The Impacts of Transportation Infrastructure in Regional Trade in Brazil: a Spatial Approach using a Gravity Model*

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Resumo

Este artigo analisa os impactos dos diferentes modais de transporte nos fluxos de comércio internacional dos estados brasileiros. Para isso, usamos a equação gravitacional estimando três modelos diferentes: dados agrupados; efeitos fixos; e efeitos aleatórios. Além disso, incluímos variáveis para os principais modais de transporte utilizados no país, isto é, modal rodoviário, ferroviário, portuário e aéreo. Finalmente, uma vez que há evidências de que existe correlação espacial nos dados, incluímos um modelo de econometria espacial, o modelo spatial lag of X (SLX). Usamos um painel que incluiu dados de comércio de 2012 a 2015 para todos os 27 estados do Brasil para os principais parceiros comerciais do país. Nossos resultados mostram que o comércio dos estados brasileiros é impactado de forma significativa pela infra-estrutura de transporte dos estados, especialmente o transporte rodoviário, mas também o transporte ferroviário e aquático. Além disso, descobrimos que a infra-estrutura ferroviária e portuária em estados vizinhos é importante para explicar as exportações de um estado. Isso explica, por exemplo, o fato de que uma proporção substancial das exportações de soja de estados como Mato Grosso, Mato Grosso do Sul e Goiás é exportada através do uso da infra-estrutura ferroviária e portuária do estado vizinho São Paulo.

Palavras-chave: Infraestrutura de transporte; comércio das regiões; econometria espacial; modelo gravitacional.

JEL: F14, R15

1 Introduction

There is strong evidence that infrastructure has important impacts on international trade. For example, Celbis, Nijkamp and Poot (2013) quantify the importance of infrastructure for trade by means of meta-analysis and meta-regression techniques that synthe-

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size various studies, especially in the case of transport and communication infrastructure. They found that a one percent increase in a country's infrastructure increases exports by about 0.6 percent and imports by about 0.3 percent. Such elasticities are especially larger in the case of developing countries.

An empirical study on the linkage between the quality of infrastructure and trade costs by Clark et al. (2004) finds that port efficiency is an important determinant of ocean freight costs. For example, they estimate that maritime transport costs in Brazil or India would fall by over 15 per cent if their port efficiency was at the level of France or Sweden. Limão and Venables (2001) find that own infrastructure explains 40 per cent of transport costs for coastal countries while own and transit country infrastructure explains 60 per cent of transport costs for landlocked countries.

There have been also recent studies that seeked to evaluate the influence of transportation costs and logistics infrastructure on a regional level. Cruz, Silva and Lima (2008) use ten infrastructure and regional development indicators to conclude that infrastructure indicators were very important for the economic development of Brasil's states. In turn, both Vickerman (1995) and Camagni and Capello (2013) discussed potential benefits of an improved infrastructure network and its capability of fostering both regional competitiveness and economic development.

An important issue is the relation between transport infrastructure endowment and regional connectivity and the possibility to foster international cargo flows (Li and Qi, 2016). The possibility to invest in expanding the transport network in order to enhance the benefits of an increased level of connectivity into international markets is an important point of many economic policies and it is of particular importance for some specific world regions that are strongly dependent from international trade for their economic growth, such as the Latin America and the Caribbean (e.g. Wilmsmeier and Hoffmann, 2008; Catalayud et al., 2017).

Thus, transport infrastructure is one of the key factors that impacts regional trade. In fact, over 80% of international trade involves maritime services (UNCTAD, 2016) and that infrastructure affect the most the international connectivity of a given region (e.g. Guerrero et al., 2016), as well as the regional economic structure and its propensity to international trade (e.g. Ducruet and Itoh, 2016). Martínez-Zarzoso et al. 2003 showed the importance of maritime networks to foster international trade.

However, in spite of this level of importance, recent transport policies and related infrastructure investments in Brazil have not been appropriate (Garcia-Escribano et al., 2015), and several bottlenecks have been registered with many critical issues related to port activities and cargo distribution (Galvão et al., 2017). In fact, many policies aiming at increasing the efficiency of the overall transport system have reduced effects due to inconsistency of transport policies (e.g. Sá Porto et al., 2014). Within this scenario, the possibility to estimate the link between trade and transport infrastructure (mainly ports) in Brazil assume a particular relevance.

The objective of this paper is to assess the impacts of the different transportation modals on the international trade flows of Brazilian states. The contribution of this article is threefold. First, we used a recent data set, a panel that included trade data from 2012 to 2015 for all of Brazil's 27 states to the country's main trade partners. We estimated the gravity equation using three different models: a pooled cross section model, a fixed effects model and a random effects model. Moreover, we included variables for all of the main modes of transportation that are mostly used within the country, namely, road, rail, water and air modals, and then we evaluated the impact of each modal on the states trade.

Finally, there is evidence that there is spatial correlation in the data. Exports of one state can be influenced by the transportation infrastructure of neighboring states. For example, in Brazil a large part of soy production from the states of Mato Grosso, Mato Grosso do Sul and Goiás is exported using the rail and port infrastructure of the neighbour state of São Paulo. In order to model these effects, we included a fourth model, a spatial model lag of X model (SLX) within the spatial econometrics framework.

