level. The most striking change happened in the CIS countries, which are geographically located between Europe and Asia. The improvement of their terms of trade together with a better macroeconomic policy after the global economic crisis allowed them to improve their connectivity sharply after 2009. It is worth mentioning the massive infrastructure investments that the governments of these countries have undertaken during the past decade.

The lower part of Table 1 represents the average connectivity scores for countries, which we classify according to their geographic condition. Similar to Kurmanalieva (2006), we confirm the beneficial geographic location of coastal countries. In all cases, we find that coastal countries have the highest connectivity score. They are in a much better position than other countries, far above the world average. However, their average number of cheapest paths gradually decreases over time. Although the average potential score for landlocked countries is the lowest, their actual connectivity score quickly increases over time. This indicates an improvement in connectivity. The connectivity score for islands is below the global average but also increases over time, though at a slower pace. The slower pace of the connectivity score increase for islands indicates that remoteness is more difficult to overcome than landlockedness. The general picture that emerges from the potential connectivity scores demonstrates the geographic advantages of coastal countries and the natural disadvantage of remote islands and landlocked countries. While most islands and landlocked countries could overcome their natural geographic barriers, landlocked countries in the CIS, Asia, and America could increase the number of cheapest paths by four times compared with the potential level.

#### **4. EMPIRICAL MODEL OF TRADE COSTS**

A review of the empirical literature on trade cost determinants shows that a multitude of studies have conducted empirical investigations of the trade cost model, finding a negative and statistically significant correlation between distance and trade costs. Hence, most of them have agreed that distance only cannot fully define trade costs (Radelet and Sachs 1998; Kuwamori 2006). According to Limao and Venables (2001), it can explain only 10% of variability in transportation costs. Moreover, it does not vary across time and commodity and therefore cannot capture the time series and cross-commodity idiosyncratic features of trade costs.

Therefore, there are many other factors that determine trade costs besides distance. Geographic barriers, like mountainous terrain, borders, or a remote location, are some of them. The nature of a commodity, like perishability, dangerousness, or size, also adds to the trade cost variability. Geographic conditions, like landlockedness or remoteness, are natural barriers to trade. Due to the absence of direct access to sea routes, landlocked countries have to pay higher costs of transportation. A number of studies have pointed out the importance of infrastructure for the reduction of trade costs. Bougheas, Demetriades, and Morgenroth (1999) studied the determinants of transportation costs and reported a statistically significant impact of cross-border infrastructure on bilateral trade. Other studies (Hummels 1999, 2001; Limao and Venables 2001; Martinez-Zarzoso and Suarez-Burguet 2005) have indicated a significant role of transport infrastructure, geographic conditions, the type of transportation, macroeconomic and trade policy, competition, and regulations. Martinez-Zarzoso and Nowak-Lehmann (2006) analyzed the impact of transport conditions, time of transit, and port infrastructure quality and efficiency on bilateral trade data of Spain with Turkey and Poland and found a significant impact of the quality of these services.

The objective of this part of the paper is to analyze the ways in which infrastructure quality and cross-border connectivity together with other variables are connected with trade costs. As we noted previously, the concept of cross-border connectivity is an emerging idea in the literature, and studies have not yet used it as a determinant to explain international trade costs. Since the transportation of goods across multiple borders should be quick and efficient and have a low cost before they arrive at their final destination, it is plausible that better infrastructure quality and cross-border connectivity, which affect firms' ability to perform these operations, should reduce the trade costs. In addition, economic strength and geographic and idiosyncratic characteristics of various countries or country groups, like remoteness, landlockedness, or a beneficial geographic location close to global trade centers, can determine trade costs. With these considerations in mind, we posit an empirical model of the following form:

$$\log\left(\frac{cif}{fob}ratio\right) = b_0 + b_1 * \log(distance) + b_2 * \log(connectivity) + b_3 * \log(infrastructure\ quality) + etc$$

We use a dataset of trade costs and their determinants that we compiled for 173 countries in the world. The CIF/FOB ratio acts as a proxy for trade costs. The source of these data is the IMF's bilateral trade statistics database. This database uses the value of exports from the reporting country to all other partner countries at the exporter's border (free on board (FOB)) and the value of imports at the importer's border (cost, insurance, freight (CIF)). We calculate the CIF/FOB ratio for each country pair. The CIF/FOB ratio is greater than 1 when the cost of a good at the importer's border is higher than the cost of the good at the exporter's border. There are some complications with these data that arise because of discrepancies in the trade statistics, like many missing and zero values, which lead to very high or very low CIF/FOB ratios. By definition, the FOB price cannot be higher than the CIF price. This is why, to solve the data problem, we exclude all cases with a CIF/FOB ratio smaller than 1 from the estimation. Similarly, we assume that the FOB price cannot be 5 times smaller than the CIF price and delete all cases with a CIF/FOB ratio greater than 5.

