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## Port infrastructures and trade: Empirical evidence from Brazil<sup>☆</sup>

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### A B S T R A C T

In this study, we analyse the impact of port infrastructure on trade by estimating a gravity equation for exports (imports) of Brazilian states towards (from) all main Brazil's trading partners. In particular, we consider exports (imports) of the 27 Brazilian states towards (from) 30 of Brazil's most important trading partners over the period 2009–2012. By estimating a set of gravity equations with the Poisson pseudo-maximum likelihood estimator, we find that an increase in port infrastructure (as proxied by the piers extension in each Brazilian state normalized by that state's area) is associated to large increases in Brazilian exports, while the impact on imports is more mixed and generally lower. Our results are robust to controlling for a series of state and country fixed effects.

### 1. Introduction

The relation among transport endowment, efficient transport/logistics services and trade is well documented by a number of policy (e.g. [Arvis et al., 2012](#)) and scientific (e.g. [Limao and Venables, 2001](#)) papers. Several scholars (e.g. [Vickerman, 1995](#); [Camagni and Capello, 2013](#)) and international institutions (e.g. World Bank [e.g. [Arvis et al., 2012](#)], European Union [e.g. [Purwanto, 2010](#)], OECD [e.g. [Merk, 2012](#)]) have discussed the potential benefits of an improved infrastructure network and its capability of fostering both regional competitiveness and economic development. Within this framework, it is relevant to highlight the link among the transport infrastructure endowment, the level of regional connectivity, and the international freight flows (e.g. [Li and Qi, 2016](#)). Transport network investments aimed at improving connectivity with international markets is an important issue within the debate on expansive policy interventions, especially for those countries whose economic growth is heavily linked to international trade, such as the Latin America and the Caribbean (e.g. [Wilmsmeier and Hoffmann, 2008](#); [Calatayud et al., 2017](#)).

Different transport systems – and related infrastructure – affect regional competitiveness and trade openness in a number of ways, as shown by the results of those studies analyzing the role of air transport connectivity (e.g. [Graham, 1998](#)), land modal solutions (e.g. [Handy, 2005](#); [Coşar and Demir, 2016](#)) and maritime transports (e.g. [Wilmsmeier et al., 2006](#)). Moreover, logistics plays an essential role in linking together different transport networks and favoring international production chains (e.g. [Bensassi et al., 2015](#); [World Bank, 2012](#); [Hesse and Rodrigue, 2006](#)).

Within this framework, it is important to stress that over 80% of international trade involves maritime services ([Unctad, 2016](#)), giving to port infrastructure a crucial role to improve international connectivity and propensity to international trade for a given

<sup>☆</sup> The views expressed here are those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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region (e.g. Guerrero et al., 2016; Ducruet and Notteboom, 2012; Ducruet and Itoh, 2016). Moreover, as also underlined by Rodrigue et al. (2016), transport systems are normally represented by networks in which nodal infrastructure (such as ports) plays a key role, by promoting accessibility and fostering local competitiveness for the hosting regions.

Indeed the relationship between transport infrastructure and international trade has been increasingly investigated by the economic literature. The importance of transport endowment for international openness is well documented for all the main transport modes (e.g. Moreno and Lopez-Bazo, 2007; Arbués et al., 2015), with maritime networks playing a major role in fostering international trade (e.g. Martínez-Zarzoso et al. 2003). In particular, a positive influence of sea access on regional export performance, has been highlighted by some studies (e.g. Cizkowicz et al., 2013; Matthee and Naudé, 2008); moreover, spillover effects stemming from maritime regions to landlocked ones are found to favor the exporting activity (e.g. Marquez-Ramos, 2016).

Most studies focus on the effects of port infrastructure, or port related transport systems, on the regional economy (e.g. Hall, 2009; Ng and Gujar, 2009; Bottasso et al., 2013, 2014; Song and van Geenhuizen, 2014; Wang et al., 2017), but only few of them (e.g. Portugal Perez and Wilson, 2012; Celbis et al., 2014; Olarreaga, 2016) try to assess the link between international trade and maritime infrastructure endowment. Hence, it seems that this issue is still under-investigated, despite evidence in favor of this relation is supported at both theoretical and empirical level.

A related issue that has been receiving increasing attention in recent years is the link between transport costs and trade: for instance, Clark et al. (2004) show that port efficiency is an important determinant of shipping costs and that port efficiency differentials can be explained by excessive regulation, the prevalence of organized crime and the country's overall infrastructure endowment. In turn, Haddad et al. (2010) apply a spatial, interregional CGE model to simulate the impacts of increases in port efficiency in Brazil. They evaluate three different scenarios and conclude that in all cases improvements in port efficiency lead to a faster growth, more competitiveness and more openness of the Brazilian economy. Similarly, Tiller and Thill (2017) apply a Trade Impedance Quotient to better evaluate if transport costs are acting as trade barriers in South America, potentially limiting benefits of trade on the related regions. Interestingly, Cassey (2011) focuses on USA exports data observed in 2003 and shows the importance of analyzing the link between the geographical characteristics, as affected by the transport system, and international trade; the author suggests that such analysis provides further insights with respect to the study of transport costs.

The current paper contribute to this literature since we analyse the impact of port infrastructure on trade by estimating a gravity equation with Poisson quasi-maximum likelihood techniques for exports (imports) of Brazilian states towards (from) all main Brazil's trading partners. In particular, we consider exports (imports) of the 27 Brazilian states towards (from) 30 of Brazil's most important trading partners over the period 2009–2012 and we quantify the impact of port infrastructure endowment on the international trade and its distribution over different Brazilian regions.

In terms of econometric identification strategy, we follow the most recent econometric practice to deal with endogeneity and simultaneity concerns in the estimation of gravity equations by including a full set of trading partners fixed effects, which control for any unobserved time-invariant heterogeneity at the level of any possible combination between a Brazilian state and a foreign country. Moreover, in the most extended model specifications we also control for a full set of foreign countries-by-year and Brazilian regions-by-year fixed effects, which in turn control for unobserved time-varying shocks at the level of each foreign country and each Brazilian region (which are the aggregate of various Brazilian states), respectively. In other words, the inclusion of trading partners as well as Brazilian regions-by-year fixed effects, allows us to identify the effects of Brazilian port infrastructure on Brazilian trade by exploiting only port infrastructure variation over time across Brazilian states within a Brazilian region, thereby controlling for the various unobserved determinants of trade and port infrastructure developments in the most possible granular way, given our data. This is a significant improvement in terms of econometric strategy with respect to the previous studies that have attempted to estimate the effect of port infrastructures on trade.

The choice of Brazil is mainly related to its peculiar economic structure and its presence on foreign markets: as underlined by Boehe et al. (2016), Brazilian exports strongly affect local company performance and regional growth. Moreover, the role played by Brazil in the WTO seems to reveal the government's desire to foster Brazilian international visibility (Hopewell, 2015). Despite this, transport policies (e.g. Nuñez and Önal, 2016) and related investment (e.g. Garcia-Escribano et al., 2015) are not always consistent with the objectives of the government and several bottlenecks have been registered in the transport network, with many critical issues related to port activities and freight distribution (e.g. Barros et al., 2015; Galvão et al., 2017). Given the abovementioned scenario, investigating the link between trade and transport infrastructure (mainly ports) in Brazil assumes particular policy relevance.