The paper is structured as follows. After this brief introduction, in Section 2 we briefly review the literature on the gravity model and present a spatial model based on the gravity equation, while in Section 3 we present the econometric models and the data used in this article. We present our main results in section 4. In the last section we present our conclusions and possible further research on this subject.

2 Literature Review

In this section we will briefly review the existing literature on the gravity model. We will introduce the gravity equation and present some of the different applications in which the gravity model have been used. Next, we will present a spatial econometrics model based on the gravity equation that can be used to assess the impacts of transportation infrastructure (road, rail, water and air) on the Brazilian states trade.

2.0.1 The Gravity Model

The gravity model has been extensively used in international economics. It was first proposed in order to account for the factors that explained the size of trade flows between two countries. These factors were of three types: one type includes the factors related to the total potential supply of the exporting country. A second type includes the factors related to the total potential demand of the importing country. And a third set of factors was the resistance to trade, be it natural or artificial trade resistance). These three types of factors are represented in the original gravity model, proposed independently by Tinbergen and Pöyhönen, and later refined by Linnemann (SÁ PORTO, 2002, p.8):

$$X_{ij} = a_0(Y_i)^{a1}(Y_j)^{a2}(N_i)^{a3}(N_j)^{a4}(Dist_{ij})^{a5}\exp(pref^{a6})\varepsilon_{ij} \quad (1)$$

where X_{ij} is the dollar value of exports from country i to country j; Y_i is the nominal value of country i's Gross Domestic Product (GDP); Y_j is the nominal value of country j's GDP; N_i is the population of country i; N_j is the population of country j; $Dist_{ij}$ is the distance between the commercial centers of the two countries, and is used as a proxy for the trade resistance variables; $pref$ is a *dummy* variable which equals to 1 if both countries belong to a specific preferential trade area and zero otherwise; and ε_{ij} is the error term. The coefficients a_0 through a_6 are to be estimated by the regression.

In its original form, the main deficiency of the gravity model was the lack of a solid theoretical microeconomic foundation. The model described by equation (1) above is not an economic model, although plausible (SÁ PORTO, 2002). Anderson (1979) attempted to establish a more solid microeconomic theoretical foundation for the gravity equation. Bergstrand (1985; 1989) extended the theoretical foundations of the gravity equation by incorporating prices variables and by incorporating factor endowments and preferences variables. Later Anderson and Van Wincoop (2003) developed a method that consistently and efficiently estimates a theoretical gravity equation, making it solid from the theoretical point of view.

Moreover, the gravity equation has been very successful in explaining trade empirically; the estimation of the equation above applied to the trade of 80 countries, explained some 80 percent of the variance of the data (SÁ PORTO 2002, p.10). It has also been used pervasively in models that try to assess the welfare effects of economic integration (such as Aitken 1973, Soloaga and Winters 2001, Reis et al. 2014, among many others). Some studies have tried to evaluate the impacts of economic integration on the different regions of participating countries (e.g Bröcker (1988), Sá Porto and Canuto (2004), Sá Porto and Azzoni (2007), among others.[1]

It has also been used widely on trade facilitation issues. Trade Facilitation (TF) is defined as the simplification, harmonization, standardization and modernization of procedures of international trade (MACEDO; SÁ PORTO, 2011, p.162). Portugal-Perez and Wilson (2010) evaluate whether TF reforms improve the export performance of developing countries, and they show that reforms using TF measures substantially improve the export performance of developing countries.

Wilson, Mann and Otsuki (2003) use a gravity model to evaluate the relationship between trade facilitation and trade flows in the Asia-Pacific region, and found that regulatory barriers and port inefficiency deter trade and improvements in customs and greater e-business use significantly expand trade. And Sá Porto, Canuto and Morini (2015) assess

[1] For a wider literature review on the gravity model and on the regional impacts of preferential trade arrangements, see Reis et al.(2014), Cardamone (2007) and Sá Porto and Azzoni (2007).

the impacts of selected TF measures, such as the authorized economic operator program and the single-window program, on international trade flows. They found that the presence of an authorized economic operator program and the existence of a single-window program will improve countries' trade performance.

The role that the quality of infrastructure plays on a country's trade performance is evaluated by Nordas and Permartini (2004). They look at the impact of the quality of infrastructure (road, airport, port and telecommunication, and the time required for customs clearance) on total bilateral trade and on trade in the automotive, clothing and textile sectors. They found that the quality of infrastructure is an important determinant of trade performance, whereas port efficiency has the largest impact on trade among all infrastructure indicators.

Finally, Porojan (2001) revisits the gravity model of trade in the light of the increasingly acknowledged findings of spatial econometrics. He explores the empirical performance of the gravity model when the inherent spatial effects are explicitly accounted for within the framework of spatial econometrics (e.g., ALMEIDA, 2012). His main finding is that, when the inherent spatial effects are explicitly taken into account, the magnitude of the estimated parameters changes considerably and, with it, the measures on the predicted trade flows. More specifically, the traditional formulation seriously overestimates the size of the trade flows to and from 'island' countries, while underestimating it for countries who have large trading neighbours. Moreover, the large explanatory power of regional trading bloc membership dummy variables vanishes when spatial effects are included in the model specification.

