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Railway and road discrete choice model for foreign trade freight between Antioquia and the Port of Cartagena

Modelo de elección discreta entre ferrocarril y carretera para mercancías entre Antioquia y el Puerto de Cartagena

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ABSTRACT

Most Colombian freight is transported on roads with barely acceptable conditions, and although there is a speculation about the need for a railway for freight transportation, there is not a study in Colombia showing the variables that influence the modal choice by the companies that generate freight transportation. This article presents the calculation of demand for a hypothetical railway through a discrete choice model. It begins with a qualitative research through focus group techniques to identify the variables that influence the choice of persons responsible for the transportation of large commercial companies in Antioquia (Colombia). The influential variables in the election were the cost and service frequency, and these variables were used to apply a Stated Preference (SP) and Revealed Preference (RP) survey, then to calibrate a Multinomial Logit Model (MNL), and to estimate the influence of each of them. We show that the probability of railway choice by the studied companies varies between 67 % and 93 %, depending on differences in these variables.

Keywords: Discrete choice model, foreign trade freight, stated preferences, freight transportation.

RESUMEN

La mayoría de la mercancía Colombiana se transporta en unas carreteras con unas condiciones apenas aceptables, y aunque se especula acerca de la necesidad de un ferrocarril para transportar mercancías, no hay un estudio en Colombia demostrando las variables que influyen en la elección modal por las empresas que generan el transporte de mercancías. Este artículo presenta el cálculo de la demanda de un ferrocarril hipotético mediante un modelo de elección discreta. Se inicia con una investigación cualitativa a través de técnicas de grupo focal con el que se identifican las variables que influyen en la elección entre las personas encargadas del transporte de grandes empresas comerciales en Antioquia (Colombia). Las variables influyentes en la elección fueron el costo y la frecuencia de servicio, y esas variables fueron usadas para aplicar una encuesta de Preferencias Declaradas (PD) y de Preferencias Reveladas (PR), calibrar un Modelo Logit Multinomial (MNL) y estimar la influencia que tiene cada una de ellas. Se demuestra que la probabilidad de elección del ferrocarril por parte de las empresas estudiadas varía entre 67 y 93 %, dependiendo de las diferencias en esas variables.

Palabras Clave: Modelo de elección discreta, carga de comercio exterior, preferencias declaradas, transporte de carga.

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Introduction

One of the main challenges of the public transport administration in Latin American countries is to justify investments in rehabilitation or new construction of railway projects. To overcome this situation, it is necessary to establish the main variables influencing the choice between roads and railway systems competing in the same corridor. These variables could vary among the decision makers in the companies that send and receive foreign trade freight towards and from the ports. Additionally, it is necessary to develop models to simulate the portion of the market (demand) that would be transported by every mode, in order to plan in a suitable way the infrastructure investment for transportation plans. Several investigations (ICF International, 2009; Forkenbrock, 2001; Pons, 2011), have demonstrated the convenience of using a railway system as complement of roads for freight transportation.

On the one hand, there has been considerable research in freight choice models with application in countries

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like United States, Australia, Russia, and other European countries, using socioeconomics and latent variables. For example, in the United States, authors illustrated the general methodology of estimation on stated-preference experiments constructed from revealed-preference choices through an application to shippers' choice of route and mode along the Columbia/Snake River system (Train & Wilson, 2008). In Denmark (Rich, Holmblad, & Hansen, 2009), for freight modal choice among five transportation modes (including railway mode), several variables related with cost and time (travel time, congestion time in roads, waiting time, etc.) were taken into account for the estimation and validation of a freight demand model for the Oresund region, based on OD matrices and level-of-service data alone. Other authors developed models empirically (García, Martínez, & Piñero, 2004), based on frequency, distance, traffic restrictions, cost, travel time, damage that the freight can suffer, delays, etc., applied to the Spanish foreign freight by the port of Valencia. A similar situation can be observed in France (Jiang, Johnson, & Calzada, 1999), where the distance, accessibility to the transport, transport facilities and the shipping method, are critical determinants in the choice of transportation mode. Again the choice of variables for estimation models is performed empirically and they use reveled data.

