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How Infrastructure Shapes Comparative Advantage

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This paper provides evidence that domestic trade costs are a source of comparative advantage. First, I build an international trade and internal geography model with transportation features and input-output linkages. Then, I simulate how a large road project, *Ruta del Sol*, impacts the comparative advantage of Colombia. This road improves access to global markets for heterogeneous regions. My results show that the project shifts the comparative advantage of Colombia towards manufacturing. Industry linkages reinforce this effect. Hence, I confirm that a country's comparative advantage is shaped by domestic trade costs, in addition to classical determinants like endowments, technology, and institutions. Lastly, my results suggest that road infrastructure is key for the structural transformation of developing nations.

KEYWORDS

transportation, comparative advantage, trade costs, input-output linkages

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Como la infraestructura determina la ventaja compartiva

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Este trabajo proporciona evidencia de que los costos del comercio interno son una fuente de ventajas comparativas. En primer lugar, se construyó un modelo de comercio internacional y geografía interna considerando características de transporte y vínculos insumo producto. Luego, se simuló cómo un gran proyecto vial, *Ruta del Sol*, impacta en las ventajas comparativas de Colombia. Este proyecto mejora el acceso a los mercados globales para regiones heterogéneas. Los resultados muestran que el proyecto desplaza las ventajas comparativas de Colombia hacia el sector manufacturero. Los vínculos productivos refuerzan este efecto. Por lo tanto, se confirma que la ventaja comparativa de un país está determinada por los costos del comercio interno, además de los determinantes clásicos como las dotaciones, la tecnología y las instituciones. Por último, los resultados sugieren que la infraestructura vial es clave para la transformación estructural de las naciones en desarrollo.

KEYWORDS

transporte, ventaja compartiva, costos comerciales, vínculos insumo producto

1 | INTRODUCTION

Comparative advantage is a fundamental concept in international trade theory. Standard trade models typically examine the role of technology, institutions, and factor endowments to explain patterns of specialization. However, this approach is limited by the fact that we only observe the patterns of international trade generated by regions well connected to global markets. This is especially true for developing nations, as the quality of infrastructure varies substantially within these countries (IADB, 2013). Whether domestic trade costs within a country influence comparative advantage has not been studied in the literature.

This paper shows that domestic trade costs are indeed determinants of comparative advantage in a developing country context. As new infrastructure projects change the structure of the national transportation network and the manner in which industry linkages propagate shocks across regions, it is necessary to use a quantitative model to understand the mechanisms by which changes in domestic trade costs affect comparative advantage. Therefore, I build an international trade and internal geography model with input-output linkages, road networks, and heterogeneous international shipping routes. I use the model to understand the effects of completing a large infrastructure project currently in construction (*Ruta del Sol*) on the comparative advantage of Colombia. I show that the completion of the project increases the share of manufacturing exports and reduces the share of mining exports. That is, the highway project shifts the comparative advantage of Colombia away from the mining sector and towards manufacturing goods.[1]

My objective is to provide evidence that the spatial distribution of domestic trade costs is a driver of the national comparative advantage. Although my results indicate that *Ruta del Sol* benefits the manufacturing exports the most, the shift in comparative advantage does not need to be towards the manufacturing sector to confirm the main hypothesis of this paper. It could be the case that other road projects shift the comparative advantage of Colombia towards agriculture or mining. Such hypothetical results would be consistent with the main idea of the paper.

Colombia is an ideal context to analyze the impact of infrastructure on comparative advantage because the country is similar to several developing nations along a number of dimensions. First, Colombia's exports are concentrated in a small number of goods, particularly mining products. Second, there is variation in the access to global markets among Colombian departments.[2] In many developing countries there is a similar situation, with some regions with excellent access to global markets and others that are almost isolated due to poor infrastructure. Third, there is heterogeneity in the comparative advantage of Colombian regions. Many large middle-income nations share this characteristic.

I develop a framework in which departments in Colombia trade with each other and with the rest of the world. The model includes input-output linkages between three tradable sectors (agriculture, mining, and manufacturing) and a non-tradable sector (services). This characteristic allows trade costs to affect both output prices and production costs. Lastly, I include a realistic transportation feature: the existence of different shipping routes when departments and the rest of the world trade with each other. The model produces a tractable expression for international trade flows between a department and the rest of the world, through specific ports of exit or entry (a department-port gravity equation).

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[1] Throughout the paper, I measure the comparative advantage of Colombia in a sector by using the share of exports. This works as a proxy to measure comparative advantage. When the Balassa Index of Revealed Comparative Advantage is used for small open economies and highly aggregated sectors, the denominator of the index is fixed. French (2017) documents that revealed comparative advantage is useful to analyze the patterns of comparative advantage for different economies.

[2] A department is the official administrative region of Colombia, similar to states in the United States of America.

To take the model to the data, I combine four data sources: detailed customs administrative data, a survey of transportation flows, a national input-output matrix, and geospatial data that I create using digital and scanned physical road maps. The customs data allow me to obtain international trade flows between departments and the rest of the world, with information about the port used for exit or entry. The transportation survey allows me to obtain a proxy of domestic sectoral trade flows. Finally, using the geospatial data and Dijkstra's algorithm, I obtain travel times between any location within Colombia for both modern and historical road networks.

There are two parameters that govern my model. The first parameter defines the relationship between trade costs and travel times, and the second parameter defines the heterogeneity of the use of shipping routes for goods traded between Colombian departments and the rest of the world. To recover the values of these parameters, I estimate a department-port gravity equation using an instrumental variable approach. My instrument is the distance between locations using historical road networks during periods in which the characteristics of the Colombian economy were very different compared to the current economic circumstances. This approach is based on Baum-Snow, 2007; Michaels, 2008; Duranton, Morrow, and Turner 2014, for the United States. Besides, Duranton (2015) uses the same historical maps to estimate a gravity equation for the internal trade flows of Colombian cities. After obtaining the value of the parameters of my model, I run counterfactual simulations.

My main counterfactual experiment considers the effects of the infrastructure program *Ruta del Sol* on the sectoral exports of Colombia. The project's objective is to modernize the highway that connects the Atlantic seaports with the capital of the country, Bogota Capital District, and the department that surrounds it geographically, Cundinamarca[3]. Together, the city of Bogota and Cundinamarca are among the main exporters of manufacturing and agricultural products in Colombia[4]. Given the structure of the road system in Colombia, *Ruta del Sol* also improves substantially the access to international markets for several departments that specialize in the mining sector. Hence, the expected effect of this highway project on national sectoral exports is unclear a priori. Additionally, given the structure of the input-output linkages in Colombia, the reduction in domestic trade costs will propagate in a way that one sector might benefit more than others.

The results of my counterfactual experiment show that the completion of the infrastructure project increases the share of national manufacturing exports by at least three percentage points, while the share of national mining exports falls. This result is likely to be a lower bound for different reasons, such as the fact that the model allows new roads to impact agriculture, mining and manufacturing equally [5], and that I do not consider the impacts of improvements of infrastructure in the competition of the transportation sector (Allen et al, 2020). To understand the importance of this result, it is important to highlight that between 1992 and 2018, the share of mining exports in Colombia has grown sixteen percentage points.

The results from my simulations imply that the road project can potentially reverse the upward trend of the specialization of Colombia in mining goods and shift the comparative advantage of Colombia towards the manufacturing sector. This result does not imply that the non-manufacturing exports fall, but rather that manufacturing exports grow more than

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[3] The city of Bogota is both the capital of the country and the capital of the department of Cundinamarca, but from a legal standpoint Bogota is not part of Cundinamarca. According to government documents, the city of Bogota includes 21 municipalities that belong to the department Cundinamarca (CONPES, 2014)

[4] Cundinamarca and Bogota together exported 27 and 21% of the agricultural and manufacturing exports in 2013, one year before the inauguration of the first segment of *Ruta del Sol*.

[5] There is evidence that roads are less likely to impact the transportation of coal or oil, see Allen et al (2020), Alvear-Sanin (2008), Pachon and Ramirez (2006), and McRae (2017).

the exports of other sectors. So, the infrastructure project can potentially reverse any existing crowd-out effects of the mining boom on the Colombian manufacturing sector, caused by potential Dutch disease effects (Alcott and Keniston, 2018).

I analyze the main forces driving my results by modeling alternative counterfactual scenarios, in which I isolate the different effects of *Ruta del Sol*. I consider separately the effects of the road project on domestic trade costs, international trade costs, and on both domestic and international trade costs without including input-output linkages. The results of my simulations show that industry linkages make the shift of the comparative advantage of Colombia towards manufacturing stronger. When I simulate the effects of *Ruta del Sol* without industry linkages, the increase in the share of manufacturing exports is lower than the growth observed in my main counterfactual scenario, which does include the linkages. This is due to the fact that the manufacturing sector benefits more from access to tradable intermediate inputs, relative to the mining sector, and that the road project improves the access of intermediate inputs for a department with comparative advantage in manufacturing.

I contribute to the literature on the determinants of comparative advantage. My main contribution is to show that the spatial structure of domestic trade costs is a source of national comparative advantage. This finding is particularly relevant in developing countries where domestic trade costs are high, thereby generating differences in regional access to global markets within a country (Atkin and Donaldson, 2015). To my knowledge, recent international trade literature has paid little attention to the direct link that exists between the spatial distribution of domestic trade costs and national comparative advantage.

The results of this paper complement the existing literature that evaluates the welfare impacts of transportation infrastructure (see Allen and Arkolakis, 2019 for a summary of this work). Nevertheless, it is important to point out that this paper is not about the measurement of the welfare impacts of Colombian road projects. Although I provide estimates of welfare impacts of *Ruta del Sol* by region, such welfare results are provided to complement the main result of the paper: the impact of a road infrastructure in the national comparative advantage of a country.

My results also complement the work done in the industrial policy literature regarding the welfare impacts of policies that target specific manufacturing sectors. Nevertheless, this paper is not about evaluating an industrial policy that focuses on the manufacturing sector per se (see Lashakaripour and Lugovskyy 2020, Bartelme et al, 2018 for recent developments of this literature using general equilibrium models), nor to determine whether targeting a sector with a transportation policy is welfare-improving. Such work is beyond the scope of this paper. Moreover, if my findings would be different, for example that *Ruta del Sol* reinforces the comparative advantage of Colombia in the mining sector, the hypothesis of this paper would still be confirmed.

Another main difference of this paper with respect to the recent industrial policy literature is that although transportation policies target specific regions, road infrastructure projects benefit all the sectors that operate in these targeted region, either by increasing the access to other markets or to intermediate goods from other regions. Although an intuitive idea would be to target a specific sector by using transportation policy on a region highly specialized in such sector, ex-ante the general equilibrium impacts are difficult to predict due the presence of road network effects and industry linkages. Hence, the transportation policy might generate different outcomes than the expected ones. My results illustrate this point. For example, although Cundinamarca and Bogota are direct beneficiaries of *Ruta del Sol* and they export a quarter of the total agricultural exports of Colombia, my model shows that the share of national agricultural exports decreases when *Ruta del Sol* is completed.

The main theme of this paper, how internal trade costs shape national comparative advantage, is related to Deardoff (2014). He shows that the transportation costs of a nation to countries that are geographically close impact its comparative advantage. He defines the term *local comparative advantage*, which measures comparative advantage considering such transportation costs. With this concept, it is possible to explain situations in which a country has a comparative advantage in a specific sector, even though production costs are high. Such cases may exist due to low transportation costs between the economy and its neighboring nations. I focus exclusively on how the comparative advantage of a country is shaped exclusively by its internal transportation costs, while Deardoff (2014) focuses on transportation costs to the neighboring economies.

The closest papers to this work, are Duranton, Morrow, and Turner (2014), and Duranton (2015). These papers use applied microeconomics methods to show that urban centers with better infrastructure can specialize in sectors that produce heavy goods. Unlike these papers, I focus on how roads affect specialization at a national level. Additionally, I differ by using an international trade model to run counterfactual scenarios that examine how a large infrastructure project can change comparative advantage. Furthermore, my theoretical framework considers the role of industry linkages.

Other work related to the determinants of comparative advantage includes papers regarding how migration affects specialization (Arkolakis, Lee and Peters, 2018; Bahar and Rapoport, 2018; Morales, 2019; Pellegrina and Sotelo, 2019), how the quality of institutions is a source of comparative advantage (Levchenko, 2007) or how domestic trade costs influence crop choices in developing countries (Allen and Atkin, 2018; Morando, 2019). This paper also speaks to the theoretical research regarding the dynamics of comparative advantage (Matsuyama, 1992; Krugman, 1987; Levchenko and Zhang, 2016; Hanson, Lind, and Muendler 2015).

In the international trade literature, there is an increasing interest in the effects of infrastructure projects. This includes work on how infrastructure projects impact different outcomes of regions or cities (Banerjee, et al 2012; Baum-Snow, et al 2016; Coatsworth 1979; Donaldson and Hornbeck, 2016; Faber, 2014; Fogel 1962; Holl, 2016; Jing and Liao, 2018; Perez-Cervantes, 2014), the welfare impact of infrastructure projects (Allen and Arkolakis 2019; Alder, 2019; Asturias et al, 2018; Donaldson 2018; Xu 2018), and the impacts of infrastructure on international trade (Cosar and Demir, 2016; Ducruet et al, 2019; Xu, 2016).

To my knowledge, only two papers consider structural models that consider jointly domestic and international trade in a general equilibrium setting: Fajgelbaum and Redding (2018) on the structural transformation of Argentina during the period 1869-1914, and Sotelo (2020) on how roads affect agricultural trade in Peru. I depart from the existing literature by highlighting the role of industry linkages in explaining the effects of infrastructure in economic outcomes. Specifically, I show that input-output linkages propagate the effects of lower domestic trade costs. Although the previous work on infrastructure considers the effects of domestic trade costs on exports by sector, the interactions between industry linkages and infrastructure have not been examined in detail. I demonstrate that such linkages are crucial in explaining the impact of infrastructure on sectoral exports. This is because the existence of such linkages generates uneven effects of changes in domestic trade costs on exports across sectors.

Lastly, my results are relevant for the literature on the Dutch disease. The work on this topic has been extensive, as Van der Ploeg (2011) points out. My results show that improving the domestic integration of regional markets in specific ways can minimize the specialization of an economy in a single sector. More precisely, my paper is closely related to one of the main mechanisms of the Dutch disease, the crowd-out of the manufacturing sector after a resource boom (Allcott and Keniston, 2018). In the case of Colombia, specific changes in the spatial distribution of domestic trade costs have the potential to generate improvements in the manufacturing sector. In a country in which industry linkages are such that access to intermediate inputs has a major impact on the costs of the manufacturing sector, specific improvements in transportation can offset the crowd-out of the manufacturing sector caused by a commodity boom.

The rest of the paper is organized as follows. Section 2 describes the data and provides motivating facts. Section 3 presents the model. Section 4 describes how I take the model to data. Section 5 reports the results of my counterfactual exercises. Section 6 concludes.

2 | DATA AND BASIC PATTERNS

2.1 | Data

This paper combines five datasets that allow me to measure domestic sectoral trade flows between Colombian departments, international trade flows between departments and the rest of the world by sector and port of exit/entry, input-output linkages, domestic trade costs, and international trade costs. My analysis focuses in four sectors (agriculture, mining, manufacturing and services) and uses data for 2013 whenever possible. For some cases, I use data from 2012 due to data restrictions. I select 2013 as the base year because it is a period before the official inauguration of one of the segments of the road I selected for my counterfactuals, *Ruta del Sol*, in 2014 [6].

Customs data. I use a dataset created by the National Directorate of Taxes and Customs (DIAN, in Spanish) and the National Administrative Department of Statistics (the official statistical agency of Colombia, or DANE in Spanish) that contains all the shipments of exports and imports of Colombia. The data includes information such as harmonized system code, the department of origin/destination, and the city-port of exit/entry.[7]

Transportation and geography. I create a fully digitized road network that represents the primary highway system of Colombia in 2012[8], based on physical and digital maps of the Ministry of Transportation and the National Institute of Roads (INVIAS). My main analysis focuses on roads, given that the share of total shipments (measured in tons) shipped via road is 73%, as of 2013 (ANIF, 2014).[9] For each highway segment, I have information on whether the road is paved, if it crosses a city, and whether the road is under public management or administered by a public-private partnership via the legal figure of *concesion*. Roads under the legal status of *concesion* are paved and tend to have better geographical and topographical characteristics than the rest of the roads.[10]

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[6] The first segment of *Ruta del Sol* was inaugurated at the end of 2014, but the segment was incomplete. As of 2020 this segment of *Ruta del Sol* still remains incomplete (El Tiempo, 2020).

[7] I define a city-port as the location through which the products exit/enter the country. In the customs data, there is a total of 19 city-ports that are actively used for international shipments. The use of a city-port is based on the fact that goods could exit via a specific city, through different methods. For example, firms could use the seaport or the international airport located in Cartagena. In such cases, I do not differentiate by the method of transportation. Hence, in this example I would define Cartagena as a city-port of exit.

[8] Given that the transportation of goods mainly occurs via trucks, I do not consider the secondary road system (composed by roads administered by the Departments) nor the tertiary road system (managed by municipalities) and I focus exclusively in the primary road system. I do this because I do not have the status of the secondary or tertiary roads. Moreover, there are maps elaborated by the Ministry of Transportation, which contains graphical data about the annual flow of trucks by road. These maps show that most of the truck traffic use the primary road system. See IGAC (2005) for the most recent maps regarding truck flows across the country.

[9] The use of fluvial shipments is very limited, the railroad network is used exclusively for a specific route for the transportation of commodities, and the use of air cargo for domestic trade is relatively small (Duranton, 2015)

[10] Pachon and Ramirez (2006) explain that since the mid-90s, the Colombian government partially privatized some segments of the primary road system under the legal figure of public-private partnerships (concesiones,

I estimate the travel times using Dijkstra's algorithm. I assign a speed of 30 km/hour for unpaved roads. The speeds for paved roads are 50 km/hour for paved roads in urban areas, 80 km/hour for paved highways outside urban centers, and 100 km/hour for paved roads under the legal figure of *concesion*. The speeds for paved and unpaved roads are like the ones used by Allen and Atkin (2016) for the Indian highway system. I have two differences with respect to Allen and Atkin (2016). First, I define different speeds for paved roads under *concesion*. Second, I assume a lower speed when the highways cross a Colombian city. I describe in the Appendix A2 why I consider the roads under *concesion* to be of higher quality, which leads me to assign them higher speed values.

Survey of cargo flows. I use the 2013 Survey of Origin/Destination of Cargo Transportation of the Ministry of Transportation to obtain proxies of domestic trade flows for the agricultural and manufacturing sectors. Specifically, I use the data on total weight cargo flows between different Colombian locations, measured in metric tons. Additionally, I use data regarding oil production and refining from the Ministry of Energy and Mines and the public oil company Ecopetrol, to generate domestic trade flows for the mining sector.

Input-output linkages. Data to calibrate the parameters of input-output linkages come from two sources: the World Input-Output Table of 2013 (Timmer, Dietzenbacher et al., 2015) and Colombia's input-output table produced by DANE for the year 2010.

2.2 | Motivating facts

This section describes four empirical facts about Colombian departments that motivate the theoretical framework. First, Colombian exports are concentrated in a few goods, mostly mining ones. Second, the Colombian departments specialize in different sectors. Third, departments differ in their access to international markets, which generates differences in the international trade costs between departments and the rest of the world. Fourth, when the departments trade with the rest of the world, they do not use a single city-port to trade. Lastly, the agricultural and manufacturing sectors purchase a larger share of intermediate tradable goods compared to the mining sector.

Fact 1, Colombian exports are concentrated in a few goods. Figure 1 plots the share of exports of *traditional products* as a fraction of total exports. This category was created by Colombian government agencies for specific goods, given the historical concentration of exports in these products.[11] As figure 1 shows, during the past three decades, Colombia experienced an upward trend in the specialization of mining goods.

Colombia was considered the standard case of an agricultural commodity-dependent nation by international agencies due to its dependence on coffee exports (FAO, 2002). More recently, an oil boom has reduced the share of coffee in the national exports. Recent official documents elaborated by the Colombian government highlight the dependence of the country on commodity exports (DNP, 2019).

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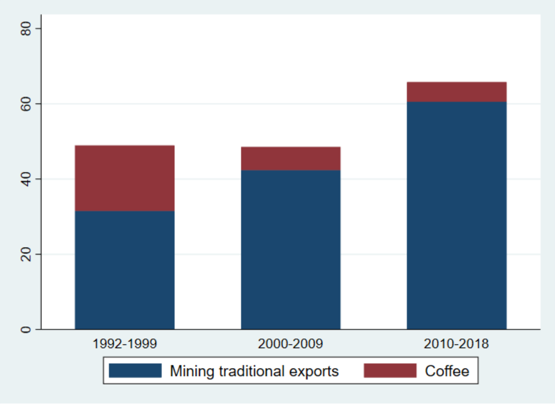
in Spanish). These roads were renovated/built by private companies, and the payments are split in two types: a direct government payment and the income generated by charging a fixed-fee to users of the highways).

[11] This term is commonly used by government agencies such as the National Department of Planning or the statistical agency DANE. It groups the following products: coal, oil, coffee, and nickel-alloy.

FIGURE 1 Share of "traditional" exports according to Colombia's statistical agency DANE (%)



Notes: The bars show the average annual share of "traditional" with respect to total exports, for the period indicated in the x-axis. Source: Official website of Colombia's official statistical agency DANE.