In this article, it is also important to model spatial effects on the trade of Brazilian states using a spatial econometrics model. As the exports of one state can be influenced by the infrastructure of neighboring states, we have to account for spatial correlation effects. In fact, there is strong evidence that the Brazilian states trade data exhibit spatial correlation. For example, the large iron ore flows produced in the state of Pará are exported through the use of the rail and port infrastructure of the neighbour state of Maranhão. It is also the case of soy exports of the central western states of Mato Grosso, Mato Grosso do Sul and Goiás, which are mainly exported through the port of Santos in the neighbour state of São Paulo. We will account for spatial effects by using a spatial lag of X model (SLX).

2.1 Gravity Model Including Infrastructure Modals

Following from the model presented in equation (1), in this section we will derive a version of the gravity model that includes infrastructure modals and incorporates spatial effects. Assume that international trade is restricted to two countries and two goods, where each country specializes in the production of a commodity. It exports one commodity to the other country, and it imports the other country's commodity. Thus, country i has its demand and supply represented by the following equations:

$$X_{ii}^{D} = D_{ii}(Y_i, N_i, p_i, p_j, t_{ji}) \tag{2}$$

$$X_{ij}^{D} = D_{ij}(Y_j, N_j, p_i, p_j, t_{ij}) \tag{3}$$

$$X_{i}^{S} = S_i(Y_i, N_i, p_i) \tag{4}$$

where X_{ii}^{D} is the internal demand of goods produced by the country i; X_{ij}^{D} is the demand of country i's product by country j; X_{i}^{S} is the supply of country i; Y_i is country i's GDP; N_i is country i's population; p_i is the internal price of product produced by country i , Y_j is country j's GDP; N_j is country j's population; p_j is the internal price of product produced by country j and t_{ij} is the transportation cost from country i to country j, whereas t_{ji} is the transportation cost from country j to country i.

One can divide the transportation cost between country i and country j (t_{ij}) into two components: internal transportation cost (t_{ij}^{i}), defined as the cost of transporting the goods from their place where they are produced to the port of exit from territory i (be it a waterway port, or road, rail or pipeline), and the external transportation cost (t_{ij}^{e}), defined as the cost of transporting from the last point within state i until its destination in j. Thus, we have:

$$t_{ij} = t_{ij}^{i} + t_{ij}^{e} \tag{5}$$

Then the system of equations above is shown as follows:

$$X_{ii}^{D} = D_{ii}(Y_i, N_i, p_i, p_j, t_{ji}^{i}, t_{ji}^{e}) \tag{6}$$

$$X_{ij}^{D} = D_{ij}(Y_j, N_j, p_i, p_j, t_{ij}^{i}, t_{ij}^{e}) \tag{7}$$

$$X_{i}^{S} = S_i(Y_i, N_i, p_i) \tag{8}$$

By the equilibrium condition:

$$X_{i}^{S} = X_{ii}^{D} + X_{ij}^{D} \tag{9}$$

which can be rewritten as: $X_i^{ES} = X_{ij}^D$

where X_i^{ES} is the external supply of country i, that is, the supply left after the internal market's demand is fulfilled. We can assume the following format for these equations:

$$X_{ij}^D = \gamma Y_j^\alpha N_j^\beta p_i^o (t_{ij}^e)^\delta (t_{ij}^i)^\theta \tag{10}$$

$$X_{ij}^{ES} = \varpi Y_i^\sigma N_j^\phi p_i^\pi \tag{11}$$

If we isolate good i's price (p_i) and the volume of exports (X_{ij}), by the equilibrium conditions we can obtain:

$$X_{ij}^* = X_{ij}.p_i = \tag{12}$$

$$\gamma^{(\pi+1)\xi} \varpi^{-(o+1)\xi} Y_i^{-(o+1)\sigma\xi} N_i^{-(o+1)\phi\xi} Y_j^{(\pi+1)\alpha\xi} N_j^{(\pi+1)\beta\xi} (t_{ij}^i)^{(\pi+1)\delta\xi} (t_{ij}^e)^{(\pi+1)\theta\xi} =$$
$$a_0 Y_i^{a1} Y_j^{a2} N_i^{a3} N_j^{a4} (t_{ij}^i)^{a5} (t_{ij}^e)^{a6}$$

Onde $\xi = 1/(\pi - o)$

Thus, as in the original model of equation (1), one can assume that, for estimation purposes, the external transportation costs (t_{ij}^e) can be proxied by the distance between the distance and by a preferential trade dummy variable. In its turn, the internal transportation costs (t_{ij}^i) can be proxied by the country's logistics infrastrucutre conditions. If we add a variable for each transportation mode, we can obtain:

$$X_{ij}^* = a_0 Y_i^{a1} Y_j^{a2} N_i^{a3} N_j^{a4} Dist_{ij}^{a5} road^{a6} rail^{a7} port^{a8} air^{a9} \exp(a_{10} pref) \tag{13}$$

where each variable are defined as in equation (1), *road* equals country i's road, *rail* equals country i's rail conditions, *port* equals country i's port conditions and *air* equals country i's air infrastructure conditions. In logarithm terms, equation (13) will look like the following, where each variable have been previously defined:

$$\ln X_{ij} = \ln a_0 + a_1 \ln Y_i + a_2 \ln Y_j + a_3 \ln N_i + a_4 \ln N_j + a_5 \ln Dist_{ij} + \tag{14}$$

$$a_6 \ln road + a_7 \ln rail + a_8 \ln port + a_9 \ln air + a_{10} pref + \ln \varepsilon_{ij}$$