The paper is organized as follows: Section 2 will focus on the Brazilian framework and on the data used in our analysis. Section 3 is dedicated to the methodology and the description of the econometric strategy. Section 4 discusses empirical results while Section 5 addresses conclusive remarks and focus on policy implications of our analysis.

## 2. Data and institutional setting

During the last decade Brazil has been one of the fastest growing markets and the biggest South American economy: real economic growth averaged more than 3.7% above the continental value and only in the last couple of years registered a reduction (IMF – International Monetary Fund, 2017). Similarly, GDP in purchase power parity pro-capita has registered an almost constant growth in the last 15 years – with only few years of negative records – and an average value of more than 3%. Most of Brazilian economy is now connected to international trade, being one of the leading export countries for many raw materials as well as finished products. Brazil is one of the two main world suppliers of iron ore and coal and also one of the top leading countries in export of other primary sector outcomes, being the third exporter of agricultural products as well as the first chemical industry producer of the southern hemisphere (OECD, 2016). According to IMF statistics (2017), the value of exported goods has increased 8 times in the last thirty years, with

**Table 1**  
Brazilian main commodity Exports and Imports by HS Group, in 2016.  
Source: Own elaboration from Comtrade database, 2017

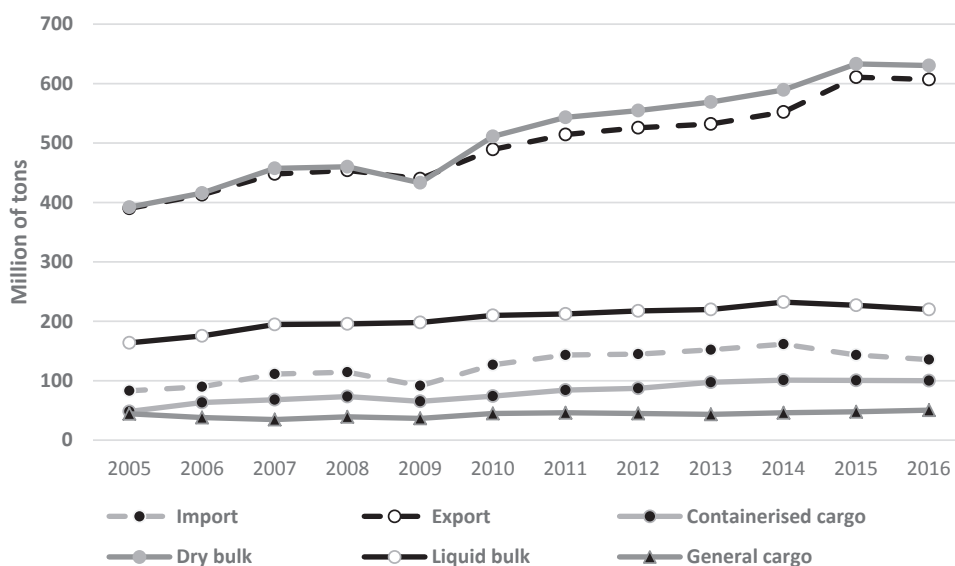
HS code	HS Chapter Description	Value US\$
<i>Export</i>		
12	Oil seeds and oleaginous fruits; miscellaneous grains, seeds, etc.	19,557,937,674
26	Ores, slag and ash.	15,816,098,724
02	Meat and edible meat offal.	12,655,793,496
84	Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof.	11,647,180,661
27	Cocoa and cocoa preparations.	11,581,277,848
87	Vehicles other than railway or tramway rolling-stock, and parts and accessories thereof.	10,971,032,674
17	Sugars and sugar confectionery.	10,585,664,649
72	Iron and steel.	7,892,012,402
47	Pulp of wood or of other fibrous cellulosic material; recovered (waste and scrap) paper or paperboard.	5,575,278,935
23	Residues and waste from the food industries; prepared animal fodder.	5,538,918,337
<i>Import</i>		
84	Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof.	21,124,300,180
85	Electrical machinery and equipment and parts thereof, etc.	16,942,608,828
27	Cocoa and cocoa preparations.	15,142,175,558
87	Vehicles other than railway or tramway rolling-stock, and parts and accessories thereof.	9,955,443,182
29	Organic chemicals.	8,327,954,364
30	Pharmaceutical products.	6,389,498,894
31	Fertilisers.	6,002,709,569
39	Plastics and articles thereof.	5,916,006,970
90	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus, etc.	4,757,979,125
38	Miscellaneous chemical products.	3,810,338,458

import values that have grown even more.

The incredible growth of Brazil has put under severe stress the transport system, with a registered increase of inefficiencies (e.g. Barros et al., 2015) and critical conditions of main transport infrastructure. Since seaports are the main gateway to foreign markets, maritime related infrastructure are of particular importance in order to support and favor the growth process.

According to the AAPA database (American Association of Port Authorities, 2017), in 2016, 63% of Brazilian international maritime transport – in tons – was generated by dry bulk cargo, mainly iron ore and soybeans exports to China. However, containerized cargo accounted for only 10% of the total handled tons, thus showing the relative small size of the Brazilian container port industry. Table 1 shows the main traded cargo by sea: freight bulk accounts also for most of the traded value for both import and export. The first ten traded cargoes (shown in Table 1) represented 60% of the 2016 value of the Brazilian export and 71% of the import.

Fig. 1 shows main ports related trends in relation to Brazilian seaport activity over the period 2005–2016 for both the seaborne trade and the main handled cargo categories. It can be observed that dry bulk has experienced a stable growth until 2015 (with the



**Fig. 1.** Brazilian ports trends.  
Source: own elaboration from ANTAQ data, 2017

exception of the 2008–2009 reduction due to the international financial crisis) and a similar pattern is observed for containerized cargo, which still represents a low share of the overall activity.

Such picture is likely to be related to the import/export unbalance situation of the country. Indeed dry bulk activities are related to export flows, while container traffic is mainly related to import flows linked to the demand for finished products.

Despite the fast growth rate of the Brazilian international trade, the deficiencies of the country in terms of infrastructural endowment and its management are described in several research papers that evaluate the high costs of the Brazilian logistics (e.g. Wanke and Zinn, 2004; Fleury and Hijjar, 2008) and maritime systems (e.g. Wanke et al., 2011; Wanke, 2013).

The Logistics Performance Index [LPI] (World Bank, 2017a) has constantly grown until 2010, while in the last six years it registered a reduction in its overall value (from 2.75 in 2007 to 3.20 in 2010 to 3.09 in 2016). This decrease is mainly due to the index component related to logistics, while the infrastructure endowment component has been stable during the past 7 years. Nevertheless, Brazil registered one of the highest LPI value in South America, despite other developing countries of the region (e.g. Chile) are currently registering both higher values and faster growth trends. However, Brazil scores poorly in the Doing Business Indicators (World Bank, 2017b) ranking 123 out of 190 considered countries, with particular issues in terms of administrative procedures related to international trade (in which rank 149th worldwide). Such poor performance might have negatively impacted the performance of the Brazilian transport system.

