How Infrastructure Shapes Comparative Advantage

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Abstract

This paper studies the effects of domestic trade costs on comparative advantage. I build a model of international trade and internal geography, that considers both international shipping routes and input-output linkages. I use the model to simulate how a large infrastructure project, Ruta del Sol, affects the specialization of Colombia, a country with concentration on mining exports. This road improves the access to global markets for both mining and manufacturing regions. To quantify the model, I use customs administrative records, a transportation survey, and geospatial data generated from both physical and digital road maps. My results indicate that the road project weakens the specialization of the country in mining, thus altering comparative advantage. Lastly, I provide evidence that the shift in specialization is magnified when industry linkages are considered. The results show that the spatial distribution of domestic trade costs affect national comparative advantage, a determinant not considered before in the international trade literature.

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1 Introduction

Comparative advantage is a fundamental idea in international trade theory. Neoclassical trade models typically examine the role of technology, institutions, and factor endowments such as land, labor, and capital to explain the sources of specialization. Nevertheless, in developing countries, this approach is limited by the fact that we only observe the comparative advantage of regions well connected to the global markets, as the quality of infrastructure varies within developing nations.[1] Therefore, the spatial distribution of domestic trade costs may determine a country's comparative advantage.

The objective of this paper is to analyze whether domestic trade costs are determinants of comparative advantage in a developing country context. As new infrastructure projects may change the structure of the national transportation network or how industry linkages propagate shocks across regions and sectors, the answer is far from obvious. To answer this research question, I build an international trade and internal geography model with input-output linkages, road networks, and 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. Therefore, the highway project shifts the comparative advantage of Colombia away from the mining sector and towards manufacturing.[2]

Colombia is an ideal context to analyze the impact of infrastructure on specialization. First, the country is a standard case of a developing nation with a high concentration of exports in a few goods, particularly mining products. Second, there is variation in the access to global markets among Colombian departments.[3] Third, there is heterogeneity in the comparative advantage of Colombian departments.[4] Finally, Colombian departments do not use a single port to trade with the rest of the world.

Informed by these facts, 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).[5] 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.[6] The model produces a tractable expression for the international trade flows between a department and the rest of the world, that use specific ports of exit/entry (a department-port gravity equation).

To take the model to the data, I combine four data sources: detailed customs administrative data with information about the port of exit/entry, a survey of transportation flows, data regarding

[1] Oxford Economics (2017) and IADB (2013).

[2] For a small open economy, the share of exports of a sector is informative about the comparative advantage of the economy when I use the Balassa Index of Revealed Comparative Advantage. This is because the denominator of the Balassa index is fixed when it is used for small countries and with highly aggregated sectors.

[3] A department is the official administrative region of Colombia.

[4] I measure comparative advantage using the Balassa index.

[5] See Caliendo and Parro (2015)

[6] I adapt the framework of Allen and Arkolakis (2019) to my context. I also include some characteristics of the model of Duranton, Morrow and Turner (2014).

oil production and refineries, 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 and the oil production/refinery data allow me to obtain a proxy of domestic sectoral trade flows. Finally, using the geospatial data and the Dijkstra's algorithm, I obtain travel times between any location within Colombia for both modern and historical road networks.

To recover the main parameters of my model, 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.[7] After I obtain the value of the parameters of my model, I run counterfactual simulations. To do this, I re-write the equilibrium conditions in changes between two different equilibria, the equilibrium without the project *Ruta del Sol* and the counterfactual equilibrium that includes the completion of the infrastructure project. Using an equilibrium in changes reduces the number of parameters necessary to run the counterfactual simulations.[8]

My main counterfactual experiment considers the effects of the infrastructure program *Ruta del Sol* on the sectoral exports of Colombia. The project has the objective of modernizing the highway that connects Cundinamarca, the largest and most populated department of Colombia, with the Atlantic seaports. This department is the main exporter of manufacturing and agricultural products. A road network effect derived from this government program is that several departments that specialize in the mining sector also improve their access to global markets. Hence, the expected effect of this highway project in the national sectoral exports is unclear a priori. Additionally, given the structure of the input-output linkages in Colombia, the benefits of the reduction in domestic trade costs can propagate in such a way that one sector benefits more than others.

The results of my counterfactual experiment show that the completion of the infrastructure project increases the share of manufacturing exports by four percentage points, approximately. Given the upward trend of the share of mining exports of Colombia during the past three decades, this result implies 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 the manufacturing exports grow more than the exports of other sectors.

To analyze the main force driving my results, I run alternative counterfactual exercises, 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. My alternative simulations show that industry linkages help to increase the manufacturing exports substantially. When I simulate the effects of *Ruta del Sol* without industry linkages, the increase in the share of manufacturing exports is one third of the growth observed in my main counterfactual experiment, which does consider these linkages.

My work contributes to the international trade literature regarding the determinants of com-

[7] Duranton, Morrow, and Turner (2014), Duranton (2015), Baum-Snow (2007) and Michaels (2007) use a similar approach.

[8] I follow the exact-hat algebra approach of Dekle, Eaton and Kortum (2008).

parative advantage. My main contribution is to show that domestic trade costs can be a source of national comparative advantage. This finding is specially relevant in developing countries where domestic trade costs are high, thereby generating differences in regional access to global markets within a country.[9] To my knowledge, no previous literature has provided evidence that a direct link exists between domestic trade costs and national comparative advantage. The closest work to this paper, is Duranton, Morrow, and Turner (2014) and Duranton (2015), who find that urban centers with better infrastructure can specialize in sectors that produce heavy goods.

Other work regarding the determinants of comparative advantage includes papers regarding how migration affects specialization (Pellegrina and Sotelo, 2019; Arkolakis, Lee and Peters, 2018; Bahar and Rapoport, 2018; Morales, 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 economics, there is an increasing interest in the effects of infrastructure projects. This includes work on how infrastructure improvements affect either domestic outcomes, or trade flows between a country and the rest of the world (Alder, 2019; Allen and Arkolakis 2019; Coatsworth 1979; Cosar and Demir, 2016; Donaldson 2018; Donaldson and Hornbeck, 2016; Faber, 2014; Fogel 1962; Holl, 2016; Xu, 2016, Xu 2018). To my knowledge, only two papers consider jointly domestic outcomes and international trade: Fajgelbaum and Redding (2018) on the structural transformation of Argentina during the early 20th century and Sotelo (2019) on how roads affect agricultural trade in Peru. I depart from the existing literature by highlighting the role of industry linkages when I examine 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 sectoral effects, the interactions between industry linkages and infrastructure have not been examined in detail.

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 with information regarding the 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 considers data for 2013.

[9] See Atkin and Donaldson (2015).

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.[10]

Transportation and geography. I create a fully digitized road network that represents the primary highway system of Colombia,[11] 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).[12] 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.[13]

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, with the difference that I define different speeds for paved roads under *concesion*. I describe in the Appendix A 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.

[10]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.

[11]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.

[12]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)

[13]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, 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).

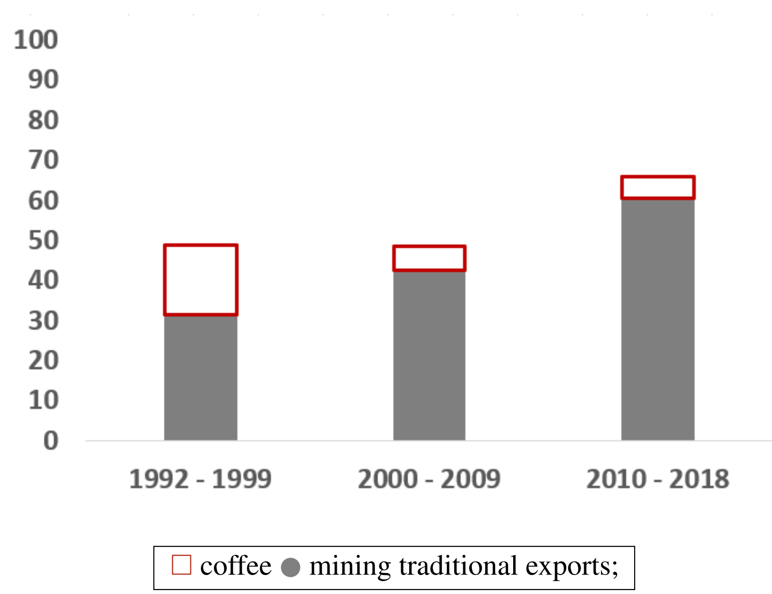
2.2 Motivating facts

This section describes four empirical facts about Colombian departments that motivate the theoretical framework. First, the Colombian exports show a high concentration in a few goods, mostly mining ones. Second, the Colombian departments specialize in different sectors. Third, departments show high variation in their access to international markets, which generates differences in the international trade costs between departments and the rest of the world. Lastly, when the departments trade with the rest of the world, they do not use a single city-port to trade, which implies traders tend to show heterogeneity in their international shipping routes.

