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Paving the Road to Export

Assessing the Trade Impacts of Road Quality

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ABSTRACT[•]

Assessing the trade impacts of domestic transport costs is data demanding and analyses that examine the effects of road quality, a critical aspect in regional and public policy, practically do not exist in the international trade literature. The few studies available rely mostly on distance-based measures as proxies of transport costs which impede analyzing the trade effects of transport-infrastructure improvements. In this paper, we combine highly disaggregated records of export flows with detailed geo-referenced information of the Colombian transport network, including its road quality, as well as real measures of transport costs of shipping goods within the country to measure the trade impacts of improving road quality. We find that the trade effects of improvements in road quality are relatively small on average; however, there is considerable heterogeneity in the magnitude of the effects. We show that longer routes have larger shares of their roads in poor conditions; accordingly, the trade impacts of shipments originated in remote regions are found to be quite substantial.

JEL Codes: F10, R10, O2
Key word: Transport costs, road quality, regional exports

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I. Introduction

It is increasingly recognized that traditional trade barriers, like tariffs, are no longer the main obstacles to international trade (Clark, Dollar and Micco, 2004). Recent research for Latin America, for example, shows that ad-valorem freight rates are today significantly higher than ad valorem tariffs and that the effects of transport costs on export volumes and export diversification are more important than the effects of tariffs (Moreira, Volpe and Blyde, 2008).

That transport costs affect international trade is, of course, not a recent finding. Economists have been estimating gravity-like models for decades showing that distance is negatively associated with trade flows. Distance, of course, matters primarily because of transport costs. Recently, the international trade literature has started to employ more real measures of transport costs to examine their effects on trade (e.g. Hummels, 2001; Clark, Dollar and Micco, 2004; Hummels, Lugovskyy and Skiba, 2009; Micco and Serebrisky, 2006, and Moreira, Volpe and Blyde, 2008). Still, one shortcoming of this ongoing literature is the focus on the international component of transport costs, largely ignoring the effects of domestic transport costs on trade flows.

Transport costs, however, do not stop (or start) at the border. All the goods that a country exports, for example, have to travel first within the country before they are shipped to other markets. Situations in which within-country transport costs represent a significant portion of total transport costs incurred in international trade transactions are indeed common. For example, it has been shown that domestic freight costs account for 36.6% of international transport costs in the United States (Rouslang and To, 1993). Volpe and Blyde (2011) also show exports episodes in which the within-country distances represent non-trivial shares of the total distance of the shipment. Therefore, high domestic transport costs could potentially hamper trade flows in a significant way. Despite its importance, the literature on the trade impacts of domestic transport costs is scarce and in particular analyses that examine the role of road quality, a critical aspect in regional and public policy, practically do not exit. This paper seeks to fill this gap in the literature.

Analyzing the trade impact of road quality improvements is data demanding. One needs precise information on the geographical origin of the exports, the routes employed within the country, the conditions of the road network and the associated transport costs of using such a

network. This explains the scarcity of assessments in this area. The data limitations particularly on transport costs have forced researchers to work with more or less partial proxies, such as road distance to the nearest most used exit node (see, e.g., Matthee and Naudé, 2008; and Granato, 2008) or to the international border with the main trading partner (see, e.g., Costa-Campi and Viladecans-Marsal, 1999), the shortest travel time to the main seaports (see, e.g., Albarrán et al., 2009), binary variables capturing the presence of an airport or a port in the origin region (see, e.g., Costa-Campi and Viladecans-Marsal, 1999), and regional transport infrastructure density (see, e.g., Nicolini, 2003). But the use of proxies like distance imposes severe limitations for analyzing how freight costs change to improvements in transport infrastructure. As a result, even though the existing evidence point to a general negative relationship between domestic transport costs and trade, most of the the empirical analyses are silent about how road quality affect trade flows.

Focused on a developing country, Colombia, this study overcomes the aforementioned data limitations by combining highly disaggregated records of export flows with detailed geo-referenced information of the Colombian transport network, including its road quality, as well as real measures of transport costs of shipping the goods within the country to examine the trade effects of road quality. In particular, the analysis assesses how changes in road quality affect export performance after estimating a relationship between regional exports and the costs of moving exports from their location of production to the ports of shipment. The results show that the trade effects of improvements in road quality are relatively small on average; however, there is considerable heterogeneity in the magnitude of the effects. We show that longer routes have larger shares of their roads in poor conditions; accordingly, the trade impacts of shipments originated in remote regions are found to be quite substantial.

The next section explains the estimating methodology which takes in consideration key insights from various economic geography and trade models. Section III describes the construction of the different datasets and section IV presents the results. The concluding remarks are presented in section V.

II. Methodology

The point of departure of our model is a simple log-linear relationship between regional exports and domestic transport costs:

$$E_{jrpt} = \beta_0 + \beta_1 \cdot tc_{jrpt} + \mu_{jrpt} \tag{1}$$

where E_{jrpt} is the log of exports of good *j* from region *r* to port *p* in year *t* [1], tc_{jrpt} is the log of 1+ad-valorem transport costs of shipping good *j* from region *r* to port *p* in year *t*, and μ_{jrpt} is the error term. A chief econometric concern with this equation, however, is the potentially large number of omitted variables that could bias the econometric results. For instance, there might be several factors leading to the initial agglomeration of firms in a particular region and consequentially inducing a large level of exports from this place. Regressing regional exports on a measure of domestic transport costs without controlling for these factors is likely to produce biased results. In what follow we rely on key elements of the economic geography literature to address this issue.

One insight from economic geography models is the notion that plant-level scale economies interacted with transport cost leads to the agglomeration of firms in the large market. Sometimes referred as the home-market effect, firms tend to locate in the large market because they will be able to enjoy larger profits derived from lower transport costs and from a drop in their average production costs. A second set of factors that could lead to agglomeration has to do with the presence of externalities. To the extent that externalities are localized, economic activity tend become geographically concentrated over time. Empirical support to this idea has been found, for example, in Glaeser et al. (1992), Jaffe et al. (1993) and Henderson et al. (1995). A third factor is related to the presence of backward-forward linkages. The original Hirschman's (Hirschman, 1958) concept that vertical relationships between industries create a pattern of interdependent industry location has been formalized many times in the literature (e.g. Venables, 1996; Krugman and Venables, 1995). Other factors attracting firms to particular locations are known under the general heading of natural amenities and local public goods (Combes, Mayer

[1] Port here refers to ports, airports or borders.

and Thisse, 2008). These factors can range from natural endowments (like the presence of lakes or rivers) to public services (like schools, hospitals or telecommunication infrastructure).