In order to enhance the level of competitiveness and efficiency of Brazilian ports, governmental bodies have implemented several policy interventions (e.g. Galvão et al., 2017). However such actions have had limited success, mainly because of the lack of continuity in the implementation of plans aimed at improving the country's logistics system and the insufficient coordination among transport policies, as for the case of the Short Sea Shipping solution (e.g. Sá Porto et al., 2014). Indeed Ng et al. (2013) underline that a lack of coordination among different Brazilian transport authorities and logistics stakeholders, together with the presence of institutional barriers, limits the development of an efficient transport system. In accordance with the authors' findings, current practices generate deficiencies that hinder the integration among different transport and logistics systems in Brazil. These barriers negatively affect most of the international trade operations, generating bias due to the "face-to-face" operations (e.g. custom clearance) that also affect the reliability of the overall transport system.

Thus, despite the importance of international trade for the Brazilian economy, the infrastructure that serve foreign freight flow – as well as their management – still suffer from several critical issues. Interestingly, in spite of the overall length of the Brazilian coast line (i.e. over 7000 km), cargo movement in seaports is quite concentrated, with the port of Santos alone handling around 30% of the overall Brazilian total cargo volume, and only other two ports overpass the 10% quota (ANTAQ, 2017). From a geographical point of view, the majority of main ports are located in the South and only a few harbors serve the northern part of the country (mainly in relation of iron ore export flows). Such distribution increases the pressure to the land transportation system and generates potential bottlenecks in order to serve regions far from the shoreline (as demonstrated, for instance, by the severe congestion registered on the road between Santos – the main national port – and Sao Paulo – the most populated and industrialized area of the country). According to the Central Intelligence Agency (CIA) Factbook (2017), Brazil currently registers over 28,000 km of rail network but only a small percentage is actually electrified (around 3%) and 4 different gauges are present, limiting long distance trips and efficient intermodal transport. Similarly, road transport quality is relatively low, with about 80% of the road network being unpaved, with only one-fifth of the road network being paved and only few main road corridors (CNT, 2016).

The abovementioned country's characteristics underline both the importance of trade in the Brazilian economy and the different role of main transport infrastructure in fostering freight flows distribution, with ports having a strategic role for Brazilian companies.

### 2.1. The database

Brazil is a federation composed by 27 states, the majority of them directly facing the sea (Fig. 2), even though the concentration of main ports in the South does not assure an equal access to maritime services to the different maritime regions.

In order to perform the analysis, for each Brazilian state – equivalent to TL2 OECD geographical aggregation – trade data relative to the main trading partners (30 countries, covering 80% of the Brazilian import and export flows) have been collected for the period 2009–2012. Main economic, social and infrastructure related variables have been taken into consideration, as resumed in Table 2.

The geographical distribution of foreign trade, GDP, population and trade across states is represented in Fig. 3 that shows how such distributions are concentrated in few areas of the country. The main 5 states (i.e. Sao Paulo, Rio de Janeiro, Minas Gerais, Parana, and Rio Grande do Sul) account for more than 65% of the distribution of all main economic indicators, and for about 40% of the population. Considering foreign partners, it is important to underline that all main partners (with the partial exception of Argentina) are far from the South American continent, so that the presence of an adequate maritime infrastructure system becomes crucial.

Table 3 shows the distribution per State of main port related characteristics, highlighting a relative difference in the port endowment, with main port facilities located in three regions (e.g. Sao Paulo, Rio de Janeiro, and Rio Grande do Sul). Despite this, all Brazilian maritime regions register the presence of developed port facilities as well as relevant physical characteristics in terms of draft. Table 4 resumes descriptive statistics of the variables used in the empirical analysis for Brazilian states only and suggest the existence of huge differences among them, in all the considered indicators. The high variance of the variables is a proof of the unbalanced situation within the country as far as economic, social and endowment indicators is concerned. It is also interesting to underline that infrastructure endowments exhibits a variation (even if small) over time, probably associated to the high infrastructure investment in some key regions planned by the government in order to meet the growing demand (e.g. Barros et al., 2015).

Table 5 in turn shows the spatial concentration of the main economic and infrastructure related variables over the Brazilian

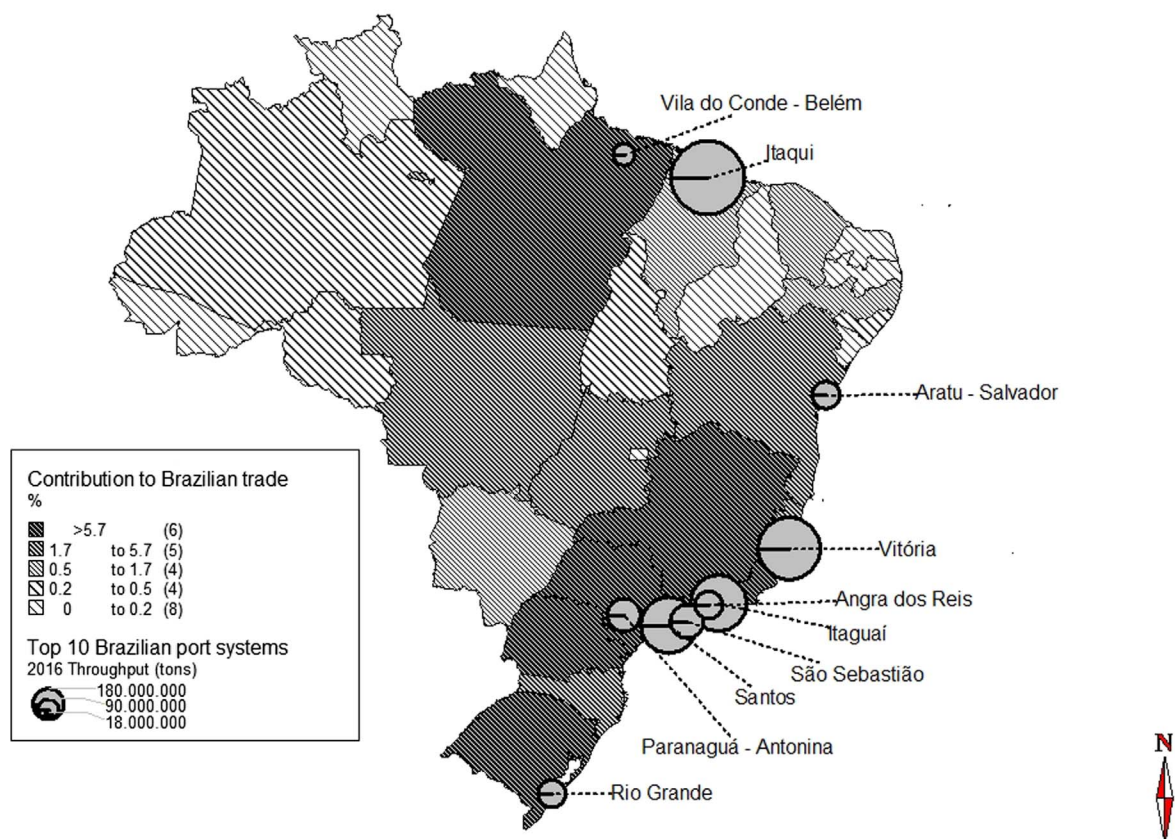


Fig. 2. Contribution of Federal States to Brazilian trade.