In order to incorporate spatial effects to the model presented in equation (13) above, we have to further transform the model as follows. The infrastructure built in one state can affect the exports of a neighbouring state. Thus, there is spatial dependency of one state exports to the transportation infrastructure (road, rail, port and air) of other neighbouring states. A general spatial lag model is defined as follows:

$$Y = \alpha + \rho WY + \beta X + \varepsilon \tag{15}$$

where Y is the dependent variable, X is the vector of independent variables and W is the spatial correlation weight matrix (ALMEIDA, 2012). In our specific case, the dependent variable state's exports, exhibit spatial dependency to the set of transportation variables of neighbouring states. This can be modeled by using a spatial model with lag in X, also known as SLX model. This model does not include any global or local spatial lag term, that is, no spatial lag effect on the dependent variable or on the error term. There is a spatial lag only in the independent variables. In our case, we include a spatial lag for the transportation variables:

$$Y = \alpha + \beta X + \theta WX' + \varepsilon \tag{16}$$

where Y is the dependent variable, X is the vector of independent variables, W is the spatial correlation weight matrix and X' is the set of spatial lagged transportation variables.

3 Econometric Model and Data

In this section we will present our model designed to assess the impacts of the different transportation infrastructure modals on the international trade flows of the Brazilian states. We use a standard gravity model, using variables that have traditionally been used to explain trade, such as importer's and exporter's GDP, importer's and exporter's population, distance between the capital of the importer to the capital of the exporter, tariffs (in this case defined as the weighted average tariff that Brazil's states imposes to importers on its products) and dummy variables for preferential trade agreements. In this last case, we included dummies for the following five agreements: NAFTA, Mercosur, EU, APEC and PAL.[2] We also used a dummy variable to account for adjacency, in order to verify whether the adjacency of a Brazilian state to an importing country affects the trade of the Brazilian states[3].

[2]The most relevant regional blocs for Brazil are: NAFTA = North America Free Trade Area; Mercosur = Southern Common Market; EU = European Union; APEC = Asia-Pacific Economic Cooperation; PAL = Pacific Alliance. Initially, we also included other regional blocs but only these five blocs were significant for Brazilian states' trade. For a complete and updated list of regional trade arrangements and its comprising countries, go to the WTO's site:http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx

[3]In order to capture specific time effects on the panel, we added time dummies for each year of the 2012-2015 period. However, for all four models the coefficients of the time dummies were all not significant, and were not stable, being negative in some cases and positive in others. Thus, we did not include time dummies in the final models.

Moreover, we augmented the standard gravity model by adding infrastructure variables for all of the main transportation modes that are mostly used within the country: road, rail, water and air. For that assessment, we included the following variables: 1) Road mode – Road and RoadQuality, which are, respectively, the total road length in kilometers of a specific state in Brazil, and the total extention of roads in kilometers of the state's highways that classified as in good or excellent state; 2) Rail mode – the total rail length in kilometers in the state; 3) Water mode – Quay and Depth, which are, respectively, the total extension in meters of quay in all ports in the state, and the average depth of all ports in the state; and 4) Air mode – the total length in meters of landing strip of all of state's airports. These variables were used as proxy for the main transportation infrastructure modals available. Our estimated model then looks like the one shown in equation 14.

Besides this first model that included the infrastructure variables mentioned above (which we call nonstandardized model), in a second model we normalized the infrastructure variables by the total area of the state (which we call standardized model[4]). Thus, Road/Ext and RoadQuality/Ext are, respectively, the total road length in kilometers divided by the total area of the state, and the total extention of roads in kilometers divided by the total area of the state of highways that classified as good or excellent; Rail/Ext is the the total rail length in kilometers in the state divided by the total area of state; Quay/Ext is the total extension of quay in meters in all ports in the state divided by the total area of the state; and Air/Ext is the the total length in meters of the landing strip of all of state's airports divided by the total area of the state.

Thus, our first model (nonstandardized model) is as follows:

$$\ln X_{ij} = \ln a_0 + a_1 \ln Y_i + a_2 \ln Y_j + a_3 \ln N_i + a_4 \ln N_j + a_5 \ln Dist_{ij} + \tag{17}$$

$$a_6 Adjacent + a_7 Nafta + a_8 Mercosur + a_9 EU + a_{10} APEC + a_{11} PAL + a_{12} \ln road +$$

$$a_{13} \ln roadQuality + a_{14} \ln rail + a_{15} \ln quay + a_{16} \ln deph + a_{17} \ln air + \ln \varepsilon_{ij}$$

where X_{ij} is the dollar value of exports from state i to country j; Y_i is the nominal value of state i's Gross Domestic Product (GDP); Y_j is the nominal value of country j's GDP; N_i is the population of state i; N_j is the population of country j; $Dist_{ij}$ is the distance between the commercial centers of state i and country j; Adjacent is a dummy variable equal to 1 if a state and a country are adjacent (share borders); Nafta, Mercosul, and EU are dummy variables equal to 1 if the partner country belongs to that bloc, and zero otherwise. We

[4] In this model, all infrastructure variables were standardized but one, depth. The reason for this is that this variable was constructed already as the average depth within all ports of each state, thus it did not need to be normalized.

also include the Dummy12, Dummy13, and Dummy14, time dummy variables equal to 1 if the export from state i to country j occurred in that specific year (years 2012, 2013 and 2014, respectively), and zero otherwise. The variables Road, RoadQuality, Rail, Quay, Depth, and Air are defined above.