Several proxies have been used in the economic geography literature to estimate the effects of these forces on outcomes like regional wages. For instance, a density measure consisting on the employed in the region divided by its surface area is frequently used to capture the home-market effect. Various indexes of regional diversification have been employed to capture the effects of inter-industry externalities. Measures of endowments, like arable land, or several classes of public investments are also normally used to account for the presence of natural endowments and/or the existence of public goods. The list of factors can be quite large and normally varies depending on the focus of the investigation with variables like regional GDP, the average skilled level of the population or the number of firms in the region being a few more examples.

In our empirical model we need to control for the possibility that high volumes of regional exports might be in part associated with the agglomeration of economic activity that could result from these forces. We could tackle this issue by adding several of the variables cited above. However, as the list of factors is potentially large, we could still run into an omitted variables problem. Our preferred strategy is to use dummy variables to capture these regional effects. Indeed we choose a set of fixed effects that capture this and other aspects that may influence the location decision of a firm. Specifically, we include fixed effects to control for the full panel dimension of the trade flows as well as an array of commodity-year, region-year and product-year fixed effects. Equation (1) then changes to:

$$E_{jrpt} = \beta_1 \cdot tc_{jrpt} + \alpha_{jrp} + \alpha_{jt} + \alpha_{rt} + \alpha_{pt} + \alpha_t + \mu_{jrpt} \qquad (2)$$

where α_{jrp} is a set of commodity-region-port fixed effect and α_{jt} , α_{rt} , α_{pt} and α_t are commodity-year, region-year, port-year and year fixed effects, respectively. The rationale for including α_{jrp} is that exporters specializing in the production of a given commodity may choose their location such as to maximize the likelihood to export by taking into account both regional aspects as well as access to ports. The fixed effect α_{jrp} captures this endogenous location decision related to export behavior. The next three fixed effects α_{jt} , α_{rt} , α_{pt} control for

regional characteristics, like the propensity for agglomeration as mentioned above, for port characteristics, like port efficiency and for commodity-specific characteristics like the tradability of the good or the technology of its production.[2] They also control for the evolution of these variables over time. Finally, α_t controls for any country-wide-time-variant factors like exchange rate shocks.

III. Construction of Datasets

III.A. Transport Costs

As mentioned in the introduction, most analyses that examine the effect of domestic transport costs on trade volumes rely on distance or travel time-based proxies of transport costs which normally impede examining the impact of infrastructure investments. In this study we significantly improve the distance and time-base proxies of transport costs employed in the literature by explicitly estimating the transport costs associated with shipping goods within the country. Specifically, we employ a methodology that combines real (time-varying) freight costs and Geographic Information System (GIS) analysis to calculate the associated distance- and time-related costs that add up to the total transport costs incurred within the country. This is important because the effects of improvements in the transport network are associated with both distance and time-related costs, as we will show later.

The methodology is based on Combes and Lafourcade (2005) and Appendix A sketches the key insights of the calculations. The procedure is based on the assumption that profit-maximizing firms have incentives to select the least-cost route between any two locations. Therefore, the domestic route that each firm uses from the production facilities to the exiting customs in shipping each of its products can be identified combining spatially geo-referenced data of the road network of the country with real truck operating costs and feeding this information into a GIS software that solves for the least-cost route between the locations.

[2] For instance, there might be differential use of imported inputs across sectors generating heterogeneous impacts via the transportation of those inputs. To the extent that the use of imported inputs is sector related, the commodity-year fixed effect captures this differential impact. For robustness, we also include a commodity-region-year fixed effect in order to account for the possibility that the differential impacts of imported inputs are not only sector-related but potentially sector and regionally related.

III.B. Geographical Scale and Trade Data

We work at the municipality level using the 1,111 municipalities identified in the 2005 economic census (carried by DANE). We exclude two dozen municipalities (like San Andrés and Providencia islands) because either we do not have information on their road networks or because they are not physically connected with the rest of the country with roads in the primary, secondary or tertiary networks (like some municipalities in the Amazonas Department). For each municipality we calculate its centroid consisting on the weighted average of all the x and y coordinates of the perimeter of the municipality. The centroid is where we locate geographically the origin of the exports for each municipality.

We work with exports at the 6-digit HS level. The database includes information on the municipality of origin and the custom through which the merchandise exits the country. Therefore, for each export value, we have a record of the origin of the shipment and the national custom employed. These trade data come from the Colombian national custom's authority *Dirección de Impuestos y Aduanas Nacionales* (DIAN). Regarding the customs, there were a total of 20 active customs during the period of consideration. These customs are distributed across the country in various ports, airports and land borders and were located in the transport network using their precise addresses. The 1,111 origins and the 20 destinations comprise a total of 22,220 potential routes. Figure 1 illustrates, geographically, an example of the outcome from the optimization process. It depicts the least-cost routes from one origin, Bogota D.C., to four custom destinations: Barranquilla, Buenaventura, Cartagena, and Santa Marta ports.

Once we obtained the transport costs of shipping 1 ton of generic merchandise along any route, we then calculate the ad valorem transport costs for each product transported through this route as follows:

$$tc_{jrpt} = (C_{rpt}) \cdot \frac{w_{jrpt}}{E_{jrpt}} \tag{3}$$

where tc_{jrpt} is the ad valorem transport cost as defined before, C_{rpt} is the transport costs of shipping 1 ton of generic merchandise from region *r* to port *p* in year *t* (see Appendix A.1), w_{jrpt} is the weight (expressed in tons) of good *j* that is transported from region *r* to port *p* in year *t*, and E_{jrpt} is its export value as defined before.

One potential bias generated by the methodology used to construct the transport costs in this study is related to the selection of the least-cost route as the route that defines the transport costs between any two locations. If shipping companies deviate largely from the least-cost route, then the transport costs that they face might differ from the ones estimated in this study. Note that in principle the least-cost route is not an unrealistic assumption, profit maximizing shipping companies have the incentives to select the cheapest route between any two locations. However, there might be factors outside their control that preclude them to do so (i.e. certain road regulations, restrictions, lack of security in particular roads, etc.).