Fact 1, Colombia exports are concentrated in a few 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).

Figure 1 plots the share of exports of *traditional products* as a fraction of total exports. This category was created by the Colombian government agencies for specific goods, given the historical concentration of exports in these products.[14] As figure 1 shows, during the past three decades, Colombia experienced an upward trend in the specialization of mining goods.

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



Notes: The bars show the average annual share of "traditional exports" with respect to total exports, for the period indicated in the x-axis. The source of the data is the official website of DANE.

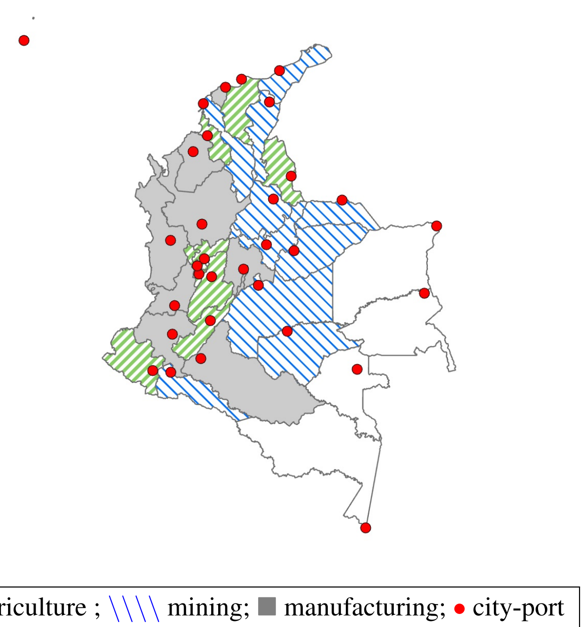
[14]This term is commonly used by government agencies such as the National Department of Planning or the statistical agency DANE. It groups the following products: coal, oil, coffee, and nickel-alloy.

Fact 2, Colombian departments specialize in different sectors. Using customs data from 2013, I build a Balassa Index of Revealed Comparative Advantage for every department. The formula of this index is

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

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. After I obtain the values of the Balassa index, I select the sector in which every department shows the highest level of specialization. With this information, I construct figure 2 to provide evidence that there is variation in the sectoral specialization of Colombian regions.

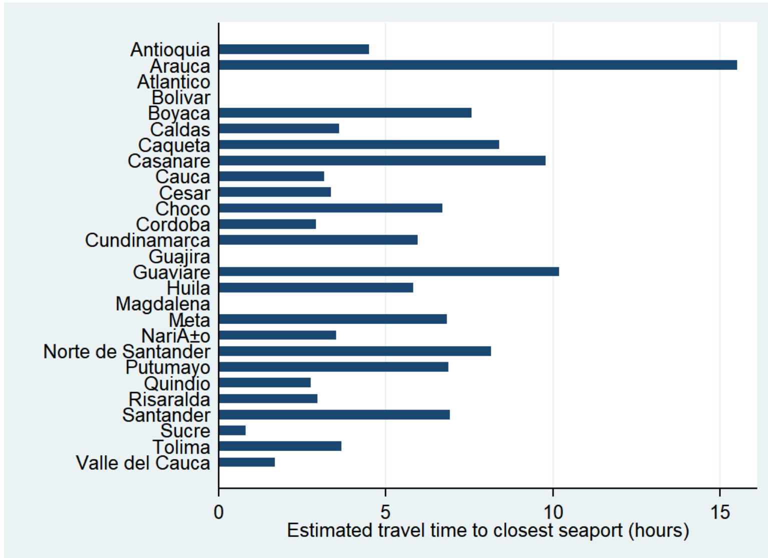
Figure 2. Map indicating the sector with the strongest comparative advantage of every department (highest value of the Balassa Index)



Notes: I do not consider the departments of Guainia, Leticia, San Andres y Providencia, Vaupes, and Vichada. Additionally, I merge Bogota with the department of Cundinamarca. See Appendix A for more details.

Fact 3, Colombian regions do not have uniform access to international markets. The 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/entered the country via seaports, figure 3 helps to illustrate the access to international markets of every Colombian department.

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



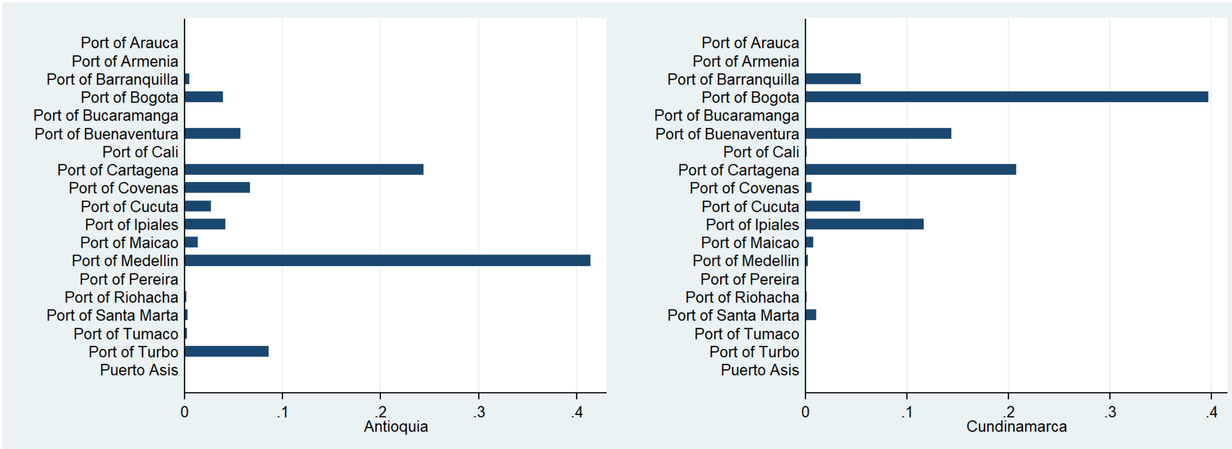
Notes: I estimate the travel times between the capital of every department and the closest seaport using Dijkstra's algorithm, according to the speed values described in section 2.1. I do not consider the departments of San Andres y Providencia, Guainia, Leticia, Vichada and Vaupes.

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.[15] The main explanation for this is that every city-port has logistical advantages for the shipment of specific goods. For example, the seaport of Covenas is ideal for oil products, the airport of Bogota has excellent logistical conditions for the shipment of flowers, while the seaport of Santa Marta has very good logistical capacity for handling steel and cement products.

[15]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 19 city-ports that appear in the customs data. For more details about the city-ports, see Appendix A.