Fact 2, Colombian departments specialize in different sectors. Using customs data from 2013, I build a Regional Index of Revealed Comparative Advantage (RCA) for every department. My objective is to show how a department specializes in a sector, relative to the specialization of Colombia in this same industry. The formula of this index is

$$RCA_{s,d} = \left(\frac{Exports_{s,d}}{Total\ Exports_{d}}\right) / \left(\frac{Exports_{s,Colombia}}{Total\ Exports_{Colombia}}\right)$$

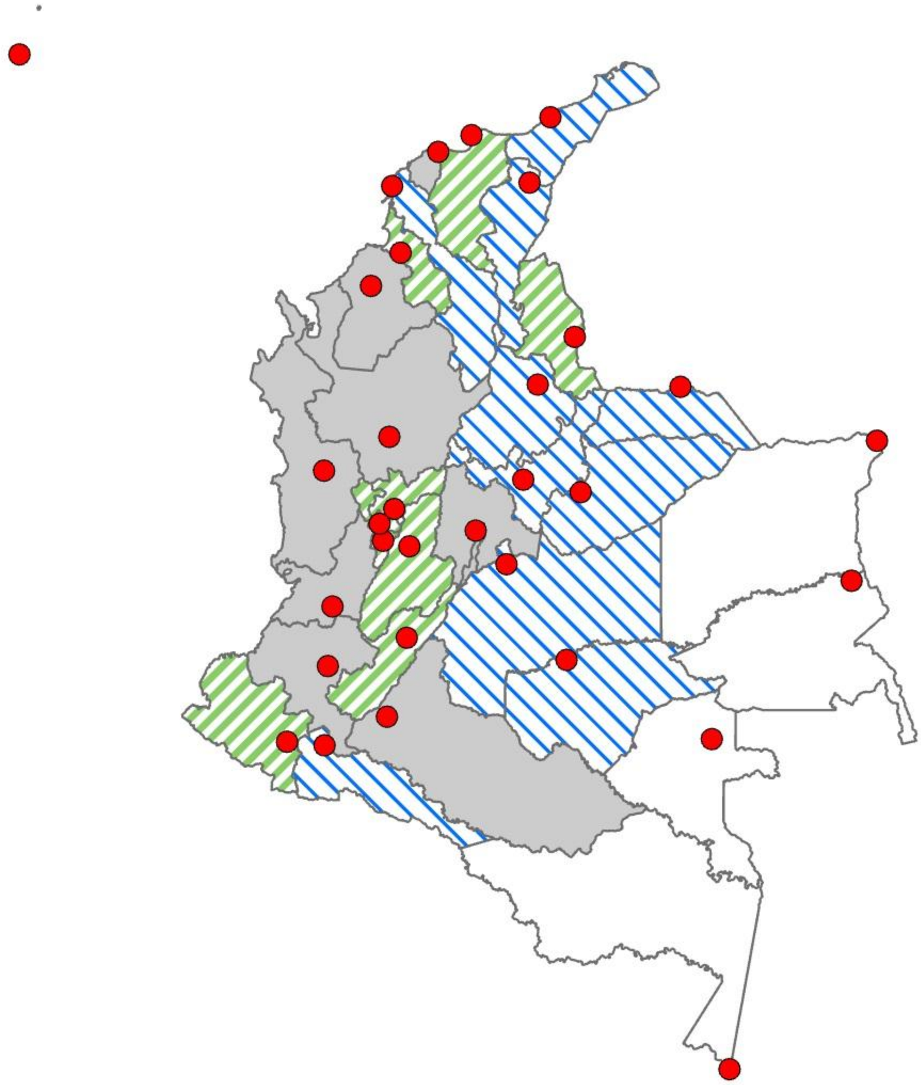
where s stands for a sector and d is a department. The index is the proportion of the exports of a department in sector s, divided by the proportion of Colombia's exports in industry s.

Intuitively, if the value of this ratio is high, a department is more specialized in sector s relative to the level of specialization of the entire Colombian economy in this industry. To obtain the Balassa Index of Revealed Comparative Advantage of every region (Balassa, 1966), the Regional index needs to be multiplied by the Balassa Index for Colombia. I use a regional index, instead of the Balassa index because I want to measure how every region is different than the Colombian economy, in its trade with the rest of the world.

After I obtain the values of the index, I select the sector in which every department shows the highest level of specialization. It is crucial to highlight that if a department is one of the main exporters for two sectors, I select the one with the highest Balassa Index (for example, Cundinamarca and Bogota are the main exporters of agricultural and manufacturing goods). With this information, I construct figure 2 to provide evidence that there is variation in the sectoral specialization of Colombian regions.

Fact 3, Colombian regions do not have uniform access to international markets. Colombian departments have heterogeneity in their access to global markets, given the existing geography of the country and the structure of the transportation network. To show this, Figure 3 displays the estimated travel times between the capitals of every department and the seaports of the country. (Given that 86% of exports and 70% of imports in 2013 exit or entered the country via seaports, figure 3 helps to illustrate the access to international markets of every Colombian department). The figure illustrates how some departments have immediate access to seaports, while for others it takes more than five hours to reach these ports.

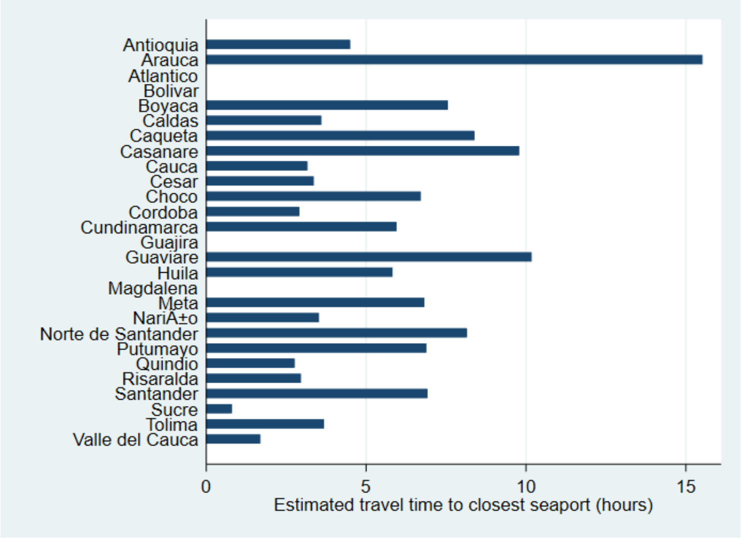
FIGURE 2 Map that indicates the sector with the strongest comparative advantage of every department (highest value of the Balassa Index)



// agriculture; \\ mining; ■ manufacturing; • city-port

Notes: I do not consider the departments of Guainia, Leticia, San Andres y Providencia, Vaupes, and Vichada. They have a white background. Additionally, I merge Bogota with the department of Cundinamarca. See Appendix 1 for more details. Source: Customs administrative data created by Colombia's official statistical agenct DANE and the Colombian tax authority DIAN.

FIGURE 3 Estimated travel times between the capital of the department and the closest seaport



Notes: I estimate the travel times between the capital of every department and the closest seaport using Dijkstra's algorithm, according to the speed values described in section 2.1. I do not consider the departments of San Andres y Providencia, Guainia, Leticia, Vichada and Vaupes. See Appendix A1 for more details. Source: own calculations using geospatial data on ArcGIS based on the official road maps of the Ministry of Transportation of Colombia.

Fact 4, Colombian departments use multiple ports to trade with the rest of the world. Several departments have enough logistical infrastructure to trade with the rest of the world, such as airports, international land bridges, and seaports. In spite of this, most of the firms in the departments use different city-ports to trade with the global markets.

Figure 4 shows that the goods exported by the largest two departments of Colombia (Cundinamarca and Antioquia) are sent to other countries via different city-ports, even though Cundinamarca and Antioquia have large city-ports to serve international trade shipments.[12] The main explanation for this is that every city-port has logistical advantages for the shipment of specific goods, even within the same sector. For example, if I look at manufacturing goods, the seaport of Coveñas is ideal for naphta products (a chemical manufacturing good), the international airport of Bogota has excellent logistical conditions for the shipment of textiles, while the seaport of Santa Marta has very good logistical capacity for handling steel and cement products.

Fact 5, Colombian mining sector purchases a smaller share of intermediate tradable inputs relative to agriculture or manufacturing. Data from the input-output table of Colombia in 2010 shows that mining is the sector with the lowest share of purchases of intermediate tradable inputs, 47.1% among the three large tradable sectors considered in this paper (agriculture, minining, and manufacturing). The share of purchases of intermediate tradable inputs by the agriculture and manufacturing sectors is 69.5% and 68.8%, respectively.

This fact highlights the relative importance of access to tradable intermediate inputs by

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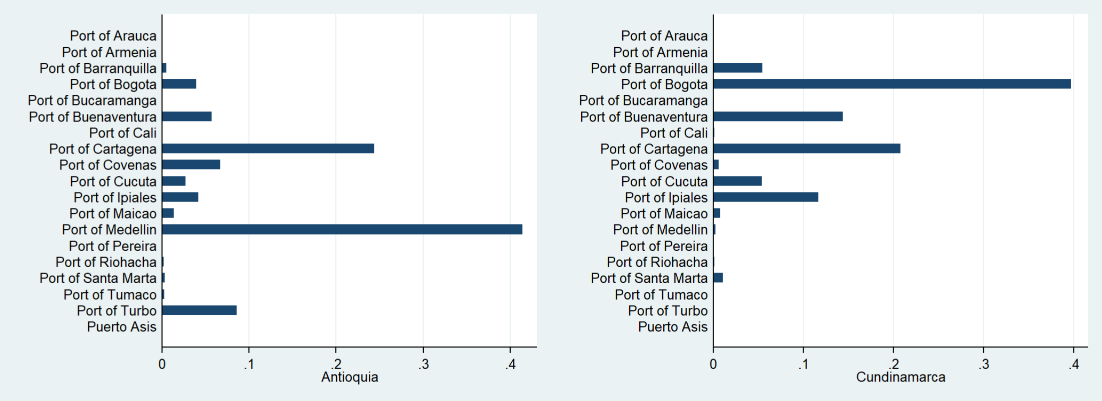
[12] The city of Bogota located in the department of Cundinamarca posses the largest airport in the country, El Dorado International Airport, which has capacity to handle cargo shipments. The city of Medellin located in Antioquia has the Jose Maria Cordova International Airport, which also has infrastructure for the shipment of cargo.

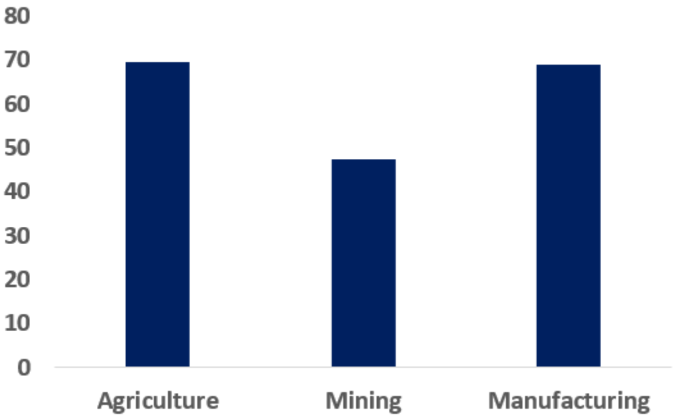
FIGURE 4 Use of city-ports to export goods by the largest two Colombian departments (% of total department exports)



Notes: The vertical axis considers the 20 city-ports included in the customs data. For more details about the city-ports, see Appendix A7. Source: own calculations using geospatial data in ArcGIS based on the official road maps of the Ministry of Transportation of Colombia.

the agricultural and the manufacturing firms. One of the direct impacts of better transportation infrastructure is better access to intermediate inputs, given that lower transportation costs reduce the price of such inputs (Fiorini, et al, 2019).

FIGURE 5 Intermediate input purchases of tradable goods by sector (% of total purchases)



Notes: I consider tradable goods to those economic actitivities that are classified as agriculture, mining, or manufacturing. **Source:** Colombia's input-output table of 2010 created by official statistical agency, DANE.

3 | MODEL

In this section, I describe my theoretical framework, define the equilibrium concept, provide an expression for a gravity equation, and explain how to translate changes in the road system into changes on the trade costs.

3.1 | General framework

Geography. Consider an economy composed of Colombian departments and the rest of the world. The locations trade with each other. The departments are indexed by d and the rest of the world is indexed by RoW. There are $\bar{d}$ departments in Colombia. The set of Colombian departments is $D = \{1, ..., \bar{d}\}$ and the set of all locations is $Z = \{1, ..., \bar{d}, RoW\}$. Each location is indexed by subscripts $n, j \in Z$. Trade between departments and the rest of the world require the use of city-ports ρ (see Fact 4). There is a total of $\bar{\rho}$ city-ports. The set of city-ports is $\mathbb{P} = \{1, 2, ..., \bar{\rho}\}$.

I define an international shipping route as an ordered pair that consists of a department d and a city-port ρ. An *export route* consists of an ordered pair department, city-port $r_\chi = (d, \rho)$. There is a total of $\bar{d}\bar{\rho}$ export routes. The set of export routes is $R_\chi = D \times \mathbb{P}$. The subset of export routes for a department d is defined as $R_{\chi,d} = \{(d, \rho) : \rho \in \mathbb{P}\}$. An *import route* consists of an ordered pair city port-department $r_\mu = (\rho, d)$. There are $\bar{d}\bar{\rho}$ import routes. The set of import routes is $R_\mu = \{\mathbb{P} \times D\}$. The subset of import routes for a department d is defined as $R_{\mu,d} = \{(\rho, d) : d \in D\}$

Goods. There are two types of goods, intermediates and composite goods. The intermediate good is tradable, while the composite good is non-tradable. The composite good is used in every location by firms to produce intermediate goods or by households for final consumption. These are standard assumptions in Caliendo and Parro (2015). There are four sectors in the economy: agriculture (a), mining (m), manufacturing (i) and services (z). Sectors are indexed by $k, s \in \{a, m, i, z\}$. The intermediate good firms in location j and sector k produce the intermediate good. The firms that produce composite goods buy from suppliers across different locations and create an aggregated composite using a Dixit-Stiglitz aggregator. The market structure in all sectors is perfect competition.

Trade costs between departments and the rest of the world. International trade between a department, d, and the rest of the world, RoW, require specialized traders, as in Allen and Arkolakis (2019). There is a continuum of specialized traders $\eta \in [0, 1]$. Traders choose among all the shipping routes when they export or import goods.[13] These traders face capacity constraints when moving goods internationally.

Figure 6 helps to understand the concept of international shipping routes. When Cundinamarca exports to the rest of the world, it can choose among multiple city-ports to send goods abroad. Each red arrow in the figure is an export route for Cundinamarca. If the arrows were in the opposite direction, they would represent import routes.

Every specialized trader faces a productivity shock that is specific to the international shipping route and to every sector k. This implies that the cost of a specialized trader η when it uses an international shipping route r_t is $\tau_{r_t,k}/z_{r_t,k}(\eta)$. I define the international shipping cost for trader η as the lowest international shipping cost across different routes, when the trader ships a good between department d and RoW, that is

$$\tau(\eta) = \min_{r_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \text{ for } t \in \{\chi, \mu\} \tag{1}$$

where τ_{r_t} is the shipping cost along route r_t for goods of sector k, $z_{r_t,k}(\eta)$ is the productivity draw for a specific international shipping route r_t to transport goods of sector k, and subscript t defines whether the shipping route is used to export or import goods.

The productivity draw $z_{r_t,k}(\eta)$ follows a Frechet distribution with parameters $(A_{r_t,k}, \theta_k)$, where $A_{r_t,k} > 0$ and $\theta_k > 0$. The Frechet parameter $A_{r_t,k}$ is the scale parameter of the Frechet distribution. The shape parameter θ_k represents the heterogeneity of productivities

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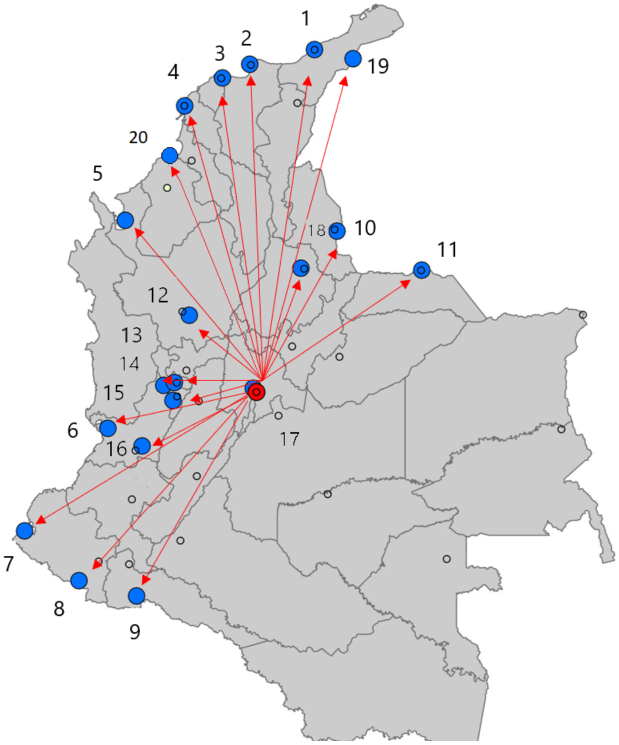
[13] Intuitively, firms choose logistical companies to ship goods between a department and the rest of the world (e.g. Fedex, UPS, McLane Company, JR Freight, etc.)

FIGURE 6 Example of export routes ($d = Cundinamarca, \rho$)



1. Riohacha
2. Santa Marta
3. Barranquilla
4. Cartagena
5. Turbo
6. Buenaventura
7. Tumaco
8. Ipiales
9. Puerto Asis
10. Cúcuta
11. Arauca
12. Medellín
13. Manizales
14. Pereira
15. Armenia
16. Cali
17. Bogotá
18. Bucaramanga
19. Maicao
20. Coveñas

of the routes r_t regarding the transportation of sector-k goods. The higher the value of θ_k, the lower the heterogeneity in the productivities of the routes. The lower the value of θ_k, the higher the heterogeneity in these productivities. Thus, the case in which $\theta_k \to \infty$ imply that traders use the same city-port to move goods between departments and the rest of the world. Low values of θ_k suggests that traders use different city-ports for international shipments, that is, they opt for different routes to export or import goods.

When agents buy exported or imported goods, they are randomly assigned with specialized traders. Thus, the iceberg trade cost between a department d and the rest of the world RoW is the expected trade cost across the continuum of traders, as in Allen and Arkolakis (2019).

$$\tau_{dRoW,k} \equiv E[\tau(\eta)] = E\left[\min_{r_t,k} \frac{\tau_{r_t}}{z_{r_t,k}(\eta)}\right] \tag{2}$$

The expression for the iceberg trade cost between any department d and the rest of the world RoW becomes a tractable expression due to the Frechet distribution

$$\tau_{dRoW,k} = \Phi_x^{-\frac{1}{\theta}}\Gamma\left(\frac{1+\theta_k}{\theta_k}\right) \text{ where } \Phi_k = \sum_{r_t} A_{r_t}\tau_{r_t}^{-\theta_k} \tag{3}$$

where Γ is the gamma function.

Although I do not explicitly include congestion in the city-ports, they are implicitly modeled by the shape parameter θ_k. This is because if departments tend to use the same city-port because its the logistics capacity is very large and no congestion is generated by this behavior, then θ_k will have a very high value. But if congestion in a large city-port forces traders to use multiple city-ports (which implies the usage of multiple routes), then the value of θ_k will be low.

International shipping costs. Following Duranton, Morrow, and Turner (2014), I define the international shipping cost of route $r_t = (d, \rho)$ as $\tau_{r_t} \equiv \tau_\rho \tau_{d\rho} \tau_d$. This implies that the international shipping cost of a route depends on logistical characteristics of department d, denoted by τ_d, the logistical capacity of the port ρ, represented by τ_ρ, and the department-port shipping costs, expressed as $\tau_{\rho d}$. The latter is a function of $T_{d\rho}$, which is the travel time between a department d and a city-port ρ, therefore we have $\tau_{d\rho} = f(T_{d\rho})$.[14]. Unfortunately, due to data restrictions I cannot model how congestion impacts travel times. That would require detailed traffic data regarding the movement of vehicles along the primary road network before the inauguration of *Ruta del Sol*.

Trade costs between departments in Colombia. There are standard iceberg trade costs for every sector. I denote the trade costs between department $d_1 \in D$ and department $d_2 \in D$ for sector-k goods as $\tau_{d_1 d_2,k}$. Icerberg trade costs between departments are a function of travel times along the least cost route that connects these departments, $T_{d_1 d_2}$, that is $\tau_{d_1 d_2} = f(T_{d_1 d_2})$.

Domestic traders are homogeneous, hence they always choose the same optimal road when sending goods from d_1 to d_2. Implicitly, this implies that all the trade flows are shipped through the least cost road between d_1 and d_2. If I would consider the existence of a continuum of traders for domestic trade, the previous assumption could be interpreted as having a very high value for the shape parameter θ that represents the heterogeneity in the use of roads across two locations within Colombia. The assumption is consistent with Allen and Arkolakis (2019), who find that domestic traders moving goods across two cities within a country tend to choose the same least cost road. As I mentioned previously, data constraints prevent me from including congestion in the model.

Preferences. The consumers' preferences living in location n are represented by a Cobb-Douglas utility function given by

$$U_n = \prod_{k=1}^{K} (C_n^k)^{\alpha_n^k} \text{, with } \sum_{k=1}^{K} \alpha_n^k = 1 \tag{4}$$

where α_n^k is the share of sector k in the final demand and C_n^k is the level of consumption of the composite good. The income of households in location n is denoted by I_n. Households' income are the sum of payments to labor and transfers, that is $I_n = w_n L_n + D_n$. The transfers are equal to deficits as in Dekle, Eaton and Kortum (2008).

Labor supply. Agents live in location $n \in Z$ and supply one unit of labor. There are L_n workers in location j. There is perfect labor mobility across sectors, but no labor mobility across locations (this implies no labor mobility across Colombian departments, and workers cannot migrate from the departments to the rest of the world). This decision is based on modeling and data restrictions (mainly, the lack of bilateral migration flows between Colombian departments and the rest of the world). [15] Moreover, recent empirical evidence

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[14] The assumptions have implications about the symmetry of shipping costs of export and import routes $\tau_{r_\chi} = \tau_{r_\mu} = \tau_d \tau_{dp} \tau_\rho$ if $r_\chi = (d, \rho)$ and $r_\mu = (\rho, d)$

[15] The decision regarding no labor mobility across regions is based on different factors. First, using a standard Economic Geography model (Allen, 2019) would imply perfect labor mobility across all locations, and thus the model would allow the presence of international migration, a topic beyond the scope of this paper. A second option would be to add a migration model. I opted not to do this due to the lack of data regarding bilateral migration flows between Colombian departments and the rest of the world. Lastly, as I discuss with detail in section 5.3, my estimates regarding the impact of *Ruta del Sol* in the share of manufacturing exports are a lower bound, when I assume an immobile labor model.

suggests that migration in Colombia is mainly driven by civil violence, and much less by favorable conditions in the destination labor markets (Calderon-Mejia and Ibañez, 2015).