We performed a simple exercise to evaluate whether this should be a source of concern. In Colombia, the minimum freight value that a registered transport company must pay to the owner of a vehicle is regulated by the Ministry of Transportation. This value is updated every year and is published in a matrix of origins and destinations comprising a total of 18 origins and 22 destinations (for the year 2008). These freight values are obtained using calculations that combine real transport costs gathered from surveys by the Ministry of Transportation.[3] While the methodology used by the Ministry is similar to the one in this study, in the sense that they calculate the total cost of a route that combines distance and time related costs (see Appendix A), the Ministry does not use an optimization process to select the least-cost route. The information about the routes between locations used by the Ministry is based on the most commonly used routes by transport companies gathered also from the surveys. With this information, they estimate the transport costs across all pair of origins-destinations they have selected.[4] In order to validate the methodology that we employed in this study, we estimated the transport costs for the same group of cities and compared them with the estimates of the Ministry. The correlation between the two estimations (across all the pairs of cities) is equal to 0.93 and significant at the 1% level. Therefore, as the two estimations do not deviate in any considerable way, the selection of the least-cost route as the route that defines the transport costs between any two locations should not be a reason of concern.

Another potential econometric concern is related to the existence of modes of transportation different than roads. If certain activities employ alternative modes of

[3] We use the same surveys in this paper to obtain the operating costs of the truck industry in the country.
[4] While we could potentially use these transport costs in our analysis, they are limited to the cities analyzed by the Ministry. Using these figures would not only restricted the geographical extension of the analysis (for example, not

transportation, the costs of shipping - and consequentially the trade effects of transport costs - are not necessarily bounded by the road network of the country. Not accounting for these alternative modes of transportation could generate biased econometric results. In Colombia, however, most of the cargo within the country is carried by trucks. According to the Ministry of Transportation, for example, around 95% of all non-coal cargo (in tons) is transported by trucks and the rest 5% is divided across rail, air and the fluvial modes. This implies that no significant biases should be expected by focusing on road-related transport costs. Having said this, it is worth noting that within some industries it is well-known that the main mode of transportation is not the truck. These industries are essentially mining and particularly the coal industry which uses primarily the rail system. Thus, the transport costs in this industry are not referenced by the road-related transport costs estimated in this analysis. Therefore, we exclude this industry from the analysis.[5]

IV. Econometric Results

IV.A. Estimation Results

In this section we present the estimation of equation (2). The estimation is for the period 2004-2006 and is carried at the 6-digit HS level. Column (1) in table 1 presents the initial outcome when the regression is estimated with all the sectors of the sample pooled together. Columns (2)-(4) also present the results when equation (2) is estimated separately for three groups of goods: agriculture, mining and manufactures. The product groups are defined according to the WTO classification which in turn defines goods according to the Revision 3 of the Standard International Trade Classification (SITC).[6] The econometric results in columns (1)-(4) indicate unequivocally that exports are negatively correlated with the level of domestic transport costs. All the coefficients are statistically significant and comparable in magnitudes with those in Hummels (2001) which uses a similar empirical specification for the treatment of ad valorem transport costs in the estimation. In the rest of the columns (5)-(16) we repeat these regressions

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all the departments are included in these data) but would also induce some potential biases because not all the cities with customs are included.

[5] Specifically we exclude the industry HS-2dig: 27

[6] For details see: http://www.wto.org/english/res_e/statis_e/technotes_e.htm

but allow for alternative sets of fixed effects. In general, the results remain very similar indicating that the outcome is very robust to changes in the specification of the model.

It is worth noting that a potential limitation of this econometric model is the possible existence of reverse causality between ad valorem transport costs and trade. This can occur, for instance, if the government favors transport-related investments precisely in those regions that are already exporting successfully. One way to examine whether this should be a matter of concern is to re-estimate the equations using only historic municipalities and historic ports and then compare the results. The argument is that the location of historic sites predates the modern influence of international trade on the location of the exporters or shipping platforms. Indeed, most historic sites in Colombia dated back from Spanish colonial times when international trade was not a priority for development. For example, Bogota, the capital of the country, was founded in the middle of the territory after Spanish expeditions traveled from Santa Marta -in the coast- and along the Magdalena river in search for gold. The expedition settled on a fertile land that was already inhabited by indigenous people. We also employ great circle distances instead of the true distances for the calculation of the transport costs. The use of the great circle distance minimizes the potential bias generated by the government favoring transport infrastructure projects in some regions over others. We therefore, re-run the econometric model using only municipalities and ports created prior to the year 1800 and employ great circle distances to construct the associated ad valorem transport costs. The resulting elasticities for all goods, agriculture, mining and manufactures are -7.80, -6.84, -5.57 and -8.24, respectively, and they are all significant at the 1% level.[7] The results are clearly very similar to those presented in Table 1, suggesting that the endogeneity issue should not be a concern.

IV.B. Assessing the Impact of Road Quality

We now employ the estimated results to simulate what would be the effect on regional exports of a reduction in transport costs generated by improvements in road quality. Specifically, we simulate the reduction in transport costs that would arise if the conditions of all the roads identified as “bad” and “regular” by INVIAS improve to good. It is worth mentioning that in 2005, the year that we used for the information on road conditions, 47% of the primary road

[7] Detailed results available from the author upon request

network (under the jurisdiction of INVIAS) was in good condition, 33% in regular condition and 20% in bad condition.

It is worth noting that improving the condition of a road reduces the costs of transportation through two effects: first, it increases the speed by which the road can be traversed and consequentially, it reduces all the costs that are associated with time. Second, it lowers the maintenance, repair, tire and depreciation costs associated with using that road (see Appendix A.1).

The reductions in transport costs generated by the improvement in road quality vary greatly depending on the route. For instance, while the average reduction in transport cost for all the routes is equal to 11.6% the standard deviation is 7%. This is because some routes have large shares of roads in regular and bad conditions while others are in good conditions for the most part. The large standard deviation implies that there are several routes with declines in transport costs below 5% but also many routes with declines in transport costs above 15%. Indeed, we observe several routes with reductions in transport costs as high as 30%. Figure 2 shows the distribution of the reductions in transport costs for all the routes.[8]

It is also important to mention that the correlation between the decline in transport costs and the initial level of transport cost is positive (0.51) and significant at the 1% level. In other words, routes with initially higher levels of transport costs tend to exhibit larger declines. This is explained because the regions with initially higher transport costs are mostly associated with longer routes and longer routes tend to have larger shares of roads in poor conditions, as shown in Figure 3.