Then our second model (standardized model) is as follows:

$$\ln X_{ij} = \ln a_0 + a_1 \ln Y_i + a_2 \ln Y_j + a_3 \ln N_i + a_4 \ln N_j + a_5 \ln Dist_{ij} + \qquad (18)$$

$$a_6 Adjacent + a_7 Nafta + a_8 Mercosur + a_9 EU + a_{10} APEC + a_{11} PAL + a_{12} \ln road/ext +$$

$$a_{13} \ln roadQuality/ext + a_{14} \ln rail/ext + a_{15} \ln quay/ext + a_{16} \ln deph + a_{17} \ln air/ext +$$

$$\ln \varepsilon_{ij}$$

Where all the variables have been previously defined. We used panel data[5] that included trade data from 2012, 2013, 2014 and 2015 for all trade flows between Brazil's 27 states and the country's main 60 trade partners[6]. We included all observations of non-zero trade between countries, and then we estimated each model in four different ways[7]: Pooled Cross Section (PCS) estimation; a Fixed Effects (FE) estimation; a Random Effects (RE) estimation; and a spatial lag of X (SLX) estimation. We estimated the two models in equations (17) and (18) for all of the first three estimation techniques.

For the fourth estimation method, the SLX method, we tried to account for the evidence that there is spatial correlation in the data. Exports of one state can be influenced by the infrastructure of neighboring states. We modeled these effects by using a SLX model, where transportation variables for the states are included but also their spatial lags (that is, the transportation variables for the neighbouring states) are included. Thus, the nonstandardized model in equation (17) will look as follows:

[5]The source of the trade data is SECEX (2016). The GDP and the population data for the countries in the sample was obtained from the World Bank (2016). The GDP and the population data for the states was obtained from IBGE (2015). The distance and adjacency information were extracted from the World Atlas MPC CD-ROM. The information on regional blocs comes from WTO (2016a), and the tariff data comes from WTO (2016b). Finally, the data on the infrastructure variables come from the annual reports from Pesquisa CNT Rodovias (2015), Ministério dos Transportes (2015) and Ministério da Indústria, Comércio Exterior e Serviços (2015).

[6]The 60 partner countries that account for about 90% of Brazil's trade are: Argentina, Australia, Austria, Belgium, Bulgaria, Bolivia, Canada, Chile, China, Colombia, Costa Rica, Denmark, Dominican Republic, Ecuador, Egypt, Finland, France, Germany, Greece, Guatemala, Hong Kong, Honduras, Hungary, Indonesia, India, Iran, Iraq, Ireland, Israel, Italy, Japan, Kuwait, Malaysia, Morocco, Mexico, Netherlands, New Zealand, Nigeria, Norway, Paraguay, Peru, Portugal, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, Ukraine, Uruguay, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela and Vietnam.

[7]The four equations were estimated using Stata.

$$\ln X_{ij} = \ln a_0 + a_1 \ln Y_i + a_2 \ln Y_j + a_3 \ln N_i + a_4 \ln N_j + a_5 \ln Dist_{ij} + \quad (19)$$

$$a_6 Adjacent + a_7 Nafta + a_8 Mercosur + a_9 EU + a_{10} APEC + a_{11} PAL + a_{12} \ln road +$$

$$a_{13} \ln roadQuality + a_{14} \ln rail + a_{15} \ln quay + a_{16} \ln deph + a_{17} \ln air + a_{18} \ln WRoad +$$

$$a_{19} \ln WRoadQuality + a_{20} \ln WRail + a_{21} \ln WQuay + a_{22} \ln WDepth + a_{23} \ln WAir +$$

$$\ln \varepsilon_{ij}$$

Where WRoad, WRoadQuality, WRail, WQuay, WDepth, and WAir are defined as the spatial lag[8] of the transport infrastructure variables (Road, RoadQuality, Rail, Quay, Depth, and Air).

The standardized model in equation (18) will then look as follows:

$$\ln X_{ij} = \ln a_0 + a_1 \ln Y_i + a_2 \ln Y_j + a_3 \ln N_i + a_4 \ln N_j + a_5 \ln Dist_{ij} + \quad (20)$$

$$a_6 Adjacent + a_7 Nafta + a_8 Mercosur + a_9 EU + a_{10} APEC + a_{11} PAL + a_{12} \ln road/ext +$$

$$a_{13} \ln roadQuality/ext + a_{14} \ln rail/ext + a_{15} \ln quay/ext + a_{16} \ln deph + a_{17} \ln air/ext +$$

$$a_{18} \ln Wroad/ext + a_{19} \ln WroadQuality/ext + a_{20} \ln Wrail/ext + a_{21} \ln Wquay/ext +$$

$$a_{22} \ln Wdeph + a_{23} \ln Wair/ext + \ln \varepsilon_{ij}$$

where WRoad/Ext, WRoadQuality/Ext, WRail/Ext, WQuay/Ext, WDepth, and WAir/Ext are defined as the spatial lag of the transport infrastructure variables (Road/Ext, Road-Quality/Ext, Rail/Ext, Quay/Ext, Depth, and Air/Ext). We then estimated the two models in equations (19) and (20) for the SLX estimation techniques.