We define the distance data as the haulage distance between the capital cities of all countries. For each country, it is the average distance to all its trading partners. We test the WEF index of infrastructure quality and our measure of cross-border connectivity as additional determinants of trade costs together with dummy variables for landlocked countries and islands. To control for idiosyncratic characteristics, we add the fixed time and spatial effects that the year and region/country group dummies capture.

Table 2 shows the result of a cross-country regression of trade costs. There are seven columns with estimated regressions. The first three columns in the table present a basic model with alternative variations of the cross-border connectivity measure. The last four columns show the regression results with the inclusion of various regional dummies and their interaction with the infrastructure quality variable and the cross-border connectivity measure. The reported R-statistics are bigger in the last four columns, indicating the importance of additional variables in the explanation of transport cost variations.

**Table 2: Empirical Regression of Trade Costs**

Trade Cost	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP per capita	-0.030***	-0.037***	-0.041***	-0.043***	-0.040***	-0.047***	-0.045***
Distance	0.433***	0.404***	0.411***	0.443***	0.441***	0.508***	0.394***

Infrastructure quality	0.012	-0.041	-0.029	-0.043	<b>-0.051*</b>	<b>-0.035*</b>	<b>-0.044*</b>
Logistic performance index	<b>-0.245***</b>						
Connectivity			-0.009**	-0.017***	<b>-0.018***</b>	<b>-0.043***</b>	<b>-0.013*</b>
Potential connectivity		-0.008**					
Landlocked				-0.092**	-0.050	0.004	0.167*
Connectivity for Landlocked						0.056**	0.056**
Infrastructure quality for Landlocked						-0.163***	-0.299***
Island				0.052*	0.021	0.054	0.055
Connectivity for Island						-0.077***	-0.074**
Infrastructure quality for Island						0.195**	0.186*
America	<b>-0.075***</b>	<b>-0.061***</b>	<b>-0.057***</b>	<b>-0.065***</b>	<b>-0.081***</b>	<b>-0.085***</b>	0.003
Asia	<b>-0.142***</b>	<b>-0.204***</b>	<b>-0.189***</b>	<b>-0.200***</b>	<b>-0.206***</b>	<b>-0.206***</b>	-0.062
CIS	-0.011	0.037	-0.010	0.024	-0.020	0.007	-0.206
Europe	<b>-0.062***</b>	<b>-0.087***</b>	<b>-0.087***</b>	<b>-0.079***</b>	<b>-0.092***</b>	<b>-0.085***</b>	0.198**
Middle East and Oceania	0.047*	0.019	0.030	0.021	0.039	0.004	0.129
Island in America					0.115**		
Island in Asia					0.044		
Island in Europe					0.161**		
Island in M. East and Oceania					-0.069		
Landlocked in America					-0.034		
Landlocked in Asia					0.008		
Landlocked in CIS					0.092*		
Landlocked in Europe					-0.228***		
Connectivity for America							-0.028***
Connectivity for Asia							-0.021*
Connectivity for CIS							-0.030**
<b>Trade Cost</b>	<b>(1)</b>	<b>(2)</b>	<b>(3)</b>	<b>(4)</b>	<b>(5)</b>	<b>(6)</b>	<b>(7)</b>
Connectivity for Europe							-0.022*
Connectivity for Middle East and Oceania							-0.018
Infrastructure quality for America							0.019
Infrastructure quality for Asia							-0.041
Infrastructure quality for CIS							0.274
Infrastructure quality for Europe							-0.133**
Infrastructure quality for M. East and Oceania							-0.047
Years 2010–2014	0.018	0.013	0.014	0.012	0.013	0.016	0.224***
Years 2015–2018	0.016	-0.001	0.003	-0.010	0.001	0.005	0.188***
Connectivity – Years 2010–2014							-0.036***
Connectivity – Years 2015–2018							-0.018*
Infrastructure quality – Years 2010–2014							-0.051
Infrastructure quality – Years 2015–2018							-0.085**
Landlocked – Years 2010–2014				0.040			
Landlocked – Years 2015–2018				0.098**			
Island – Years 2010–2014				0.009			
Island – Years 2015–2018				0.044			
Observations	364	310	345	345	345	345	345
R-squared	0.92	0.94	0.94	0.94	0.94	0.95	0.95

Note: All the variables, except for the dummy variables, are in natural logarithms. \*\*\*, \*\*, and \* indicate significance at the 1%, 5%, and 10% levels.