To perform the simulation we used the econometric estimates from columns (2)-(4) in table 1, our preferred specification. The simulated reduction in domestic transport costs induces an average increase of export of 2%. However, there is a large heterogeneity on the magnitude of these results. The gains are found to be generally larger for exports with the initially higher

[8] It is worth mentioning that the reduction in transport costs generated by this simulated improvement in road quality is likely to be a lower bound for two reasons: first, we do not have information on the road quality on the secondary or tertiary road networks of the country even though they are used –together with the primary road network- to select the least-cost routes. For all the roads on the secondary and tertiary networks we have made the conservative assumption that they are all in good conditions. Second, the primary road network with information about road quality is limited to the roads under the jurisdiction of INVIAS, the public entity in charge of the roadways. This excludes the roads under concessions contracts with the private sector. Roads under concession contracts in the primary network represent 17% of all the roads. Once again, we have made the conservative assumption that all these roads are in good conditions.

transport costs, as shown in Figure 4. This is mostly explained by what we already mentioned that the routes with the highest transport costs tend to be the longest routes, and those normally have larger shares of roads in regular and bad conditions.

V. Concluding Remarks

While there is a booming literature analyzing the effects of international transport costs on trade flows using real freights, there is practically no empirical evidence on how freight costs within a country affects trade performance. Applying a novel methodology that combines real freight costs and Geographic Information System (GIS) analysis to the case of Colombia, this paper measures the extent to which domestic transport costs act as a friction to international trade. The econometric results indicate unequivocally that exports are negatively correlated with the level of domestic transport costs.

The novel estimation of real freight costs in this study separate this analysis from the traditional practice of using distance as a proxy of transport costs and allows us to examine the trade impact of road quality, a policy issue that has not received much attention in the literature. We study the impact of road quality by simulating a reduction in transport costs that would arise if the conditions of all the roads identified as “bad” and “regular” by the national road authority improve to good. Employing conservative assumptions we find that this simulated improvement in road conditions decreases average transport costs in about 12%. The increase in exports is relatively small on average, but there is considerable dispersion in the magnitude of the effects. We find substantial trade impacts for shipments with initially high transport costs. This is because initially high transport costs are normally associated with longer routes and those tend to have larger shares of roads in poor conditions. The results confirm that internal transport costs can significantly constraint international trade flows and that addressing issues of road quality can make this constraint less binding. In Colombia, this is particularly important for exporters in remote regions who typically have to transit large shares of roads in poor conditions.

References

Ahlin, K. and J. Granlund. 2002. "Relating Road Roughness and Vehicle Speeds to Human Whole Body Vibration and Exposure Limits" *The International Journal of Pavement Engineering*. Vol 3(4)

Albarran, P., R. Carrasco and A. Holl. 2009. "Transport Infrastructure, Sunk Costs and Firm's Export Behavior" Working Paper 09-22. Universidad Carlos III de Madrid.

Alvarez, Roberto, and Ricardo López. 2005. "Exporting and Performance: Evidence from Chilean Plants". *Canadian Journal of Economics*. Vol 38, No.4: 1385-1400.

Anselin, L., R. Florax, and S. Rey. 2003. *Advances in Spatial Econometrics*. Springer

Aw, B., S., Chung, and M. Roberts (2000). "Productivity and turnover in the export market: micro-level evidence from the Republic of Korea and Taiwan (China), *World Bank Economic Review,* 14, 65-90

Barnes, G. and P. Langworthy. 2003. "The Per-Mile Costs of Operating Automobiles and Trucks" Report No. MN/RC 2003-19. Published by Minnesota Department of Transportation

Benedictis, G., G. Calfat and R. Flores Jr. 2006. "Challenging the pro-development role of trade agreements when remoteness counts: the Ecuadorian experience" Working Paper 2006.5, University of Antwerp.

Bernard, Andrew, Jonathan Eaton, Bradford Jensen and Samuel Kortum. 2003. "Plants and Productivity in International Trade". *American Economic Review*. Vol 93, No 4: 1268-1290.

Clark, Ximena, David Dollar and Alejandro Micco. 2004. "Port Efficiency, Maritime Transport Costs, and Bilateral Trade". *Journal of Development Economics*. Vol 75: 417-450.

Clerides, S., S. Lach, and J. Tybout (1998). "Is Learning by Exporting Important? Micro-dynamic Evidence from Colombia, Mexico and Morocco", *Quarterly Journal of Economics*, 113.

Combes, P.-P., and M. Lafourcade. 2005. Transport Costs: Measures, Determinants, and Regional Policy. Implications for France. *Journal of Economic Geography*. 5.

Combes, P.-P., T. Mayer and J.-F. Thisse. 2008. *Economic Geography, the Integration of Regions and Nations*. Princeton University Press.

Costa-Campi, M. T. and M. Viladecans-Marsal. 1999. "The District Effect and the Competitiveness of Manufacturing Companies in Local Productive Systems". *Urban Studies*. 36.

Glaeser, E. L., H. Kallal, J. Sheinkman, and A. Schleifer. 1992. “Growth in Cities”. *Journal of Political Economy*. 100.

Granato, M.F. 2008. “Regional Export Performance: First Nature, Agglomeration…and Destiny? The Role of Infrastructure”. Mimeographed document.

Harris, C. 1954. “The Market as a Factor in the Localization of Industry in the United States”. *Annals of the Association of American Geographers*. 64

Henderson, J. V., A. Kuncoro, and M. Turner. 1995. “Industrial Development in Cities”. *Journal of Political Economy*. 103.

Hirschman, A.O. 1958. *The Strategy of Economic Development*. Yale University Press, New Haven.

Hummels, David. 2001. “Toward a Geography of Trade Costs”. Department of Agricultural Economics, Purdue University. Mimeographed document.

Hummels, David & Lugovskyy, Volodymyr & Skiba, Alexandre. 2009. “The Trade Reducing Effects of Market Power in International Shipping”. *Journal of Development Economics*. Vol 89, No 1: 84-97

Jaffe, A., M. Trajtenberg, and R. Henderson. 1993. “Geographic Location of Knowledge Spillovers and Evidenced by Patent Citations” *Quarterly Journal of Economics*. 108.

Krugman, P., and A.J. Venables. 1995. “Globalization and the Inequality of Nations”. *Quarterly Journal of Economics*. 110.

Lafourcade, M., and E. Paluzie, 2008. “European Integration, FDI and the Geography of French Trade” *Regional Studies* (forthcoming).

Matthee, M., and W. Naudé. 2007. “The Determinants of Regional Manufactured Exports from a Developing Country”. Research Paper No. 2007/10. UNU-WIDER World Institute for Development Reconomics Research.