3.2 | Production

Production of intermediates. Following Caliendo and Parro (2015), the production of intermediate goods requires labor and composite goods from all sectors. The production technology of intermediate goods has constant returns to scale and for location n is defined by

$$q_{n,k} = A_{n,k} l_{n,k}^{\beta_n^{l,k}} \Big[\prod_{s \in \{a,m,i,z\}} m_{s,k}^{\beta_n^{s,k}} \Big] \tag{5}$$

where $\beta_n^{l,k} + \sum_s \beta_n^{s,k} = 1 \; \forall \; n \in \{1, ..., \bar{d}, W\}$. I denote by $m_{s,k}$ the amount of composite good of sector s used in the production of sector k, $\beta_n^{s,k}$ is the parameter that defines the share of composite goods from sector s used in the production of intermediates for sector k goods produced in location n, $\beta_n^{l,k}$ is the share of value added of sector k in location n, $A_{n,k}$ is the productivity of sector k in location n, l_n^k is the amount of labor necessary for the production of good of sector k in location n,
Firms price at unit cost $\frac{c_{n,k}}{A_{n,k}}$, where $c_{n,k}$ is the unit cost of an input bundle in location n. This can be expressed as

$$c_{n,k} = \phi_{n,k} (w_n)^{\beta_n^{l,k}} \prod_s (P_{n,s})^{\beta_n^{s,k}} \tag{6}$$

where $\phi_{n,k} \equiv (\beta_n^{l,k})^{-\beta_j^{l,k}} (\beta_j^{a,k})^{-\beta_j^{a,k}} (\beta_j^{i,k})^{-\beta_j^{i,k}} (\beta_j^{m,k})^{-\beta_j^{m,k}} (\beta_j^{z,k})^{-\beta_j^{z,k}}$ is a constant, and $P_{j,s}$ is the price of a composite intermediate good from sector s in location j. The cost function captures the input-output linkages between industries: if the price of the composite good in one industry changes, it will affect the unit cost of the rest of the sectors.
Production of composite goods. Firms that produce composite goods in location j for sector k purchase the intermediate goods from suppliers across different locations. The production technology of composite goods uses a Dixit-Stiglitz aggregator:

$$Q_{n,k} = \Big[\sum_j (q_{jn,k}^{\delta})^{\frac{\sigma_k - 1}{\sigma_k}} \Big]^{\frac{\sigma_k}{\sigma_k - 1}} \tag{7}$$

where $Q_{n,k}$ is the number of units of the composite goods that the firms supply in location n (recall the composite good is non-tradable), σ_k is the elasticity of substitution between intermediates of sector k, and $q_{jn,k}^{\delta}$ is the sector-k demand of intermediate good of location n that were produced in location j.
Prices. Given the existence of perfect competition, the price of a good of sector k consumed by location n and produced in j considers the unit cost and the trade costs between locations, that is

$$p_{jn,k} = \frac{c_{j,k} \tau_{jn,k}}{A_{j,k}} \tag{8}$$

using this expression, I derive the price of the composite good of sector k in location n

$$P_{n,k} = \Big[\sum_j p_{jn,k}^{1-\sigma_k}\Big]^{\frac{1}{1-\sigma_k}} = \Big[\sum_j \Big(\frac{\tau_{jn} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k}\Big]^{\frac{1}{1-\sigma_k}} \tag{9}$$

where the second equality comes from using (8). Using the previous prices of sector k, I can obtain the price index of location n:

$$P_n = \prod_k \Big(\frac{P_{n,k}}{\alpha_{n,k}}\Big)^{\alpha_{n,k}} \tag{10}$$

3.3 | Trade flows and expenditure shares

Solving the optimization problem of the firms that produce the composite good, I obtain an expression for the demand of intermediate good in sector k, denoted by $q_{jn,k}^{\delta}$. Combining it with the price of intermediate good $p_{jn,k}$ and aggregating, I derive an expression for the total expenditure by location n on goods from sector k produced in location j

$$X_{jn,k} = \Big(\frac{\tau_{jn} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k} Q_{n,k} P_{n,k}^{\sigma_k - 1} \tag{11}$$

The trade flows equation can also be expressed as

$$X_{jn,k} = (\tau_{jn})^{1-\sigma_k}\Big(\frac{Y_{j,k}}{\Pi_{j,k}^{1-\sigma_k}}\Big) Q_{n,k} P_{n,k}^{\sigma-1} \tag{12}$$

where $\Pi_{j,k}^{1-\sigma_k} \equiv \sum_{\bar{n}} \tau_{j\bar{n}}^{1-\sigma_k} X_{\bar{n},k} P_{\bar{n},k}^{\sigma_k - 1}$. The term $X_{\bar{n},k}$ is the total expenditure of location $\bar{n}$ in goods of sector k. Finally, let $\lambda_{jn,k}$ be the fraction of expenditure of n in sector-k goods produced by location j:

$$\lambda_{jn,k} \equiv \frac{X_{jn,k}}{\sum_l X_{ln,k}} = \Big(\frac{\tau_{jn} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k} (P_{n,k})^{\sigma_k - 1} \tag{13}$$

3.4 | Total expenditure and trade balance

The total expenditure of location n in sector-k goods $X_{n,k}$ is composed by the expenditure by firms and households, on composite goods used in the production of intermediates and final consumption, respectively:

$$X_{n,s} = \sum_k \beta_n^{s,k} \sum_j X_{j,k} \lambda_{nj,k} + \alpha_{n,s} I_n \tag{14}$$

where I_n denotes the total income of sector n, composed by labor income and transfers. The total income in location n is $I_n = w_n L_n + D_n$, where D_n is the total deficit of n.

The total trade deficits sum up to zero across all locations ($\sum_n D_n = 0$) and the total trade deficits are the sum of sectoral trade deficits, $D_n = \sum_k D_{n,k}$. A sectoral trade deficit $D_{n,k}$ is defined as $D_{n,k} = M_{n,k} - E_{n,k}$ where $M_{n,k} = \sum_j X_{n,k} \lambda_{jn,k}$ represents the total imports of country n of sector-k goods and $E_{n,k} = \sum_j X_{j,k} \lambda_{nj,k}$ is the total exports of n of sector-k goods. I consider total trade deficits as exogenous, but the sectoral trade deficits are endogenous, as in Caliendo and Parro (2015).

Considering the definition of total trade deficit for any location n, I can express the trade balance equation as

$$\sum_k \sum_j X_{j,k} \lambda_{nj,k} = \sum_k \sum_j X_{n,k} \lambda_{jn,k} - D_n \tag{15}$$

Labor market clearing. By aggregating the total expenditure of location n in sector k, equation (14), across all sectors and combining it with the trade balance equation (15), I get an expression for the labor market clearing (see Appendix C).

$$w_n L_n = \sum_k \beta_n^{l,k} \sum_j X_{nj,k} = \sum_k \beta_n^{l,k} \sum_j X_{j,k} \lambda_{nj,k} \tag{16}$$

3.5 | Equilibrium

In this section, I define the world equilibrium. Then, I describe the equilibrium in changes, which requires fewer parameters than the original equilibrium. By doing this, I simplify the estimation procedure.

3.5.1 | Equilibrium in levels

Definition 1. World equilibrium in levels. *The equilibrium is a set of wages* $\{w_{n,k}\}_{n \in Z, k \in \{a,m,i,z\}}$, *prices* $\{P_{n,k}\}_{n \in Z, k \in \{a,m,i,z\}}$, *and labor allocations* $\{L_n\}_{n \in Z}$ *under the assumption of perfect labor mobility across sectors and immobile labor across locations that solve equations (6), (9), (13), (14) and (15).*

3.5.2 | Equilibrium in changes

Solving the previous equilibrium requires the knowledge of many parameters that are difficult to estimate, such as the sectoral productivities $\{A_{n,k}\}$. An option to reduce the number of parameters needed to calibrate the model, is to express the equilibrium in changes.

I follow the exact-hat algebra method of Dekle, Eaton and Kortum (2008) that allows me to estimate the model with fewer parameters. For example, let x' be the value of any variable in the new steady state and define the change in the value of variables between the old and the new equilibrium as $\hat{x} = x'/x$. Thus, I obtain an expression for any variable in the new equilibrium as $x' = \hat{x}x$. The following definition, considers the original equilibrium in terms of changes. The equilibrium in changes is like the one of Caliendo and Parro (2015), but without taxes. Another crucial difference is that in my model, the sources of changes in trade costs comes from transportation policy instead of coming from trade policy.

Definition 2: Equilibrium in terms of changes. *Let* $(\mathbf{w}, \mathbf{P})$ *be an equilibrium under trade costs* $\{\mathbf{fi_{jn}}\}_{\mathbf{j,n \in Z}}$. *Consider a different equilibrium* $(\mathbf{w}', \mathbf{P}')$ *under trade costs* $\{\mathbf{fi'_{jn}}\}_{\mathbf{j,n \in Z}}$. *Let* $(\hat{w}, \hat{P})$ *be an equilibrium under trade costs* $\{\mathbf{fi'_{jn}}\}_{\mathbf{j,n \in Z}}$ *relative to* $\{\mathbf{fi_{jn}}\}_{\mathbf{j,n \in R}}$, *where variable* $\hat{x}$ *represents relative changes, that is* $\hat{x} = \frac{x'}{x}$. *Then, the equilibrium conditions (6), (9), (13), (14) and (15) can be expressed in relative changes:*

(i) *Cost of input bundle*

$$\hat{c}_{n,k} = (\hat{w}_n)^{\beta_n^{lk}} \prod_{s \in \{a,m,i,z\}} (\hat{P}_{ns})^{\beta_n^{sk}} \tag{17}$$

(ii) *Expenditure shares*

$$\hat{\lambda}_{jn,k} = (\hat{\tau}_{jn,k})^{1-\sigma_k}(\hat{c}_{j,k})^{1-\sigma_k}(\hat{P}_{n,k})^{\sigma_k-1} \tag{18}$$

(iii) *Prices*

$$\hat{P}_{n,k} = \Big[\sum_j (\hat{\tau}_{jn}\hat{c}_{j,k})^{1-\sigma_k}\lambda_{jn,k}\Big]^{\frac{1}{1-\sigma_k}} \tag{19}$$

(iv) *Total expenditure*

$$X'_{n,s} = \sum_k \beta_n^{s,k} \sum_j X'_{j,k}\lambda'_{nj,k} + \alpha_{n,s} I'_n$$

$$X'_{n,s} = \sum_k \beta_n^{s,k} \sum_j X'_{j,k}\hat{\lambda}_{nj,k}\lambda_{nj,k} + \alpha_{n,s}[\widehat{w_n} w_n L_n + D'_n] \tag{20}$$

(v) *Trade balance*

$$\sum_k \sum_j X'_{j,k}\lambda'_{nj,k} = \sum_k \sum_j X'_{n,k}\lambda'_{jn,k} - D'_n$$

$$\sum_k \sum_j X'_{j,k}\hat{\lambda}_{nj,k}\lambda_{nj,k} = \sum_k \sum_j X'_{n,k}\hat{\lambda}_{jn,k}\lambda_{jn,k} - D'_n \tag{21}$$

3.6 | Department-port gravity equation

I generate an expression for international trade flows between department d and the rest of the world, RoW, that use a specific city-port ρ (or specific international shipping route r_t). For the case of the trade flows between the rest of the world and the departments, equation (12) becomes a different expression. This is necessary, given I need to include the role of the specialized traders on the international trade flows. To do this, I obtain the share of exports/imports that use route r_t and combine it with equation (3), which defines the relationship between international shipping costs and trade costs between a department and the rest of the world, to generate a department-port gravity equation.

Shares of international shipping routes. Using the properties of the Frechet distribution, I obtain an expression for the shares of trade flows that are shipped via a specific international shipping route r_t for $t \in \{\mu, \chi\}$. Define $G_{r_t}(c)$ as the probability that the *international shipping cost* of a good sent via route r_t is lower than a cutoff c.

$$G_{r_t,k}(c) \equiv \Pr\Big[\frac{\tau_{r_t}}{z_{r_t,k}(\eta)} \leqslant c\Big]$$

$$G_{r_t,k}(c) = 1 - \exp[-A_{r_t}(\tau_{r_t})^{-\theta_k}c^{\theta_k}] \tag{22}$$

Let $G_{t,k}(c)$ be the probability that a good shipped via route r_t has an *observed cost* lower than c. This probability is expressed as

$$G_{t,k}(c) \equiv \Pr\{\tau_s(\eta) \leqslant c\} = \Pr\Big[\min_{r_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \leqslant c\Big]$$

$$G_{t,k}(c) = 1 - \exp[-c^{\theta}\Phi_{t,k}], \text{ where } \Phi_k = \sum_{r_t} A_{r_t}\tau_{r_t}^{-\theta_k} \tag{23}$$

Finally, define π_{r_t} as the probability that a good is shipped via route r_t as

$$\pi_{r_t,k} = \Pr\{\tau_{r_t,k}(\eta) \leqslant \min_{\nu_t \in R_{t,d} \setminus r_t} \tau_{\nu_t,k}(\eta)\}$$

$$\pi_{r_t,k} = \frac{A_{r_t}\tau_{r_t}^{-\theta_k}}{\Phi_{t,k}} \tag{24}$$

Similar to Eaton and Kortum (2002), I can show that the distribution of international shipping costs is the same, no matter which route is used (see Appendix C]). This implies that $\pi_{r_t,k}$ also represents the share of the value of exports or imports between a department d and RoW, sent via route r_t.

Trade flows between department and rest of the world via a city-port. I obtain an expression for the trade flows between departments and the rest of the world shipped via a specific route r_t. Consider as example, the export flows that use route $r_t = (d, p)$:

$$X_{dRoW,k,r_t} = X_{dRoW,k}\pi_{r_t,k}$$

$$X_{dRoW,k,r_t} = (\tau_{dRoW,k})^{1-\sigma_k}\left(\frac{Y_{RoW,k}}{\Pi^{1-\sigma_k}_{RoW,k}}\right)Q_{d,k}P^{\sigma-1}_{d,k}\pi_{r_t,k}$$

Inserting (3) and (24) into the expression for trade flows between any department d to RoW, that are sent via route $r_t = (d, p)$, I get:

$$X_{dRoW,k,dp} = \left[\Phi_k^{-\frac{1}{\theta}}\Gamma\left(\frac{1+\theta}{\theta}\right)\right]^{1-\sigma_k}\left(\frac{Y_{RoW,k}}{\Pi^{1-\sigma_k}_{RoW,k}}\right)Q_{d,k}P^{\sigma-1}_{d,k}\left[\frac{A_d A_\rho(\tau_d\tau_p\tau_{dp})^{-\theta_k}}{\Phi_{t,k}}\right] \tag{25}$$

To obtain the previous result, I assume that $A_{r_t} = A_{dp} = A_d A_\rho$. This implies that the scale parameter of the Frechet distribution, which governs the behavior of the productivities of the shipping routes, depends on a productivity transportation factor related to the department, and another productivity transportation factor related to the ports. The assumption is economically intuitive. To see this, notice that if any of these factors increases, then the international trade costs between departments and the rest of the world fall ($\tau_{dRoW} \downarrow$) as equation 3 shows, and the probability that the route $r_t = (d, \rho)$ is used also increases ($\pi_{r_t,k} \uparrow$) as equation 24 illustrates.

For the international shipping costs, I use the expression $\tau_{r_t} = \tau_p\tau_{dp}\tau_p$. A similar expression can be obtained for imports using a particular international shipping route. Notice that the assumption regarding the productivity term for the international shipping routes implies symmetric trade costs.

There are two characteristics of the department-port shipping costs τ_{dp} that matter for the theoretical framework. First, they affect the share of trade flows X_{dRoW} and X_{RoWd} that are traded via port ρ through international shipping routes $r_x = (d, \rho)$ and $r_m = (\rho, d)$, respectively, through the term π_{r_t}. Second, the department-port shipping costs affect the trade costs between department d and the rest of the world, $\tau_{d\ RoW}$. Such effects are economically intuitive. Consider that τ_{dp} depends on the infrastructure that connect d and ρ. If an infrastructure project reduces the road distance between d and ρ, then port ρ will be used more often ($\uparrow \pi_{r_t}$), and the department d will better connected to the global markets ($\downarrow \tau_{dRoW}$).

3.7 | Estimation of changes in trade costs due to new infrastructure projects

I can use the *equilibrium in changes* previously defined in section 3.5 only if I take as given a specific change in the vector of trade costs, $\hat{\tau}$. The objective of this paper is to evaluate how a new road infrastructure project change the national comparative advantage. Hence, I need to define how improvements in the Colombian road network lead to changes in trade costs. To facilitate the comprehension of this process, figure 6 illustrates how new infrastructure projects translate into changes in trade costs.

Estimation of the change in trade costs between departments and the rest of the world. Consider a large infrastructure project that changes the travel times across all international shipping routes from $\{T_{r_t}\}$ to $\{T'_{r_t}\}$. If the function between trade costs and travel times is known, $\tau = f(T)$, then it is possible to obtain both the old and the new international shipping costs along all routes, τ_{r_t} and τ'_{r_t}, respectively. I use the function $\tau_{r_t} = \exp(\beta_{time} T_{r_t})$, which is a standard assumption in international trade and economic geography models. I discuss with detail the value of the parameter β_{time} in section 4.

Using the exact algebra method of Dekle, Eaton and Kortum (2009) with the transportation model equations (3) and (24), I can obtain the change in shares of trade flows between d and RoW that use international shipping route r_t

$$\hat{\pi}_{r_t,k} = \frac{(\hat{\tau}_{r_t})^{-\theta_k}}{\sum\limits_{\nu_t \in R_t} \pi_{\nu_t,k}(\hat{\tau}_{\nu_t})^{-\theta_k}} \tag{26}$$

and the change in trade costs between department d and RoW is expressed as

$$\hat{\tau}_{dRoW,k} = \left[\sum_{r_t \in R_t} \pi_{r_t,k}(\hat{\tau}_{r_t})^{-\theta_k} \right]^{-\frac{1}{\theta_k}} \tag{27}$$

where π_{dRoW,r_t} is the share of exports of department d to the rest of the world that use the route r_t. I can estimate this share using customs administrative data.[16].

Estimation of the changes in trade costs between departments. I obtain the travel times before the infrastructure project is built,$\{T_{d_1 d_2}\}_{d_1,d_2 \in D}$, and after the highway is completed, $\{T'_{d_1 d_2}\}_{d_1,d_2 \in D}$. Then, I can get both the old and the new trade costs between departments ($\tau_{d_1 d_2}$ and $\tau'_{d_1 d_2}$, respectively) using directly the function $\tau_{d_1 d_2} = f(T_{d_1 d_2}) = \exp(\beta_{time} T_{d_1 d_2})$. I do this because I assume there is no heterogeneity in the use of shipping routes between any two departments. Once I obtain the old and the new trade costs for the domestic trade model, I can calculate directly the change in trade costs for trade flows

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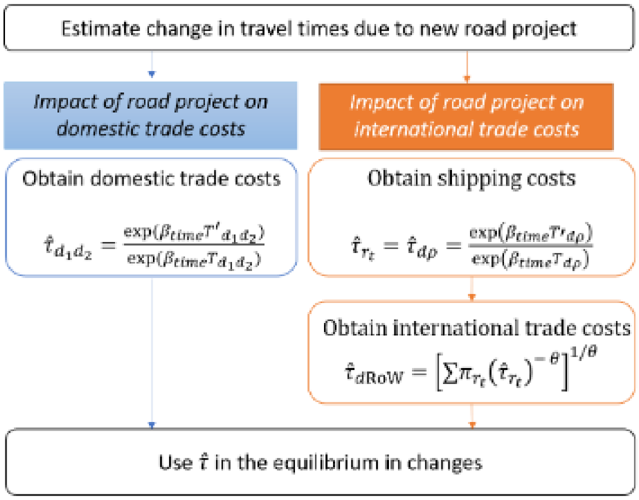
[16] The shares of the export flows transported through a specific route might not necessarily be the same as the shares of imports shipped through this route (i.e. $\pi_{dRoW,r_t} \neq \pi_{RoWd,r_t}$). Hence, to make the counterfactual consistent with symmetric trade costs, I estimate the change in trade costs between any department and the rest of the world using the shares of total trade flows.

across departments, $\hat{\tau}_{d_1 d_2} = \frac{\tau'_{d_1 d_2}}{\tau_{d_1 d_2}}$.

FIGURE 7 Steps to obtain changes in trade costs



4 | TAKING THE MODEL TO DATA

4.1 | Parameters of the model

Tables 7 and 8 in the Appendix B. describe with detail the data and issues related to the estimation of the international trade model parameters, including consumption parameters (i.e. utilify function parameters), production parameters, trade deficits, and expenditure shares. I follow standard methods for the estimation of these parameters: most of them use IO tables, international trade flows, and domestic trade flows. A detailed discussion about the transportation model parameters is in sections 4.3, 4.4, and 4.5. To see additional notes regarding the data, Appendix A provides more details.

4.2 | Solving the model

I solve the model using the algorithm of Caliendo and Parro (2015). I make two adjustments: I do not need to consider how tariffs affect the expenditure function, and my measure of welfare does not need to consider tariff revenue.

4.3 | Parameters of the transportation model

The department-port gravity equation (25) does not allow me to estimate the parameters that determine the dispersion of productivity of the shipping routes by sector, θ_k. To see this, consider the standard assumptions in international trade and economic geography models regarding the relationship between department-port shipping costs, τ_{dp}, and the travel time from the department to the city-port, T_{dp}.

$$\tau_{dp} = \exp(\beta_{time} T_{dp}) \tag{28}$$

where $T_{d\rho}$ is the travel time between department d and ρ and β_{time} is the parameter that defines the relationship between the department-port shipping costs of a route $\tau_{d\rho}$ and the travel time between department d and city-port ρ. By inserting this expression in the department-port gravity equation (25), and taking logs I obtain

$$\ln(X_{dRoW,k,d\rho}) = \alpha + \alpha_{d,exporter} + \alpha_{d,importer} + \alpha_{RoW,exporter} + \alpha_{RoW,importer} \tag{29}$$

$$+\alpha_{\rho} - \mu_{t,k}(T_{d\rho}) + \epsilon_{d\rho}$$

where $\mu_{t,k} = \theta_k \beta_{time}$, and T_{dp} is the travel time between department d and city-port ρ. The terms $\alpha_{d,exporter}$ and $\alpha_{d,importer}$ are department fixed effects, specifically for the cases when a department is exporter or importer, respectively. The variables $\alpha_{RoW,exporter}$ and $\alpha_{RoW,importer}$ are fixed effects when the RoW is exporter or importer, respectively. Moreover, α_{ρ} represents the city-port fixed effects. Using this structural regression, I get an estimate of $\mu_{t,k}$. Given that I cannot estimate separately the parameters β_t and θ_k, I use the value of β_{time} from previous literature. Specifically, I use the value reported by Allen and Arkolakis (2019). I elaborate about the value of this parameter in section 4.5.