In Colombia, Estrada (2008) estimated a model of the freight transport distribution but only considered the road mode, and Márquez (2009) made a model of the transport network in Colombia based only on externalities.

Despite such studies, there is no evidence of a relevant investigation establishing the most influential variables from the point of view of businessmen decision-makers, where they choose a freight transportation mode on corridors where the road could compete with a railway, in a corridor dedicated mainly to import-export trade.

Thus, this article is aimed at identifying the most influential variables in the choice of a freight transportation mode. It also illustrates a way to model the modal choice in a market segment if the construction of a railway is planned to connect a capital city with a port more than 500 km away, and where currently there is only one road that connects them.

The proposed methodology is applied to the case of a corridor in Colombia, between the city of Medellin and the Port of Cartagena.

Methodology

The following methodology to estimate a discrete choice model using the most influential variables in the choice between a road and a hypothetical railway consists of the following steps:

1. Identify foreign trade products transported between the city and the port under study, and the companies that transport these products.

2. Perform a focus group with logistics managers or decision makers of these manufacturing companies in order to identify the influential variables in modal choice.

3. Perform a Stated Preferences (SP) and Revealed Preferences (RP) survey to these companies to obtain the data for modeling the modal choice.

4. Estimate the discrete choice model: Multinomial Logit Model (MNL) using the surveys.

Case study: Antioquia-Colombia

70 % of Colombian freight is transported by roads that are built and maintained by the State. Nevertheless, only 15 % of 160 000 km of road network is paved, and only about 50 % of it is in a suitable condition (Ministerio de Transporte de Colombia, 2012). Therefore, the negative impact that this precarious situation has on the economy and on the competiveness of the country due to road deterioration is undeniable.

Colombia has a limited and inefficient railway system with only two segments of 193 km and 150 km joining coal mines with their respective seaport, widely used to transport and export coal, maintained by two private companies: Drummond and Cerrejón. Around 30 % of the freight handled in Colombia is transported through these 343 km of railways, although in this case it is used only for exporting the coal.

Road freight transportation in Colombia exhibits many disadvantages, such as high operating costs, negative impact on the environment, accelerated pavement fatigue due to trucks, high accident rates, high fuel consumption, high travelling times, etc.

Academics and industry personnel have recognized the enormous need for a freight railway system in Colombia to boost the national economy and to encourage competition, but although there was a network of more than 3000 km in the beginning of the past century, there is currently no evidence of studies concerning the effects of a new network. This is more urgent if it is considered that since 2012 Colombia entered into force the Free-Trade Agreement with the U.S.A.

The case study is located in the Province of Antioquia - Colombia, the second most crowded Province of Colombia with about 6,5 million inhabitants in 2015 (13,4 % of the total Colombian population) and an area of 63 000 km^2 (5,5 % of the total area of the country). The analysis is limited to import and export general freight along a corridor from Medellín, the capital of the region, to the Port of Cartagena in the Atlantic Ocean, northern Colombia.

Foreign trade freight in Antioquia

During the first half of 2009, Antioquia foreign trade mobilized 1 875 833 tons by sea, of which 35,4 % corresponded to general freight; 57,8 % were bulk and 6,7 % were refrigerated (Bustamante, 2009).

Antioquia (with almost 20 % of the Colombian GDP) has 6 % of the total foreign trade tonnage mobilized in Colombia, and 12 % of general freight.

During the first half of 2009 Antioquia imported 1 574 259 t by sea, of which 30 % corresponded to general freight, 68 % were bulk and 2 % were refrigerated. For the total imports of Colombia, Antioquia represented 18 %, but 14 % considering only the general freight.

In the same period, Antioquia exported by sea 301 375 t, of which 65 % were general freight (including coffee), 32 % were refrigerated freight (mainly bananas), and the remaining 3 % was bulk: 2 % solids and 1 % liquid.