In line with the expectation, the distance variable has a strong positive correlation coefficient. A large distance is associated with a high transport cost. All else being equal, a 1% increase in distance leads to a 0.4–0.5% increase in trade costs. High income, for which the GDP per capita is a proxy, is linked with relatively low transport costs, with a statistically significant negative coefficient. The logistic performance index variable in equation (1) has a statistically significant negative sign, indicating that better quality of logistical services allows a reduction in the trade costs. Infrastructure quality has a crucial, though not always statistically significant, negative impact on trade costs. The better the quality of infrastructure in a country, the lower the trade cost. It is possible to explain the weak statistical significance of infrastructure quality data by the tight mutual dependence that exists between a country's infrastructure development and its connectivity with its neighbors and the rest of the world.

It is important that the estimated coefficients of all the cross-border connectivity measures in equations (2–7) are in line with the expectations and have a negative and statistically significant impact coefficient. Potential connectivity is a distance-based measure and represents the number of shortest paths. The coefficient of potential connectivity variable in equation (2) indicates that a 1% improvement in connectivity is associated with a 0.008% reduction in trade costs. The cheapest paths' number or actual cross-border connectivity estimate is statistically significant with the expected negative sign, meaning that an increase in actual connectivity of 1% leads to a 0.01–0.04% decrease in trade costs.

The regional dummies confirm the hypothesis that a reduction in transportation and trade costs has happened in many countries in the world. The effect is the greatest in magnitude for the dummies for Asia and Europe. The regional dummies for Europe and America also have a statistically significant coefficient but with a relatively smaller magnitude. The interaction of regional dummies with the connectivity measure in equation (7) shows that the improvement of cross-border connectivity is especially important for the CIS, America, Europe, and Asia. Infrastructure quality is especially important for European countries, which the statistical significance of the interaction of the infrastructure variable with the dummy variable for Europe in equation (7) shows.

Although there are no stable and significant effects on the CIF/FOB ratio in the case of the geographic dummies for islands and landlocked countries, the study finds that the coefficients for island dummies have a positive sign. This is probably because disadvantaged countries have different degrees of success in overcoming trade costs. For instance, the negative and significant coefficient for landlocked countries in Europe in equation (5) shows their success in reducing their trade costs, while landlocked countries in the CIS conversely suffer from high costs of international trade. Similarly, according to equation (5), islands in America and Europe are in a more disadvantaged position because of their geographic isolation than their peers in other regions.

The dummy variable for time periods shows that trade costs generally increased after 2010. However, the interaction with connectivity and infrastructure quality in equation (7) suggests that the development of infrastructure and better cross-border connectivity helped countries to cut their trade costs and gain better access for their commodity trade.

## 5. CONCLUSION

This paper presented new evidence on the links between infrastructure development, cross-border connectivity, and trade costs by employing various measures of infrastructure quality and connectivity. It also proposed a new method for cross-border connectivity estimation derived from graph and network analysis for a set of 173 countries. It subsequently tested the derived measure of connectivity in a trade cost regression.

The first key finding of this paper is the confirmation of the importance of cross-border connectivity for trade. Our new measure of cross-border connectivity shows that trade itself was an important factor that allowed most countries in the world to overcome their potential conditions embedded in their geographic location. One way in which it contributes to trade development is through its impact on the reduction of trade costs. The empirical regression of trade costs supports this. The estimated coefficients of all the connectivity measures support the theoretical predictions and improve the R-squared estimate of the regression. We found that a 1% increase in actual or potential connectivity leads to a 0.01–0.04% decrease in trade costs.