Source: own elaboration from ANTAQ data, 2017

Table 2

Collected variables.

Sources: MDIT – Ministry of Development, Industry and Trade; Brazilian Statistical Office; WB – World Bank; World Atlas PC; WTO – World Trade Organization; CNT Road Research; ANTAQ – Port regulator in Brazil; ANAC – airport regulator in Brazil; ANTF – Rail regulator in Brazil, various years

Variable	Description	Source	Unit
Trade	Trade (exports or imports) between the 27 Brazilian state and a partner country (30 countries).	MDIT	US\$
GDP-1	Gross Domestic Product (GDP) of a Brazilian state (or a partner country)	Brazilian Statistical Office	US\$
GDP-2	Gross Domestic Product (GDP) of a partner country (or a Brazilian state)	Brazilian Statistical Office	US\$
Pop-1	Population of a Brazilian state (or a partner country)	Brazilian Statistical Office	mln
Pop-2	Population of a partner country (or a Brazilian state)	WB	mln
Distance	Distance between the capital of a Brazilian state and the capital of a partner country	World Atlas PC	km
Adjacency	Whether the Brazilian state and the partner country share a common border	World Atlas PC	Dummy
Mercosur	Whether the partner country belongs to the Mercosur preferential trade agreement	WTO	Dummy
Nafta	Whether the partner country belongs to the North America Free Trade Area trade agreement	WTO	Dummy
EU	Whether the partner country belongs to the European Union trade agreement	WTO	Dummy
Road	Total road extension in a Brazilian state	CNT Road Research	km
Road Quality	Total road extension in a Brazilian state that are classified as good or excellent by CNT	CNT Road Research	km
Road Ext	Total road extension in a Brazilian state divided by the state's total area	CNT Road Research	km per sqm
Road Quality-Ext	Total road extension in a Brazilian state that are classified as good or excellent by CNT divided by the state's total area	CNT Road Research	km per sqm
Cais	The indicator shows the total quay or pier extension in ports of a Brazilian state	ANTAQ	m
Cais Ext	Total quay or pier extension in ports of a Brazilian state divided by the state's total area	ANTAQ	m per sqm
Calado	Average depth of all ports in a Brazilian state	ANTAQ	m
Aero	Total length of airports in a Brazilian state	ANAC	m
Aero Ext	Total extension of airports in a Brazilian state divided by the state's total area	ANAC	m per sqm
Ferro	Total rail extension in a Brazilian state	ANTF	km
Ferro Ext	Total rail extension in a Brazilian state divided by the state's total area	ANTF	km per sqm

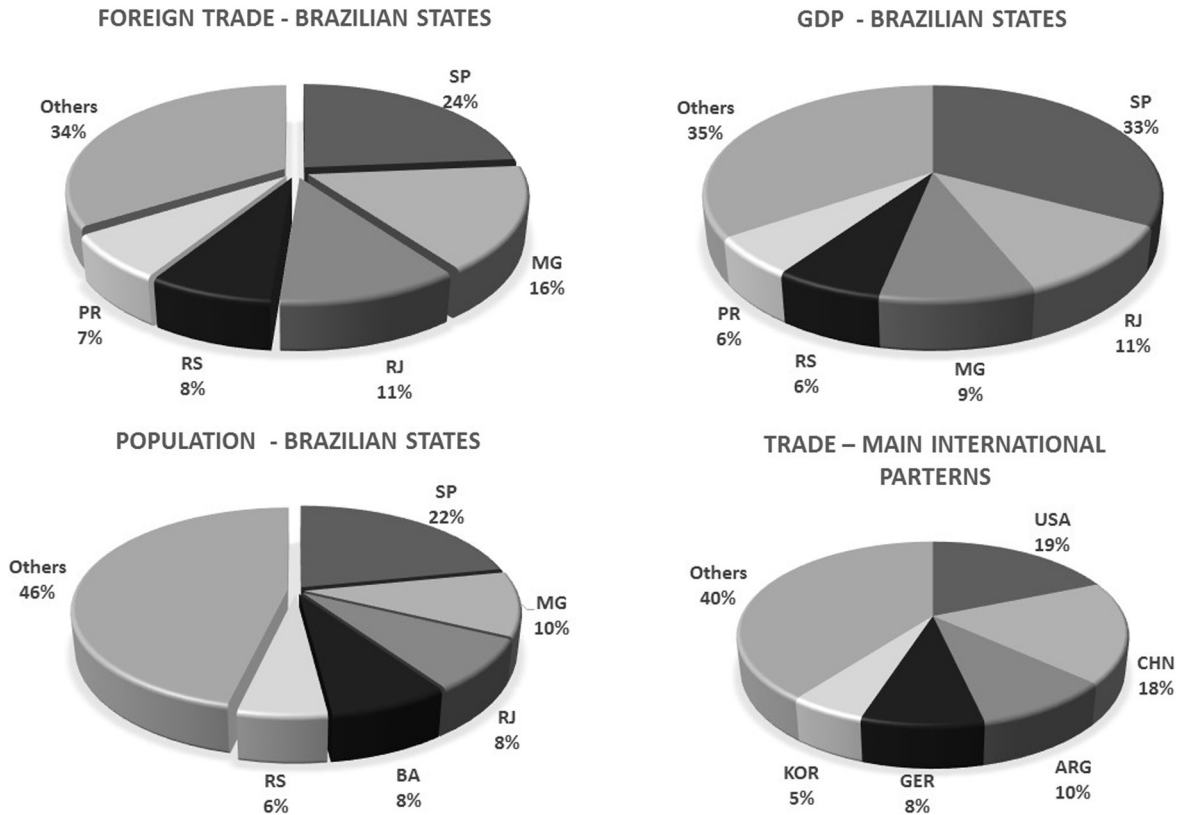


Fig. 3. Geographical distribution of the main economic and social variables..  
 Source: MDIT and Brazilian Statistical Office, 2017. SP – Sao Paulo; MG – Mina Gerais; RJ – Rio de Janeiro; BA – Bahia; RS – Rio Grande so Sul; PR – Parana

States. The concentration is measured using the Herfindhal-Hirschmann Indicator (HHI) over the different Brazilian States. On the one hand, nodal infrastructures (i.e. airport and ports) are spatially concentrated – if the State extension is taken into consideration – given their role in the local economies and their needs in terms of location and connected regions. On the other hand, network infrastructures (i.e. rail and road) are either not concentrated (roads, even considering their quality) or slightly concentrated (rail). Moreover, the main economic indicators (i.e. GDP and trade) are slightly concentrated (and this is mainly connected to the economic leading role of specific regions, such as Sao Paulo) while the population is fairly spread over the country.