Freight type in the study

The overall summary of foreign trade freight in Antioquia, excluding perishables (refrigerated), reflects a potential of 3 500 400 t/year, highlighting the large participation of bulk solids, which accounted for 60 % of the total tonnage and general freight, representing 38 % of the total tonnage (Bustamante, 2009).

Table 1 shows the type of freight distribution. This freight is distributed among the ports of the country as follows: 49 % through the port of the Pacific Ocean (Buenaventura), and the rest through the Atlantic Ocean ports, with 29 % through Cartagena, 11 % through Barranquilla, and 11 % through Santa Marta. But the general freight distribution is more concentrated in Cartagena, with 51,7 % of the general freight.

Table 1. Summary of foreign freight without perishable items in Antioquia, first half of year 2009 (thousand tons). Source: Adapted from (Bustamante, 2009).

Freight type	Imports	Exports	Total	%
General freight	470,6	194,9	665,5	38 %
Solid bulk	1 037,2	5,5	1 042,7	60 %
Liquid bulk	37,9	4,2	42,0	2 %
Total	1 545,6	204,6	1 750,2	100 %

The location of Medellín (Antioquia's Capital), the ports, the real road and the idea (dashed line) of a new railway from Medellin to Cartagena seaport are illustrated in Figure 1.

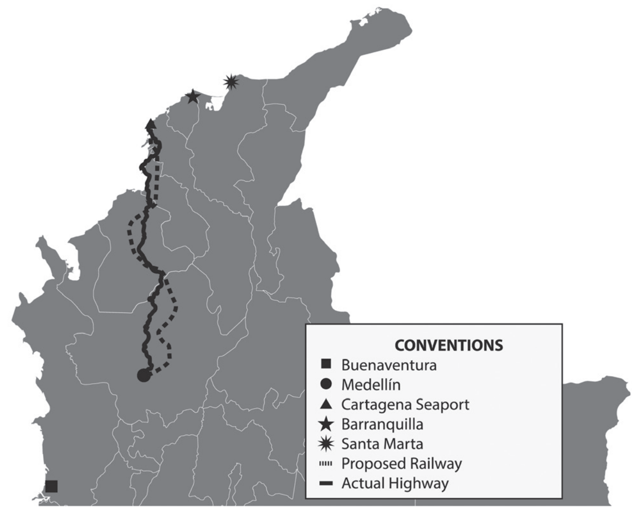

Figure 1 Corridor between Medellín and the seaport of Cartagena - main seaports of Colombia.

RESULTS

Focus group

Following the criteria of performance of a focus group (Breen, 2006, Krueger, 1991), the focus group was composed of eight people responsible for the area of transportation and foreign trade of four big freight companies in the region, with a 5,6 % of the imported freight and 23,3 % of the total exported freight in Antioquia. These companies were: OMYA (chemical products), Cristalería Peldar S.A (glass), Sofasa (vehicles) and Productos Familia (paper products). Six questions designed for this purpose were asked.

From this focus group, two variables were identified for the choice of freight transportation mode between road and railway: cost and service frequency (Pineda Jaramillo & Sarmiento Ordosgoitia, 2014). These variables will be used for stated-preferences survey design.

The travel time and the reliability of the delivery were not identified as important, as currently these variables are very unreliable due to the real conditions of the roads and capacity limitations of Colombian Ports. Moreover, the details of possible delays in the transfer operations to change the freight from trucks to trains in the origin and destination points are not known yet, although it is known that the travel time in the segment of rail line is reliable.

In order to create the set of hypothetical situations to be chosen by the individuals surveyed, independent factors or variables can be expressed in continuous scale with their levels (e.g. high, medium and low rates); or discrete scale with their levels (e.g. safety with their high and low levels, which on a discrete scale would be 0 and 1). In this way, it is understood that the number of possible combinations grows exponentially with the number of attributes involved; for which fractional factorial designs (Kocur, Adler, Hyman,

& Aunet, 1982) are most commonly used. Following the experimental design raised by (Kocur, Adler, Hyman, & Aunet, 1982), experimental plan code 34 was chosen, indicating that the SP survey will have a total of six cases.