Modelling using panel data often is better than estimating cross-section models, as it helps to account for different econometric problems: first, using panel data aids in avoiding possible omitted variables biases (JOHNSTON; DiNARDO, 2001). Moreover, cross section models tend to underestimate the trade volume between pairs of countries with high volume of trade, and to overestimate it for pairs of countries with low volume

[8]We constructed these variables by multipling each transportation variable by the W Matrix, the spatial correlation matrix. This is a 27 by 27 matrix, with a line and a column for each one of the 27 Brazilian states. It was constructed with zeroes and ones based on the contiguity criteria, that is, a state is considered contiguous to another if they shared borders. If two states were contiguous, the matrix carries a one, and zero otherwise.

of trade. This "heterogeneity bias" can be overcome by removing the gravity model's assumption of a sole intercept for all trade flows between pair of countries (CHENG; WALL, 2005). Both problems could be solved using a fixed effects (FE) model[9] , as the ones used in Sá Porto and Canuto (2004) and in Sá Porto and Azzoni (2007).

Another point is that, often in gravity models there are zero trade flows between some country pairs, which could introduce problems, because the log-linearized model is not defined for observations with zero trade. In order to remove the influence of trade pairs with zero trade flows, we use an approach similar to the one used by Castilho (2001): for all models we solved this problem by substituting each zero flow by a very small value, 0,001. Finally, we performed tests to detect the presence of heteroscedasticity and autocorrelation in the data, the Breusch-Pagan test and the Wooldridge test, respectively. They showed the presence of heteroscedasticity and autocorrelation in the data, which were corrected by using panel data in the fixed effects and random effects models with heteroscedasticity and autocorrelation correction in Stata[10].

4 Results

The results of the estimations of the nonstandardized model (displayed in equations 17 and 19) and the standardized model (displayed in equations 18 and 20) are shown respectively in Tables 1 and 2. We will first analyze the results for the coefficients of the Pooled Cross Section (PCS), the Fixed Effects (FE) and the Random Effects (RE) estimations. The coefficients for the GDP of the states and the importing countries have the expected signs (positive) and were significant for all of the three estimation methods (PCS, FE and RE) in both models (standardized and non-standardized), and displayed coefficients comparable to previous studies. For example, the GDP coefficient of the states is equal to 0.94 (Table 1) in the case of the RE estimation in the non-standard model. This means that, for a 1% increase in the GDP of the states, trade between the states and the countries of the sample grows by 0.94%. For the population variables in both models and for all estimation techniques the coefficient were either not significant or did not had the unexpected sign (FE estimation). Thus, population is not important to explain Brazilian states' trade. As for the coefficient of the distance variable, it was significant and very close to minus one (except for the FE model, in which case it is not defined). For the tariffs variable, they were significant and had the expected sign in all models. Thus, our findings here confirm the typical results in gravity equations, namely, that distance and tariffs are associated to lower trade; moreover, we note that states/countries with larger

[9]Note also that, in the Fixed Effect (FE) model, variables that are invariant with time, such as distance and adjacency variables, are eliminated (CHENG; WALL, 2005).

[10]We applied the xtscc command in Stata in the FE and RE models.

GDPs trade more with each other[11].

The coefficients of the adjacency variable were significant and positive in all models (except in the FE model, in which it is not defined), indicating that even when we control for distance, Brazilian states tend to trade more with neighbouring countries. For example, the coefficients were equal to 0.94 (Table 1) and 0.91 (Table 2), in the RE estimation in the non-standard and standard models, respectively. This last coefficient of the adjacency variable shows that states which have a border with Brazil the partner country tends to export 148% more than with other countries in the sample[12].

As for the dummy variables for trade agreements, they were significant and had the expected signs for the five blocs only in the RE estimation. For example, the coefficients of dummies of the five trade agreements on the RE estimation of the nonstandard model in Table 1 were equal to 0.17, 0.21, 0,69, 1,01 and 0.38, respectively, indicating that, between 2012 and 2015, exports of Brazilian states for these three countries blocs were, respectively, 18%, 23%, 99%, 174% and 46% higher than exports to other countries in the sample[13].

Regarding the transportation variables included in the model to capture the effects of the national transport infrastructure on the international trade of Brazilian states, in the case of the coefficients for the road length variables, whether or not normalized by the total area of the exporting state, they were all significant and had the expected sign. In the non-standard and standard models for the RE estimation the coefficients were equal to 0.89 and 0.95, respectively. In the latter case, for example, an increase of 1% in the total length of state roads implies in an increase of 0.95% in trade for Brazilian states. By contrast, the total extention of roads variables that classified as good or excellent state were not significant, meaning that an increase in the quality of roads is not as important for states trade as the increase in its total length.