**3. Econometric strategy**

The estimation of gravity equations has a long tradition in the empirical trade literature, at least since the pioneering work of Tinbergen (1962), but only recently they have been micro-founded, i.e. explicitly derived from microeconomic theory. In particular, various trade theories (Head and Mayer, 2015) have shown that bilateral trade flows  $T_{ij}$  (i.e. exports of country  $i$ , the origin country, to country  $j$ , the destination country) can be expressed, in a cross sectional context, as in Eq. (1)<sup>1</sup>:

$$T_{ij} = \frac{Y_i}{\Pi_i^{-\phi}} \frac{E_j}{P_j^{-\phi}} D_{ij}^{-\phi} \tag{1}$$

where  $Y_i$  represents total output of the origin country,  $E_j$  total expenditure in the destination country (both usually proxied by GDP),  $D_{ij}$  is a vector of variables that might affect trade costs between any pair of countries, such as distance, common languages, barriers to trade, infrastructure, customs unions, etc., while  $\phi$  represents the elasticity of trade flows with respect to trade costs. In turn,  $\Pi_i$  and  $P_j$  represents the inward and outward multilateral resistance indexes introduced by Anderson and van Wincoop (2003), that capture the general equilibrium effects in trade.<sup>2</sup> In particular, the authors show that these multilateral indexes, associated to a country market potential and degree of openness to trade, are functions of trade costs (see for a nice exposition Fally (2015)).

<sup>1</sup> Eq. (1) can be derived also from those new economic geography type of models featuring transportation costs and transportation infrastructures recently reviewed by Redding and Turner (2017). For instance, Duranton (2015) studies the effects of roads within and between cities on the level of trade for a sample of Colombian cities. He shows that a 10% increase in the stock of highways within a city is associated to a 3–5% increase in both the value and weight of exports.

<sup>2</sup> It can be shown (Baldwin and Tagliani, 2006) that  $P_j$  is the CES ideal price index in the destination country, while  $\Pi_i$  is a function of trade costs. See also Head and Mayer (2015).

**Table 3**

Brazilian port endowment.

Source: Own elaboration on ANTAQ data

Brazilian States	Quay (m)				Draft (m)			
	2009	2010	2011	2012	2009	2010	2011	2012
Acre	0	0	0	0	0	0	0	0
Alagoas	1057	1057	1057	1057	10.5	10.5	10.5	10.5
Amapá	0	0	0	0	0	0	0	0
Amazonas	621	621	621	621	10	10	10	10
Bahia	3410	3410	3410	3410	33	33	33	33
Ceará	1050	1054	1054	1054	10.3	10.3	10.3	10.3
Distrito Federal	0	0	0	0	0	0	0	0
Espírito Santo	1970	1970	1970	1970	10.67	10.67	10.67	10.67
Goiás	0	0	0	0	0	0	0	0
Maranhão	1616	1616	1616	1936	9.7	9.7	11.5	11.5
Mato Grosso	0	0	0	0	0	0	0	0
Mato Grosso do Sul	0	0	0	0	0	0	0	0
Minas Gerais	0	0	0	0	0	0	0	0
Pará	2994	3092	3092	3092	29.5	29.5	29.5	29.5
Paraíba	602	602	602	602	11	11	11	11
Paraná	3131	3131	3131	3315	21.1	21.1	21.1	21.1
Pernambuco	4545	5815	5815	5815	26	26	27	27
Piauí	0	0	0	0	0	0	0	0
Rio de Janeiro	9420	9420	10,030	10,070	61.4	61.4	61.4	61.4
Rio Grande do Norte	938	938	938	938	25	25	25	25
Rio Grande do Sul	12,032	12,562	12,562	12,562	25.68	25.68	26.5	26.5
Roraima	0	0	0	0	0	0	0	0
Roraima	0	0	0	0	0	0	0	0
Santa Catarina	2602	3132	3215	3215	34.1	34.1	36.6	36.6
São Paulo	11,947	11,947	12,505	12,505	26.3	26.3	27	27
Sergipe	0	0	0	0	0	0	0	0
Tocantins	0	0	0	0	0	0	0	0

Source: Own elaboration on ANTAQ data

This has important implications for the econometric estimation of gravity equations. Indeed, traditionally a restricted version of Eq. (1) was estimated, namely one omitting the multilateral resistance indexes. However, because they are a function of all determinants of trade costs, their omission generates a correlation between the error term and the included regressors in the vector  $D_{ij}$ . In fact, simply controlling for some of the determinants of market potential and trade costs, such as distance or  $GDP$ , is not likely to be enough in order to remove any correlation between the included variables and the error term, given the difficulty in observing some of these factors.

Most of the recent empirical literature has therefore tackled the omitted variable bias affecting the estimation of “first generation” or “naïve” versions of gravity equation by augmenting the latter with origin and destination country fixed effects, as in Eq. (2) below, where  $d_i$  and  $d_j$  are fixed effects for country  $i$  and  $j$ , respectively<sup>3</sup>:

$$T_{ij} = Y_i E_j D_{ij}^{-\phi} \exp(\varphi_i d_i + \varphi_j d_j) \quad (2)$$

Since multilateral resistance terms can be time varying, when panel data are available, regressions with exporter-importer fixed effects, exporter-by-year and importer-by-year fixed effects can be estimated, as suggested by Baldwin and Taglioni (2006):

$$T_{ijt} = Y_{it} E_{jt} D_{ijt}^{-\phi} \exp(\varphi_i d_{it} + \varphi_j d_{jt} + \varphi_{ij} d_{ij}) \quad (3)$$

where  $d_{it}$  and  $d_{jt}$  represent country of origin and destination fixed effects that are allowed to vary over time, while  $d_{ij}$  represent fixed effects for any combination of countries of origin and destination.

Traditionally, Eqs. (2) and (3) have been brought to the data by log-linearization and estimated with OLS. However, this approach creates possible important econometric problems as highlighted by Santos Silva and Teneyro (2006). First, in some trade datasets there is a non-negligible share of observations with zero trade: in this case researchers either dropped entirely these observations or transformed the data by adding 1\$ to the trade variable in order to be able to take logarithms, even if this procedure might generate non negligible bias in parameter estimates.<sup>4</sup> Moreover, the authors show that, in the presence of heteroscedasticity, the estimates of parameters of log-linearized models are biased. This can be seen by noting that the stochastic version of (3) is the following equation (where  $\eta_{ijt}$  is an error term):

<sup>3</sup> See Head and Mayer (2015) for other, more structural, estimation approaches.

<sup>4</sup> Indeed, zero trade data are not random as they are more likely in the case of small countries that are more distant from each other. See Santos Silva and Teneyro (2006) for a discussion.