4.4 | Estimation of gravity equation

Although it is possible to use OLS to estimate $\mu_{t,k}$ using (29), there are concerns about the presence of endogeneity given the existence of unobservables correlated with both the travel time between a department d and city-port ρ and the international trade flows between such pair, $X_{dRoW,k,d\rho}$. Consider that $\epsilon_{d\rho}$ represents a bilateral cost/demand shifter of the international trade flows using the route $r_t = (d, \rho)$. The main source of endogeneity is the fact that the Colombian national government could target the pair department city-port, (d, ρ), through infrastructure policies that affect both the demand/cost shifter of international trade flows, $\epsilon_{d\rho}$, and the travel times $T_{d\rho}$.

To solve this endogeneity issue, I use an instrumental variable approach. This approach requires a valid instrument $Z_{d\rho}$. The instrumental variable needs to be relevant, $E[Z_{d\rho}T_{d\rho}] \neq 0$, and exogenous, $E[Z_{d\rho}\epsilon_{d\rho}] = 0$. I consider two instrumental variables: the distance between ports and capitals of departments using the road network of Colombia in 1938, and the distance between city-ports and the capitals of departments using the 17th-century colonial roads of the Viceroyalty of New Granada. These instrumental variables are similar to the ones used by Duranton (2015) to analyze the domestic trade between Colombian cities. I discuss the validity of the instrument below. Duranton, Morrow, and Turner (2014), Baum-Snow (2007), and Michaels (2008) also use a similar approach.

The road network of 1938 served specific regional purposes because railroads played a major role in the transportation of goods. Therefore, the transportation policies implemented by the Colombian national government focused on the expansion of the railroad network (Pachon and Ramirez, 2006; Alvear-Sanin, 2008). Also, as Duranton (2015) pointed out, the road infrastructure did not serve international trade purposes. For example, the two most populated Colombian cities (Medellin and Bogota) did not have a road connection to the Atlantic seaports (Appendix C contains images of the historical maps).

Duranton (2015) describes with detail the characteristics of the colonial road network (*caminos reales*). Some of the *caminos reales* were used by the indigenous tribes that lived in the country before the Spanish colonizers arrived. They mainly consisted of trails and paths used by the Spanish colonizers to travel to the interior of Colombia. To travel along these trails, it was necessary to use mules. Therefore, Duranton (2015) argues that internal trade was very small within colonial towns. Moreover, the first census implemented in Colombia at the beginning of the 19th century (two centuries after the colonial routes were established) indicates there were less than 2.4 million people in the country (DANE, 2019).[20] According to the 2018 census generated by DANE, Colombia had a population of 48.2 million persons. To sum up, the economic conditions that lead to the establishment of the colonial routes were very different, relative to the current economic circumstances that define which city-port a department uses to trade with the rest of the world.

The distance using an old road network is correlated with the travel times using the current road network, given that it is easier and less costly to build new roads using existing old paths or roads, relative to constructing new roads using new land. The exogeneity of my instrumental variables comes from the fact that given the economic conditions that explain the structure of the old road networks, it is highly likely that the current demand/cost shifters of the trade flows for a pair department city-port, (d, ρ), are uncorrelated with distance using old road networks, given that these network were built when the structure of the Colombian economy was different. In the 17th century, domestic trade in the country was relatively small. During 1938, Colombia was mainly an agricultural economy. Given that for some department-port pairs, there is not a connection in the old road networks, I created two categorical indices based on the estimated road distances between locations using Dijkstra's algorithm, one for each road network.

Table 2 reports the results of my estimation, combining both instrumental variables. There is no evidence of weak instrumental variables, given the value of the F-statistic of the first stage (Stock and Yogo, 2005). Moreover, the 2SLS estimates are more precise, compared to the OLS estimates. As a robustness check, Appendix E contains results for the regressions using OLS, 2SLS, LIML methods. For the latter, I show results using 1938 roads as instruments, colonial routes as instruments, and combining both instrumental variables. As the tables in the Appendix E show, the estimates of the instrumental variable regressions do not change depending on whether I use 2SLS or LIML, or depending on whether I use one or two instrumental variables. In the presence of weak instruments the 2SLS estimates would be bias towards the OLS estimates, while the LIML estimates would not, as Angrist and Pischke (2009) point out. Nevertheless, the 2SLS and the LIML estimates are very similar.

TABLE 1 Empirical results of the gravity equation

Method	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Sector	agriculture		mining		manufacturing	
$-\mu_{t,k}(\text{time}_{dp})$	-0.3282	-0.5274	-0.2293	-0.5199	-0.2880	-0.6182
	(0.3410)	(0.0576)	(0.4100)	(0.0642)	(0.3190)	(0.0592)
F-statistic (1st stage)	-	13.94	-	13.94	-	13.94
N	1,026	1,026	1,026	1,026	1,026	1,026
R-squared	0.5430	0.5230	0.4600	0.4180	0.6910	0.6531

Notes: The categorical variables that I use as instrumental variables have a value of 1 if the department and the port are in the same city; a value of 2 if the distance between the locations is 1-300 kilometers for the 1938 road network, and 1-330 km for the colonial road network; a value of 3 if the distance between locations is 300-700 kilometers using the 1938 road system and 330-830 kilometers using the colonial path system; a value of 4 if the distance is larger than 700 km using 1938 roads, or the distance is longer than 830 kilometers using the 17th century roads; and a value of 5 for those locations unconnected using the old road network.

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[20] The first census of Colombia was implemented in 1822, and included the nations of Venezuela, Panama, Colombia and Ecuador, which were part of the former Republic of Colombia.

Given that there is a negative sign multiplying the parameter $\mu_{t,k}$ according to my structural model, then the value of this parameter is positive. Table 2 shows that the magnitude of the OLS estimate is smaller in absolute value, compared to the magnitude of the 2SLS estimate. This implies that any unbservable governments policies that are affecting both exports between department-port pairs and their travel times, are being targeted at regions with large travel times with respect to city-ports (or equivalently, poor infrastructure). This is consistent with the evidence provided by Pachon and Ramirez (2006) and Alvear-Sanin (2008) regarding infrastructure policies in Colombia.

4.5 | Estimation of the parameter of elasticity of substitution of shipping routes

To obtain estimates of the parameters $\theta_k \forall k \in \{a, m, i, z\}$, I use estimates of β_{time} from Allen and Arkolakis (2019). The authors consider the function $\tau_{nj} = exp(\beta_{time} T_{nj})$ in their estimation procedure, where T_{nj} is the travel time between locations n and j. They report $\beta_{time} = 0.08$ for a trade elasticity $\sigma = 9$. If I use the elasticity of substitution $\sigma = 6$, then $\beta_{time} = 0.13$. I report my estimates of the parameter θ_k in table 3.

A potential concern is that the estimate of β_{time} comes the context of the American network road system. The empirical evidence of Atkin and Donaldson (2015) shows that the relationship between intra-national trade costs and distance/travel times is very different in developing countries (Ethiopia and Nigeria) relative to the United States.

Although this may represent a concern, there is a caveat. First, data from the World Bank suggests that for the year 2012, Colombia's quality of infrastructure for trade and logistics was much higher compared to the African countries analyzed by Atkin and Donaldson (2015)[21]. This suggests that, even though the values for the parameter β_{time} may not be the same for the United States and Colombia, their differences must be much smaller than the reported by Atkin and Donaldson (2015) between the two African countries and the United States.

As a robustness check, I run my counterfactuals with higher values of β_{time}. Specifically, I consider that the parameter can be 10% and 20% higher than the one from Allen and Arkolakis (2019) as it is shown in table 3. I assume this given that it could be the case that the impact on the iceberg trade costs is much larger for developing nations, compared to the U.S. For the purpose clarity, Appendix H contains graphs on how the values of the parameters θ_a, θ_m and θ_i change the size of the reduction of trade costs between Colombian departments and the rest of the world for different sectors when *Ruta del Sol* is completed As the value of β_{time} increases, the reduction in these trade costs is larger. Hence, by using the parameter value of Allen and Arkolakis (2019) in my simulations, $\beta_{time} = 0.13$, I am being conservative on my estimates of the reduction of trade costs due to the completion of *Ruta del Sol*.

To interpret the magnitudes of the estimate of the parameter θ_k, it is necessary to recall that it represents the shape parameter of the Frechet distribution. Economically, it represents the dispersion of the productivities of the international shipping routes (or equivalently, the dispersion of productivities of the city-ports). A high value for θ_k implies low heterogeneity in the productivity of the city-ports to export a good from sector k. A low value, represents high heterogeneity in the productivities of the city-ports.

Given the values that I report in Table 3 for the estimates of the parameter $\theta_k \forall k \in \{a, m, i, z\}$, this implies that for all three sectors, the city-ports show high levels of heterogeneity in their productivities. Intuitively, this implies that firms within a department tend to choose different city-ports to export and import goods from the rest of the world. This is

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[21] In 2012, Colombia ranked 64th in the Logistics Performance Index of the World Bank (there are 168 positions). Ethiopia and Nigeria's positions were 141 and 118, respectively. The United States ranked 4th.

consistent with Empirical Fact 4. From a theoretical perspective, this implies that according to the specialized traders in the transportation model, the city-ports have a high elasticity of substitution.

TABLE 2 Values for θ_k for different values of β_{time}

Parameter	$\theta_{agriculture}$	θ_{mining}	$\theta_{manufacturing}$
Values when $\beta_{time} = 0.13$ (Allen and Arkolakis, 2019)	4.06	4.00	4.76
Values when $\beta_{time} = 0.143$ (10% higher than baseline)	3.69	3.64	4.32
Values when $\beta_{time} = 0.156$ (20% higher than baseline)	3.38	3.33	3.96

Notes: To obtain the values of θ_k, I use the estimates of $\hat{\mu}_{t,k}$ shown in Table 2 for every sector $k \in \{a, m, i, z\}$ and the value of β_{time} from Allen and Arkolakis (2019). Then, I adjust the value of β_{time} upwards.

5 | THE IMPACT OF *RUTA DEL SOL* ON COMPARATIVE ADVANTAGE

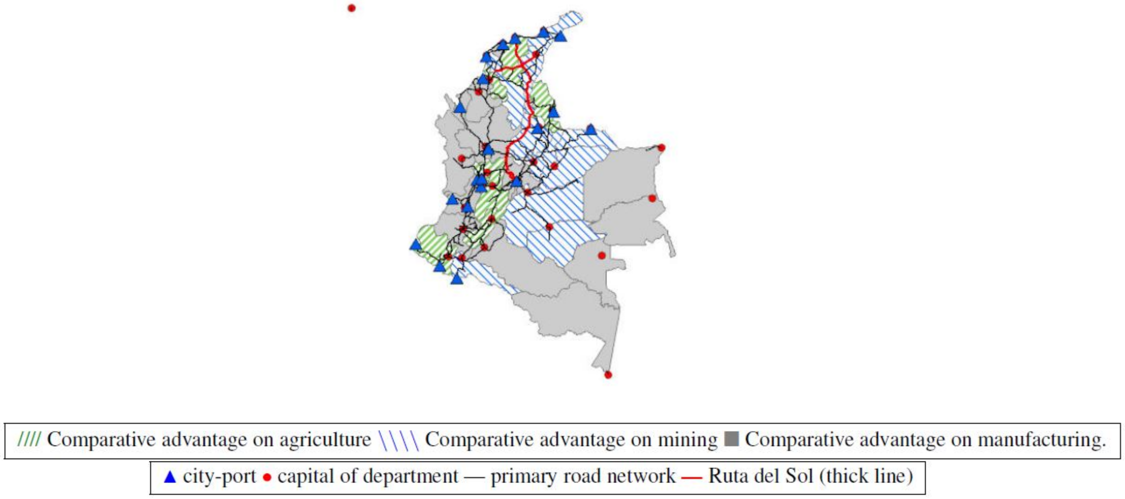
5.1 | Context of the road project to understand the potential export impacts

I evaluate the effects of the construction of the infrastructure road project *Ruta del Sol*. The project consists of the construction, renovation, and expansion of lanes for 1,071 kilometers of the primary road system. The objective of the highway is to improve the connectivity between the center of the country and the Atlantic Ocean seaports. There was an unsuccessful attempt to start construction in 1997. A decade later, the Colombian government made a second attempt to start the project in 2009.

The project consists of three segments, *Ruta del Sol I, II*, and *III*. The bidding process occurred in 2009, and contracts were negotiated and signed the following year (INCO, 2010a; INCO 2010b and INCO 2010c). The beginning of the construction for different segments started in the period 2010-2011. The project has faced multiple delays in its completion, but many sub-segments were inaugurated during the period 2014-2019 as the local media reported (El Espectador, 2019; La Republica, 2014, Semana 2019). As of 2020, all three major segments remain incomplete (El Tiempo, 2020).

To measure the effects of the infrastructure project on travel times, I create a road network that includes improvements in the segments that already exist and those segments not built yet. I consider that after the completion of the project, the speed of the roads improves from 80 km/hour (approximately 50 miles/hour) to 100 km/hour (approximately 60 miles/hour). The latter is the same speed that Allen and Atkin (2016) use for highways in India. I chose a small positive change in speed derived from the completion of the project for the existing road segments for two reasons. First, I focus on higher speed since one of the main objectives of the project is to guarantee the existence of two lanes for every direction along the highway. This improvement particularly benefits trucks, by increasing physical maneuverability, particularly in the areas where the highways cross hilly regions. Such improvement has a direct impact on the speed of all vehicles, but I assume the increase in speed to be smaller for trucks, which are the main vehicles used for cargo. Second, the choice of a very small change in the speed suggests that, if in some sub-segments of *Ruta del Sol* the increases in speed are much larger, then my estimate regarding the impacts of the road project on the national comparative advantage are a lower bound.

FIGURE 8 Location of the project *Ruta del Sol* and comparative advantage of Colombian departments (measured with the Balassa Index)

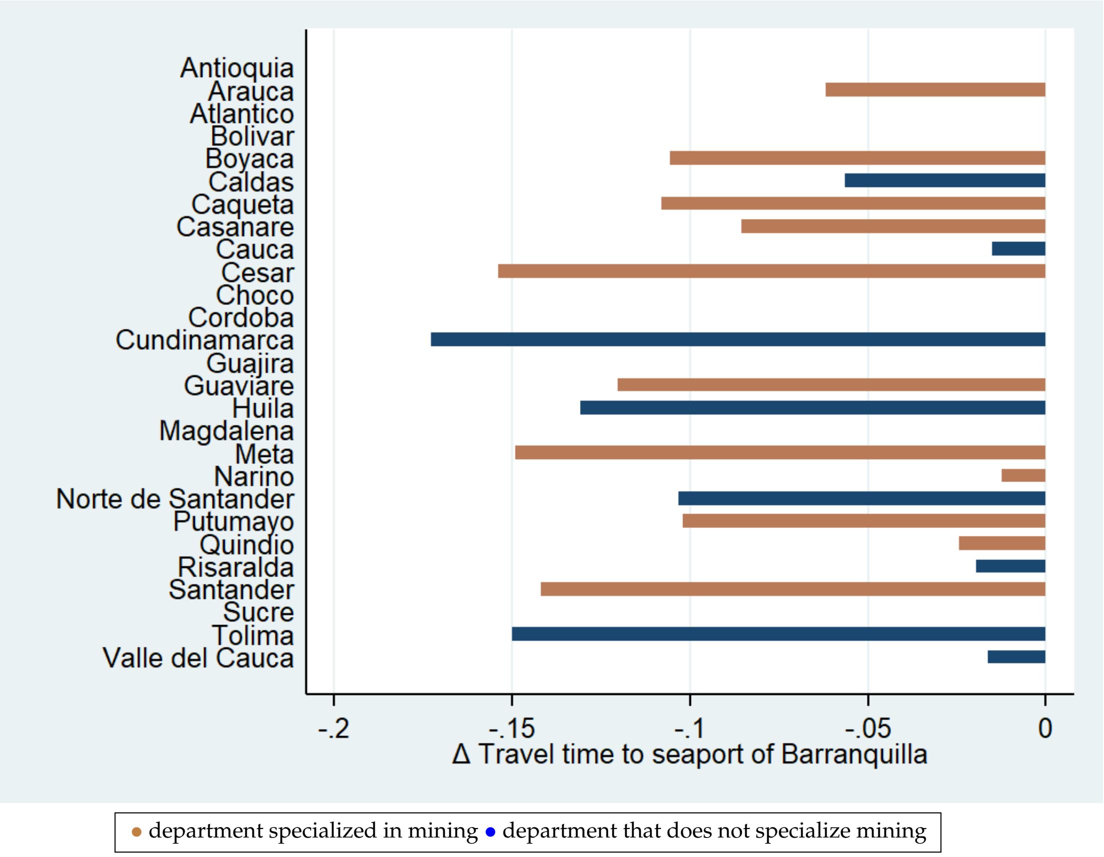


Notes: The colors/figures that fill the area of every department show the sector with highest value of the Balassa index. The red dot outside the mainland of the country is a city in the island of San Andrés, in the department of San Andrés y Providencia.

A priori, the effects of *Ruta del Sol* on the comparative advantage of Colombia are unclear. Figure 8 shows that the road crosses regions that specialize in different sectors. The project improves the connectivity between the department of Cundinamarca, which specializes in manufacturing, and the Atlantic seaports. But it also reduces the travel times between departments that specialize in mining and the same seaports. The graphs in Appendix F show that the international trade costs τ_{dRoW} fall for several departments and all tradable sectors, according to the predictions of my framework.

There are two major policy changes that could be relevant for my results, because they occur around the same years as the beginning of the construction of *Ruta del Sol*: the beginning of the implementation of a free trade agreement with the United States, and the start of the process to access the OECD. The first issue does not represent a problem, given that the main goods purchased by the United States from Colombia are mineral fuels, agricultural goods, and metals (Office of the United States Representative, 2021). These goods are part of the "traditional" exports of Colombia (see Fact 1). The second policy change does not represent an issue either due to the choice of base year I selected, 2013. Around that year the OECD and Colombia had discussions regarding the membership, the OECD set up the terms for the OECD accession, and technical accession discussions occur between the multilateral organization and Colombia. The Colombian government signed official documents with the OECD until 2014, and such legal agreements were ratified by the Congress the same year (OECD, 2021).

FIGURE 9 Reduction in travel distance between department and seaport of Barranquilla (%)



Notes: The change in travel times is measured as a fraction of the original travel times, without Ruta del Sol. I calculate the specialization of every department with the Balassa Index. I estimate the travel times between the capital of each department (shown in the vertical axis) and the city-port of Barranquilla (the city has a seaport and an international airport) for a baseline scenario and a new scenario. For the baseline, I assume that the existing segments that already exist (but will be improved) have a speed of 80 km/h. For the scenario in which the project is completed, these existing segments will have a speed of 100 km/h. In addition, I include the planned new segments. Thus, the new scenario, in which the road project is completed, includes both the new and the improved road segments of *Ruta del Sol*.

5.2 | Relevance of the parameter that defines relationship between trade costs and travel times

A potential concern regarding the evaluation of the effects of new infrastructure on sectoral exports is the choice of the value of β_{time}, which comes from the American road system. The value of the parameter affects the results given that it determines how changes in travel times in the Colombian primary road system lead to changes in domestic and international trade costs.

Although I do not have the true value of β_{time} for Colombia, there are reasons to believe the value of this parameter is higher in Colombia compared to the United States. This idea is supported by the empirical evidence of Atkin and Donaldson (2015), which suggests that travel times have a larger effect on trade costs in developing nations, relative to the United States' context. As a robustness check, I report how the completion of Ruta del Sol impact the trade trade costs between departments and the rest of the world for different values of β_{time}, for all three major sectors (agriculture, mining, and manufacturing). These results are in Appendix H. The graphs of this appendix illustrate that using the value of β_{time} from Allen and Arkolakis (2019) leads to conservative estimates regarding the reduction of trade costs caused by the completion of *Ruta del Sol*.

5.3 | Quantifying the impact of the completion of *Ruta del Sol* on the comparative advantage of Colombia

In this subsection, I provide some a short description of the calibration and the counterfactual simulations of the model, and I describe the results from my simulations regarding the impact of *Ruta del Sol* in the shares of manufacturing sector of Colombia.

I use mostly data 2013 to calibrate and solve the model, with some exceptions due to data availability. All my data comes from periods before the inauguration of segment I of *Ruta del Sol* in 2014. In the simulations, I model the change between two equilibria: from the state of the Colombian national road system in 2012 to how the entire road system would look like if all three segments of *Ruta del Sol* were completed (the year 2012 is the closest year for which I have official road maps from the Ministry of Transportation of Colombia).

Following Caliendo and Parro (2015), first I calibrate my model using my deficit data for all locations, and then I solve the model by imposing a zero aggregate deficit. This no-deficit economy will be considered my base year for all simulations. I do this because in the model, changes to transportation costs do not affect the size of the trade deficits, given that the deficits are treated as exogenous. [21].

I report the effects of my simulations on the share of agricultural, mining, and manufacturing exports in table 4. As I mentioned before, for small open economies and aggregated sectors, the share of exports for a specific sector is a good proxy to measure shifts in the comparative advantage of a country in a specific sector (this share is the numerator of the Balassa index of Revealed Comparative Advantage).

I implement my simulations under different values for the share of expenditures of departments on their own goods for the case of domestic trade of Colombian departments, ν_{dd}, and for different values of the parameter that relates the travel times and the trade costs, β_{time}. It is important to highlight that ν_{dd} represents how open or closed these departments are with respect to other departments, in terms of the purchases of tradable goods [22]. Moreover, in the main counterfactuals of the following sections of the paper, I focus on the results using the most conservative estimate of β_{time}.