3 Model

3.1 General framework

Geography. Consider an economy composed of Colombian departments and the rest of the world. These locations trade with each other. The departments are indexed by d and the rest of the world is indexed by RoW. 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 figure 5). 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 which consists of a department d and a city-port ρ. An *export route* consists of an ordered pair department, city-port $r_x = (d, \rho)$. There is a total of $\bar{d}\bar{\rho}$ export routes. The set of export routes is $R_x = \{(d_n, \rho_m)\}_{n=1,m=1}^{\bar{d},\bar{\rho}}$. The subset of export routes for a department d is defined as $R_{x,d} = \{d, \rho_m\}_{m=1}^{m=\bar{d}}$. An *import route* consists of an ordered pair city port-department $r_m = (\rho, d)$. There are $\bar{d}\bar{\rho}$ import routes. The set of import routes is $R_m = \{(\rho_m, d_n)\}_{n=1,m=1}^{\bar{d},\bar{\rho}}$. The subset of import routes for a department d is defined as $R_{m,d} = \{\rho_m, d\}_{m=1}^{m=\bar{\rho}}$

Goods. There are two types of goods, intermediates and composite goods. There are four sectors in the economy: agriculture (a), mining (m), manufacturing (i) and services (z). Sectors are indexed by $k \in \{a, m, i, z\}$. Intermediate good firms in location n and sector k produce a unique variety of intermediates $\omega_k \in \Omega_{n,k}$. Firms that produce composite goods buy varieties from suppliers across different locations and produce 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 $\iota \in [0,1]$. Traders choose among all the shipping routes when they export or import goods.[16] Figure 5 clarifies the concept of international shipping 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 ι when it uses an international shipping route r_t is $\tau_{r_t,k}/z_{r_t,k}(\iota)$. I define the international shipping cost for trader ι as the lowest international shipping cost across different routes, when the trader ships a good of sector k from/to department d to/from RoW, that is

$$\tau_s(\iota) = \underset{r_t}{min} \frac{\tau_{r_t,k}}{z_{r_t,k}(\iota)} \text{ for } t \in \{x, m\} \tag{1}$$

where τ_{r_t} is the shipping cost along route r_t for goods of sector k, $z_{r_t,k}(\iota)$ 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. This productivity draw follows a Frechet distribution with parameters $(A_{r_t,k}, \theta_k)$. 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 of city-ports regarding the transportation of sector-k goods.

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).

$$\tau_{dRoW,k} \equiv E[\tau_s(\iota)] = E\Big[\underset{r_t,k}{min} \frac{\tau_{r_t}}{z_{r_t,k}(\iota)}\Big] \tag{2}$$

Using the properties of Frechet distribution, the expression for the icerberg trade cost between any department d and the rest of the world becomes

$$\tau_{dRoW,k} = \Phi_x^{-\frac{1}{\theta}} \Gamma\Big(\frac{1+\theta_k}{\theta_k}\Big) \tag{3}$$

where Γ is the gamma function.

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 connectivity between department d and port ρ, expressed as $\tau_{\rho d}$. The latter is a function of the travel times between d and ρ, T_{dp}, therefore $\tau_{d\rho} = f(T_{d\rho})$.[17]

[16] Intuitively, firms choose logistical companies to ship goods to/from the rest of the world (e.g. Fedex, UPS, McLane Company, JR Freight, etc.)

[17] The assumptions have implications about the symmetry of shipping costs of export and import routes $\tau_{r_x} = \tau_{r_m} = \tau_d \tau_{dp} \tau_\rho \text{ , } if\ r_x = (d, \rho)\ and\ r_m = (\rho, d)$

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 $\tau_{d_1 d_2,k}$. Iceberg 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. This 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.

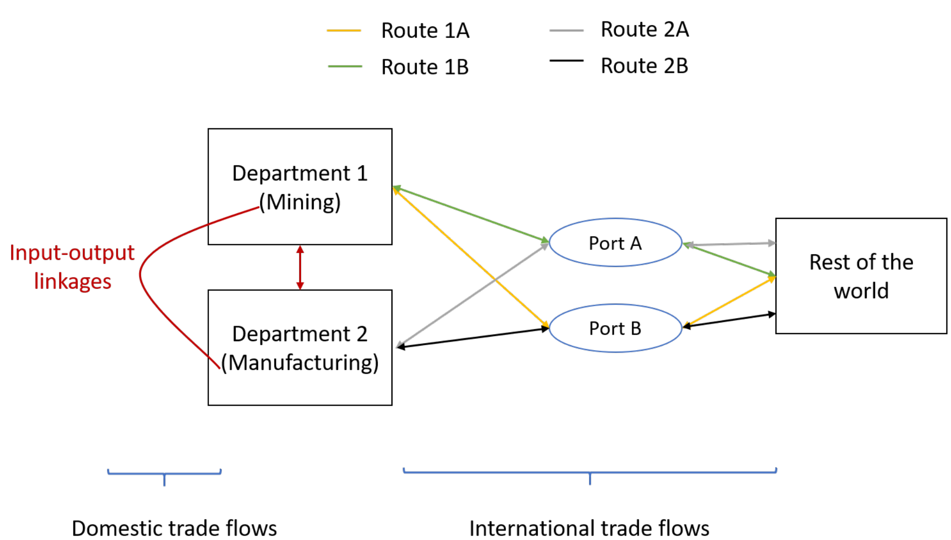
Preferences. Consumers' preferences are represented by a Cobb-Douglas utility function given by

$$U_j = \prod_{k=1}^{K} (C_j^k)^{\alpha_j^k} \text{ , with } \sum_{k=1}^{K} \alpha_j^k = 1 \tag{4}$$

where α_j^k is the share of sector k in final demand and C_j^k is the level of consumption of composite intermediate good. The income of households 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 n. There is perfect labor mobility across sectors, but no labor mobility across locations (this implies no labor mobility across Colombian departments).

Figure 5. Economic environment



3.2 Production

Production of intermediates. The production of a variety ω_k of intermediate goods requires labor and composite goods from all sectors. Technology for variety ω_k has constant returns to scale and it is defined by

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

where $\beta_n^{l,k} + \sum_s \beta_n^{s,k} = 1 \;\forall\; n.$ I denote by $m_{s,k}(\omega_k)$ 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, $\beta_n^{l,k}$ is the share of value added of sector k, $A_{z,k}$ is the productivity of sector k, $l_n^k(\omega_k)$ is the amount of labor necessary for the production of good ω_k,

Firms price at unit cost $\frac{c_{n,k}}{A_{n,k}(\omega_k)}$, where $c_{n,k}$ is the unit cost of an input bundle. 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 $\phi_{n,k} \equiv (\beta_n^{l,k})^{-\beta_n^{l,k}} (\beta_n^{a,k})^{-\beta_n^{a,k}} (\beta_n^{i,k})^{-\beta_n^{i,k}} (\beta_n^{m,k})^{-\beta_n^{m,k}} (\beta_n^{z,k})^{-\beta_n^{z,k}}$ is a constant, and $P_{n,s}$ is the price of a composite intermediate good from sector s in location n. 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 n for sector k purchase the intermediate goods from suppliers across different locations. The production technology of composite goods uses a Dixit-Stiglitz aggregator:

$$Q_{n,k} = \Big[\int \sum_j q^c_{jn,k}(\omega_k)^{\frac{\sigma_k - 1}{\sigma_k}} d\omega_k \Big]^{\frac{\sigma_k}{\sigma_k - 1}} \tag{7}$$

where $Q_{n,k}$ is the number of units that the firms supply, σ_k is the elasticity of substitution between varieties of sector k and $q^c_{jn,k}(\omega_k)$ is the demand of intermediate good ω_k.

Prices. Given the existence of perfect competition, the price of a good in ω_k consumed by location n and produced in j considers the unit cost and the trade costs between locations, that is

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

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

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

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 ω_k, denoted by $q^c_{jn,k}(\omega_k)$. Combining it with the price of intermediate good $p_{jn,k}(\omega_k)$ and aggregating across all varieties, I derive an expression for the total expenditure by location n on goods from sector k produced in location j

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

Following Anderson and van Wincoop (2003), 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 $\Pi_{j,k}^{1-\sigma_k} \equiv \sum_m \tau_{jm}^{1-\sigma_k} X_{m,k} P_{m,k}^{\sigma_k-1}$. The term $X_{m,k}$ is the total expenditure of location m in goods of sector k. Finally, let $\lambda_{jn,k}$ be the fraction of expenditure of j in sector-k goods produced by location n:

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

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 on intermediates (that depends on total exports of location n) and the households' expenditure (which is a constant fraction $\alpha_{n,k}$ of the total income):

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

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.

To obtain the equation for trade balance, the trade deficit of location n will be considered as a transfer, as in Dekle, Eaton and Kortum (2008). 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 B).