The examination of the statistical data that international agencies have collected and compiled shows that the biggest improvement in infrastructure quality is the result of an increase in infrastructure investments that happened in many developing countries all over the world. The infrastructure quality variable is less significant in the trade equation, but the implications from the graphical investigation are still straightforward—the better the quality of infrastructure in a country, the lower the transport cost. The tight mutual dependence that exists between a country's infrastructure development and its connectivity with its neighbors and the rest of the world can explain the weak statistical significance of the infrastructure quality variable in the econometric regression.

The last important finding of the paper is the insight into the way in which various regions and countries benefit from infrastructure development and better connectivity. Countries in the CIS and Asia were especially successful in improving their cross-border connectivity, which led to a reduction of trade costs. America and Europe, which high-income countries dominate, also benefit from better connectivity to a relatively lesser extent. The historically high quality of infrastructure in Europe allows them to have lower trade costs. Geographically disadvantaged countries suffer from high trade costs. The regression estimation shows that landlocked countries in the CIS region on average have higher trade costs. This is why an improvement in infrastructure quality and cross-border connectivity is important for them. Our new measure of cross-border connectivity shows that, although landlocked countries have the lowest potential score, their actual connectivity measure is increasing quickly over time. This indicates an improvement in connectivity. The connectivity score for islands is below the global average and, similar to the score for landlocked countries, is increasing over time. The slower pace of this increase indicates that remoteness is far more difficult to overcome with new infrastructure. Islands in America and Europe are in a more disadvantaged position because of their geographic isolation than their peers in other regions.

These results primarily have important policy implications. Islands and especially landlocked countries need to continue improving their infrastructure quality and connectivity with their neighboring countries and the rest of the world. Since the benefits from infrastructure development do not manifest instantaneously, this is an area that requires long-lasting attention and investments as well as significant devotion to building better connectivity and cooperation with neighboring countries. The approach that this study proposes for the measurement of cross-border connectivity can provide useful input for policy makers and practitioners in terms of evaluating the current situation, prioritizing areas for intervention, and assessing the potential impacts. A possible extension of this approach is the use of data for the price for specific transport modes, like roads, railroads, and air transport, instead of the overall CIF/FOB trade data. Other possible extensions of this work may include the application of various approaches in network analysis as well as the exploration of different transportation modes for the estimation of cross-border connectivity.

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## APPENDIX A: COUNTRY COVERAGE

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### Africa—48 countries

*Coastal:* Algeria; Angola; Benin; Cameroon; Democratic Republic of Congo; Republic of Congo; Cote D'Ivoire; Djibouti; Egypt; Equatorial Guinea; Eritrea; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Mauritania; Morocco; Mozambique; Namibia; Nigeria; Senegal; Sierra Leone; South Africa; Sudan; Tanzania; Togo; Tunisia

*Landlocked:* Botswana; Burkina Faso; Burundi; Central African Republic; Chad; Ethiopia; Lesotho; Malawi; Mali; Niger; Rwanda; Uganda; Zambia; Zimbabwe

*Island:* Comoros; Madagascar; Mauritius; Sao Tome and Principe; Seychelles

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### America—35 countries

*Coastal:* Argentina; Belize; Brazil; Canada; Chile; Colombia; Costa Rica; Dominican Republic; Ecuador; El Salvador; Guatemala; Guyana; Haiti; Honduras; Mexico; Nicaragua; Panama; Peru; Suriname; United States; Uruguay; Venezuela

*Landlocked:* Bolivia; Paraguay

*Island:* Antigua and Barbuda; Bahamas; Barbados; Bermuda; Dominica; Grenada; Jamaica; St. Kitts and Nevis; St. Lucia; St. Vincent and Grenadines; Trinidad and Tobago

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### Asia—22 countries

*Coastal:* Bangladesh; Brunei Darussalam; Cambodia; People's Republic of China; Hong Kong, China; Macau, China; India; Indonesia; Republic of Korea; Malaysia; Pakistan; Thailand; Viet Nam

*Landlocked:* Bhutan; Lao People's Democratic Republic; Mongolia; Nepal

*Island:* Japan; Maldives; Philippines; Singapore; Sri Lanka

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### CIS—12 countries

*Coastal:* Georgia; Russian Federation; Ukraine

*Landlocked:* Armenia; Azerbaijan; Belarus; Kazakhstan; Kyrgyz Republic; Moldova; Tajikistan; Turkmenistan; Uzbekistan