TABLE 3 Results of the simulations under different parameters

Row	Simulation	ν_{dd}	β_{time}	Change in the share of agricultural exports	Change in the share of mining exports	Change in the share of manufacturing exports
1	Completion of Ruta del Sol (departments buy a higher amount of tradable goods from other departments)	0.25	0.13	-0.8%	-2.1%	2.9%
2	Completion of Ruta del Sol (departments buy a lower amount of tradable goods from other departments)	0.4	0.13	-0.7%	-1.9%	2.6%
3	Completion of Ruta del Sol (departments buy a higher amount of tradable goods from other departments)	0.25	0.143	-1.5%	-3.0%	4.6%
4	Completion of Ruta del Sol (departments buy a lower amount of tradable goods from other departments)	0.4	0.143	-1.4%	-2.6%	4.0%

Note: ν_{dd} is the share of expenditures of a department in its own goods for the agricultural and manufacturing sector (only considering the domestic trade flows). The base year for all simulations is a deficit-zero economy, which was previously calibrated with non-zero deficits, as in Caliendo and Parro (2015)

Under different values of the parameters that govern the trade and transportation framework, the results are similar: the infrastructure project *Ruta del Sol* leads to a higher share of manufacturing exports, even though it increases the connectivity of several mining

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[21] Caliendo and Parro (2015) describes the simulation details of their method regarding trade deficits in pages 19 and 20

[22] See section 4 "Taking the model to the data" for more details

departments, as Figure 9 illustrates. Interestingly, the share of agricultural exports falls, even though Cundinamarca and Bogota export a quarter of the total agricultural exports of Colombia and they are one of the main direct beneficiaries of *Ruta del Sol*.

It is key to notice that as the value of β_{time} increases, the shift of Colombia's comparative advantage towards the manufacturing sector becomes larger (compare rows 3 and 4 vs. rows 1 and 2 in Table 4). This implies that if *Ruta del Sol* reduces the trade costs between departments and the rest of the world by more than I estimate (which is likely, as I discussed in section 5.2), then the road project would generate a larger change in the national comparative advantage.

5.4 | Why my estimates are a lower bound

There are reasons to suggest that the previous estimates are a lower bound. These include the fact that the model overestimates the impacts of roads in the transportation of the mining sector; recent findings regarding how road infrastructure improvements increase competition in the transportation sector; the fact that I assume that *Ruta del Sol* has a relatively small positive impact on the speed of vehicles; the conservative value of the paramater that relates travel times with trade costs β_{time}, and the assumption of immobile labor that I implement due to data restrictions on migration flows department - world, which prevents regions to take advantage of lower wages when they experience an immigration wave due to an export boom.

First, I allow the improvement in the national road to impact the movement of mining goods from departments to ports of trade. Nevertheless, the main mining export goods of Colombia, coal and oil, tend to use extensively other methods of transportation such as railroad or pipelines (Allen, et al 2020; Alvear-Sanin, 2008; Pachon and Ramirez, 2006; McRae, 2017). Therefore, it is more likely that road improvements benefit more the transportation of agricultural and manufacturing goods, relative to the transportation of mining goods. Given that in the model, the impact of the improvements of roads in the department-port shipping costs $\tau_{d\rho}, \tau_{\rho d}$ is assumed to be the same for all sectors (see equation 28), this suggests that the model overestimates the impacts of roads in the mining exports of Colombian departments.

A second reason is that recent literature suggests that improvements in roads lead to higher competition between transportation firms, as Allen, et al (2020) suggest for the case of Colombia. My general equilibrium model abstracts from these impacts, since they are beyond the scope of the paper. If the completion of *Ruta del Sol* would also decrease the markups of the transportation services from the interior departments to the coast, then my model's results do not include the benefits of the reduction in the price of shipment of goods caused by a more competitive transportation industry.

A third reason is the change in speed used in my estimation is relatively small. It is likely that in some sections of *Ruta del Sol*, the increases in speed will be much larger than 10 miles per hour. This is due to two factors. Firstly, several sections of the road include the construction of doubles lanes on existing road sub-segments that currently only have one lane. Secondly, the design of the road includes tunnels and bridges that will make it easier to travel along hilly regions of Colombia (parts of the infrastructure project are built over Colombia's Oriental Mountain Range or *Cordillera Oriental*).

The fourth reason to believe the results are a lower bound is that I use a conservative value of the parameter that defines the relationship between travel times and trade costs, the one β_{time} reported by Allen and Arkolakis (2019), which is for the United States. As I discuss in section 5.2, this is a conservative estimate and it is likely that its value is higher for developing nations. As the graphs in Appendix G show, a larger value of β_{time} would translate into a much higher reduction of trade costs.

Lastly, due to different issues mentioned in section 3.1, including data restrictions regarding bilateral migration flows between departments and rest of the world, I assume workers do not move across locations. Therefore, if a department experiences an export boom caused by road improvements, it will also experience a rise in its total income. The rise in the department's income would lead to a positive wage growth, and this would cause higher production costs, thus ameliorating the size of the export boom. But under a different model in which workers can move across Colombian departments, an immigration wave to the department experiencing an export boom would counteract the rise in wages and production costs. Hence, I expect the size of the export boom to be much larger if I relax the assumption of labor spatial immobility. Moreover, as I show in the sections regarding the mechanisms, the shift in the comparative advantage of Colombia in the simulations occur because the interior departments[23] experience a large manufacturing export boom (mainly Cundinamarca-Bogota). With worker mobility across regions, I would expect the manufacturing export boom in the interior departments to be larger.

5.5 | Mechanisms: the role of industry linkages and the structure of the road system

To understand the forces driving the shift of the comparative advantage of Colombia towards manufacturing, I analyze the increase in the share of manufacturing exports under different counterfactual scenarios that consider separately the road network effects of *Ruta del Sol*, with and without input-output linkages.

In the first alternative counterfactual (Figure 5, row 2), I close the input-output linkages but I allow for the impact of the road infrastructure project on both domestic and international trade costs (see equation 5). This implies that firms producing intermediate goods exclusively use labor as input. The second alternative counterfactual (Figure 5, row 3) allows for the existence of input-output linkages, but only takes into account the effects of *Ruta del Sol* on the domestic trade costs. Lastly, I run a third alternative counterfactual simulation (Figure 5, row 4), in which I consider industry linkages, but I assume the road project only affects international trade costs, and it does not change domestic trade costs.

TABLE 4 Results of alternative simulations

Row	Simulation	Increase in the share of manufacturing exports $(\bar{\mu}_{dd} = 0.3\,, \beta_{time} = 0.13\,)$
1	**Main simulation: All the effects of *Ruta del Sol***	+2.9
2	Impacts of *Ruta del Sol* without IO linkages	+2.4
3	*Ruta del Sol* only reduces trade costs between departments and RoW (with IO linkages)	+1.8
4	*Ruta del Sol* only reduces trade costs between departments (with IO linkages)	+0.8

Note: The simulation without industry linkages (IO linkages) considers that to produce intermediates, only labor is used, and no materials are used. In equation 5, this is equivalent to assume that $\beta_n^{l,k} = 1$. When I use the Balassa index for Colombia, the share of exports of a sector is a good proxy of its comparative advantage, since the denominator of the index is given for a small open economy and if the sectors are not very disaggregated. ν_{dd} is the share of expenditures of a department in its own goods for the agricultural and manufacturing sector (only considering the domestic trade flows). The base year for all simulations is a deficit-zero economy, which was previously calibrated with non-zero deficits as in Caliendo and Parro (2015).

The alternative simulations provide insights about the forces driving my results. The first insight is the access to foreign intermediates is key for the increase of manufacturing exports. In the third row, I consider that *Ruta del Sol* only benefits trade between Colombian departments, but the industry linkages are still present. As a result, the national share of manufacturing exports still increases, but by a small amount, 0.8 percentage points.

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[23] The interior departments in Colombia are those that do not have an Atlantic coast

Nevertheless, notice that if *Ruta del Sol* only benefits trade between Colombian departments and the rest of the world, then the growth in the share of manufacturing exports is much larger (Figure 5, third row). This suggests that access to foreign intermediates is key for the shift of comparative advantage towards manufacturing.

The second insight is that the existence of industry linkages increases the shift of comparative advantage generated by the road project. The presence of such linkages benefit the manufacturing sector the most. To see this, notice that in the second row, when the input-output linkages are not considered, the reductions in trade costs lead to an increase in the comparative advantage of Colombia in manufacturing goods, but this growth is smaller than the increase from the main counterfactual (first vs. second row).

These counterfactuals show the relevance of industry linkages when we measure the impact of road projects, using general equilibrium models. These linkages are not usually considered in existing studies regarding the effects of infrastructure improvements. Failure to consider these linkages will result in a biased estimation of the impacts of lower trade costs on trade flows for specific sectors.

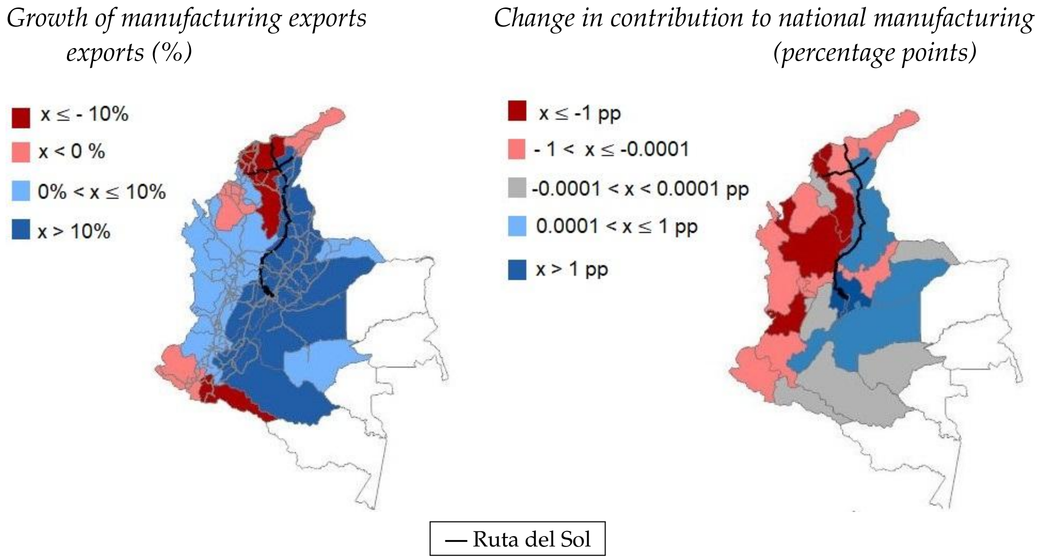
5.6 | Spatial effects of Ruta del Sol

To complement the results from the alternative counterfactuals, the following two maps in Figure 10 display the simulated impact of *Ruta del Sol* on the manufacturing export activity across Colombian departments for the main counterfactual with parameters $\beta_{time} = 0.13$, $\nu_{dd} = 0.25$. The table with the data used in the maps is available in Appendix I. There are two interesting patterns. The first one is that the contribution to Colombia's manufacturing exports of Bogota and Cundinamarca increases substantially as the map in the left of Figure 10 shows. Together, their export share increases by 11.3 percentage points, while the other two main manufacturing departments, Valle del Cauca and Antioquia, reduce their contribution to the manufacturing exports by 4.6 and 1.2 percentage points, even though their manufacturing export activity also grows. This is partially explained by a much larger growth in the manufacturing exports of Bogota and Cundinamarca.

A second pattern is that the manufacturing export activity across all sectors moves away from the northwest where the Atlantic coast is, towards the interior departments of Colombia. This also occurs for the agriculture and mining sectors (see maps in Appendix I). This pattern shows that the reduction of trade costs between interior departments and the Atlantic seaports caused by *Ruta del Sol* shifts spatially the export activity. Hence, *trade liberalization* caused by the infrastructure project generates a geographic reorganization of exporting activity for two types of departments: the ones connected by the road, and departments located in the south and east of the road, in the interior of Colombia. This is consistent with the existence of road network spillovers of Ruta del Sol.

Lastly, Figure 11 shows a map with the welfare estimates derived from the main counterfactual. The table with the data used in this map is in Appendix J. Some departments experience slightly welfare losses (less than 2%), but around sixteen departments experience substantial welfare gains, between 1.8 and 12.3% , especially those along the road. Again, the network effects are present since several departments located to the south and the east of *Ruta del Sol* experience welfare gains. An interesting pattern is that many departments in the Atlantic Coast have large welfare gains (higher than 7%), even though their export activity fell. This could be partially explained by the growth in the access to cheaper goods from the interior of Colombia.

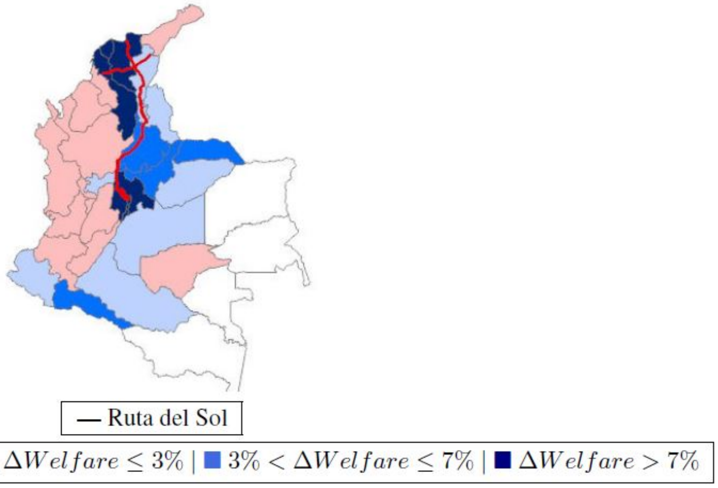
FIGURE 10 Impact of Ruta del Sol on manufacturing export activity


Growth of manufacturing exports exports (%)

Change in contribution to national manufacturing (percentage points)

Notes: (1) Even if a department experiences very large growth in its mining exports, it could be the case that its contribution to the national mining exports is very small, hence their contribution to national shares of mining exports changed by less than 0.001 percentage points (2) Results from the main counterfactual. The value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that establishes the relationship between trade costs and travel time is a conservative value, $\beta_{time} = 0.13$.

FIGURE 11 Impact of Ruta del Sol on welfare of Colombian departments



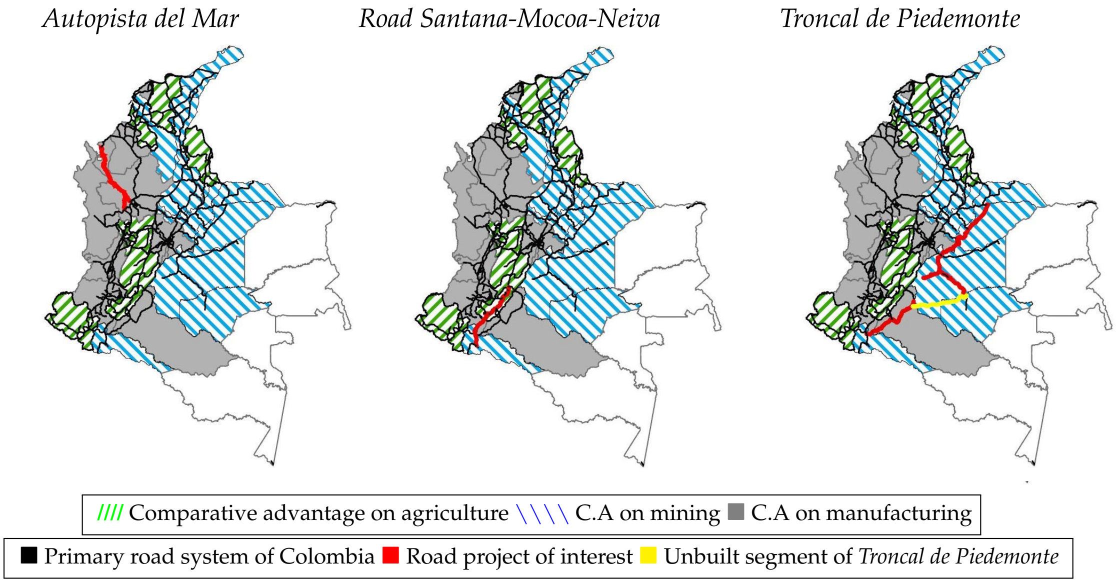
Notes: Results from the main counterfactual where the value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$, and the value of the parameter that defines that relationship between trade costs and travel time is a conservative value, $\beta_{time} = 0.13$.

5.7 | Quantifying the impact of other road projects on Colombia's comparative advantage

I measure quantitively the impact of three important road projects on the comparative advantage of Colombia: (i) *Autopista del Mar* (connects the second largest city of Colombia with the Atlantic coast), (ii) *Road Santana-Mocoa-Neiva* (southern part of National Route 45, a backbone of the primary road system), and (iii) *Troncal de Piedemonte* (also known as National Route 65). The projects I consider are policy relevant, since they are part of the most recent large infrastructure plan of the Colombian government called 'Plan Maestro de Transporte Intermodal" or Master Plan of Multimodal Transportation, proposed in 2015 (Fedesarrollo, 2015).

Two of these roads have been planned since the 1950s. The completion of Autopista del Mar and the segment Santana-Mocoa-Neiva was suggested by a World Bank mission lead by economist Lauchlin Currie in the 1950s (Alvear-Sanin, 2008). The entire construction of Troncal de Piedemonte would imply the completion of Route 65, a backbone road that would mainly benefit isolated southern regions. I show the location of these three road projects in Figure 12. Regarding the simulations, for the cases of *Autopista del Mar* and *Road Santana-Mocoa-Neiva*, I assume that the speed in these two roads improves from 80 km/h to 100 km/h. For the case of *Troncal de Piedemonte*, I consider construction of new segments and that all the segment has a speed of 80 km/h. The reason I made this distinction is because a very large segment of *Troncal de Piedemonte* has not been built yet due to geographical characteristics (tropical forest with high altitude). For this segment, there is neither a rural road nor a unpaved road.

FIGURE 12 Location of road infrastructure projects in Colombia



Autopista del Mar *Road Santana-Mocoa-Neiva* *Troncal de Piedemonte*

//// Comparative advantage on agriculture \\\\ C.A on mining ■ C.A on manufacturing

■ Primary road system of Colombia 🟥 Road project of interest 🟨 Unbuilt segment of *Troncal de Piedemonte*

In table 5, I provide the results from the simulations for each road. There are two interesting patterns found in the outcomes of the simulations. First, Autopista del Mar, a road that improves the transportation infrastructure between Medellin and the Atlantic coast, can increase Colombia's comparative advantage in manufacturing more than Ruta del Sol. Second, there exist infrastructure projects that can push the national comparative advantage towards mining, such as Road Santana-Mocoa-Neiva, and Troncal de Piedemonte.

The fact that Autopista del Mar can increase the comparative advantage of the nation in manufacturing relies on two factors: location and road network effects. First, it benefits Medellin, one of the main manufacturing hubs in Colombia. Second, the road is located in the western part of the country. As we can see in figure 12, the network effects seem to be concentrated among the western departments, given that the regions south of the road get better access to the Atlantic coast.

Similarly, the roads Santana-Mocoa-Neiva and Troncal de Piedemonte benefit the mining sector due to same two reasons as the previous case: geographical location and small road network effects on non-mining departments. The first reason is that the road projects are in the eastern region of Colombia, where departments with comparative advantage in mining are located. We can observe this in figure 12. A second reason is that roads located in the east seem to have small road network impacts on non-mining departments. As we can notice in the figure, the departments with comparative advantage in manufacturing and agriculture are located west of the road projects, and most of the exports sent abroad use the seaports located to the west and north of these agricultural and manufacturing departments.

5.8 | Heterogeneous impacts on the manufacturing sub-sectors

To complement the previous results, I analyze the impacts of the four infrastructure projects mentioned above on different manufacturing sub-sectors. To do so, I modified the existing model and re-estimate most of its parameters: instead of having a representative manufacturing sector, the model now has a total of eight sectors: three large sectors (agriculture, mining, and services) and five manufacturing sub-sectors (food industrialized products, non-metal basic manufacturing, electrical goods, mechanical products and machinery, chemical products, and metal basic manufacturing). The objective of these simulations is to find the manufacturing sub-sectors that are more sensitive to changes in the national road network. I particularly focus on the relative contribution of each manufacturing sub-sector the growth or fall of national comparative advantage in manufacturing.

TABLE 5 Impact of different road projects in the comparative advantage of Colombia

Simulation	Change in the share of agricultural exports (percentage points)	Change in the share of mining exports (percentage points)	Change in the share of manufacturing exports (percentage points)
Ruta del Sol	-0.7	-1.7	2.4
Autopista del Mar	-1.1	-4.1	5.1
Road Santana-Mocoa-Neiva	-0.8	3.1	-2.4
Troncal de Piedemonte	-0.2	10.2	-10.0

Note: All the simulations consider the main model, that includes input-output linkages. The value of the parameter that defines the share purchases of a department of goods produced by itself is $\mu_{d\,d} = 0.5$. The value of the parameter that defines the relationship between travel times and trade costs is $\beta = 0.13$. For the roads Autopista del Mar and Road Santana-Mocoa-Neiva, I assume the entire segments increase their speed from 80 km/h to 100 km/h. For Troncal de Piedemonte, I assume that the unbuilt segment is constructed and that the entire road has a speed of 80 km/h.

The results of the simulations are in table 6. There are two caveats to such results. First, the input-output linkages will change compared to the main model. The reason for this is that each manufacturing sub-sector in the new model uses both labor and intermediate inputs from other sectors differently, compared to a representative manufacturing sector in the main model I used for my simulations. That is, the parameters of the production function of each manufacturing sub-sector are different from the parameters of the production function of a representative manufacturing sector, (see equation 5). For example, the share of value added in a representative manufacturing sector is 0.30, but for the different manufacturing sub-sectors in the new model, the value of this parameter can be between 0.22 and 0.38, depending on the manufacturing sub-sector. On a similar fashion, the contribution of the agricultural sector intermediate goods to the production of manufacturing goods is 0.13 in the original model, but the value of this parameter in the new model with different manufacturing sub-sectors can be between 0.00 and 0.36, depending on the sub-sector. It is important to highlight that I made an exception regarding the re-estimation of the parameters in the new model. I assumed in the new model with eight sectors that the elasticity of substitution between ports, θ_k is the same across all manufacturing sub-sectors. Hence, it is important to be careful in the interpretation of the size of the changes in the share of sectoral exports. Given this, I focus on comparing the relative contribution of each sub-sector relative to the rest of the manufacturing activities.