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

3.5 Equilibrium

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 $\{P_{n,k}\}_{n\in R, k\in\{a,m,i,z\}}$, and labor allocations $\{L_{n,k}\}_{n\in Z, k\in\{a,m,i\}}$ for all locations $n \in Z$ 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 implies the estimation of several parameters, such as the sectoral productivities $\{A_{j,k}\}$. An option to reduce the number of parameters needed to calibrate the model, is to express the equilibrium in changes.

Following Dekle, Eaton and Kortum (2008), 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. This is similar to Caliendo and Parro (2015).

Definition 2: Equilibrium in terms of changes. *Let $(\mathbf{w}, \mathbf{P})$ be an equilibrium under trade costs $\{\tau_{\mathbf{jn}}\}_{\mathbf{j,n\in R}}$. Consider a different equilibrium $(\mathbf{w}', \mathbf{P}')$ under trade costs $\{\tau'_{\mathbf{jn}}\}_{\mathbf{j,n\in R}}$. Let $(\hat{w}, \hat{P})$ be an equilibrium under trade costs $\{\tau'_{\mathbf{jn}}\}_{\mathbf{j,n\in R}}$ relative to $\{\tau_{\mathbf{jn}}\}_{\mathbf{j,n\in R}}$, 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) *Good market clearing condition*

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

(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*

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

(iv) *Total expenditure*

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

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

(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), which will be used instead of the equation (12), which is the expression for trade flows between locations. 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, to generate a department-port gravity equation.

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

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

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

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

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

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

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

$$\pi_{r_t,k} = Pr\{\tau_{r_t,k}(\iota) \leq \min_{v_t \in R_{t,d} \backslash r_t} \tau_{v_t,k}(\iota)\}$$

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

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 B). This implies that $\pi_{r_t,k}$ also represents the share of the value of exports/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 $r_t = (d, p)$:

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

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

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:

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

To obtain the previous result, I assume that $A_{r_t} = A_{dp} = A_dA_\rho$. Moreover, I use the expression for international shipping costs $\tau_{r_t} = \tau_p\tau_{dp}\tau_p$. 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 relevant characteristics of the international shipping costs τ_{dp}. 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 international shipping costs affect the trade costs between department d and the rest of the world, $\tau_{d\ RoW}$. Such effects are realistic. 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 how to obtain 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

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

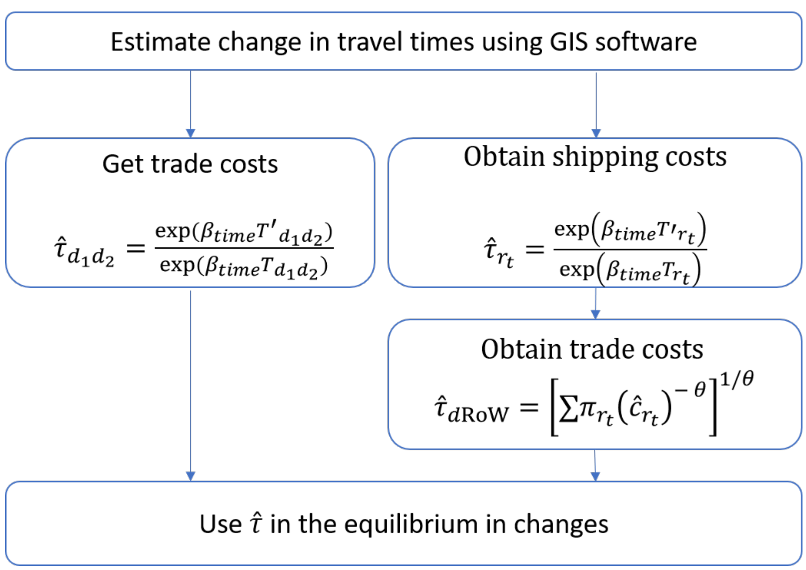
and the change in trade costs between department d and RoW is expressed as

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

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.[18].

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

Figure 6. Process of the simulation



[18]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.

4 Taking the model to data

4.1 Parameters of the Armington model

Data sources to calibrate the model. I use the following datasets (i) customs data with records about individual export and import shipments, with information about the port of entry/exit, (ii) the World IO database (WIOD), (iii) the input-output table from the Colombian statistical agency for 2010, (iv) the 2013 Transportation Survey of Origin/Destination elaborated by the Colombian Ministry of Transportation, [19] (v) crude oil production data and refinery capacity, and (vi) the Economic Accounts produced by DANE to obtain variables such as value-added and gross output at a sectoral level . Appendix A provides more details.

Production and consumption parameters. I use the same value for the elasticity of substitution for all sectors, $\sigma_k = 6 \ \forall k$. I estimate the share of value added for the rest of the world and the departments using $\beta_n^{l,k} = (VA_k)/Y_k$, where VA_k is value added of sector k and Y_k is the gross production. Given the lack of input-output tables for Colombian departments, I assume the same value for this parameter for all departments. I estimated the share of sector s in the production of sector k using $\beta_n^{s,k} = (1 - \beta_n^{l,k})\frac{C_{intermediate,k,s}}{C_{intermediate,k,total}}$, where $C_{intermediate,k,s}$ is the intermediate consumption of sector k in goods from sector s, and $C_{intermediate,k,total}$ is the total intermediate consumption of sector k. I assume identical values of these parameters for all departments. Lastly, I estimate the share of final consumption in sector k with data from the input-output tables, using the formula $\alpha_{n,k} = C_{k,final,total}/C_{final,total}$, where $C_{k,final,total}$ is the final consumption in sector k and $C_{final,total}$ is the level of total final consumption.

Trade deficits and expenditure shares: agriculture and manufacturing. My estimation of trade deficits is limited by the information of transportation survey data that serves as proxy for domestic trade flows, for the agriculture and manufacturing sectors. The trade deficit of any department d can be considered as $D_{d,Total} = D_{d,Domestic\ trade} + D_{d,International\ trade}$. Unfortunately, I cannot obtain direct estimates of domestic trade flows using the cargo transportation survey. Hence, I assume that for Colombian departments, the deficit generated from the domestic trade is very small relative to the deficit the international trade. Hence, my deficit estimations exclusively consider the customs administrative data.

Expenditure shares: agriculture and manufacturing. For the case of the expenditure shares, $\lambda_{nj,k}$, table 1 illustrates the construction of the shares. I obtain the share of expenditures of Colombia on its goods, denoted by $\gamma_{Col,Col}$, using Colombia's input-output table, the share of expenditures of rest of the world on its goods, represented by $\gamma_{RoW\ RoW}$, using WIOD tables and the customs administrative dataset. Besides, using the customs data, I obtain the share of Colombian exports for every department, expressed as γ_{dRoW}, and the department share of national imports, characterized by γ_{RoWd}.

To obtain data on domestic trade flows, I rely on the transportation survey elaborated by the Ministry of Transportation for 2013. I assume this survey exclusively reflects patterns of domestic

[19] 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

trade. I denote $\mu_{d_1 d_2}$ as the shares of expenditures of a department d_2 in goods from d_1, exclusively considering domestic trade flows. Notice these are not the shares from the Armington model $\lambda_{d_1 d_2}$ for $d_1, d_2 \in D$, because such shares consider both domestic and international trade. Unfortunately, I am not able to obtain values for the share of expenditures of departments on their goods for the case of domestic trade flows, μ_{dd}, therefore, I run my simulations under different values for this parameter ($\mu_{dd} = 0.3, 0.6$).

Table 1. Construction of the matrix of expenditure shares

Exporter ↓ Importer →	$\mathbf{RoW}$	$\mathbf{d_1}$	...	...	$\mathbf{d_D}$
$\mathbf{RoW}$	$\lambda_{RoW\,RoW} = \gamma_{RoW\ RoW}$	$\lambda_{RoW\,d_1} = (1-\gamma_{ColCol})\gamma_{RoW\,d_1}$			
$\mathbf{d_1}$	$\lambda_{d_1\,RoW} = (1-\gamma_{RoW\,RoW})\gamma_{d_1\,RoW}$	$\lambda_{d_1 d_1} = \mu_{d_1 d_1}\gamma_{ColCol}$			
...					
...					
$\mathbf{d_D}$	$\lambda_{d_D\,RoW} = (1-\gamma_{RoW\,RoW})$				$\lambda_{d_D d_D} = \mu_{d_D d_D}\gamma_{ColCol}$

Notes: μ_{ij} represents shares exclusively considering domestic trade flows between locations i and j, while γ_{mn} represents international trade flows between m and n

Trade deficits and expenditure shares: mining. I build the international and domestic expenditure shares of mining under the assumption that domestic trade flows are exclusively for crude oil between departments with oil fields and those with refineries,[20] while international trade flows include oil, coal, and minerals. I assume that those departments that are oil producers ship crude oil to the five refineries located in the departments of Bolivar, Santander, Casanare, Putumayo, and Meta.