Melitz, Marc J. 2003. “The impact of trade on intra-industry reallocations and aggregate industry productivity” *Econometrica.* Vol 71, No 6: 1695-1725

Micco, Alejandro, and Tomas Serebrisky. 2006. “Competition Regimes and Air Transport Costs: The Effects of Open Skies Agreements”. *Journal of International Economics*. Vol 70 (1): 25-51

Moreira Mesquita, Mauricio, Christian Volpe and Juan Blyde. 2008 *Unclogging the Arteries: The Impact of Transport Costs on Latin American and Caribbean Trade, Special Report on Integration and Trade.* Washington, DC, United States: Inter-American Development Bank.

Nicolini, R. 2003. “On the Determinants of Regional Trade Flows” *International Regional Science Review*. 26(4)

Rouslang D, To T, 1993. “Domestic Trade and Transportation Costs as Barriers to International Trade” *Canadian Journal of Economics*, vol.26, 208-221

Silva, J.M.C. and S. Tenreyro (2006). “The Log of Gravity” *The Review of Economics and Statistics*, Vol. 88, No. 4: 641-658.

UMTRI. 1998 University of Michigan Transportation Research Institute, *The Little Book of Profiling*, September, The Regent of the University of Michigan.

UMTRI. 2002 University of Michigan Transportation Research Institute, *Research Review*, Volume 33, Number 1.

Venables, A.J. 1996. “Equilibrium Locations of Vertically-linked Industries” *International Economic Review*. 37.

Volpe, C.M. and J. Blyde. 2011. “Shaky Roads and trembling Exports: Assessing the Trade Effects of Domestic Transport Costs Using a Natural Experiment”, Unpublished document.

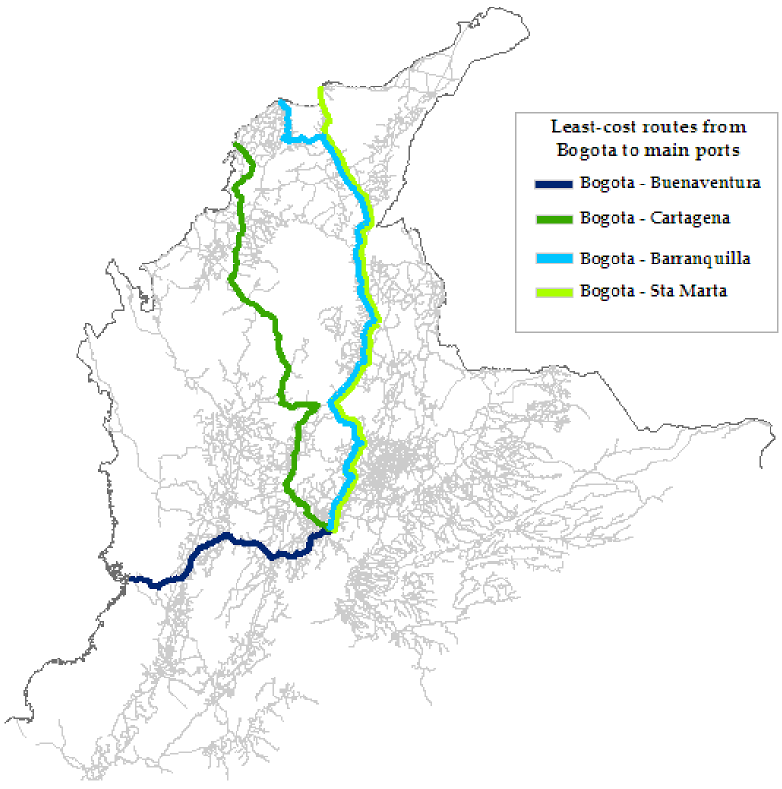
Table 1: Estimations

Regressor	(1) All industries	(2) Agriculture	(3) Mining	(4) Manuf	(5) All industries	(6) Agriculture	(7) Mining	(8) Manuf	(9) All industries	(10) Agriculture	(11) Mining	(12) Manuf	(13) All industries	(14) Agriculture	(15) Mining	(16) Manuf
Ad valorem transport costs	-7.98***	-9.01***	-6.21***	-8.06***	-7.73***	-7.95***	-5.99***	-7.79***	-7.72***	-8.02***	-5.89***	-7.77***	-9.25***	-9.27***	-5.21***	-8.23***
	(0.289)	(1.211)	(1.498)	(0.306)	(0.263)	(0.873)	(1.279)	(0.282)	(0.263)	(0.873)	(1.280)	(0.282)	(0.374)	(1.606)	(1.238)	(0.384)
Commodity-Region-Port Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity-Year Fixed Effects	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No
Region-Year Fixed Effects	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Port-Year Fixed Effects	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes
Commodity-Region-Year Fixed Effects	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	100583	10337	2739	87507	100583	10337	2739	87507	100583	10337	2739	87507	100583	10337	2739	87507
R-sq	0.90	0.93	0.93	0.89	0.90	0.93	0.93	0.89	0.90	0.93	0.93	0.89	0.90	0.93	0.93	0.89

The table shows OLS estimations of equation (2) for the period 2004-2006. Standard errors are in parentheses. The product groups are defined according to the WTO classification which in turn defines goods according to the Revision 3 of the Standard International Trade Classification (SITC).