In table 6, I provide the results of my simulations. Compared to the results of the main model for the four different road projects displayed in table 5, the sign of the growth in the share of manufacturing national exports is the same in each road project. For example, both *Ruta del Sol* and *Autopista del Mar* increase the total share of national manufacturing exports thus shifting the national comparative advantage towards manufacturing, while the road projects in the isolated regions of Colombia, *Santana-Mocoa-Neiva* and *Troncal de Piedemonte*, reduce the total share of manufacturing exports, reinforcing the comparative advantage of Colombia in the primary sectors. Moreover, the relative size of the effects is also consistent with the results of the main model. The project *Autopista del Mar* increases the national share of manufacturing exports more than the project *Ruta del Sol*. In a similar fashion, the road *Troncal de Piedemonte* reduces the share of national manufacturing exports more than the road *Santana-Mocoa-Neiva*. The main difference between these results and the ones coming from the main model are the size of the impacts on the manufacturing shares. In all cases, the changes in the share of national manufacturing exports are smaller compared to those in the main model (table 5).

TABLE 6 Change in the sectoral share of total exports (percenatege points)

Simulación	**Agriculture**	**Mining**	**Change in share of manufacturing exports**	**Food products**	**Non-metal basic manufacturing**	**Chemical products**	**Metal manufacturing**	**Machinery, electrical and mechanical goods**
Ruta del Sol	-0.83	+0.25	+0.58	-0.003	+0.02	+0.06	+0.37	+0.13
Autopista del Mar	+2.4	-6.02	+3.62	+1.2	+0.79	+0.14	+0.72	+0.76
Santana-Mocoa-Neiva	+0.6	-0.51	-0.09	+0.10	+0.06	-0.04	-0.18	-0.03
Troncal de Piedemonte	+0.40	+4.4	-4.79	-0.18	-0.41	-1.18	-2.65	-0.37

Modelo. Modelo alternativo de ocho sectores con encadenamientos industriales entre todos los sectores. **Supuestos teóricos** Parámetro que define relación entre costos de comercio y tiempos de traslado $\beta = 0.13$. Parámetro de compras de productos locales $\nu_{dd} = 0.5$ El valor de θ_k no cambia entre los diferentes sectores manufactureros **Supuestos prácticos**. Para las carreteras Ruta del Sol, Autopista del Mar y Santana-Mocoa-Neiva, asumo que todos los segmentos incrementan su velocidad en 20km/h (de 80 km/h a 100 km/h). Para Troncal de Piedemonte, asumo construcción de segmento no existente (cercano al Parque Nacional Tinigua) y que toda la carretera tienen una velocidad de 80 km/h.

The impact of the road construction in the different manufacturing sub-sectors is heterogeneous. On one side, two manufacturing sub-sectors seem to benefit substantially, or their reductions in their shares of national exports are relatively small compared to the other sectors. These sub-sectors are non-metal basic manufacturing goods, and the production of machinery, electrical and mechanical goods. Even in the case in which the comparative advantage in mining is reinforced with the construction of *Troncal de Piedemonte* and the project *Santana-Mocoa-Neiva*, these two sectors show either gains or small reductions in their shares of national exports. The manufacturing of food products has a similar behavior as the previous sub-sectors, except for the case of *Ruta del Sol* where it has a very small loss in its share of total exports.

Differently, two sectors seem to gain less from road construction of *Ruta del Sol* and *Autopista del Mar*, and their shares tend to fall the most with the completion of *Troncal de Piedemonte* or the road *Santana-Mocoa-Neiva*: chemical products, and metal manufacturing. The results on both sectors are very interesting. It is noticeable that, with the construction of *Troncal de Piedemonte*, the share of chemical manufacturing exports and metal manufacturing exports falls substantially. This is partially due to the high increase in the share of mining exports, which is an important source of intermediate goods for both of these manufacturing sub-sectors. Data on industrial linkages show that the mining goods contribute substantially to the production of both chemical and metal manufacturing goods in Colombia. This partially explains the reduction in the share of these sectors when a road reinforces the comparative advantage of Colombia in mining: as the mining goods become more expensive due to an export boom caused by *Troncal de Piedemonte*, the unit cost of chemical and metal manufacturing increases.

The previous results provide light on a third mechanism by which changes in the road network of a country shape the national comparative advantage, roads have heterogeneous impacts across manufacturing sub-sectors. The sources of this heterogeneity are multiple: import competition, industrial linkages, and regional impacts of changes in the national road network. This heterogeneity is important to understand how infrastructure impacts the structural transformation of countries. Even if a country accelerates or decelerates its structural transformation towards the manufacturing sector, the transformation will occur it in an uneven way within manufacturing activities.

5.9 | A simple empirical test

I use a event-study framework as an empirical test of the predictions of the model. I consider the beginning of the construction of *Ruta del Sol* as a treatment on the departments where the road is being built (all three sections). I use the following fixed effects regression as a simple empirical test

$$Y_{dt} = \alpha + \delta_d + \gamma \cdot 1[\text{Construction RS}]_{dt} + \epsilon_{dt} \tag{30}$$

where Y_{dt} is the outcome of interest in department d during year t, $1[\text{Construction RS}]_{dt}$ is a dummy variable with value of one if the road is being built year t, but only for the departments where the road is located. I consider the following three variables at a department level in the left hand side : manufacturing output of departments, total departmental exports, and total departmental imports. The estimate of interest is γ and its value represents the correlation between the construction of *Ruta del Sol* and the outcomes of interest.

I use as treatment the start of the construction of the road in 2010 because none of the three segments are complete and granular data regarding the status of the road is not available. Although the construction companies announced they delivered the segments of the road to the Government of Colombia, they remain incomplete by the end 2020. Even if vehicles can transit through, parts of the project are not finalized (El Tiempo, 2020). Given the lack of granular data regarding the status of every segment, the best option is to use as treatment the beginning of the construction of the project. In the absence of a granular analysis as the one of Baum-Snow, et al (2018) or Jing and Liao (2017), the best option is to assume that the start of the construction of the project should generate expectations across Colombian firms regarding a future reduction in the shipping costs from the departments to different city-ports.

I provide the results of the empirical test in table 7. The estimates of γ for all three outcomes have a positive sign, and all but one are estimated with precision. The results suggests that the start of the construction of *Ruta del Sol* is associated with higher manufacturing output, higher exports, and higher imports. It is likely that the true value of $gamma$ is much higher, mainly because there are departments that benefit from *Ruta del Sol*, even if the road is not in their territory, given that for almost all departments outside the Atlantic Coast there is a reduction in the travel times to the coast, as I document in Figure 9.

TABLE 7 Event-study using the start of the construction of *Ruta del Sol* as treatment

	Manufacturing output (billions of Colombian pesos)	**Nominal exports (millions of USD)**	**Nominal imports (USD millions)**
1[Construction RS]	1,501.2	931.0	1,081.3
	(619.9)	(474.9)	(876.0)
Constant	2,847.5	664.2	1,222.2
	(51.7)	(27.1)	(51.1)
Department FE	Yes	Yes	Yes
Obs.	480	561	463
R-squared	0.3	0.1	0.0
Departments	32	32	32

Robust standard errors in parentheses

6 | CONCLUSION

The main conclusion of this paper is that the spatial configuration of domestic trade costs is a determinant of comparative advantage. This idea is especially relevant for those countries with low quality of infrastructure. Quality of roads influence the spatial distribution of trade costs, thus influencing the availability of factor endowments and inputs for the production of goods and services across regions within an economy. Hence, to have a more comprehensive view of the comparative advantage of a country, we need to consider the spatial structure of the road system.

This idea also has policy implications. Infrastructure projects can be a tool for policymakers who aim to shift the comparative advantage of a country. Given that reductions in trade costs lead to welfare gains overall for the country, as recent economic literature predicts, the construction of roads seems to be a feasible policy alternative to change the national comparative advantage.

Specifically, in the context of Colombia, a recent and very important road project, *Ruta del Sol*, can shift the comparative advantage of the country, by strengthening the comparative advantage of the nation in the manufacturing sector. My results indicate that the share of manufacturing exports would grow at least three percentage points in the long run due to the completion of the project. The importance of this magnitude is supported by the fact that in the past three decades, the share of exports for two mining products (coal and oil) has observed a large growth, from 30% in 1992, to 58% in 2018. Besides, the reduction of the concentration of Colombian exports in mining goods is aligned with the objectives of public officials in the country.

According to the simulations of the model, the change in the comparative advantage of Colombia caused by *Ruta del Sol* has two driving forces. First, the road project increases the access to global markets for the department of Cundinamarca and for the central district of Bogota, which already export manufacturing goods. Second, the improvement in the access to inputs benefits the manufacturing firms the most, given the structure of input-output linkages of the country. According to the model results, the construction of *Ruta del Sol* would increase the opportunity cost of the mining sector in Colombia, given that the road benefits the manufacturing sector more. This result occurs even though mining exports also increase.

Lastly, my results highlight the relevance of input-output linkages when considering how infrastructure shapes comparative advantage. I show that when industry linkages are not considered, the increase in the share of manufacturing exports is lower than the growth observed for simulations that consider industry linkages. This result is specially relevant for previous work regarding the economic impacts of infrastructure projects, given that little attention has been paid to the relationship between infrastructure and input-output linkages.

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A. DATA

The following list contains detailed notes about data. This includes the geospatial dataset as well as the data regarding the calibration of all parameters. Unless otherwise indicated, I use data for 2013 in all cases.

A1. Departments merged or dropped for the analysis

I merge or drop six departments when I take the model to the data

- San Andres y Providencia. The department is an island.
- Leticia. This department trades with the rest of the world exclusively because there is a regional dynamic between two border towns.
- Bogota (merged). The data from Bogota D.C. was merged with Cundinamarca.
- Vaupes, Vichada and Guainia. The states are not connected to the primary road system. Additionally, their international trade flows are small, and these flows are linked to the regional economic activity of the small border towns in Venezuela or Brazil.

A2. Speed values for public-private roads

I assume higher speed values for public-private roads given that the characteristics of the public-private infrastructure projects suggest higher quality for these roads, relative to the standard ones. Such characteristics are publicly available via documents published by the National Agency of Infrastructure, the government office in charge of public-private infrastructure projects. Such documents include the legal contracts with information about design specifications and fines in case of violations by the construction company, as well as inspection documents.

There exists evidence that the Colombian government enforces these contracts, particularly for very expensive projects. Specifically, Alvear-Sanin (2008) documents a legal case in which the Colombian government sued an conglomerate of construction companies for breach of contract (the legal case of Commsa). The Colombian government attempted to impose the largest fine and persisted through different judiciary instances for nine years until a settlement was reached. Hence, it is safe to assume that the quality of public-private roads is higher compared to the standard roads that are directly administered by the Colombian government.

The different speeds that I used in the digital maps of the **primary road** system of Colombia are the following:

- **Unpaved roads**. 32 km per hour (19.9 miles per hour approximately)
- **Paved roads passing through urban areas**. 50 km per hour (31 miles per hour approximately)
- **Paved roads, not under the legal figure of concesion**. 80 km per hour (50 miles per hour approximately)
- **Paved roads, under the legal figure of concesion and Ruta del Sol**. 100 km per hour (62 miles per hour approximately)

A3. Trade flows

- **Oil exports**. The customs data does not record the department of origin for 55% of mining exports. This data corresponds to shipments with HS2012 codes 2709, 2710 and

2711 (petroleum and oil products). I use production data at a department level from the Colombian public oil company Ecopetrol to define the source of such flows. I assign the export flows without information about the department of origin proportionally to every department that produces oil, according to the production shares.

- **Trade between departments**.
  Agriculture and manufacturing. I use data of the estimated weight for the annual cargo flows from the Transportation Survey of Origin/Destination 2013 from the Ministry of Transportation in Colombia to create a matrix of domestic trade flows. I assume the domestic trade flows are the same for both sectors.
  Mining. I use data regarding oil production from the Ministry of Energy and Mines. I assume that only crude oil is domestically traded given that production of coal and oil represent 88% of the output of the mining sector according to the input-output matrix of Colombia created by DANE, for the year 2010. Additionally, coal is mostly exported by Colombia, according to data from the U.S. Energy Information Administration (2019). Therefore, I assume that most of the trade that occurs between departments will be crude oil from the oil fields to the states with refineries.
- **Purchases of location i to itself**.
  - Purchases of the RoW to itself, $\nu_{RoW,RoW}$. I estimated this value using data from WIOD 2013 to obtain $C_{world,final,k}$ and $C_{world,intermediate,k}$ and the customs data of Colombia to obtain this parameter.
  - Purchases of Colombia to itself, ν_{ColCol}. I estimated this using the input-output matrix produced by DANE for the year 2010.
  - Purchases of a department to itself or $\nu_{dd,k}$. I assume this number for the agricultural and manufacturing sectors. For the case of the mining sector, I obtained a proxy of this parameter for every department. To do so, I assume that all the domestic trade of mining is exclusively crude oil from the oil fields to the refineries, given that 88% of the mining production is coal and crude oil according to DANE, and that Colombia does use very little coal for energy consumption (less than 9%) according to the U.S. Energy International Agency (2019).

A4. Trade deficits

- *Trade deficits beween departments and RoW*. I use customs administrative data from DANE for the year 2013.
- *Trade deficits between departments*.
  Agriculture and manufacturing. Use data from the Transportation Survey of Origin/Destination 2013 produced by Ministry of Transportation in Colombia. I assume the trade deficits between departments are very small for agriculture and manufacturing, compared to the deficits of departments with the Rest of the world.
  Mining. Similar to the way I obtained the trade flows shares, I calculate this variable assuming that domestic trade between departments is mostly crude oil from departments with oil fields to departments with refineries.

A5. Input-output parameters

- Share of value added. Given that global input-output table of WIOD does not have data for Colombia, to estimate the parameter I consider the data for the entire world. This seems feasible given that Colombia is a very small economy, therefore it is likely that the value of this parameter for the world is the same with/without including the Colombian economy.

- Share of sector k in final demand $\beta_{i,k}$.
  - *Rest of the world*. Use final consumption column of the WIOT 2016. Due to constraints in WIOD data, I estimate the parameter for the entire world.
  - *Colombia*. I use input-output table produced by DANE for the year 2010.

A6. Data sources

The following list provides the sources for every variable used in this paper.

1. **WIOD data**. It contains data for all European countries and other major economies. Colombian data is contained in the rest of the world, thus it is not reported individually. See Timmer et al. (2015). I use the input-output table corresponding to the year 2013 (version 2016).
2. **Colombian statistical agency DANE**
   a. Input-output matrix
   b. Value added data
   c. Sectoral GDP data
3. **Colombian statistical agency (DANE)**. Provides the customs administrative data used to estimate trade flows between departments and rest of the world.
4. **Ministry of Transportation of Colombia (Ministerio de Transporte)**.
   a. Physical maps regarding the primary road system. This allows me to obtain the road distance between Colombian departments. To create the map of 2013, I use as baseline the digital road map created by the National Institute of Roads (INVIAS) for the year 2014.
   b. Data regarding the estimated weight of the cargo transported between the capitals of Colombian departments.
5. **International Monetary Fund**. Daily data for the exchange rate Colombian peso per dollar.
6. **Ministry of Mines and Energy**. Data on oil production for the year 2013 and the capacity of all refineries in Colombia.

A7. Geospatial data

I obtain information regarding the location of city-ports and capitals of departments via two sources: the main topographic world map generated by ArcGIS software, and coordinates obtained through Google Maps. For some cases, the location of the city-port was assigned to specific coordinates to make sure that the trade costs from a location to itself was normalized to 1. I describe these cases below.

1. All the goods exported via the international bridge of San Miguel are assigned to Puerto Asis in the customs data. For the purpose of the estimation of distances, I use the actual location of the port of San Miguel.
2. All the goods exported via the seaport of Mamonal (according to customs records) are assigned to the Port of Cartagena (Department of Bolivar). I do this because the seaports are located 20 minutes from each other. All the exports sent via the seaport of Mamonal are oil products.
3. When the port is located within the city limits, then I situated the capital in the same location as in the port. The cases where this occurs are: Cartagena, Santa Marta, Pereira, Barranquilla and Bogota, .

   The cases where the port of trade is located outside the city limits are: Medellin, Arauca, Cali, Armenia and Bucaramanga.

4. I did not use customs data from the ports of Inirida, Leticia, and Puerto Carreño. This is because the international trade flows of these towns are mainly influenced by the local border regions.
   - The customs data observed in the port of Leticia are mostly by regional dynamics between Leticia and Tabaratinga, Brazil.
   - The customs data from the port of Puerto Carreño are mostly driven by regional dynamics between the Colombian town and Puerto Páez, Venezuela. Puerto Carreño is highly isolated from the rest of the country.
   - I did not consider the port of Inirida since its entire economic activity is mostly driven by regional dynamics with San Fernando de Atabapo, Venezuela. The Colombian town is far from the rest of the Colombian cities. Lastly, Inirida does not report any exports or imports.
5. I did not use customs data from the port located in the island of San Andres, since it is not connected to the mainland via a road.

B. PARAMETERS OF THE INTERNATIONAL TRADE/ECONOMIC GEOGRAPHY MODEL

TABLE 8 Information about value parameters used in the model

Group	Parameter	Data used for estimation	Notes
Production parameters	Share of value added of location $n \in \{d_1, d_2, ..., \bar{d}, RoW\}$ $\beta_n^{l,k} = ValueAdded_{n,k}/Y_{n,k}$	National IO table of Colombia (DANE) and World IO database	Due to lack of regional IO tables in Colombia, I use the same parameter for every department.
	Share of sector s in the production of sector k in location n, $\beta_n^{s,k} = (1-\beta_n^{l,k})\frac{IntermediateCons_{k,s}}{IntermediateCons_{k,total}}$	National IO table of Colombia (DANE) and World IO database	Due to lack of regional IO tables for Colombia, I assume the same value of these parameters for all departments
Consumption parameters	Elasticity of substitution σ_k	Value taken from existing literature, I assume $\sigma_k = 6\ \forall k$	I use the same value for all four sectors.
	Share of sector k in the final consumption of households, $\alpha_{n,k} = C_{k,final,total}/C_{final,total}$	National IO table of Colombia (DANE) and World IO database	Due to lack of regional IO tables for Colombia, I assume the same value of these parameters for all departments.
Trade deficits	Trade deficits of RoW, $D_{RoW,Total}$	Customs administrative data (DANE)	Estimated directly from customs data
	Trade deficits of departments $D_{d,Total} = D_{d,domestictrade} + D_{d,internationaltrade}$	Customs administrative data (DANE)	I assume that the deficit generated by domestic trade is very small relative to the deficit of international trade.
Expenditure shares	Agriculture and manufacturing expenditure shares $\lambda_{nj,k}$ for $k \in \{a, i\}$	(i) World IO Database and Colombia's IO table for share of expenditures of Colombia/RoW on its own goods, (ii) Colombia's customs administrative data for international expenditure shares (iii) Ministry of Transportation's Survey for 2013, for domestic expenditure shares[21]This data was used to generate a proxy of the domestic trade flows of agriculture and manufacturing. Unfortunately, Colombia does not have a detailed Commodity Flow Survey like the United States that allows researchers to estimate good measures of domestic trade flows (iv) Colombia's crude oil production data and refinery capacity, and (v) the Economic Accounts of Colombia (DANE) to estimate value-added and gross output at a sectoral level.	Building the matrix of expenditure shares requires **international expenditures shares** related to trade data between Colombia and the rest of the world (represented by $_{,ij}$ for $i, j \in \{Col, RoW\}$) and **domestic expenditure shares** represented by $_{d_1,d_2}$, which are related to trade data between Colombian departments. To understand with detail the construction of the entire matrix of expenditure shares between departments and RoW, see Table 2. (Notice that to build the "structural" shares of the trade model $\lambda_{nj,k}$, I require the"data" shares mentioned in this table γ_{ij} and ν_{d_1,d_2})
	Mining expenditure shares $\lambda_{nj,k}$ for $k = m$	Oil production data (Colombia's Ministry of Energy and Mines), refinery capacity (Colombia's public oil company Ecopetrol and the Ministry of Energy and Mines)	I consider five assumptions (i) Domestic trade flows are exclusively crude oil flows between departments with oil fields and departments with refineries [22]86 % of the gross domestic output of the mining sector is coal and crude oil. According to the Energy International Agency, Colombia exports most of its coal production. Hence, I assume that the domestic trade flows consisted mostly of crude oil from departments with oil fields to departments with oil refineries. This means the departments that are oil producers only ship crude oil to the five refineries located in Bolivar, Santander, Casanare, Putumayo, and Meta. (ii) Refineries only use crude oil produced domestically (a realistic assumption since Colombia is an oil exporter) (iii) Departments with refineries consume all the crude oil they produce, and if there is any remaining refining capacity, the departments will import crude oil from other departments [23]I could build a more precise measure of mining domestic trade flows using pipelines information. Unfortunately, I do not have accurate geospatial data about pipeline location and capacity. (iv) I include the international trade deficit too, that is the deficits between departments and the rest of the world, using customs administrative data.