Given that Colombia is a crude oil exporter, I presume that refineries only use crude oil produced domestically. To build these domestic trade flows, I infer that departments with refineries consume all the crude oil they produce, and if there is remaining capacity, they will import crude oil from other departments. The size of such domestic imports from each department is proportional to their oil production. This assumption allows me to obtain domestic trade flows for the mining sector. Additionally, I used the customs data to obtain international trade flows of the mining sector between departments and the rest of the world.[21]

4.2 Solving the model

I solved 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.

[20] 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

[21] 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.

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 trade costs and travel time.

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

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 shipping costs of a route $r_t = (d, \rho)$ 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

$$\begin{aligned} ln(X_{dRoW,k,d\rho}) = \alpha + \alpha_{d,exporter} + \alpha_{d,importer} + \alpha_{RoW,exporter} + \alpha_{RoW,importer} \\ + \alpha_{\rho} - \mu_{t,k}(T_{d\rho}) + \epsilon_{d\rho} \end{aligned} \tag{29}$$

where $\mu_{t,k} = \theta_k \beta_{time}$, and T_{dp} is the travel time between department d and city-port ρ. 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.

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 (2007) 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 (see Appendix B).

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).[22] 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. These indices include a category for those department-port pairs unconnected in the historical road networks. 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.

[22]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.

Table 2. Empirical results of the gravity equation

Method	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Sector	agriculture		mining		manufacturing	
$-\mu_{t,k}(time_{dp})$	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.

4.5 Estimation of the parameter of the dispersion of productivity 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)[23]. 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 other 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. For the purpose clarity, Appendix E contains graphs on how the values of the parameters θ_a, θ_m and θ_i vary if I also consider the confidence intervals of my estimates of $\mu_{t,a}$, $\mu_{t,m}$ and $\mu_{t,i}$.

[23] 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.

Table 3. 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

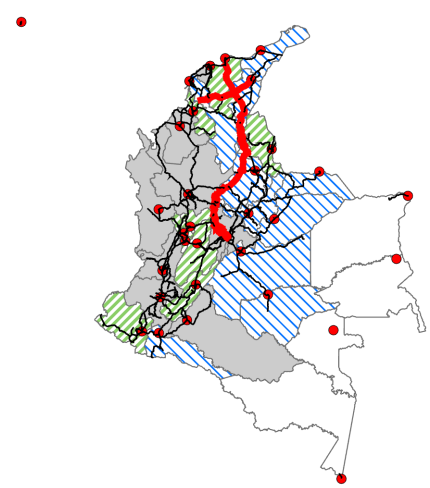
Notes: To obtain the values of θ_k, I use the estimates of $\hat{\mu}_{t,k}$ shown in Table 2 for every sector $k \in \{a, m, i, z\}$ and the value of β_{time} from Allen and Arkolakis (2019). Then, I adjust the value of β_{time} upwards.

5 The impact of *Ruta del Sol* on comparative advantage

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. 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, although many sub-segments were inaugurated during the period 2014-2019 as the local media reported (El Espectador, 2019; La Republica, 2014, Semana 2019).

Figure 7. Location of the project "Ruta del Sol"



//// department specialized in agriculture \\\\ department specialized in mining ■ department specialized in manufacturing.

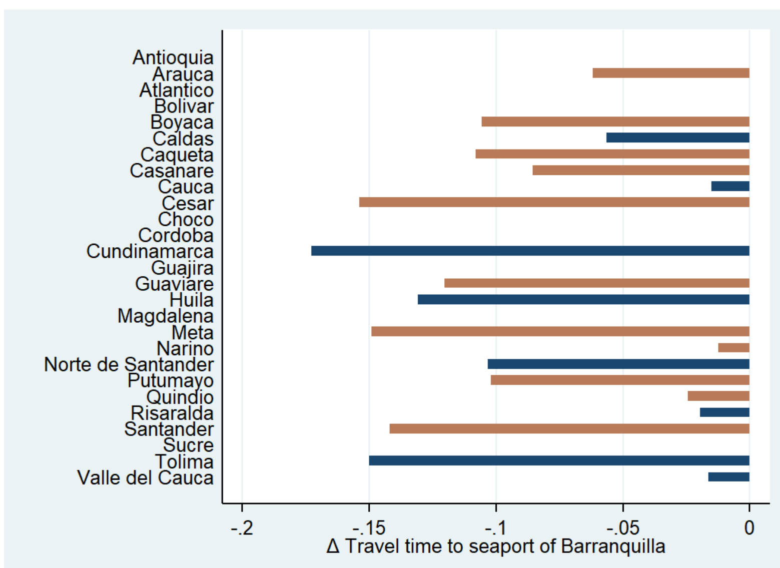
▲ city-port ● capital of department — primary road network — Ruta del Sol (thick line)

Notes: The colors/figures that fill the area of every department show the sector with highest value of the Balassa index.

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). I chose a small change in speed derived from the completion of the project for the existing road segments. One of the main objectives of the project is to guarantee the existence of two lanes 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 vehicles.

A priori, the effects of *Ruta del Sol* on the comparative advantage of Colombia are unclear. Figure 7 shows that the road crosses regions that specialize in different sectors. The project improves the connectivity of between the department of Cundinamarca, which specializes in manufacturing, and the Atlantic seaports. But also reduces the travel times between departments that sepcialize in mining and the same seaports. Moreover, graphs in the Appendix D show that the international trade costs τ_{dRoW} fall for several departments and all tradable sectors, according to the predictions of my framework.

Figure 8. Reduction in travel distance between department and seaport of Barranquilla



● department specialized in mining ● department that does not specialize mining

Notes: 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 seaport of Barranquilla 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 also 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*.

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 the results of simulations using different values of β_{time}. These results are in Appendix E.

Appendix J contains graphs with estimates of the effect of the completion of the highway *Ruta del Sol* in the trade costs $\tau_{dRoW,k}$ for different values of β_{time}. These graphs illustrate that using the value of β_{time} from Allen and Arkolakis (2019) leads to conservative estimates of the change in trade costs caused by the completion of *Ruta del Sol*.

I report the effects of my simulations on the share of agricultural, mining, and manufacturing exports in table 4. These shares are informative of the national comparative advantage for a small economy, if I use the Balassa index. As a robustness check, I implement my simulations under different values for the share of expenditures on own goods for the case of domestic trade of Colombian departments, μ_{dd}.[24]

Table 4. Results of the simulation under different parameters

	Counterfactual	$\bar{\mu}_{dd}$	$\frac{X_{agriculture,Col}}{X_{total,Col}}$	$\frac{X_{mining,Col}}{X_{total,Col}}$	$\frac{X_{manuf.,Col}}{X_{total,Col}}$	**Change in the share of manuf. exports**
	No new road	0.3	7.70 %	54.19%	38.10%	
I	Completion of Ruta del Sol	0.3	7.53 %	50.15 %	42.32 %	**+4.22**
	No new road	0.6	7.39%	55.76 %	36.85 %	
II	Completion of Ruta del Sol	0.6	7.43 %	51.37 %	41.21 %	**+4.35**

Note: μ_{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)

Under different values of the parameters that govern the trade and transportation models, 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 departments.