Definition of factors

Making a projection for the year 2016, Antioquian trade will transport approximately 1 500 000 t of general freight annually, of which approximately 55 % (825 000 t) will be transported through the port of Cartagena. Applying the 2009 percentages for export-import, 62,3 % (513,975 t) will be import freight, while 37,7 % (311 025 t) will be export freight. This scenario is conservative, since it considers only the foreign freight as one part of the potential universe where it is thought to capture a share for the railway. On the other hand, we are not considering the internal freight in the regions and the flows among regions.

Transportation cost

The average export costs by road are lower than the import costs. This is because Antioquia imports more than it exports, so in order to avoid the trucks returning empty to the ports, the transport costs are cheaper to return to port. In addition, transportation costs are higher in Colombia where a truck travels maximum 12 000 km each month In Europe and the U.S., a truck travels 20 000 – 22 000 km per month. The routes in Antioquia have no optimal quality; this also increases the transport costs.

Cost of trucking

For this research, we work with an average cost of USD 70/t for road transportation of freight from Medellín to Cartagena and vice versa, i.e. USD 0,110/t-km, based on an actual distance of 640 km road between these two points. This cost was chosen taking into account the actual average cost of trucking in Colombia for general freight.

Cost of railway transportation plus road transportation at the ends

The total cost of freight transport from the Antioquian company to the Port of Cartagena, or vice versa, used in this research shall be the sum of: the cost of road transportation from the company to the dry port located northern Medellin (USD 3,3/t), plus the cost of loading and unloading there (USD 5,4/t), plus the cost of travelling by railway from northern Medellin to the outskirts of the city of Cartagena (USD 29,8/t), plus the cost of loading and unloading out there in Cartagena (USD 5,4/t), plus the cost of road transportation from the outskirts of Cartagena to the Port of Cartagena (USD 1,7/t). This cost will be approximately USD 45,6/t, in other words, a total sum of USD 0,083/t-km.

These costs were chosen taking into account the actual costs of loading and unloading freight in the Port of Cartagena, and also the average costs of railway transportation in Cerrejón and Drummond, the two railway systems in Colombia.

Data description

66 individuals from 66 Antioquian companies were surveyed, representing 68 % of the export and import freight of the region. This sample represents a large percentage of Antioquian trade.

The variables collected in the stated preferences survey were:

- Cost [C].
- Service Frequency [F].

Secondary variables collected in the revealed preferences survey were:

- Gender of the decision-maker interviewed [GENDER].
- Percentage of own trucks of the company (0.0 %, 1.>0 %) [CAM].
- Fixed-term employees (0.<200, 1.>=200) [EMP].
- Temporary employees (0.<=30, 1.>30) [TEMP].
- Location of containers (0, North of Medellín, 1. South of Medellín) [UBI].
- Percentage of road transportation (0.<90 %, 1.>=90 %) [TC].
- Weekly freight (0.<200 t, 1.>=200 t) [CS].

In order to use variables as dummy type, the range is placed within parentheses.

Summary statistics

Some important data from the sample of 66 surveys are:

- Gender of the decision-maker interviewed: 70 % men and 30 % women.
- Percentage of trucks owned by the company: 55 % of the companies have 0 % of own trucks, and 45 % of the companies have more than 1 % of own trucks.
- Fixed-term employees: 33 % of the companies have less than 200 fixed-term employees. 67 % of the companies have more than 200 fixed-term employees.
- Temporary employees: 30 % of the companies have less than 30 temporary employees. 70 % of the companies have more than 30 temporary employees.
- Location of containers: 77 % of the companies have their containers in southern Medellin, and 23 % of the companies have their containers in northern Medellin. It is important to mention that 74 % of the companies have the same location as their containers.