**Table 4**  
Descriptive statistics.

		Average per Brazilian State					Max per Brazilian State				
		2009	2010	2011	2012	2009	2010	2011	2012	2011	2012
<i>Trade</i>		146,538,751	198,968,003	253,056,457	238,520,142	5,904,864,737	9,284,574,234	13,330,234,241	10,548,674,912		
<i>GDP</i>		60,113,407,407	79,200,147,090	91,729,435,677	83,288,181,941	542,833,000,000	709,183,702,311	806,710,713,693	732,474,458,169		
<i>Pop</i>		7,111,287	7,183,402	7,253,535	7,520,579	42,075,716	42,486,692	42,888,198	44,035,304		
<i>Distance</i>		5605	5605	5605	5605	12,046	12,046	12,046	12,046		
<i>Road</i>		7386.407	7336.111	6189.556	8016.704	33,000,000	32,993,000	24,487,000	33,952,000		
<i>Road Quali</i>		2511.554	2847.787	2345.518	2928.556	14,882,000	17,452,310	8618.956	16,905,000		
<i>Road/Ext</i>		0.052	0.050	0.049	0.055	0.169	0.169	0.169	0.170		
<i>Road Quali/Ext</i>		0.019	0.021	0.021	0.023	0.084	0.073	0.082	0.097		
<i>Cais</i>		2145.741	2235.815	1819.000	2302.296	12,032,000	12,562,000	12,562,000	12,562,000		
<i>Cais/Ext</i>		0.019	0.023	0.019	0.021	0.215	0.215	0.229	0.230		
<i>Calado</i>		12.750	12.750	12.003	13.003	61.400	61.400	61.400	61.400		
<i>Aero</i>		4813.631	4813.631	4427.853	4813.631	12,616,000	12,616,000	11,251,000	12,616,000		
<i>Aero/Ext</i>		0.072	0.072	0.074	0.072	0.984	0.984	0.984	0.984		
<i>Ferro</i>		951.959	951.959	720.180	951.959	6258.030	6258.030	2863.000	6258.030		
<i>Ferro/Ext</i>		0.006	0.006	0.005	0.006	0.042	0.042	0.042	0.042		
<b>St Dev per Brazilian State</b>											
		2009	2010	2011	2012	2009	2010	2011	2012	2011	2012
<i>Trade</i>		0	0	0	0	447,327,736	625,280,641	841,451,256	763,688,009		
<i>GDP</i>		2,800,000,000	3,604,252,772	4,155,423,697	3,773,027,517	104,222,538,008	136,423,699,976	155,515,217,577	141,204,179,885		
<i>Pop</i>		450,969	460,678	469,943	496,936	2,729,515,516,015	2,864,034,158,309	3,040,121,866,263	3,196,587,909,963		
<i>Distance</i>		371	371	371	371	2928	2928	2928	2928		
<i>Road</i>		431.000	450.000	451.000	474.000	7390.036	7401.428	5442.462	7742.197		
<i>Road Quali</i>		48.000	58.000	67.550	70.000	3207.122	3756.945	2508.845	3711.436		
<i>Road/Ext</i>		0.001	0.001	0.001	0.001	0.048	0.044	0.041	0.049		
<i>Road Quali/Ext</i>		0.000	0.000	0.000	0.000	0.022	0.022	0.022	0.027		
<i>Cais</i>		0.000	0.000	0.000	0.000	3508.701	3612.294	3129.013	3722.498		
<i>Cais/Ext</i>		0.000	0.000	0.000	0.000	0.043	0.044	0.045	0.046		
<i>Calado</i>		0.000	0.000	0.000	0.000	15.499	15.499	15.645	15.711		
<i>Aero</i>		1750.000	1750.000	1750.000	1750.000	2700.690	2700.690	2249.554	2700.690		
<i>Aero/Ext</i>		0.003	0.003	0.003	0.003	0.187	0.187	0.187	0.187		
<i>Ferro</i>		0.000	0.000	0.000	0.000	1424.801	1424.801	962.426	1424.801		
<i>Ferro/Ext</i>		0.000	0.000	0.000	0.000	0.012	0.012	0.011	0.012		



**Table 5**  
Spatial concentration of main used indicators.  
Source: Own elaboration

HHI	Airport	Railway	Road quality	Road/ext	Quay/ext	Airport/ext	Railway/ext
2009	482.64	1169.32	951.93	672.48	2080.78	2777.10	1605.11
2010	482.64	1169.32	991.10	642.66	1601.89	2777.10	1605.11
2011	469.00	1056.27	861.37	640.49	2122.22	2751.86	1620.19
2012	482.64	1169.32	943.20	659.44	2069.62	2777.10	1605.11
HHI	Trade	GDP	Pop	Road	Quay	Port draft	HHI < 1200 – no concentration; HHI ≥ 1200 – light concentration; HHI ≥ 1800 – concentration
2009	1279.20	1482.31	893.54	727.37	1324.01	897.38	
2010	1250.05	1466.55	892.02	733.40	1301.35	897.38	
2011	1212.46	1433.60	890.57	687.56	1270.38	897.18	
2012	1182.26	1433.60	873.46	703.02	1302.75	891.09	

$$T_{ijt} = Y_{it} E_{jt} D_{ijt}^{-\phi} \exp(\varphi_i d_{it} + \varphi_j d_{jt} + \varphi_{ij} d_{ij}) \eta_{ijt} \tag{4}$$

Authors show that the log-linearization of Eq. (4) does not entail biases, as long as  $\ln \eta_{ijt}$  is statistically independent from the included regressors. However, because the expected variable of the logarithm of a random variable depends both on the mean and higher moments of its distribution, if the conditional variance of  $\eta_{ijt}$  depends on the included regressors, then the expected value of  $\ln \eta_{ijt}$  would depend on the regressors too, thus introducing a bias in parameter estimates. Santos Silva and Tenreyro (2006) propose to address the bias associated to log-linearization of models like those in Eq. (5) by considering exponential models of the form  $y = \exp(x\beta)$ , which would give raise, in our case, to:

$$T_{ijt} = \exp(\ln(Y_{it} E_{jt}) - \phi \ln D_{ijt} + \varphi_i d_{it} + \varphi_j d_{jt} + \varphi_{ij} d_{ij}) \eta_{ijt} \tag{5}$$

where  $\eta_{ijt}$  is an error term and in the  $D_{ijt}$  vector there might be both variables that are entered linearly or in exponential form.<sup>5</sup> Authors argue that an efficient estimator is a pseudo maximum likelihood estimator based on the assumption that the conditional variance is proportional to the conditional mean, such as the Poisson pseudo maximum likelihood.<sup>6</sup> Moreover, Fally (2015) shows that the estimation of gravity equations with the Poisson pseudo maximum likelihood estimator and fixed effects fully captures the multilateral resistance terms.<sup>7</sup>

In this study we follow Santos Silva and Tenreyro (2006) and we estimate various versions of Eq. (5). In particular, in our most extended specification, we estimate the following equation with Poisson pseudo maximum-likelihood approach:

$$T_{ijt} = \exp(\ln(Y_{it} Y_{jt}) + \ln(P_{it} P_{jt}) + \phi P_{it} + \varphi_i d_{zi} + \varphi_j d_{zj} + \varphi_{ij} d_{ij}) \eta_{ijt} \tag{6}$$

where  $T_{ijt}$  stands for exports (imports) of Brazilian state  $i$  in year  $t$  towards (from) a trade partner country  $j$ ;  $P_{it}$  stands for port infrastructure in the Brazilian state  $i$  in year  $t$ ,<sup>8</sup> while  $Y_{it}$ ,  $P_{it}$  and  $Y_{jt}$ ,  $P_{jt}$  are  $GDP$  and population in Brazilian state  $i$  in year  $t$  and  $GDP$  and population in country  $j$  in year  $t$ , respectively.