As for the rail variable, the coefficients were significant and had the expected signs in all models, although their effects were not as strong as the road effects. The coefficients in the non-standard model (Rail – Table 1) and standard model (Rail/Ext – Table 2) for the RE estimation were equal to 0.44 and 0.55, respectively. This last number means that a 1% increase in the total length of rails will imply in a 0.55% increase in Brazilian states

[11]These results are similar to those obtained in other studies (e.g., Sá Porto, 2002; Sá Porto and Canuto, 2004, Sá Porto and Azzoni, 2007 and Reis et al., 2014, among others).

[12]As for the interpretation of the coefficients of dummy variables, in models of the type $lnY_i = \beta_1 + \beta_2 D_i + u_i$, the relative variation of Y (that is, its semi-elasticity) with respect to the binary regressor which takes values of 1 or 0 can be obtained by calculating (antilog of the estimated β_2) menos 1 vezes 100, that is, by ($\exp(\beta_2)$– 1) x 100 (JOHNSTON; DiNARDO, 2001). Thus, in this case the semi-elasticity of the state exports in relation to the adjacency dummy can be calculated as follows: (exp0,91 -1) x 100 = 148.

[13]In this example, the semi-elasticities of state exports with respect to the dummies Nafta, Mercosur, European Union, APEC and PAL of the nonstandard RE model (Table 1, third column), respectively, can be calculated as follows: (e0,17 -1) x 100 = 18; (e0,21 -1) x 100 = 23; (e0,69 -1) x 100 = 99; (e1,01 -1) x 100 = 174; and (e0,38 -1) x 100 = 46.

Table 1 – Gravity Equation Coefficients Estimates for the Trade Flows between Brazilian States and Partner Countries, PCS, FE, RE and SLX estimation methods, 2012 – 2015, non standardized model

Variable	PCS	FE	RE	SLX
Constant a0ij	-24,55*** (1,50)	406,34*** (51,98)	-26.87*** (-7.66)	-19,93*** (-2.17)
Yi	0.97*** (0.05)	0.75*** (0.03)	0.94 *** (0.7)	0.93 *** (0.06)
Yj	1.01*** (0.06)	1.13*** (0.01)	1.03 *** (0.04)	0.97 *** (0.06)
Ni	-0.05 (0.05)	-25.10 (3.48)	0.07 (0.05)	0.02 (0.05)
Nj	-0.06 (0.05)	-0.20*** (0.01)	0.038 (0.09)	-0.02 (0.05)
Distij	-0.82*** (0.08)	-	-0.77 *** (-0.09)	-0.81*** (-0.09)
Tariffij	-0.22*** (0.05)	-0.03 (0.70)	-0.18*** (0.04)	-0.12*** (0.03)
Adjacency	0.70*** (0.31)	-	0.94*** (0.12)	0.68** (0.31)
NAFTA	0.20* (0.08)	0.18* (0.13)	0.17* (0.10)	0.13* (0.10)
Mercosur	0.25* (0.15)	0.50* (0.42)	0.21* (0.13)	0.23* (0.15)
EU	0.58* (0.43)	0.66* (0.48)	0.69* (0.42)	0.58* (0.48)
APEC	1.06*** (0.09)	0.88*** (0.11)	1.01*** (0.14)	0.78*** (0.12)
PAL	0.43** (0.12)	0.48** (0.22)	0.38** (0.16)	0.27* (0.19)
Road	0.53*** (0.13)	-0,52** (-0.98)	0.89 *** (0.09)	0.21 *** (0.04)
RoadQuali	-0.22*** (0.07)	-0,14 * (-0.83)	-0.17 ** (0.19)	-0.20 ** (0.14)
Rail	0.56*** (0.06)	0.09 (3.14)	0.44 *** (0.06)	0.55 *** (0.18)
Quay	-0.19** (0.07)	1.59 *** (1.90)	-0.02 * (-0.14)	0.60 ** (0.26)
Depth	0.65*** (0.11)	0.54 * (0.38)	1.38 *** (0.52)	0.62 (0.49)
Air	-0.96*** (0.14)	-1.00 (-1.96)	-2.00** (0.26)	-0.19 (0.28)
WRoad	-	-	-	0.39 (0.60)
WRoadQuali	-	-	-	-0.35 (0.41)
WRail	-	-	-	0.40 *** (0.13)
WQuay	-	-	-	-0.54 (0.34)
WDepth	-	-	-	1.01 ** (0.49)
WAir	-	-	-	-0.73 (0.45)
R^2	0.57	0.41	0.59	0.58
Number of observations	12,96	12,96	12,96	12,96

Note: The significance levels at 10%, 5% and 1% levels are denoted by *, ** and ***, respectively, one-tail test. Xij (trade) is the dependent variable. Standard errors are given in parentheses. All variables except dummies are expressed in natural logarithms for all models. Estimation by OLS using Stata.

trade. In the case of waterways transportation, the average depth variable of all ports of a state was significant and had the expected sign in all models, meaning that this variable was important to explain Brazilian states trade. For example, in the standardized model for the RE estimation (Table 2), the coefficient of 0,89 means that an increase of 1% in the average depth of ports will imply a 0,89% impact in Brazilian states trade, a remarkable effect.