- Percentage of road transportation: All the companies surveyed transport more than 70 % of their freight by road.
- Weekly freight: 67 % of the companies transport more than 200t per week, and 33 % of the companies transport less than 200 t per week.

MNL Model results and discussion

The formulation of the MNL model is shown in Equations (1) and (2), where U is the utility of use in each of both modes. The variables β and θ correspond to specific constants and parameters to be estimated, respectively. The β of the railway is made zero in order to estimate the differential value β of the road with respect to the railway.

$$U_{ROAD} = \beta_{ROAD} + \theta_C C_{ROAD} + \theta_F F_{ROAD} + \theta_v Variable + \varepsilon \quad (1)$$

$$U_{RAILWAY} = \beta_{RAILWAY} + \theta_C C_{RAILWAY} + \theta_F F_{RAILWAY} + \varepsilon \quad (2)$$

After specifying the models, we continued with the modeling using the software BIOGEME 2.0 (EPFL, 2013). Then, the modeling started with the first model (MNL1) with the most complex specification possible, involving all variables. Then, non-significative variables were dismissed from the later models (MNL2, MNL3, etc.), and finally, a simpler model was formulated (MNL5).

Table 2 presents the results of the estimated MNL models where, for each cell, the upper value represents the value of the parameter, and the lower value (in parenthesis) shows the significance of the t-test variable. If the t-test ≥|1,96|, the variable has 95 % of significance. The results show that the expected signs of the cost (–) and service frequency (+) variables agree with reality, because if the cost increases, the utility will decrease, and if the service frequency increases, the utility of the model will increase too (see Equations (1) and (2)).

In Table 2, it can also be appreciated that the only significant variables were: cost, service frequency and gender of the decision maker. The remaining variables were not significant at all; it just shows that when choosing the transportation mode to transport the freight to and from the port, it does not depend on the configuration of the company.

Table 3 presents the ranking of the models. The following parameters were taken into account:

- The expected signs of the variables: Cost (–), service frequency (+).
- Significance of the variables' t-test ≥ |1,96| for 95 % significance.
- Likelihood-ratio test (LR) with acceptable values depending of degrees of freedom.
- Statistical Test ρ^2, higher is better.

The MNL4 and MNL5 models are better than the others. To decide between the MNL4 and the MNL5 models, we calculate the LR between them. There we return to one degree of freedom (r = 1, the "gender" variable) and the LR must be lower than 3,84, but we have to calculate it with the L(B) of MNL4 and MNL5 models (Equation (3)).

$$LR : -2\left[\text{Lrestrict} - \text{L}\right] : -2\left[-177{,}917 - \left(-175{,}97\right)\right] = 3{,}894 \quad (3)$$

Then, the MNL5 model is equivalent to the MNL4 model (maybe not with 95 % confidence, but with 94 % confidence), and therefore the MNL5 model is chosen because it is a simpler model than the MNL4 model (without the gender variable), whose formulation is shown in Equations (4) and (5):

$$U_{ROAD} = -1{,}10 - 0{,}0000106{*}C_{ROAD} + 0{,}196{*}F_{ROAD} \quad (4)$$

$$U_{RAILWAY} = -0{,}0000106{*}C_{RAILWAY} + 0{,}196{*}F_{RAILWAY} \quad (5)$$

The negative coefficient of the road specific constant (-1,10) reveals that if cost and service frequency for road and railway were equal, companies would prefer railway. This may be due to all the hardships they have had to suffer with different difficulties presented in the road along time in the region, such as paralysis of service due to the rainy season, landslides and road closures, prolonged strikes, difficult weekend service by regulations of non-circulation on Sundays and holidays at certain times, accidents with loss of freight or delays, burglaries with loss of freight, terrorist or subversive acts that affect the normal circulation, among others.

Table 2. MNL model results.