Moreover, in some specifications, where we do not control for state-country pair fixed effects, we also include standard controls in gravity equations, such the log of distance and dummies for countries belonging to specific trade areas, such as Mercosul, EU or Nafta, and a dummy for adjacent country-states.<sup>9</sup>

As it is apparent from Eq. (6) and the above discussion, we deal with the most challenging identification assumptions underlying the estimation of a gravity equation, highlighted by authors such as Anderson and van Wincoop (2003), by including various sets of fixed effects. For instance, in the export regressions our most extended specification controls for exporter-importer fixed effects ( $d_{ij}$ ), importer-by-year fixed effects ( $d_{jt}$ ) and Brazilian region-by-year fixed effects ( $d_{zt}$ ).

Indeed, as highlighted by Baldwin and Taglioni (2006), exporter-importer fixed effects account for any unobserved time invariant heterogeneity (potentially correlated with the included regressors) at the level of each exporter-importer combination. This can be associated to the existence of bilateral tariffs and non-tariff barriers to trade, distance differentials, existence of a common border, state level differences in the share of migrants from various trading partners, state level differences in Brazilian migrants towards specific trading partners,<sup>10</sup> etc. In turn, in the export (import) regression, importer (exporter)-by-year fixed effects account for unobserved time-varying macroeconomic developments in each foreign country (such as changes in tariffs, economic policies, etc.), or changes in transport infrastructure, etc.

Finally, because our variable of interest (port infrastructure,  $P_{it}$ ) varies only within Brazilian states over time, we cannot include the Brazilian states time varying fixed effects (the  $d_{it}$  in Eq. (4)), because we would not be able to identify the impact of port

<sup>5</sup> In other words, we may consider both linear and log-linear regressors.  
<sup>6</sup> It is important to note that, because the authors propose a pseudo maximum likelihood estimator, the distribution of the dependent variable need not to be Poisson at all.  
<sup>7</sup> See Egger and Staub (2016) for a comparison with alternative pseudo maximum likelihood estimators, such as the negative binomial and the gamma.  
<sup>8</sup> Ports enter linearly into Eq. (6) because in some Brazilian states there are no ports. We prefer this approach rather than add 1 to  $P_{it}$  and then take logs.  
<sup>9</sup> In all regressions we also control for the road network.  
<sup>10</sup> For the role that local communities of migrants play in shaping the export and imports of the host country, see Bratti et al. (2014), among the others.

**Table 6**  
Regression results for export.

VARIABLES	(1) Export	(2) Export	(3) Export	(4) Export	(5) Export	(6) Ln(1 + Export)	(7) Export	(8) Export
Inroad_ext	−0.177** (0.0706)	−0.109 (0.0717)	−0.111* (0.0593)	−0.162*** (0.0546)	0.0238 (0.0655)	−0.141 (0.183)	0.0233 (0.0655)	
PI	1.317 (1.368)	23.19*** (4.449)	24.06*** (4.589)	24.53*** (4.927)	25.11*** (5.113)	−17.02 (16.97)	25.11*** (5.114)	
lngdp1_lngdp2	0.791*** (0.0790)	0.149* (0.0767)	0.196** (0.0799)	0.112** (0.0445)	0.0675** (0.0269)	0.280 (0.347)	0.0679** (0.0272)	
lnpop1_lnpop2	0.191** (0.0973)	1.032 (0.670)	1.662*** (0.598)	1.629*** (0.553)	0.295 (0.402)	1.039 (0.881)	0.299 (0.402)	
Adj	0.174 (0.304)	−0.340 (0.450)	−0.329 (0.445)					
Mercosul	0.641*** (0.215)	−1.581 (1.114)	−2.958** (1.182)					
Nafta	−1.123*** (0.266)	−2.515 (2.300)	−5.351** (2.222)					
UE	−0.338* (0.184)	−1.871 (1.254)	−3.459*** (1.281)					
Lndistance	−0.765*** (0.163)	−1.144*** (0.384)	−1.153*** (0.383)					
WPI							0.718 (2.223)	
Inroad_ext_t-1								−0.648** (0.303)
PI_t-1								10.15** (4.230)
lngdp1_lngdp2_t-1								−0.0161 (0.0143)
lnpop1_lnpop2_t-1								0.786 (4.104)
Observations	3240	3240	3240	3104	3104	3240	3104	2304
Number of panel_id				776	776	810	776	768
Year F.E.	YES	YES	YES	YES	YES	YES	YES	YES
Country F.E.	NO	YES	YES	NO	NO	NO	NO	NO
State F.E.	NO	YES	YES	NO	NO	NO	NO	NO
Country-by-year F.E.	NO	NO	YES	YES	YES	YES	YES	YES
Region-by-year F.E.	NO	NO	NO	NO	YES	YES	YES	YES
Country-by-state F.E.	NO	NO	NO	YES	YES	YES	YES	YES

Robust standard errors clustered at the country-state level in parentheses. Columns 1–5 and 7–8 estimated by Poisson Pseudo maximum-likelihood. Model 6 estimated by OLS.

infrastructures. For this reason, we have grouped Brazilian countries into five regions (North, Northeast, Southeast, South and Center-West) and included regions-by year fixed effects. This strategy should allow us to capture variation over time in regional unobserved heterogeneity associated to possible regional business cycles or regional specific trade shocks, while still allowing us to identify the impact of port infrastructures on exports (see, for a similar approach, [Bratti et al. \(2014\)](#)).

Conditionally on the inclusion of these sets of fixed effects, we aim to identify the causal impact of port infrastructure on trade. Moreover, in order to further alleviate possible remaining endogeneity concerns, we also estimate a version of our gravity equation where all main variables are lagged one period and we perform the test for strong exogeneity for fixed effects models proposed by [Wooldridge \(2010\)](#).

Finally, it is important to observe that, because of the inclusion of fixed effects, we identify the impact of port infrastructure on Brazilian imports and exports only from the within Brazilian state variation over time. Although in our sample most of the variation in port infrastructures is across Brazilian states, the within variation is not negligible, at the light of the significant public investment programmes aimed to remove bottlenecks in some ports in various Brazilian states over the sample period considered in this study, as discussed in Section 2 above.

#### 4. Empirical results

In [Table 6](#) and [7](#) we report a set of regression results for Brazilian exports and imports, respectively. We focus first on exports. In the first column, we report results for a “first generation” gravity equation model estimated with a Poisson pseudo maximum-likelihood estimator, with no fixed effects, with the exception of a set of “common” year fixed effects. Empirical results show that the port infrastructure variable has a positive coefficient, although it is largely statistically insignificant. As far as the other control variables are concerned, we note that the log of the product of GDPs is positive, statistically significant and with a coefficient very close to one. Among the other significant regressors, our findings confirm the typical results in gravity equations, namely that distance is associated to lower trade; moreover, we note that countries/states more populated trade more with each other.