***; **; * significant at the 1%, 5% and 10% level respectively

Figure 1: Examples of Least-Cost Routes



Source: Author's calculations

Figure 2: Reduction in Transport Costs from Improvements in Road Quality

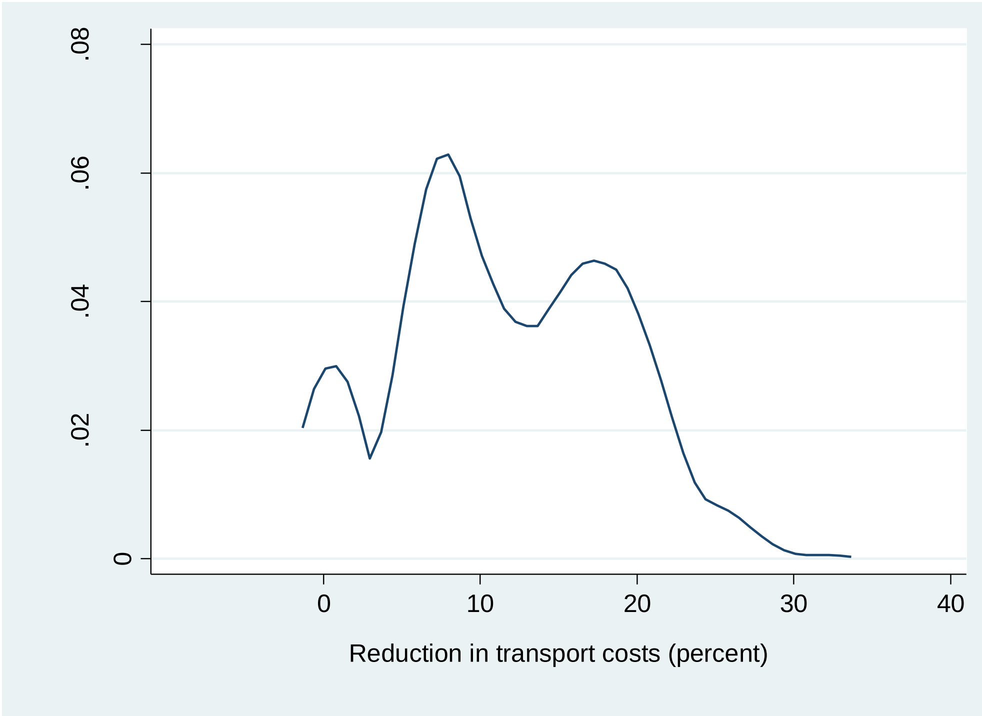


Figure 3: Route Condition and Length

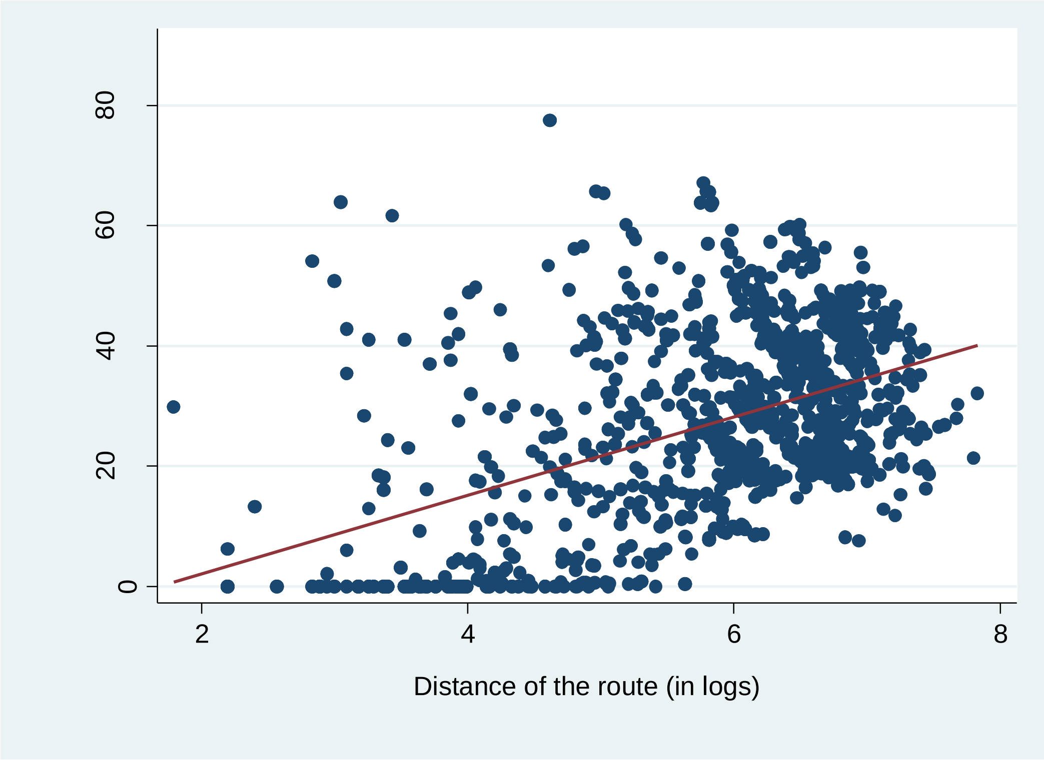
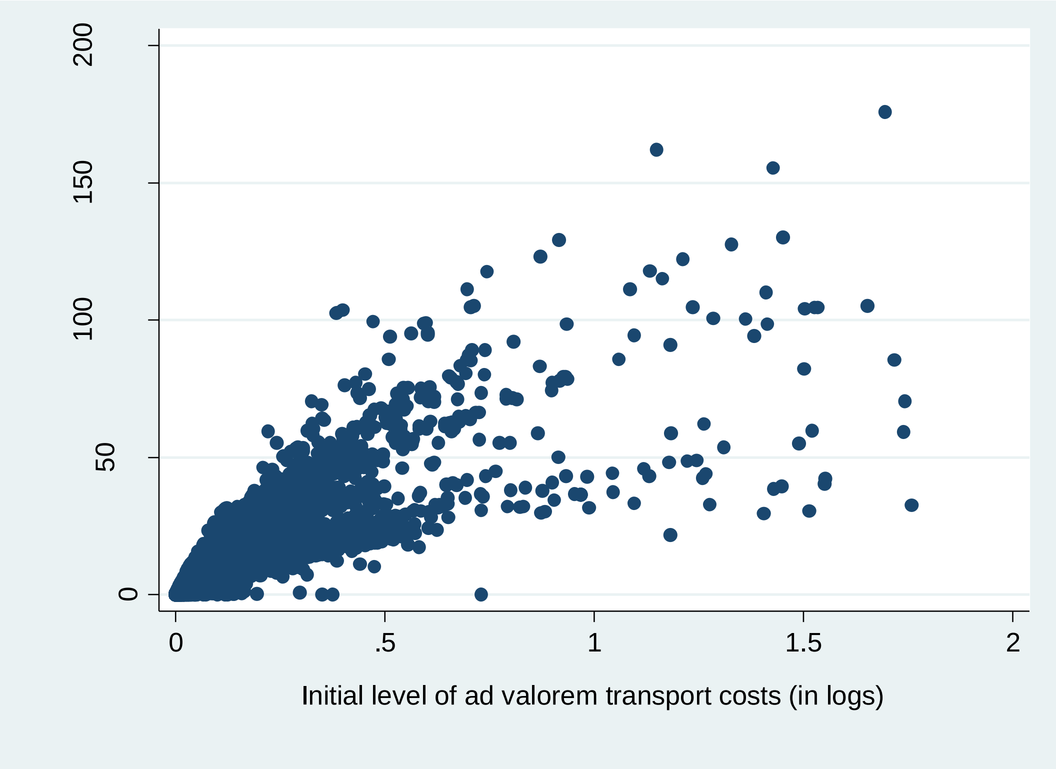


Figure 4: Export Growth from Road Improvement and Initial Transport Costs



Appendix A: Estimation of Least Cost Routes

The methodology explained here is based on Combes and Lafourcade (2005). The transport network of a country consists on a number of arcs of different types (e.g. highways, primary roads, secondary roads, etc). Along any particular arc, there are two types of costs: costs associated with distance and costs associated with time. The distance-related costs per km are essentially fuel costs, tire renewing expenses and maintenance operating costs. The time-related costs per hour are the labor costs, the insurance expenses, the depreciation costs, as well as carrier vehicle taxes and parking costs.