		MNL1	MNL2	MNL3	MNL4	MNL5
Variable	Parameter	Value	Value	Value	Value	Value
–	$\beta 1$	–0,54 (–0,9)	–0,367 (–0,62)	–0,515 (–1,33)	–0,72 (–2,22)**	–1,1 (–4,12)**
–	$\beta 2$	0 (0,00)	0 (0,00)	0 (0,00)	0 (0,00)	0 (0,00)
Cost	$\theta 1$	–0,019795 (–2,04)**	–0,019795 (–2,04)**	–0,019795 (–2,04)**	–0,019795 (–2,04)**	–0,01961 (–2,03)**
Service Frequency	$\theta 2$	0,199 (2,12)**	0,198 (2,12)**	0,198 (2,12)**	0,198 (2,12)**	0,196 (2,1)**
Gender	$\theta 3$	0,608 (2,02)**	0,589 (1,97)**	0,589 (1,97)**	0,563 (2,00)**	–
Own trucks	$\theta 4$	0,348 (1,22)	0,365 (1,28)	0,367 (1,31)	–	–
Fixed-term employees	$\theta 5$	–0,0536 (–0,12)	–	–	–	–
Temporary employees	$\theta 6$	–0,212 (–0,51)	–	–	–	–
Fixed-term and temporary employees	$\theta 7$	–	–0,0241 (–0,07)	–	–	–
Location of containers	$\theta 8$	0,125 (0,39)	0,197 (0,63)	–	–	–
Percentage of road transportation	$\theta 9$	0,0269 (0,08)	0,0301 (0,09)	–	–	–

		MNL1	MNL2	MNL3	MNL4	MNL5
Variable	Parameter	Value	Value	Value	Value	Value
Weekly freight	$\theta 10$	0,0866 (0,28)	0,0412 (0,14)	0,0414 (0,14)	–	–
Final log-likelihood	L(B)	−174,549	−174,878	−175,091	−175,97	−177,917
Rho-square	ρ^2	0,409	0,408	0,407	0,404	0,397
Likelihood-ratio Test	LR	–	–	1,084	1,758	3,894

**: Variable with 95 % of significance.

Table 3. Ranking of the MNL models.

Ranking	Model	Expected signs	Variables with t-test significance ≥ |1,96|	L(B)	LR	ρ^2
1	MNL4	Yes	4	−175,97	1,758	0,404
2	MNL5	Yes	3	−177,917	3,894	0,397
3	MNL1	Yes	3	−174,549	–	0,409
4	MNL2	Yes	3	−174,878	–	0,408
5	MNL3	Yes	3	−175,091	1,084	0,407

Market shares of transportation modes

Using the estimated model MNL5, chosen as the best of all, we calculate the market shares of the two considered transportation modes, i.e. the probability of each transportation mode (road or railway) to be chosen by companies to transport their freight from/to the port of Cartagena. Figure 2 shows the probability of choosing railway varying the service frequency parameter. Figure 3 presents the probability of choosing railway varying the cost parameter.

Figure 2 shows the probability of choosing the railway is 67 % (when the service frequency of roads is 4 days a week, and railway 2 days a week service, and the cost per ton for both road and railway is USD 54). On the other hand, the probability of choosing the railway is 93 % (when the service frequency of roads is 2 days a week, and railway 5 days a week, and the cost per ton is USD 81 for the road, and USD 38 for the railway) (*Figure 3*). Figure 2 and *Figure 3* shows that the probability of railway choice by the studied companies varies between 67 % and 93 %, depending on differences in cost and service frequency, proving the greater impact that these variables have in the election.