I analyze which departments contribute to the increase in the share of manufacturing exports in my simulations. Intuitively, the improvements in the connectivity of the department of Cundinamarca could be the main source of this growth. To confirm this, I analyze the change in manufacturing exports between two different equilibria using the following expressions

$$\Delta\ Manuf.\ Share\ Exports = \frac{X'_{i,Colombia}}{X'_{Colombia}} - \frac{X_{i,Colombia}}{X_{Colombia}}$$

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

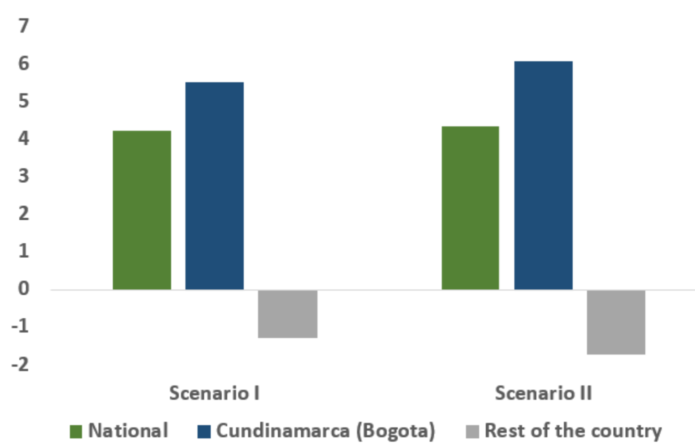
$$\Delta \; Manuf. \; Share \; Exports = \left[\left(\frac{X'_{i,b}}{X'_{Colombia}}\right) + \left(\frac{\sum_{d \neq b} X'_{d,i}}{X'_{Colombia}}\right)\right] - \left[\left(\frac{X_{i,b}}{X_{Colombia}}\right) + \left(\frac{\sum_{d \neq b} X_{i,d}}{X_{Colombia}}\right)\right]$$

$$\Delta \; Manuf. \; Share \; Exports = \left[\frac{X'_{i,b}}{X'_{Colombia}} - \frac{X_{i,b}}{X_{Colombia}}\right] + \left[\frac{\sum_{d \neq b} X'_{i,d}}{X'_{Colombia}} - \frac{\sum_{d \neq b} X_{i,d}}{X_{Colombia}}\right] \quad (30)$$

where $X_{Colombia}$ and $X'_{Colombia}$ are total exports of Colombia under the old and new equilibrium, respectively; $X_{i,d}$ and $X'_{i,d}$ are the manufacturing exports of the department d for the case of the old and new equilibrium, respectively.

Using (30), the change in share of manufacturing exports is the contribution of any department b (first term parenthesis) plus the contribution of the rest of the departments (second term in parenthesis). Hence, I decompose the growth in the share of manufacturing exports for different scenarios. I display the results of the decomposition in figure 9. These results show that the increase in manufacturing exports of Cundinamarca is the main driver of the change of national comparative advantage towards manufacturing.

Figure 9. Decomposition of growth in share of manufacturing exports (%)



Note: μ_{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)

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 (scenario A), I close the input-output linkages but I allow for the impact of the infrastructure project on both domestic and international trade costs. The second alternative counterfactual (scenario B) 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 (scenario C), in which I consider industry linkages, but I assume the road project only affects international trade costs, and does not change domestic trade costs. I report the results of these alternative counterfactual experiments in columns 2 and 3 of table 5.

Table 5. Results of alternative simulations

Scenario		Increase in the share of manufacturing exports	
		($\bar{\mu}_{dd}$ = 0.3)	($\bar{\mu}_{dd}$ = 0.6)
Main	All the effects of *Ruta del Sol*	+4.2	+ 4.4
A	Impacts of *Ruta del Sol* without considering input-output linkages	+1.2	+1.8
B	*Ruta del Sol* only affects domestic trade costs	+0.7	+0.7
C	*Ruta del Sol* only affects international trade costs	+3.6	+2.0

Note: According to the Balassa index of revealed comparative advantage, for a small open economy the share of exports in a sector is a good measure of comparative advantage (the denominator of the index is taken as given for a small open economy and if the sectors are not very disaggregated). μ_{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 alternative counterfactual simulations provide two interesting insights about the forces driving my results. The first insight is that improvements in infrastructure lead to better access to intermediate inputs. This specially benefits manufacturing exports. To see this, the results of the scenario B are informative. In this alternative simulation, I consider that *Ruta del Sol* only improves access to domestic inputs. As a result, the national share of manufacturing exports increases by 0.7 percentage points. Hence, the improvement in the access of domestic inputs alone helps to increase the share manufacturing exports.

The second insight is that the existence of industry linkages propagate the positive effects generated by the road project. The presence of such linkages benefit the manufacturing sector the most. To see this, notice that in scenario A, in which input-output linkages are not considered, the reductions in trade costs lead to an increase in the specialization of Colombia in manufacturing goods, but this growth is one third of the increase from the main counterfactual (scenario A vs. main scenario).

The alternative counterfactuals show the relevance of industry linkages when we measure the impact of road projects, using international trade models. These linkages are not usually considered in existing studies regarding the general equilibrium effects of infrastructure improvements. Failure to consider these linkages will result in the estimation of smaller effects of lower trade costs on the trade flows of specific sectors.[25]

[25]The structure of the input-output table in every country determine which sectors benefit the most from improvements in infrastructure

6 Conclusion

The main conclusion of this paper is that domestic trade costs are determinants of comparative advantage. This idea is especially relevant for those countries with low quality of infrastructure. Analyzing the standard determinants of specialization in developing nations such as factor endowments, institutions or technology, without considering domestic trade costs, leads to inaccurate conclusions regarding the comparative advantage of these nations. The reason behind this reasoning is that domestic trade costs define what factor endowments and inputs are available for the production of goods and services across regions within an economy.

This idea also has policy implications. Given that the structure of the transportation network affects the domestic trade costs, infrastructure policy can be a tool for those policymakers whose objective is to affect specialization. Given that reductions in trade costs lead to welfare gains through multiple channels, as recent economic literature predicts, the construction of roads seems to be a feasible and less distortionary policy alternative to change specialization, compared to protectionism or subsidies to specific sectors.

Specifically, in the context of Colombia, one of the most important infrastructure policy projects *Ruta del Sol*, has the potential to change the comparative advantage of the country, by weakening the specialization of the country in mining goods, while strengthening the comparative advantage of the nation in the manufacturing sector. This project has the potential to reverse the recent upward trend of Colombia's specialization on mining goods. Such result is in line with the policy objectives of public officials in Colombia.

The change in the comparative advantage of Colombia caused by *Ruta del Sol* is driven by two forces. First, the road project increases the access to global markets of the department of Cundinamarca, which specializes in manufacturing goods. Second, the improvement in access to inputs benefits the manufacturing firms the most, given the structure of input-output linkages of the country.

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 taken into account, the increase of specialization in manufacturing is smaller relative to the case when the linkages are considered. This result is specially relevant for previous work regarding the economic effects of infrastructure projects, given that little attention has been paid to the relationship between infrastructure and industrial linkages.

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Appendix

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.

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. This gives us a total of 30 departments for the trade model.
- 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.

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.

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, $\mu_{RoW,RoW}$. 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, μ_{ColCol}. I estimated this using the input-output matrix produced by DANE for the year 2010.

  - Purchases of a department to itself or $\mu_{dd,k}$. 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).

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.

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.

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.

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 eported 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. I merged the Port of Coveñas and the Port of Cartagena given that they are located in the same city (Cartagena).

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 considered all the goods that are exported via the Port of Coveñas as exported via the Port of Cartagena given that they are located in the same city (Cartagena).

5. I did not use customs data from the ports of Inirida, Leticia, San Andres, Puerto Carreño. This is because the international trade flows of these towns are mainly influenced by the local border regions. For example, the trade flows observed in the port of Leticia, Colombia are mainly driven by regional dynamics between Leticia and Tabaratinga, Brazil.