Let d_a denote the distance between the end-nodes of an arc *a*; then, the total distance-related costs incurred when connecting two locations *r* and *p* at date *t* using a route Z_{rpt} is given by:

$$C_{rpt}^{D} = \sum_{a \in Z_{rpt}} \left(fuel_t + tire_t + main_t \right) \cdot d_a \qquad \text{(A.1)}$$

Similarly, let s_a be the speed along the arc *a*, then the time for joining the arc nodes is $t_a = \frac{d_a}{s_a}$, and the total time-related costs incurred when connecting two locations *r* and *p* at date *t* using a route Z_{rpt} is given by:

$$C_{rpt}^{T} = \left(wage_t + insure_t + deprec_t + taxes_t + parking_t \right) \cdot \left(\sum_{a \in Z_{rpt}} \frac{d_a}{s_a} \right) \qquad \text{(A.2)}$$

Obviously, there could be many different routes joining locations *r* and *p*, but we are interested in the route with the lowest total costs. Therefore, if ω_{rpt} denotes the set of all possible routes that join locations *r* and *p*, the optimization problem for finding the route with the minimum transport costs (C_{rpt}) is:

$$C_{rpt} = \min_{Z_{rpt} \in \omega_{rpt}} (C_{rpt}^{D} + C_{rpt}^{T}) \qquad \text{(A.3)}$$

This optimization problem is solved using geographic information system (GIS) software (ArcView) and a digitalized transport network of Colombia. The network is populated using real distance and time-related costs data taken from the Colombian Ministry of Transportation which,

in turned, are gathered from transportation surveys conducted by the Ministry. These costs vary by class of truck and year. The class of truck chosen for this study corresponds to the most popular truck configuration used in the country. [9]

Table A.1 presents a summary of the average distance and time related costs for the year 2006. Fuel expenses are differentiated by type of terrain, and on average they represent the most significant distance-related cost while wages as well as depreciation costs account for the most significant time-related costs. Panel (3) of the table calculates the total reference cost per ton per km which is obtained by adding the total distance-related costs and the total-time related costs once the latter is divided by the average speed of the class-truck selected in the country. [10]

Our estimation of the transport costs takes into consideration the type of surface traversing the road network. According to the Ministry of Transportation, the fuel consumption of the class truck selected varies by the type of surface (see Tables A.1). Adjusting transport costs to the type of surface traversing the roadways is important particularly for a country like Colombia with a considerable area covered by mountainous terrain (see Figure A.1).

Adjustment for Road Quality

To account for the effect of the quality of the road network on transport costs, we are required to obtain information about the conditions of the roadways in Colombia as well as information on how these conditions affect the various costs of operating a truck in the country. It is worth starting with a brief discussion on measuring road quality.

The roughness of roadways is generally defined as an expression of irregularities in the road surface that adversely affect the ride quality of a vehicle and thus the user. Roughness is an important road characteristic because it impacts not only ride quality but also vehicle traversing times and maintenance/repair costs. Measuring road roughness, therefore, is particularly important. The measurement of road roughness is a relatively new practice that is spreading rapidly thanks to the development of the International Roughness Index (IRI), a standard scale produced by the World Bank in the 1990s (UMTRI, 1998) to quantify the roughness of roads. This is now the most common measurement used worldwide to describe road roughness. For a detailed discussion on the IRI, see UMTRI, 2002.

[9] This is the C-2 configuration: a 2 axis truck with a capacity to carry 9 tons. In 2005, trucks with this configuration accounted for 82% of the cargo fleet in the country and carried around 50% of all the land cargo (in tons) (Ministerio de Transporte, 2008)

The Colombian national road authority, *Instituto Nacional de Vías* (INVIAS), keeps track of the conditions of the primary roads in the country. The Institute divides the conditions of each arc in the primary road network in broad categories as “good”, “regular” and “bad”. To measure the conditions of the roads, INVIAS employs a visual inspection to provide a general assessment of the traversability condition of the road. Based on measurement guides from INVIAS, the broad categories used by the institute can roughly be matched with the IRI in the following way: good (0-3), regular (3-9) and bad (9-14), where the numbers in the parentheses correspond to the IRI.

The matching of the INVIAS categories with the IRI is particularly useful because it allows us to employ other transport studies to adjust vehicle speed and transport costs to roadway conditions based on the IRI.

Adjustment of Speed

The first adjustment that we make is related to vehicle speed. It is natural to think that vehicle speed is negatively associated with the roughness of roads, but in the absence of speed measurements taken directly on the roadways, it is difficult to assess how much drivers would slow down when the conditions of the roads deteriorate. One way to go about this is to assess how road quality determines the quality of the ride. In this area there are several international guidelines developed for health-related reasons. For example, ISO 2631-1 defines how to quantify human whole-body vibration (WBV) experienced by the driver and passengers during the ride, in relation to health and comfort. These guidelines have been used, for instance, to derive maximum speed limits. One interesting application of these guidelines is carried by Ahlin and Granlund (2002). The authors estimate a relationship between road roughness (measured in terms of the IRI), vertical human WBV and vehicle speed and combine it with ISO guidelines to convert limits for WBV to corresponding approximate limits for IRI and/or vehicle speeds.