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### Europe—31 countries

*Coastal:* Albania; Belgium; Bosnia and Herzegovina; Bulgaria; Croatia; Denmark; Estonia; Finland; France; Germany; Greece; Ireland; Italy; Latvia; Lithuania; Netherlands; Norway; Poland; Portugal; Romania; Slovenia; Spain; Sweden; Turkey; United Kingdom

*Landlocked:* Austria; Czech Republic; Hungary; Slovak Republic

*Island:* Iceland; Malta

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### Middle East and Oceania—25 countries

*Coastal:* Fiji; Iran; Israel; Jordan; Kuwait; Lebanon; Netherlands Antilles; Oman; Papua New Guinea; Qatar; Saudi Arabia; Syrian Arab Republic; United Arab Emirates; Yemen

*Island:* Australia; Kingdom of Bahrain; French Polynesia; Kiribati; New Caledonia; New Zealand; Palau; Samoa; Solomon Islands; Tonga; Vanuatu

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## APPENDIX B: STATISTICAL DATA

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### Infrastructure Quality

*Source:* Overall Infrastructure Quality, World Economic Forum, Global Competitiveness Report  
[https://tcdata360.worldbank.org/indicators/h2cf9f9f8?country=BRA&indicator=535&viz=line\\_chart&years=2007,2017](https://tcdata360.worldbank.org/indicators/h2cf9f9f8?country=BRA&indicator=535&viz=line_chart&years=2007,2017)

*Definition:* Weighted average index, which is based on an executive opinion survey—assessment of general infrastructure (e.g., transport, telephony, and energy) (1 = extremely underdeveloped; 7 = extensive and efficient by international standards).

*Years collected:* 2007–2018

*Countries covered:* 151

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### Infrastructure Investment

*Source:* Infrastructure Investment, OECD data  
<https://data.oecd.org/transport/infrastructure-investment.htm>

*Definition:* Measured as a share of GDP for total inland investment and in euros for the road, rail, air, inland waterways, and sea components, covering spending on new transport construction and the improvement of the existing network.

*Years collected:* 1995–2017

*Countries covered:* 48

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### Public Capital Investment

*Source:* Net Investment in Nonfinancial Assets, World Development Indicators (WDI) data, World Bank (from the International Monetary Fund, Government Finance Statistics Yearbook, and data files)  
<https://databank.worldbank.org/source/world-development-indicators>

*Definition:* Measured as a share of GDP for net investment in government nonfinancial assets, including fixed assets, inventories, valuables, and non-produced assets.

*Years collected:* 1995–2018

*Countries covered:* 217

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### Private Participation in Infrastructure

*Source:* PPI Database, World Bank  
<https://ppi.worldbank.org/en/ppidata>

*Definition:* Data on over 6,400 infrastructure projects in 137 low- and middle-income countries, covering projects in the energy, transport, water and sewerage, ICT backbone, and municipal solid waste (MSW) sectors. Projects include management or lease contracts, concessions, greenfield projects, and divestitures.

*Years collected:* 1995–2019

*Countries covered:* 137

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### Logistic Performance Index

*Source:* Logistics performance index, World Development Indicators (WDI) data, World Bank  
<https://databank.worldbank.org/source/world-development-indicators>

*Definition:* Weighted average index based on a survey of companies and individuals engaged in international logistics. Respondents evaluate the quality of trade and transport-related infrastructure (e.g., ports, railroads, roads, and information technology) using a rating ranging from 1 (very low) to 5 (very high).

*Years collected:* 2007–2016

*Countries covered:* 265

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### CIF/FOB data

*Source:* Merchandise exports and imports, Direction of Trade Statistics (DOTS), IMF  
<https://data.imf.org/?sk=9D6028D4-F14A-464C-A2F2-59B2CD424B85>

*Definition:* Value of merchandise exports and imports of a country vis-à-vis its primary trading partners. Imports are identified on a cost, insurance, and freight (CIF) basis and exports are reported on a free on board (FOB) basis. Reported data are supplemented by estimates, including mirror statistics, whenever such data are not available or current.

*Years collected:* 1995–2018

*Countries covered:* All IMF member states

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### Distance

*Source:* <http://www.chemical-ecology.net/java/capitals.htm>  
<http://ksgleditsch.com/data-5.html>

*Definition:* The great-circle distance (in kilometers) between capital cities.

*Countries covered:* 173

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