B. Historical maps

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

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

C. Derivations

Obtaining the expression for trade flows

By solving the firm's problem I obtain the demand of the composite good ω_k

$$q^c_{jn,k}(\omega_k) = \frac{p_{jn,k}(\omega_k)^{-\sigma_k}}{P_{n,k}^{1-\sigma_k}} Q_{n,k}$$

where $P_{n,k}$ is the price of the composite intermediate good and $p_{n,k}(\omega_k)$ 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 ω_k to composite goods firms in location n is

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

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

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

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

$$x_{jn,k}(\omega_k) = p_{jn,k}(\omega_k) \cdot q^c_{jn,k}(\omega_k) = \frac{p_{jn,k}(\omega_k)^{1-\sigma_k}}{P_{nk}^{-\sigma_k}} Q_{n,k}$$

Aggregating across varieties, I obtain the trade flows of sector k goods between location n and location j:

$$X_{jn,k} = \int x_{jn,k}(\omega_k) d\omega_k \iff$$
$$X_{jn,k} = \Big(\frac{\tau_{jn,k} c_{j,k}}{A_{j,k}}\Big)^{1-\sigma_k} Q_{n,k} P_{n,k}^{\sigma_k - 1}$$

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

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

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

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

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 $\{w_{n,k}\}_{n \in Z, k \in \{a,m,i\}}$, 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 between varieties of sector k $\{\sigma_k\}_{k \in \{a,m,i,z\}}$,*

(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.*

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

(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*[26].

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

Transportation framework

Probability that the shipping cost offer is lower than c

Consider a shipping route $r_t \in R_t$ for $t \in \{x, m\}$. Denote the potential shipping cost of a trader ι as $\tau^o_{r_t,k}$. This offer depends on the shipping cost along route r_t and a productivity draw $z_{r_t,k}(\iota)$, which follows a Frechet distribution with parameters $(A_{r_t,k}\theta_k)$.

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

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

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

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

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

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

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

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

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

Let $\tau_s(\iota)$ be the actual shipping cost of trader ι 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

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

Probability that the observed shipping cost is lower than c

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

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

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

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

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

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

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

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 ω_k 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.

$$\pi_{r_t,k} \equiv Pr\Big[\tau^o_{r_t,k}(\iota) \leq \underset{v_t \in R_t \setminus r_t}{min} \tau^o_{v_t,k}(\iota)\Big] \iff$$

$$\pi_{r_t,k} = \int_0^\infty Pr\Big[\underset{v_t \in R_t \setminus r_t}{min} \tau^o_{v_t,k}(\iota) \geq c\Big] dG_{r_t,k}(c) \iff$$

$$\pi_{r_t,k} = \int_0^\infty Pr\Big[\underset{v_t \in R_t \setminus r_t}{\cap} \{\tau^o_{v_t,k}(\iota) \geq c\}\Big] dG_{r_t,k}(c) \iff$$

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

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

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

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

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

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

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

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

$$Pr[\tau^o_{r_t}(\iota) \leq \bar{c} | \tau^o_{r_t}(\iota) \leq \min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota)] = \frac{1}{\pi_{r_t}} \int_0^{\bar{c}} Pr[\min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota) \geq c] dG_{r_t}(c)$$

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

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

$$Pr\Big[\tau^o_{r_t}(\iota) \leq \bar{c} | \tau^o_{r_t}(\iota) \leq \min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota)\Big] = \int_0^{\bar{c}} \prod_{v_t \in R_t \setminus r_t} [exp(-A_{v_t}\tau_{v_t})] \frac{d}{dc}[1 - exp(-A_{r_t}(\tau_{r_t})^{-\theta_k} c^{\theta_k})] dc$$

$$Pr\Big[\tau^o_{r_t}(\iota) \leq \bar{c} | \tau^o_{r_t}(\iota) \leq \min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota)\Big] = \frac{1}{\pi_{r_t}} \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t} \Big[- exp(-c^{\theta_k} \Phi_t |_0^{\bar{c}}) \Big]$$

$$Pr\Big[\tau^o_{r_t}(\iota) \leq \bar{c} | \tau^o_{r_t}(\iota) \leq \min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota)\Big] = \frac{1}{\pi_{r_t}} \frac{A_{r_t}(\tau_{r_t})^{-\theta_k}}{\Phi_t} \Big[1 - exp(-\bar{c}^{\theta_k} \Phi_t)\Big]$$

$$Pr\Big[\tau^o_{r_t}(\iota) \leq \bar{c} | \tau^o_{r_t}(\iota) \leq \min_{v_t \in R_t \setminus r_t} \tau^o_{v_t}(\iota)\Big] = G_{t,k}(\bar{c})$$

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

$$\tau_{dRoW} \equiv E\Big[\tau_s(\iota)\Big]$$

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

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

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

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

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

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

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

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

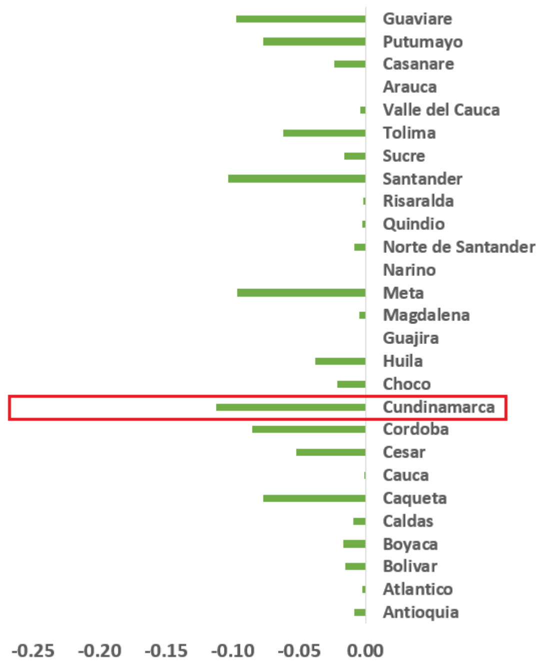
$$\tau_{dRoW} = \Phi_t^{-\frac{1}{\theta}} \int_0^{\infty} x^{\frac{1}{\theta}} e^{-x} dx$$

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

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

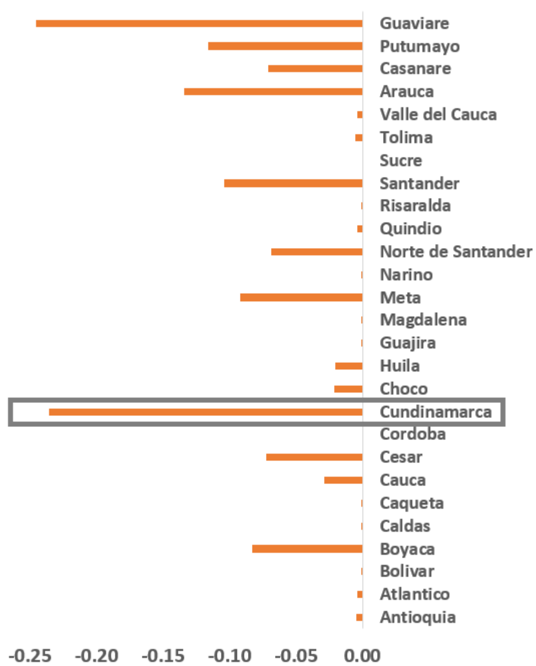
D. Reductions in trade costs $\tau_{dRoW,k}$ generated by the completion of Ruta del Sol

Figure D1. Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol



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

Figure D2. Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol



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

Figure D3. Reductions of $\tau_{dRoW,agriculture}$ caused by Ruta del Sol

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

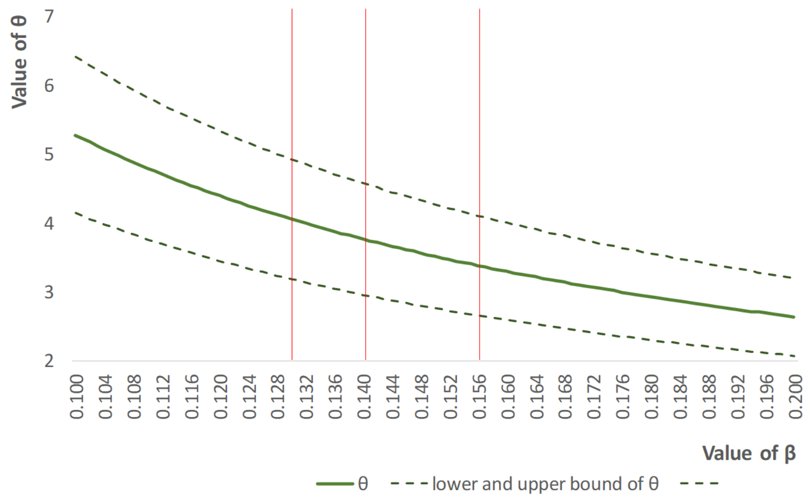
E. Robustness checks for the simulations of Ruta del Sol