Starting with the quantification of human WBV, this measurement is normally expressed in terms of the frequency-weighted acceleration at the seat of a seated person or the feet of a standing person and can be measured in units of *meters per second squared* (m/s^2). Ahlin and Granlund (2002) use the ISO guidelines in their calculation. Essentially they employ a mathematical model to first derive a relationship between road roughness, vertical human WBV

[10] Obtained from estimates by the Ministry of Transportation.

and vehicle speed. Then, using the 0.8 m/s^2 as the limit for the WBV, corresponding to "uncomfortable" according to ISO 2631, they derive the following relation between "comfortable vehicle speed", cvs [km/h], and IRI [mm/m]:

$$cvs = 80 \cdot \left(\frac{IRI}{5} \right)^{\frac{2}{1-n}}$$

where n is a parameter for the amplitude of the roughness [11]. For most of the roads, the exponent n has a value around 1.8. Therefore, for a road with roughness equal to 6 in terms of IRI, the comfortable vehicle speed should be below 50.7 km/h. At speeds above this value, the ride would be "uncomfortable" according to ISO 2631 and may have long term health consequences to the driver. We use this formula to derive driving speeds in the arcs in the Colombian network according to their conditions. Table A.2 presents the relationship between road condition, IRI and the resulting speeds that we use (column 4).

Adjustment of Maintenance, Repair, Tire and Depreciation Costs to Road Quality

While lower speeds affect transport costs of any route through the time-related costs portion of these costs, another way transport costs are affected by the quality of the road network is by the direct impact on charges that vary in direct proportion of the roadway conditions. Typically these charges are related to maintenance, tire, repair and depreciation costs. The latter is related to the reduced vehicle life.[12] Following this, Barnes and Langworthy (2003) presents a mathematical model for highway planning that calculates the costs of operating cars and trucks and also incorporates adjustments factors according to roadway conditions. The authors based their adjustment multipliers on available empirical assessments from various countries, including the US and New Zealand. According to the authors, the adjustment multiplier for maintenance, repair, tire and depreciation costs for an IRI equal or higher than 2.7 is, 1.25. In other words, maintenance, repair, tire and depreciation costs increase by 25% when the truck transits road with conditions associated with an IRI's equal or greater than 2.7. We take this study as a general

[11] The value of n is low for roads where the dominating roughness amplitudes have short wavelengths, such as on a modern designed highway with a deteriorated surface with plenty of potholes. The value of n is high for roads where the dominating roughness amplitudes have long wavelengths, such as on an ancient designed rural low volume road (Ahlin and Granlund, 2002).

[12] While there is consensus in the literature that maintenance, tire, repair and depreciation costs are affected by roadway conditions, the effect on fuel consumption is less clear. Many argue, for example, that there is no measurable difference in fuel consumption on paved roads of different roughness.

guide on how to increase maintenance, repair, tire and depreciation costs in our calculations. Table A.2 (column 5) presents the information. Essentially we increase these costs by 25% when the road is classified as "regular" and also when the road is classified as "bad". [13]

[13] Note that this is a conservative increase because it is likely that the increase in transport costs when the road has an IRI in the 8-14 range (bad) will be higher than when the road has an IRI in the 3-8 range (regular). However, we apply the same 25% increase for both regular and bad roads because we do not have information on how much higher these costs should be in bad roads as the analysis in Barnes and Langworthy (2003) do not differentiate between road conditions for IRI's higher than 2.7.

Table A.1: Operational Transport Costs

(1) Distance-related costs *Pesos per Km per Ton*		**2006**
Fuel:	Flat terrain	57.0
	Undulating terrain	80.8
	Mountainous terrain	117.7
Fuel Average		85.2
Tire		17.8
Maintance		38.2
Total		141.2

(2) Time-related costs *Pesos per Hour per Ton*	**2006**
Wages	484.7
Insurance	324.7
Depreciation	380.2
Taxes	4.7
Parking	38.0
Total	1,232.3

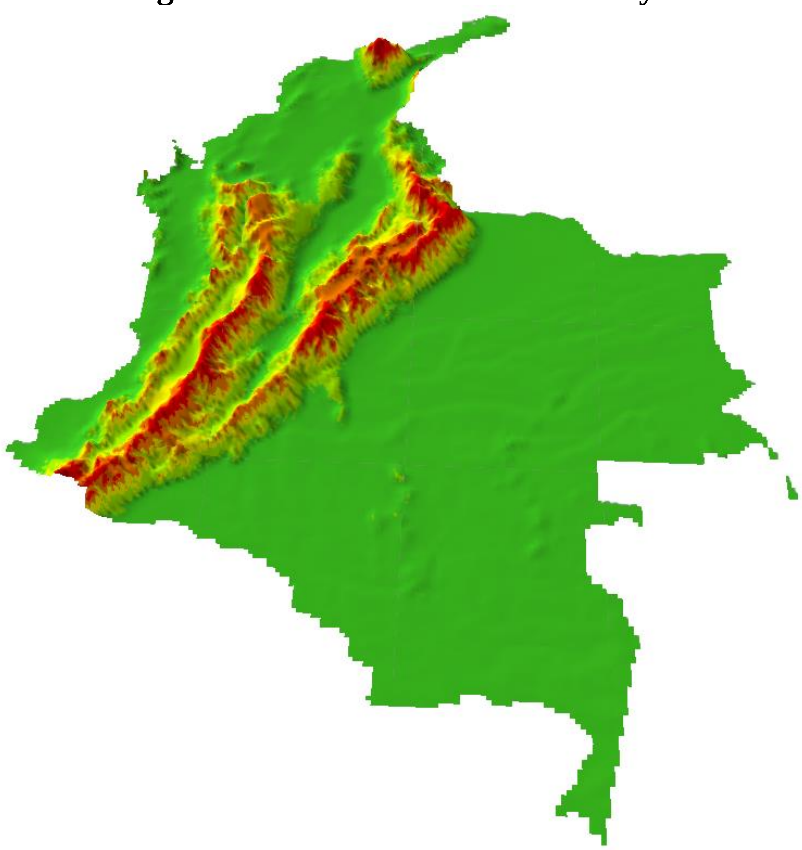
(3) Total costs *Pesos per Km per Ton*	**2006**
Total	182.23

Note: The table provides the costs of operating a truck type C-2 in Colombia according to cost figures given by the Minister of Transportation. Total costs = (distance_related costs) + (time_related costs/average speed) .
Source: Authors calculation based on data from the Ministry of Transportation, Colombia

Table A.2: Adjustment Factors to Road Quality

INVIAS classification	IRI range	IRI mid-point	Max speed	Percentage increase in costs
Good	(0 - 3)	2	Legal max speed of the road	0
Regular	(3 - 9)	6	50.7 km/h or legal max speed of the road whichever is smaller	25
Bad	(9 - 14)	11	11.1 km/h	25

Figure A.1: Colombian Surface Layer



Source: Author based on information from DIVA-GIS.org