TABLE 9 Construction of the matrix of the 'model expenditure shares' based on 'data expenditure shares'

Matrix that describes relationship between 'model expenditure shares', $\lambda_{ij,k}$, and 'data expenditure shares', $\gamma_{ij}, \nu_{d_1,d_2}$

Exporter ↓ Importer →	**RoW**	**d_1**	...	...	**d_D**
RoW	$\lambda_{RoWRoW} = \gamma_{RoW\ RoW}$	$\lambda_{RoWd_1} = (1-\gamma_{ColCol})\gamma_{RoWd_1}$			
d_1	$\lambda_{d_1RoW} = (1-\gamma_{RoWRoW})\gamma_{d_1RoW}$	$\lambda_{d_1d_1} = \nu_{d_1d_1}\gamma_{ColCol}$			
...					
...					
d_D	$\lambda_{d_DRoW} = (1-\gamma_{RoWRoW})$				$\lambda_{d_Dd_D} = \nu_{d_Dd_D}\gamma_{ColCol}$

Description of 'data expenditure shares'

$\gamma_{RoW\ RoW}$	Expenditures of the Rest of the World on its own goods
$\gamma_{Col\ Col}$	Expenditures of Colombia (the entire country) on its own goods
$\gamma_{d\ RoW}$	Share of Colombian exports to the RoW produced by department d
$\gamma_{RoW\ d}$	Share of Colombia's imports bought from the Rest of the World and sent to department d
ν_{d_1,d_2}	Shares of expenditures of department d_2 in goods from department d_1, only considering domestic trade flows.
ν_{dd}	Share of expenditures of a department on its own goods. I could not obtain values for this share, hence I run simulations for different values for this parameter e.g. $\nu_{dd} = 0.3, 0.45$

C. HISTORICAL MAPS

FIGURE 13 Map of Colombia's road network in 1938 from the Atlas de Colombia (IGAC, 2002)

FIGURE 14 Map of the colonial routes of the Viceroyalty of New Granada available in the Atlas de Colombia(IGAC, 2002)

D. DERIVATIONS

Obtaining the expression for trade flows
By solving the firm's problem I obtain the demand of the composite good

$$q^c_{jn,k} = \frac{p^{-\sigma_k}_{jn,k}}{P^{1-\sigma_k}_{n,k}} Q_{n,k}$$

where $P_{n,k}$ is the price of the composite intermediate good and $p_{n,k}$ is the price of the intermediate good in location n.

Given the existence of perfectly competitive markets, the price charged by a firm located in j that sells good of sector k to composite goods firms in location n is

$$p_{jn,k} = \frac{\tau_{jn} c_{j,k}}{A_{j,k}}$$

Plugging this into the equation for the price of the composite intermediate, $P_{j,k}$, I obtain

$$P_{n,k} = \Big[\sum_j p^{1-\sigma_k}_{jn,k}\Big]^{\frac{1}{1-\sigma_k}} = \Big[\sum_j \Big(\frac{\tau_{jn} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k}\Big]^{\frac{1}{1-\sigma_k}}$$

To obtain the expression for trade flows, combine the demand of composite good with the price, to get

$$x_{jn,k} = p_{jn,k} \cdot q^c_{jn,k} = \frac{p^{1-\sigma_k}_{jn,k}}{P^{-\sigma_k}_{nk}} Q_{n,k} \iff$$

$$X_{jn,k} = \Big(\frac{\tau_{jn,k} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k} Q_{n,k} P^{\sigma_k - 1}_{n,k}$$

Obtaining the labor market clearing
By aggregating the total expenditure of location n in sector-k goods (14) across all sectors, I obtain the total expenditure of location n

$$X_n = \sum_s X_{n,s} = \sum_s \Big[\sum_k \Big(\beta^{s,k}_n \sum_j X_{j,k}\lambda_{nj,k}\Big) + \alpha_{n,s} I_n\Big]$$

$$M_n = X_n = \sum_s \sum_k \beta^{s,k}_n \sum_j X_{j,k}\lambda_{nj,k} + w_n L_n + D_n$$

$$E_n = \sum_k \sum_j X_{j,k}\lambda_{nj,k} = M_n - D_n = \sum_k (1 - \beta^{l,k}_n) \sum_j X_{j,k}\lambda_{nj,k} + w_n L_n$$

where he first equality comes from the trade balance equation. After some algebra, I can obtain an expression for labor market clearing.

$$w_n L_n = \sum_k \beta_n^{l,k} \sum_j X_{nj,k} = \sum_k \beta_n^{l,k} \sum_j X_{j,k} \lambda_{nj,k}$$

Definition of equilibrium in levels (detailed).

The equilibrium is a set of wages $\{w_{n,k}\}_{n \in Z, k \in \{a,m,i,z\}}$*, prices* $\{P_{n,k}\}_{n \in Z, k \in \{a,m,i\}}$*, and labor allocations* $\{L_{n,k}\}_{n \in Z, k \in \{a,m,i\}}$ *for all locations* $n \in Z$ *under the assumption of labor mobility across sectors and immobile labor across locations, given the following parameters:*

(a) *trade costs* $\{\tau_{ij}\}_{n,j \in R}$,
(b) *share of value added of sector s in the production of sector k* $\{\beta_n^{s,k}\}_{n \in R, s,k \in \{a,m,i,z\}}$,
(c) *elasticity of substitution* $\{\sigma_k\}_{k \in \{a,m,i,z\}}$,
(d) *labor endowments* $\{L_n\}_{n \in R}$,
(e) *and total trade deficits* $\{D_n\}_{n \in R}$

that solve the following system of equations:

(i) *Wages.*

$$w_i = w_{i,k} \forall k$$

(ii) *Cost of an input bundle*

$$c_{n,k} = \phi_{n,k} (w_n)^{\beta_n^{l,k}} \prod_{s \in \{a,m,i,z\}} (P_{n,s})^{\beta_n^{s,k}}$$

(iii) *Prices.*

$$P_{n,k} = \left[\sum_j \left(\frac{\tau_{jn} c_{j,k}}{A_{j,k}} \right)^{1-\sigma_k} \right]^{\frac{1}{1-\sigma_k}}$$

(iv) *Trade flows shares.*

$$\lambda_{jn,k} = (\tau_{jn})^{1-\sigma_k} (c_{j,k})^{1-\sigma_k} (P_{n,k})^{\sigma_k - 1} A_{j,k}{}^{\sigma_k - 1}$$

(v) *Total expenditure.*

$$X_{n,s} = \sum_k \beta_n^{s,k} \sum_j X_{j,k} \lambda_{nj,k} + \alpha_{n,s} I_n$$

where

$$I_n = w_n L_n + D_n$$

(vi) *Trade balance*[18].

$$\sum_k \sum_{j \in R} X_{j,k}\lambda_{nj,k} = \sum_k \sum_{j \in R} X_{n,k}\lambda_{jn,k} - D_n$$

Transportation framework
Probability that the shipping cost offer is lower than c
Consider a shipping route $r_t \in R_t$ for $t \in \{\chi, \mu\}$. Denote the potential shipping cost of a trader η as $\tau^o_{r_t,k}$. This offer depends on the shipping cost along route r_t and a productivity draw $z_{r_t,k}(\eta)$, which follows a Frechet distribution with parameters $(A_{r_t,k}\theta_k)$.

$$\tau^o_{r_t,k}(\eta) = \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)}$$

It can be noticed that the higher the value of the draw, the lower the shipping cost offer along route r_t. The probability that the shipping cost offer is lower than c is given by

$$G_{r_t,k}(c) = \Pr\Big[\tau^o_{r_t,k}(\eta) \leqslant c\Big] \iff$$

$$G_{r_t,k}(c) = \Pr\Big[\frac{\tau_{r_t,k}}{z_{r_t}(\eta)} \leqslant c\Big] \iff$$

$$G_{r_t,k}(c) = \Pr\Big[z_{r_t}(\eta) \geqslant \frac{\tau_{r_t,k}}{c}\Big] \iff$$

$$G_{r_t,k}(c) = 1 - \Pr\Big[z_{r_t}(\eta) \leqslant \frac{\tau_{r_t,k}}{c}\Big] \iff$$

$$G_{r_t,k}(c) = 1 - F\Big(\frac{\tau_{r_t,k}}{c}\Big) \iff$$

$$G_{r_t,k}(c) = 1 - \exp[-A_{r_t}(\tau_{r_t})^{-\theta_k}c^{\theta_k}]$$

Let $\tau_s(\eta)$ be the actual shipping cost of trader η from department d to the rest of the world. This cost is the minimum shipping price among all potential shipping cost offers across city-ports, that is

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[18] This condition implies labor market clearing
$w_n L_n = \sum_k \beta_n^{l,k} \sum_{j \in R} X_{j,k}\lambda_{nj,k}$

$$\tau_s(\eta) = \min_{r_t} \tau^o_{r_t,k}(\eta) = \min_{r_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)}$$

Probability that the observed shipping cost is lower than c

Let $G_{t,k}(c)$ be the probability that the *observed* shipping cost $\tau_s(\eta)$ is lower than c. Therefore, I have

$$G_{t,k}(c) \equiv \Pr\Big[\tau_s(\eta) \leqslant c\Big] = \Pr\Big[\min_{r_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \leqslant c\Big] \iff$$

$$G_{t,k}(c) = 1 - \Pr\Big[\min_{r_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \geqslant c\Big]] \iff$$

$$G_{t,k}(c) = 1 - \Pr\Big[\bigcap_{r_t \in R_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \geqslant c\Big] \iff$$

$$G_{t,k}(c) = 1 - \Pr\Big[\bigcap_{r_t \in R_t} \frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \geqslant c\Big] \iff$$

$$G_{t,k}(c) = 1 - \prod_{r_t \in R_t} \Pr\Big[\frac{\tau_{r_t,k}}{z_{r_t,k}(\eta)} \geqslant c\Big] \iff$$

$$G_{t,k}(c) = 1 - \prod_{r_t \in R_t} [1 - G_{r_t}(c)]$$

Plugging the expression $G_{r_t}(c) = 1 - \exp[-A_{r_t}(\tau_{r_t})^{-\theta_k} c^{\theta_k}]$ into the previous equation, I obtain

$$G_{t,k}(c) = 1 - \prod_{r_t \in R_t} \exp\Big[-A_{r_t}(\tau_{r_t})^{-\theta_k} c^{\theta_k}\Big] \iff$$

$$G_{t,k}(c) = 1 - \exp\Big[-c^{\theta_k} \sum_{r_t} A_{r_t}(\tau_{r_t})^{-\theta_k}\Big] \iff$$

$$G_{t,k}(c) = 1 - \exp\Big[-c^{\theta_k} \Phi_t\Big]$$

where $\Phi_t \equiv \sum_{r_t} A_{r_t}(\tau_{r_t})^{-\theta_k}$.

Probability that any good is shipped via route r_t

Denote $\pi_{r_t,k}$ the probability that any good is shipped via route $r_t \in R_t$. Similar to Eaton and Kortum (2002), given that specialized traders have i.i.d. draws that are sector k specific in my framework, then $\pi_{r_t,k}$ is also the fraction of goods of sector k that are shipped via route r_t.

$$\pi_{r_t,k} \equiv \Pr\Big[\tau^{o}_{r_t,k}(\eta) \leqslant \min_{\nu_t \in R_t \backslash r_t} \tau^{o}_{\nu_t,k}(\eta)\Big] \iff$$

$$\pi_{r_t,k} = \int_0^\infty \Pr\Big[\min_{\nu_t \in R_t \backslash r_t} \tau^{o}_{\nu_t,k}(\eta) \geqslant c\Big] dG_{r_t,k}(c) \iff$$

$$\pi_{r_t,k} = \int_0^\infty \Pr\Big[\bigcap_{\nu_t \in R_t \backslash r_t} \{\tau^{o}_{\nu_t,k}(\eta) \geqslant c\}\Big] dG_{r_t,k}(c) \iff$$

$$\pi_{r_t,k} = \int_0^\infty \prod_{\nu_t \in R_t \backslash r_t} [1 - G_{\nu_t}(c)] dG_{r_t,k}(c) \iff$$

$$\pi_{r_t,k} = \int_0^\infty \prod_{\nu_t \in R_t \backslash r_t} [1 - G_{\nu_t}(c)] dG_{r_t,k}(c) \iff$$

Using the expressions $G_{\nu_t,k}(c) = 1 - \exp[-A_{\nu_t}(\tau_{\nu_t})^{-\theta_k} c^{\theta_k}]$, and $dG_{r_t,k}(c) = \frac{d}{dc}[1 - \exp(-A_{r_t}(\tau_{r_t})^{-\theta_k} c^{\theta_k})]dc$, I obtain

$$\pi_{r_t,k} = \int_0^\infty \prod_{\nu_t \in R_t \backslash r_t} \Big[\exp\Big(-A_{\nu_t}(\tau_{\nu_t})^{-\theta_k} c^{\theta_k}\Big)\Big] \Big[\frac{d}{dc}[1 - \exp(-A_{r_t}(\tau_{\nu_t})^{-\theta_k} c^{\theta_k})]\Big] dc \iff$$

$$\pi_{r_t,k} = A_{r_t}(\tau_{r_t})^{-\theta_k} \int_0^\infty \theta_k c^{\theta_k - 1} [\exp(-c^{\theta_k} \Phi_t)] dc$$

$$\pi_{r_t,k} = \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t} \Big[-\exp(-c^{\theta_k} \Phi_t|_0^\infty)\Big]$$

$$\pi_{r_t,k} = \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t}$$

Why π_{r_t} is the fraction of trade flows between department d and the rest of the world that are shipped via route r_t

So far, I have shown that π_{r_t} is the fraction of exports/imports by department d to/from the rest of the world, RoW. But this is not the same as the percentage of the value of trade flows shipped via route r_t. Hence, I need to show that the distribution of shipping cost offers is independent of the shipping route. If this is true, then I can consider r_t as the fraction of exports/imports shipped via route r_t.

I express the probability that the shipping cost offer is lower than $\bar{c}$ conditional on route r_t offering the lowest price as

$$\Pr[\tau^o_{r_t}(\eta) \leqslant \bar{c} | \tau^o_{r_t}(\eta) \leqslant \min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta)] = \frac{1}{\pi_{r_t}} \int_0^{\bar{c}} \Pr[\min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta) \geqslant c] dG_{r_t}(c)$$

$$= \frac{1}{\pi_{r_t}} \int_0^{\bar{c}} \prod_{\nu_t \in R_t \setminus r_t} [1 - G_{\nu_t}(c)] dG_{r_t}(c)$$

Combining $G_{\nu_t,k}(c)$ and $dG_{r_t,k}(c)$ with my last expression, I get

$$\Pr\left[\tau^o_{r_t}(\eta) \leqslant \bar{c} | \tau^o_{r_t}(\eta) \leqslant \min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta)\right] = \int_0^{\bar{c}} \prod_{\nu_t \in R_t \setminus r_t} [exp(-A_{\nu_t} \tau_{\nu_t})] \frac{d}{dc} [1 - exp(-A_{r_t}(\tau_{r_t})^{-\theta_k} c^{\theta_k})] dc$$

$$\Pr\left[\tau^o_{r_t}(\eta) \leqslant \bar{c} | \tau^o_{r_t}(\eta) \leqslant \min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta)\right] = \frac{1}{\pi_{r_t}} \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t} \left[- exp(-c^{\theta_k} \Phi_t |_0^{\bar{c}}) \right]$$

$$\Pr\left[\tau^o_{r_t}(\eta) \leqslant \bar{c} | \tau^o_{r_t}(\eta) \leqslant \min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta)\right] = \frac{1}{\pi_{r_t}} \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t} \left[1 - exp(-\bar{c}^{\theta_k} \Phi_t) \right]$$

$$\Pr\left[\tau^o_{r_t}(\eta) \leqslant \bar{c} | \tau^o_{r_t}(\eta) \leqslant \min_{\nu_t \in R_t \setminus r_t} \tau^o_{\nu_t}(\eta)\right] = G_{t,k}(\bar{c})$$

The distribution of shipping cost offers is the same for department d, independently of the route r_t used to transport the good. Therefore, the average value of the shipment sold/purchased by department d is independent of the route taken. This implies that we can express the fraction of the value of exports/imports that use shipping route r_t as π_{r_r}. This intuition is similar to the intuition of the result of Eaton and Kortum (2002), the best routes are more efficient, therefore such routes transport a larger share of goods to/from department d from/to the rest of the world, up to the level where the shipping cost offers are equal to the distribution of the observed shipping costs.

Trade costs between a department and the rest of the world

Using the results of the model with traders of Allen and Arkolakis (2019), define the trade cost between a department d and the rest of the world, as

$$\tau_{dRoW} \equiv E\left[\tau_s(\eta)\right]$$

$$\tau_{dRoW} = \int_0^\infty p_s(\eta) \iff$$

$$\tau_{dRoW} = \int_0^\infty p \; dG_t(p) \iff$$

$$\tau_{dRoW} = \int_0^\infty p dG_t(p) \iff$$

$$\tau_{dRoW} = \int_0^\infty p \; \frac{d}{dp}[1 - exp(-p^\theta \Phi_t)]dp \iff$$

$$\tau_{dRoW} = \int_0^\infty p \frac{d}{dp}[1 - exp(-p^\theta \Phi_t)]dp \iff$$

$$\tau_{dRoW} = \int_0^\infty \theta \Phi_t p p^{\theta-1} exp(-p^\theta \Phi_t)dp$$

Now, use change of variables, where $x = p^\theta \Phi_t$ and $dx = \theta p^{\theta-1}\Phi_t$. Therefore, I can express the integral as

$$\tau_{dRoW} = \int_0^\infty \left(\frac{x}{\Phi_t}\right)^{\frac{1}{\theta}} exp(-x)dx \iff$$

$$\tau_{dRoW} = \Phi_t^{-\frac{1}{\theta}} \int_0^\infty x^{\frac{1}{\theta}} e^{-x} dx$$

Recall that $\Gamma(t) = \int_0^\infty x^{t-1}e^{-x}dx$. If I consider $(t-1) = \frac{1}{\theta} \iff t = \frac{1+\theta}{\theta}$, then I can express the trade cost between a department d and the rest of the world as

$$\tau_{dRoW} = \Phi_t^{\frac{1}{\theta}} \Gamma\left(\frac{1+\theta}{\theta}\right)$$

E. ROBUSTNESS CHECKS FOR THE ESTIMATION OF THE ELASTICITY OF SUBSTITUTION ACROSS CITY-PORTS θ_k

TABLE 10 Results for the estimation of $\theta_{agriculture}$

Instrument	None	Colonial routes and 1938 roads		1938 roads		Colonial routes	
Method	**OLS**	**2SLS**	**LIML**	**2SLS**	**LIML**	**2SLS**	**LIML**
$-\mu_{t,k}(time_{dp})$	-0.3282	-0.5274	-0.5274	-0.5279	-0.5279	-0.5272	-0.5272
	(0.0341)	(0.0578)	(0.0578)	(0.0693)	(0.0693)	(0.0604)	(0.0604)
F-statistic (1st stage)	-	13.94	13.94	11.27	11.27	13.27	13.27
N	1,026	1,026	1,026	1,026	1,026	1,026	1,026
R-squared	0.5430	0.5230	0.5230	0.5229	0.5229	0.5231	0.5231

Standard errors in parentheses

TABLE 11 Results for the estimation of θ_{mining}

Instrument	None	Colonial routes and 1938 roads		1938 roads		Colonial routes	
Method	**OLS**	**2SLS**	**LIML**	**2SLS**	**LIML**	**2SLS**	**LIML**
$-\mu_{t,k}(time_{dp})$	-0.2293	-0.5199	-0.5200	-0.5065	-0.5200	-0.5261	-0.5261
	(0.0410)	(0.0642)	(0.0642)	(0.0768)	(0.0642)	(0.0672)	(0.0672)
F-statistic (1st stage)	-	13.94	13.94	11.27	11.27	13.27	13.27
N	1,026	1,026	1,026	1,026	1,026	1,026	1,026
R-squared	0.4600	0.4180	0.4180	0.4218	0.4180	0.4162	0.4162

Standard errors in parentheses

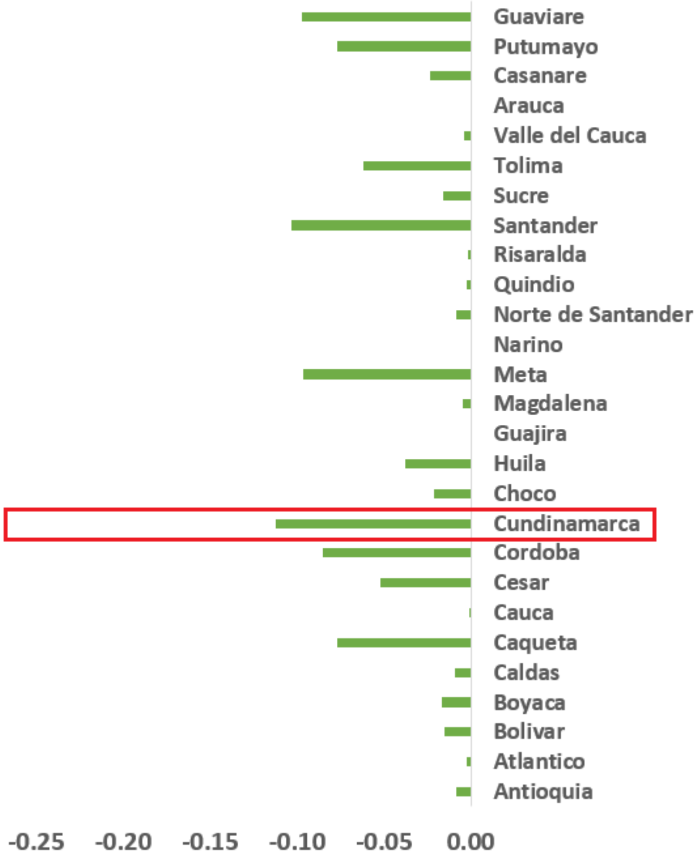
TABLE 12 Results for the estimation of $\theta_{manufacturing}$

Instrument	None	Colonial routes and 1938 roads		1938 roads		Colonial routes	
Method	**OLS**	**2SLS**	**LIML**	**2SLS**	**LIML**	**2SLS**	**LIML**
$-\mu_{t,k}(time_{dp})$	-0.2880	-0.6182	-0.6215	-0.6843	-0.6843	-0.5877	-0.5877
	(0.0319)	(0.0592)	(0.0595)	(0.0728)	(0.0728)	(0.0613)	(0.0613)
F-statistic (1st stage)	-	13.94	13.94	11.27	11.27	13.27	13.27
N	1,026	1,026	1,026	1,026	1,026	1,026	1,026
R-squared	0.6910	0.6531	0.6524	0.6364	0.6364	0.6598	0.6598

Standard errors in parentheses

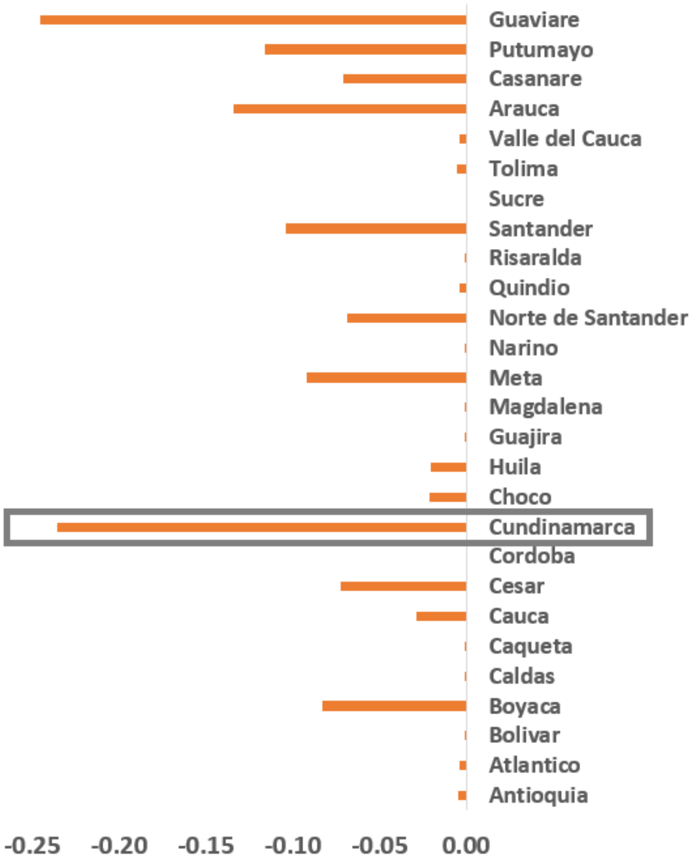
F. REDUCTIONS IN TRADE COSTS $\tau_{dRoW,k}$ GENERATED BY THE COMPLETION OF RUTA DEL SOL

FIGURE 15 Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol



Note: I simulate the change in international trade costs using the value of β_{time} from Allen and Arkolakis (2019).