Table E1. Effects of the "Ruta del Sol" infrastructure project in sectoral exports of Colombia under different values of β_{time}

Scenario	$\bar{\mu}_{dd}$	Value of β_t that defines impact of project on τ_{dRoW}	$X_{agr.}/X_{total}$	X_{mining}/X_{total}	$X_{manuf.}/X_{total}$	Δ **share of manufacturing exports**
	0.3	No project (baseline scenario)	7.70 %	54.19%	38.10%	
A		0.13	7.53 %	50.15 %	42.32 %	**+4.22**
B		0.143	7.14 %	49.13 %	43.73 %	**+5.63**
C		0.156	6.9 %	47.3 %	45.8 %	**+7.72**
	0.6	No project (baseline scenario)	7.39%	55.76 %	36.85 %	
D		0.13	7.43 %	51.37 %	41.21 %	**+4.35**
E		0.143	7.09 %	50.41 %	42.51 %	**+5.65**
F		0.156	7.05 %	48.44 %	44.51 %	**+7.65**

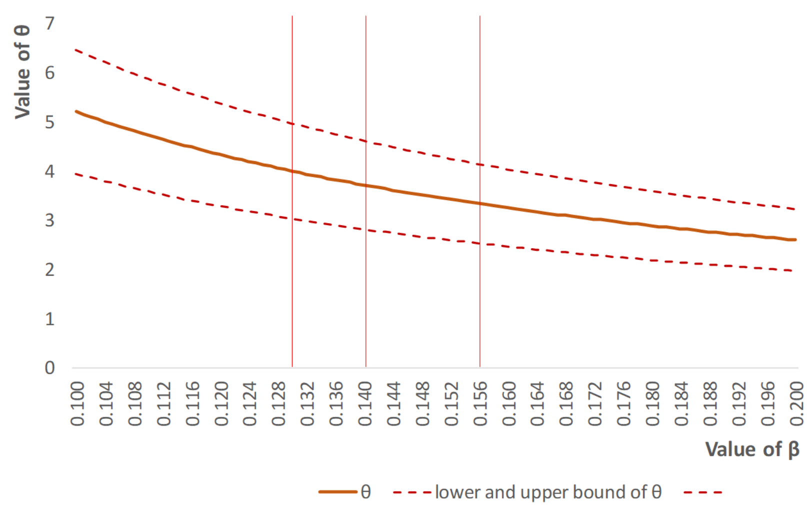
F. Values of θ_k considering the confidence intervals of $\hat{\mu_k}$

Figure F1. Value of parameter θ_a when considering the confidence interval of $\hat{\mu_a}$



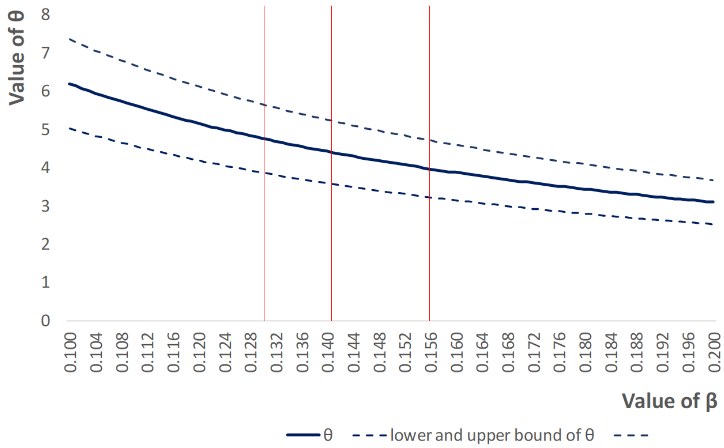
Notes: I use the estimate of $\hat{\mu_a}$ obtained using 2SLS. See Table 2.

Figure F2. Value of parameter θ_m when considering the confidence interval of $\hat{\mu_m}$



Notes: I use the estimate of $\hat{\mu_m}$ obtained using 2SLS. See Table 2.

Figure F3. Value of parameter θ_i when considering the confidence interval of $\hat{\mu}_i$



Notes: I use the estimate of $\hat{\mu}_i$ obtained using 2SLS. See Table 2.

G. Simulated change in trade costs after the completion of the highway ”Ruta del Sol”

Figure G1. Simulated change in trade costs before/after Rutal del Sol is finished for agricultural sector

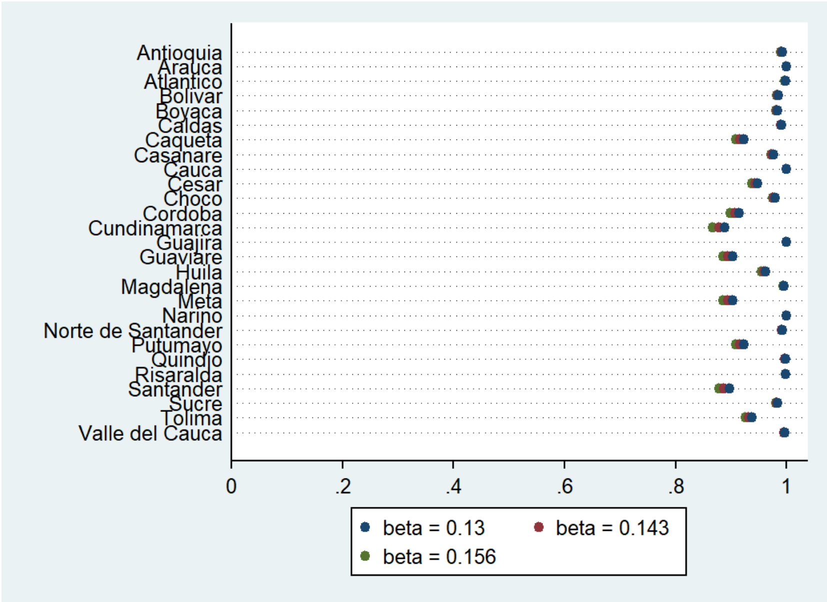


Figure G2. Simulated change in trade costs before/after Rutal del Sol is finished for mining sector

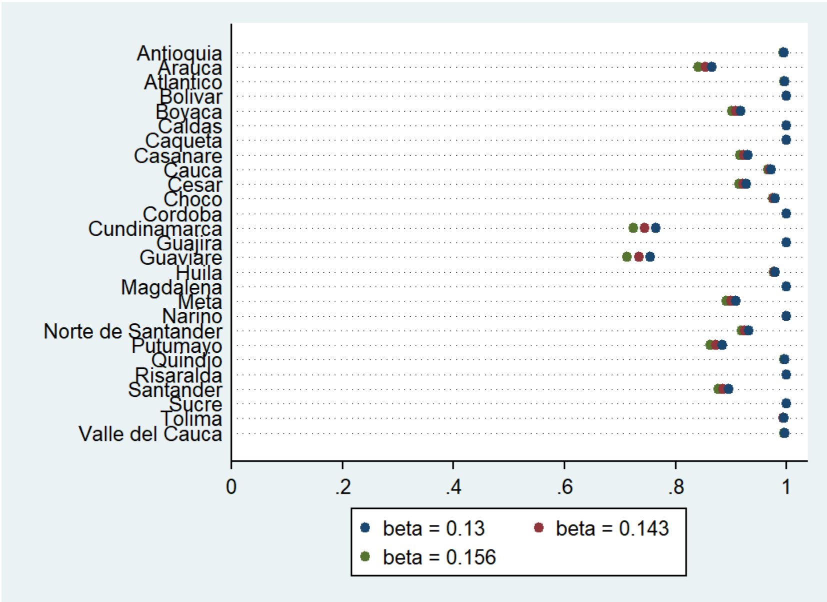


Figure G3. Simulated change in trade costs before/after Rutal del Sol is finished for manufacturing sector