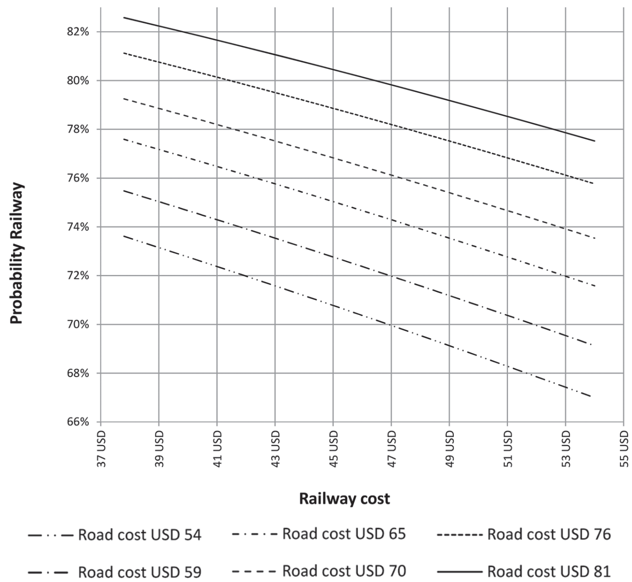

Figure 2 Probability of choice railway varying the service frequency of both modes (a) service frequency: road 4 days weekly, railway 2 days weekly.

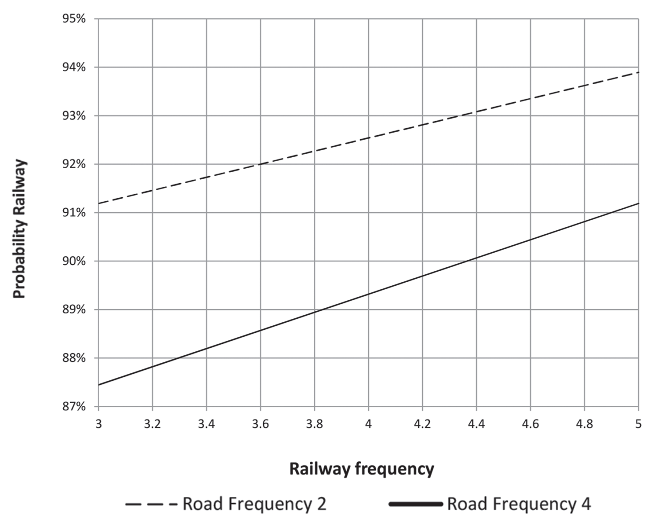

Figure 3 Probability of choice railway varying the cost of both modes (a) cost: Road USD 81, railway USD 38.

Conclusions

From the focus group it was identified that the influential variables in the choice between road and railway for general foreign trade freight in Antioquia are cost and service frequency. As long as the railway system is more affordable and offers a competitive service frequency compared to road transportation, as stipulated in this proposal, all export-import freight companies that use the port of Cartagena (Atlantic Ocean) would be potential customers. Also, if there were education campaigns directed towards businessmen in the region, to show them other options like railways would be effective, Antioquian businessmen who are now rooted in road transportation would start looking at other options, such as the proposed railway between Medellin and Cartagena.

If there was an increase in the demand of products, it would increase the freight that has to be mobilized in Colombia. This means service frequency of the railways would need to increase as well, which in turn requires more workforce. This would provide a greater amount of jobs, so that truck drivers would have new job options in freight transport by railway or job reconversion.

If a good railway transport system in Colombia was implemented, the companies could use railways to mobilize as much freight as possible, and use the trucks for shorter distances (does not apply in fragile products that must continue to be transported by truck, but those that allow multimodal transportation). This would bring great benefits to reduce fatigue on pavements and increase their useful life, and would minimize the accelerated deterioration of roads, and so increase the budget to pave more roads in Colombia or increase the useful life of existing ones. In addition, being able to easily and quickly mobilize more products inside the country to ports, the transportation costs of products would be reduced, and the Colombian market would be more competitive.

In this paper a bimodal discrete choice model with cost and service frequency as the main variables was estimated. The probability of choosing railway fluctuates between 67 % in the worst case, up to 93 % in the best case for companies transporting general foreign freight; this only shows that the railway system would have wide acceptance in the region.

Additional work is suggested to explore other models with companies moving internal national freight and bulk foreign trade freight, and the possibility of using the freight railways in Colombia not only for freight transportation but also for passenger transportation, especially in corridors where the topography allows connecting cities with a potential market of trips among them.

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