FIGURE 16 Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol



Note: I simulate the change in international trade costs using the value of β_{time} from Allen and Arkolakis (2019).

FIGURE 17 Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol

Note: I simulate the change in international trade costs using the value of β_{time} from Allen and Arkolakis (2019).

G. Robustness checks for the simulations of Ruta del Sol

TABLE 13 Impacts of the completion of Ruta del Sol on sectoral exports of Colombia, for different values of the parameters ν_{dd} (share of expenditures of a department on its own goods) and β_{time} (parameter that defines the relationship between travel times and trade costs)

Scenario	ν_{dd}	β_{time}	Share of agricultural exports	Share of mining exports	Share of manufacturing exports	Change in the share of agricultural exports	Change in the share of mining exports	Change in the share of manufacturing exports
Baseline	**0.25**	**0.13**	**10.1**	**41.1**	**48.8**	**-**	**-**	**-**
	0.25	0.13	9.3	39.0	51.7	-0.8	-2.1	2.9
	0.25	0.143	8.5	38.1	53.4	-1.5	-3.0	4.6
	0.25	0.156	7.9	35.8	56.3	-2.1	-5.4	7.5
Baseline	**0.4**	**0.13**	**9.9**	**41.2**	**48.9**	**-**	**-**	**-**
	0.4	0.13	9.2	39.3	51.5	-0.7	-1.9	2.6
	0.4	0.143	8.5	38.6	52.9	-1.4	-2.6	4.0
	0.4	0.156	8.0	36.5	55.5	-1.9	-4.7	6.6
Baseline	**0.5**	**0.13**	**9.9**	**41.1**	**48.9**	**-**	**-**	**-**
	0.5	0.13	9.2	39.5	51.3	-0.7	-1.7	2.4
	0.5	0.143	8.5	38.9	52.5	-1.4	-2.2	3.6
	0.5	0.156	8.1	37.0	54.9	-1.9	-4.1	6.0
Baseline	**0.6**	**0.13**	**10.3**	**40.6**	**49.2**	**-**	**-**	**-**
	0.6	0.13	9.2	39.7	51.1	-1.1	-0.9	2.0
	0.6	0.143	8.5	39.4	52.1	-1.7	-1.2	2.9
	0.6	0.156	8.1	37.6	54.2	-2.1	-2.9	5.9

Notes: The base year for all simulations is a deficit-zero economy, which was previously calibrated with non-zero deficits as in Caliendo and Parro (2015)

H. Simulated change in trade costs after the completion of the highway *Ruta del Sol*

FIGURE 18 Simulated change in trade costs before/after Rutal del Sol is finished for agricultural sector

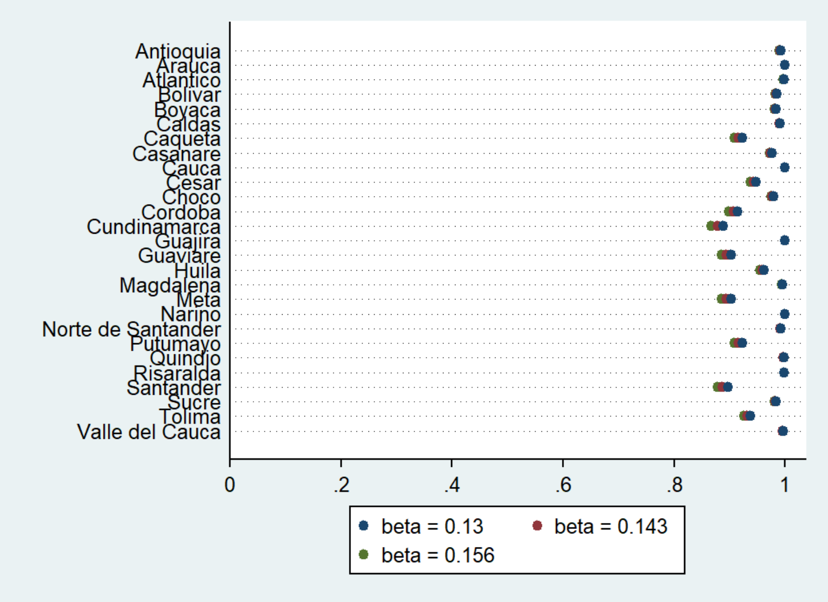


FIGURE 19 Simulated change in trade costs before/after Rutal del Sol is finished for mining sector

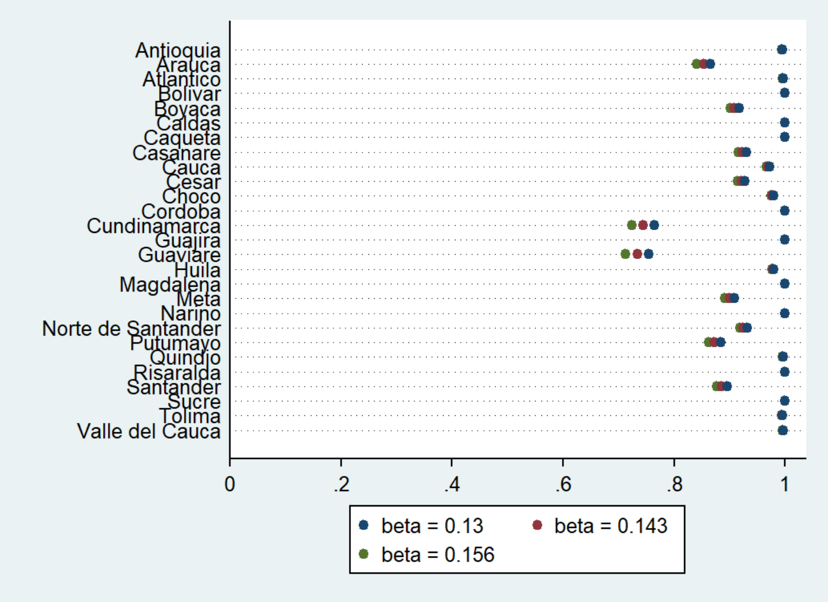
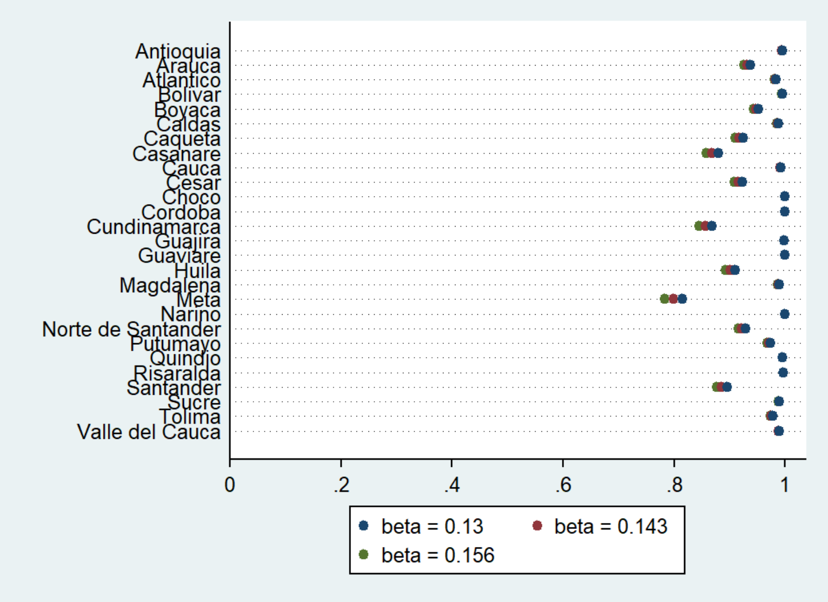


FIGURE 20 Simulated change in trade costs before/after Rutal del Sol is finished for manufacturing sector



I. SPATIAL EFFECTS OF EXPORTING OF *Ruta del Sol*

TABLE 14 Change in manufacturing export activity across departments due to *Ruta del Sol*

Department	**Growth of manufacturing exports**	**Change in share of national manufacturing exports**
Antioquia	2.7	-4.604
Atlantico	-23.6	-2.132
Bolivar	-30.7	-2.209
Boyaca	12.4	-0.065
Caldas	4.8	-0.266
Caqueta	30.9	0.000
Cauca	6.0	-0.275
Cesar	40.2	0.006
Cordoba	-0.3	-0.816
Cundinamarca	68.5	11.286
Choco	2.6	-0.004
Huila	61.8	0.009
Guajira	-1.9	-0.009
Magdalena	-32.8	-0.049
Meta	153.1	0.037
Narino	-1.5	-0.009
Norte de Santander	37.2	0.112
Quindio	5.2	-0.003
Risaralda	4.8	-0.124
Santander	54.0	0.301
Sucre	5.6	0.000
Tolima	13.7	-0.010
Valle del Cauca	7.9	-1.180
Arauca	1.8	0.000
Casanare	74.8	0.003
Putumayo	-12.5	0.000
Guaviare	3.8	0.000

Notes: Results from the main counterfactual where the value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$..

Notes: (1) Even if a department has a large growth in its mining exports, it could be the case that its contribution to the national mining exports is very small, hence their contribution to national shares of mining exports changed by less than 0.0001 percentage points (2) Results from the main counterfactual. The value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$..

FIGURE 21 Growth of the agricultural exports of a department, due to completion of *Ruta del Sol* (the color indicates the interval of the % growth)

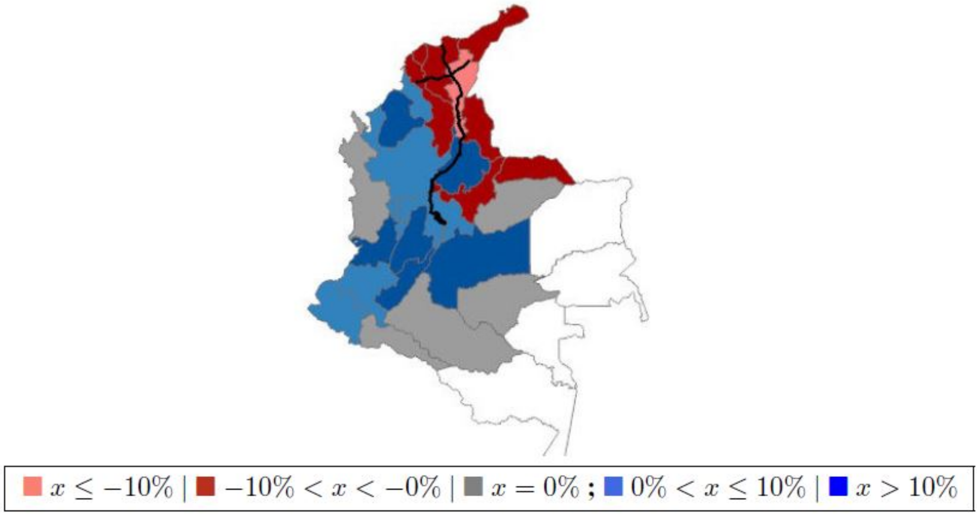
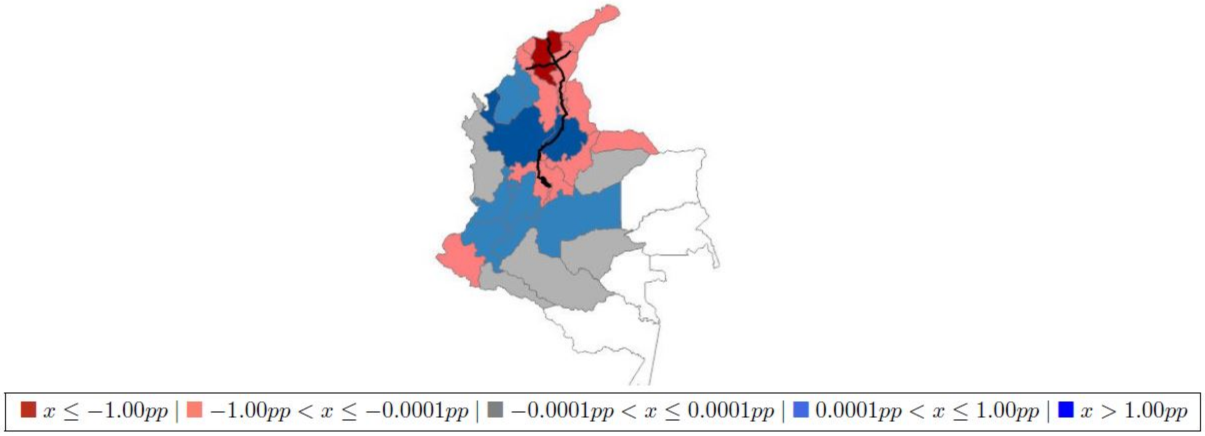


FIGURE 22 Change in the department's contribution to the national agricultural exports of Colombia, before and after *Ruta del Sol* (the color indicates the interval of the change in percentage points)



Notes: Results from the main counterfactual where the value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$..

TABLE 15 Change in agricultural export activity across departments due to *Ruta del Sol*

Department	**Growth of agricultural exports**	**Change in share of national agricultural exports**
Antioquia	8.9	1.144
Atlantico	-54.3	-0.309
Bolivar	-58.0	-0.426
Boyaca	-11.3	-0.027
Caldas	1.9	-0.075
Caqueta	0.0	0.000
Cauca	6.0	0.080
Cesar	-7.6	-0.273
Cordoba	55.3	0.912
Cundinamarca	1.2	-0.804
Choco	0.0	0.000
Huila	16.2	0.756
Guajira	-13.7	-0.007
Magdalena	-63.2	-2.971
Meta	18.2	0.001
Narino	3.0	-0.008
Norte de Santander	-12.4	-0.163
Quindio	9.6	0.173
Risaralda	9.1	0.216
Santander	34.1	1.182
Sucre	8.9	0.036
Tolima	41.7	0.440
Valle del Cauca	10.4	0.128
Arauca	-37.2	-0.005
Casanare	0.0	0.000
Putumayo	0.0	0.000
Guaviare	0.0	0.000

FIGURE 23 Growth of exports of mining goods of a department, due to *Ruta del Sol* (the color indicates the interval of the % growth)

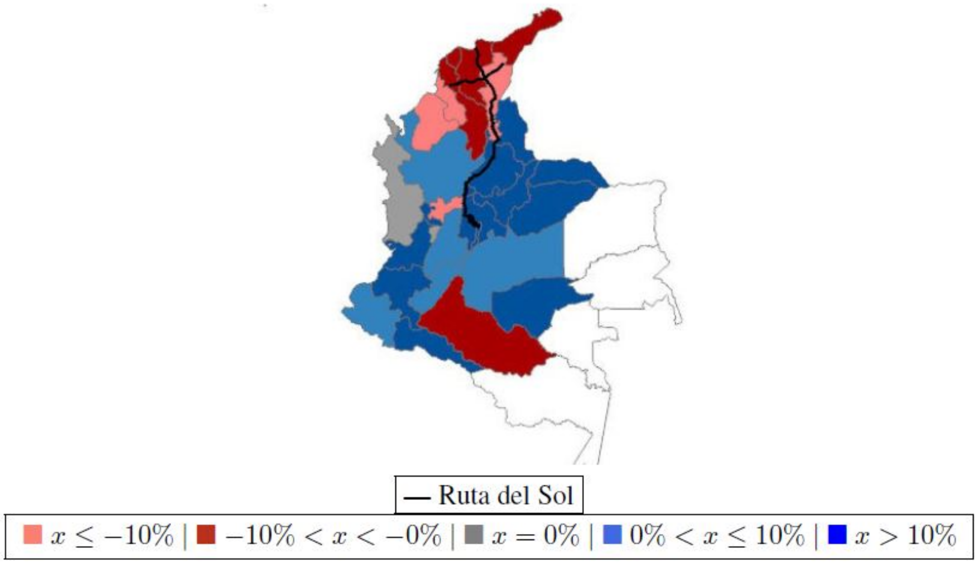
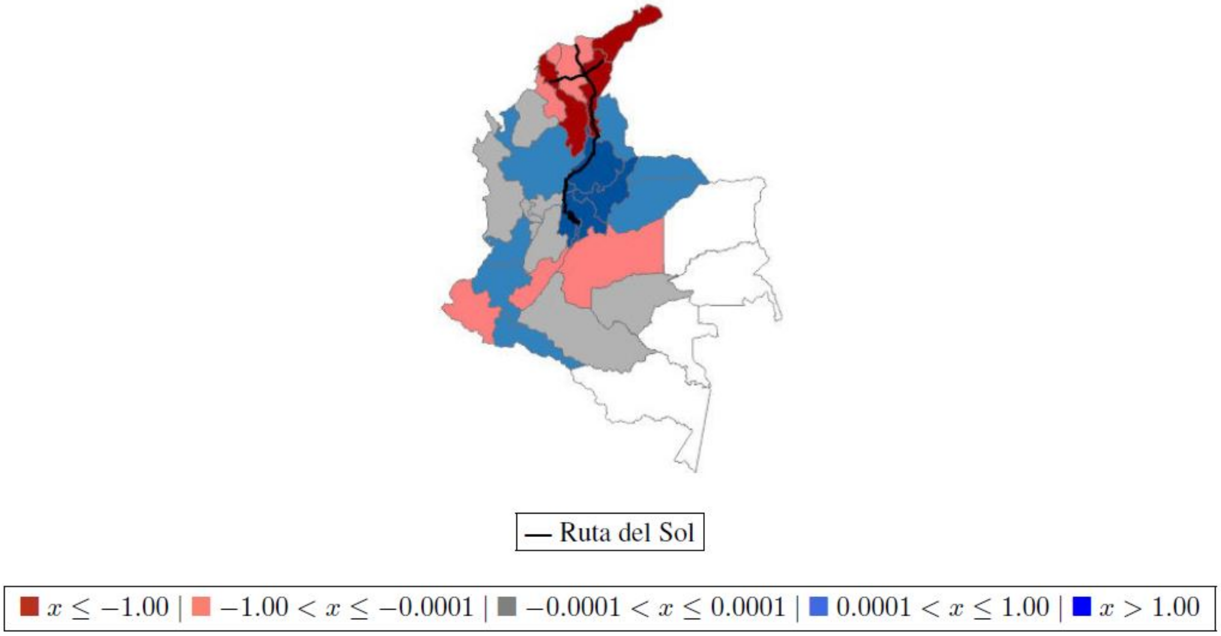


FIGURE 24 Change in the department's contribution to the national mining exports of Colombia, before and after *Ruta del Sol* (the color indicates the interval of the change in percentage points)



Notes: (1) Even if a department has a large growth in its mining exports, it could be the case that its contribution to the national mining exports is very small, hence their contribution to national shares of mining exports changed by less than 0.001 percentage points (2) Results from the main counterfactual. The value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$..

TABLE 16 Change in mining export activity across departments due to *Ruta del Sol*

Department	Growth of mining exports	Change in share of national mining exports
Antioquia	9.3	0.061
Atlantico	-61.7	-0.056
Bolivar	-66.9	-2.508
Boyaca	27.9	1.076
Caldas	-3.5	0.000
Caqueta	-18.6	0.000
Cauca	25.5	0.023
Cesar	-7.5	-1.204
Cordoba	-0.8	0.000
Cundinamarca	102.6	1.860
Choco	0.0	0.000
Huila	3.8	-0.064
Guajira	-18.5	-1.544
Magdalena	-71.6	-0.109
Meta	6.2	-0.047
Narino	4.8	-0.001
Norte de Santander	17.2	0.056
Quindio	0.0	0.000
Risaralda	10.3	0.000
Santander	22.5	1.210
Sucre	-0.7	-0.003
Tolima	6.4	0.001
Valle del Cauca	12.7	0.006
Arauca	17.1	0.519
Casanare	10.1	0.503
Putumayo	14.2	0.219
Guaviare	380.3	0.001

Notes: Results from the main counterfactual where the value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$..

J. WELFARE EFFECTS OF *Ruta del Sol* ACROSS DEPARTMENTS

TABLE 17 Changes in welfare across Colombian departments, due to the completion of *Ruta del Sol*

Department	Change in welfare
Antioquia	-0.5
Atlantico	9.0
Bolivar	10.8
Boyaca	3.2
Caldas	0.3
Caqueta	2.4
Cauca	-0.5
Cesar	2.6
Cordoba	-0.3
Cundinamarca	7.3
Choco	-0.7
Huila	-0.4
Guajira	-0.8
Magdalena	12.3
Meta	2.3
Narino	0.1
Norte de Santander	1.8
Quindio	-1.0
Risaralda	-1.2
Santander	3.1
Sucre	-0.7
Tolima	-0.7
Valle del Cauca	-1.0
Arauca	6.4
Casanare	2.0
Putumayo	5.9
Guaviare	-1.7

Notes: Results from the main counterfactual. The value for the parameter of the share of expenditures of a department in goods produced by itself is $\nu_{dd} = 0.25$. The value of the parameter that defines that relationship between trade costs and travel time is $\beta_{time} = 0.13$.