As for the other waterway variable, the average length of quay was significant on the fixed effects estimation (FE); in the other cases, it was significant only in one case (RE estimation of the standardized model), implying that this variable may not be important to explain states trade. Finally, the air mode of transportation was not significant to explain the trade of Brazil's states, as its coefficients did not have the expected signs in neither case. Thus, we conclude that these results suggest that in general Brazilian states trade is impacted in a significant manner by the states' transportation infrastructure, especially road transportation, but also rail and water transportation. That is, improvements in these transport modals will improve remarkably states' trade performance.

Finally, as to the results of the spatial model (SLX technique), the results of the estimations of the nonstandardized and standardized models (displayed in equations 19 and 20) are shown respectively in the last column of Tables 1 and 2. We will bypass the discussion on the coefficients for GDP, population, distance, tariffs, adjacency and preferential trade arrangements, as their results are quite similar to the ones already analyzed. Even the results of the coefficients for the transportation variables were similar here.

The assessment of the spatial lag variables of each transportation variable yielded interesting results. First, we notice in both models that the spatial lagged variables for road, road quality, quay and air were not significant, and had the wrong sign (in the case of road quality and air). Thus, in spite of the fact that Brazil had a large road infrastructure (which is important to explain states trade), one state's infrastructure does not impact significantly its neighbours. Moreover, the spatial lagged for rail and depth were significant and had the right sign in both non-normalized and normalized models. For example, in the non-normalized model (Table 1), these two coefficients were equal to 0.40 and 1.01, respectively. This means that, *ceteris paribus*, an increase of 1% in rail infrastructure and depth of ports in neighbouring states will improve states exports by 0.40% and 1.01%, respectively.

This result helps explaining an important part of Brazil's state exports. For example, a significant proportion of the country's soy production is carried out in landlocked states such as Mato Grosso, Mato Grosso do Sul and Goiás, which is then exported and transported by truck and rail to the port of Santos in the neighbour state of São Paulo. In the same manner, a large part of iron ore production is produced in states of Pará and Minas Gerais, which is exported using the rail and port infrastructure of the neighbour states of Maranhão and Espírito Santo, respectively. Thus, in the case of rail and port infrastructure investments, it seems that investments in infrastructure may benefit one state's exports but also its neighbours' exports.

5 Conclusions

Transportation infrastructure is a key variable in explain trade of the Brazilian states. In this article, we analyzed the impacts of the different transport modals on the international trade flows of Brazilian states. For that we used a gravity model, estimated using four different estimation techniques: Pooled Cross Section; Fixed Effects; Random Effects; and Spatial Lag Effects. Moreover, we included variables for all of the main modes of transportation that are mostly used within the country: road; rail; water; and air modals. We used a panel that included trade data from 2012, 2013, 2014 and 2015 for all of Brazil's 27 states to the country's 60 main trade partners.

We found that road length, rail length and depth of ports were important variables to explain the trade for Brazilian states in general. Thus, improvements in states' transportation infrastructure, especially road, rail and port transportation, will enhance states' trade performance.

Moreover, we found that rail and ports infrastructure in neighbouring states are important to explain state exports. By using a SLX spatial econometrics model, we confirmed the hyphothesis that Brazilian states exports exhibit spatial correlation effects. This explains the fact that a large proportion of soy exports from central western states (as Mato Grosso and Goiás) use the rail infrastructure and the port of Santos from the neighbour state of São Paulo. It is also the case of iron ore exports, which are produced in the states of Pará and Minas Gerais and then are exported using the rail and port infrastructure of the neighbour states of Maranhão and Espírito Santo, respectively.

Thus, road, rail and water transportation modals are very important to explain the trade for Brazilian states in general, not only from its direct effects but also from regional spillover effects (in the case of rail and port infrastruture). Investments, public and private, in these modals of transportation are welcomed if Brazil's regional trade is to be improved.

This study can be extended in several ways. First, a model could be built in order to explain the effects of transportation infrastructure on Brazilian interregional trade patterns. Moreover, a longer term data panel and other spatial econometrics models could be used in order to confirm the direct and the regional spillover effects from infrastructure investments.

Abstract

This paper analyzes the impacts of the different transportation modals on the international trade flows of Brazilian states. For that we used a gravity equation, estimating three different models: Pooled Cross Section; Fixed Effects; and Random Effects. Moreover, we included variables for all of the main modes of transportation that are mostly used within the country, namely, road, rail, water and air modals. Finally, since there is evidence that there is spatial correlation in the data, we included a spatial econometrics model, a spatial lag of X model (SLX). We used a panel that included trade data from 2012 to 2015 for all of Brazil's 27 states to the country's 60 main trade partners. Our results show that Brazilian states trade is impacted significantly by the states' transportation infrastructure, especially road transportation, but also rail and port transportation. Moreover, we found that rail and ports infrastructure in neighbouring states are important to explain state exports. This explains, for example, the fact that a substantial proportion of soy exports of the states of Mato Grosso, Mato Grosso do Sul and Goiás is exported through the use of the rail and port infrastructure of the neighbour state of São Paulo.

Keywords: Transportation infrastruture; regional trade; spatial econometrics; gravity model.

JEL: F14, R15

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