**Table 7**  
Regression results for import.

VARIABLES	(1) Import	(2) Import	(3) Import	(4) Import	(5) Ln(1 + Import)	(6) Import
Inroad_ext	−0.119 (0.125)	0.0965 <sup>*</sup> (0.0584)	0.0884 <sup>*</sup> (0.0494)	−0.0202 (0.0730)	0.781 (0.493)	
CaisExt2	0.922 (1.029)	1.554 (3.908)	0.115 (2.974)	1.849 (2.924)	13.75 (19.71)	
lngdp1_lngdp2	0.954 <sup>***</sup> (0.0907)	−0.143 <sup>*</sup> (0.0743)	0.0110 (0.0112)	0.0155 (0.0133)	−0.0372 (0.359)	
lnpop1_lnpop2	0.136 (0.0856)	0.962 <sup>*</sup> (0.572)	0.0514 (0.410)	−0.267 (0.383)	−0.125 (1.139)	
Adj	1.348 <sup>***</sup> (0.271)	1.070 <sup>***</sup> (0.394)				
Mercosul	0.516 (0.415)	1.590 (1.108)				
Nafta	−0.839 <sup>***</sup> (0.268)	1.592 (2.029)				
UE	−0.313 (0.235)	0.737 (1.144)				
Indistance	−0.658 <sup>***</sup> (0.215)	−0.341 (0.440)				
Inroad_ext_t-1						0.195 (0.139)
PI_t-1						7.668 <sup>**</sup> (3.436)
lngdp1_lngdp2_t-1						0.00884 (0.00893)
lnpop1_lnpop2_t-1						−4.464 (2.984)
Constant	−30.92 <sup>***</sup> (3.575)	−9.502 (17.56)				
Observations	3240	3240	3076	3076	3240	2292
Number of panel_id			769	769	810	764
Year F.E.	YES	YES	YES	YES	YES	YES
Country F.E.	NO	YES	NO	NO	NO	NO
State F.E.	NO	YES	NO	NO	NO	NO
Country-by-year F.E.	NO	NO	YES	YES	YES	YES
Region-by-year F.E.	NO	NO	NO	YES	YES	YES
Country-by-state F.E.	NO	NO	YES	YES	YES	YES

Robust standard errors clustered at the country-state level in parentheses. Columns 1–4 and 6 estimated by Poisson Pseudo maximum-likelihood. Model 5 estimated by OLS.

Among free trade areas agreements, we note that Brazilian states tend to export more to countries belonging to the Mercosul agreement, and less to Nafta and EU countries.<sup>11</sup> Finally, we surprisingly find that roads are negatively associated to exports, although we will see this result is not very robust across specifications.<sup>12</sup>

In the next columns we start including some of the fixed effects considered in Eq. (6). In particular, in column 2 we add separate exporter and importer fixed effects: for the port infrastructure variable, this means that we are identifying its impact through the within Brazilian state variation over time. We can note that its coefficient is now much larger and statistically significant at 1% level.

In turn, the *GDP* coefficient is now much lower, but still statistically significant. Among the other regressors, only distance continues to have a statistically significant effect. In column 3 we let importer (i.e. foreign countries) fixed effects to change over time by including importer-by-year fixed effects, while in column 4 we also add importer-exporter fixed effects, and in column 5 also a full set of Brazilian regions-by-year fixed effects<sup>13</sup>: reassuringly, the coefficient of the port infrastructure variable remains pretty stable and statistically significant.

In turn, in column 6 we estimate by *OLS* a log linear version of the equation reported in column 5 by adding 1 to the export variable: in this case, the coefficient of port infrastructure is negative, but largely insignificant. Even if, as shown by Santos Silva and

<sup>11</sup> This is partially due to the fact that Brazil has a preferential trade agreement with Mercosul countries and not with Nafta and EU countries.

<sup>12</sup> One explanation for a negative coefficient of the road variable might be linked to possible measurement error bias. In fact, it is reasonable to think that different types of roads, such as motorways or rural roads, have a differential effect on trade, but unfortunately we do not have information on roads characteristics and on their quality, such as number of lanes, etc. Suppose that during our sample period there was a stronger increase in roads in Brazilian States with declining exports, but this increase in roads was of a very poor type, while for other States experiencing a smaller increase in roads that increase mainly concerned high quality roads. In this scenario we believe it is reasonable to think that the coefficient of roads would have a negative bias in our regressions.

<sup>13</sup> It is important to note that in these regressions the coefficient of log GDP and log population are identified only through the GDP and population variation within Brazilian states, because the variation over time in importing countries is entirely captured by the importer-by-year fixed effects. Results are robust to dropping both log GDP and log population variables.

Tenreiro (2006), results obtained from the Poisson should be preferred on theoretical grounds, as a robustness check we have implemented the RESET test for misspecification suggested by the same authors. In particular, for both regressions reported as column 5 and 6 we have computed the fitted values, which have then been included in squared form into the respective regressions: statistically significant coefficients of squared fitted values is a signal of model misspecification. We find that,<sup>14</sup> while in the case of the Poisson model (column 5) we cannot reject at the 10% level the null hypothesis that squared residuals are equal to zero, we fail to reject the null hypothesis, at whatever confidence level, in the case of the log-linear model, thus concluding that the latter might indeed be misspecified.

In column 7 we explore the existence of possible spillover effects of ports, by including in the same specification of column 5, the spatial lag of port infrastructure (WPI), where the matrix of weights is of the contiguity type. Regression results suggest that the spatial lag of port infrastructure has a positive coefficient, pointing towards the existence of positive spillovers, although the effect is imprecisely estimated. Nevertheless, it seems fair to say that this issue should be explored more deeply, such as by using appropriate spatial econometric techniques.<sup>15</sup>

Finally, in column (8) we seek to alleviate additional endogeneity concerns by including all variables lagged one period: as we can see, the impact of port infrastructure remains positive and statistically significant, but with a coefficient that is more than halved.

As discussed in Section 3 above, one of the empirical strategy we adopted to address possible endogeneity issues, has been to rely on a set of fixed effects. In particular, the export-importer fixed effects control for any unobserved determinant of both exports and Brazilian port infrastructures; moreover, the Brazilian region-by-year fixed effects also take into account unobserved time-varying shocks that drive both exports and the expansion of port infrastructure that are common within a Brazilian region. Nevertheless, one could still have concerns of possible simultaneity between ports infrastructures and trade even after accounting for this wide set of fixed effects.<sup>16</sup> In order to test the reliability of our results, we have carried out the strong exogeneity test proposed by Wooldridge (2010). Indeed, in a panel model with fixed effects,  $PI_{it}$  should be uncorrelated with the error term at all lags and leads<sup>17</sup>: therefore, Wooldridge (2010) suggests including lags and leads (i.e. anticipatory effects) in the regression. While the statistical significance of a lag is not problematic because we could re-interpret the equation as a distributed lag one, a statistically significant lead is likely to capture some underlying trend that could make our results suspicious. We have therefore re-run our most extended and general specification (Model 5) including one lag and one lead of port infrastructures. Results, not shown but available upon request, suggest that neither the lag nor the lead are statistically significant at conventional levels of confidence: reassuringly, the coefficient of  $PI_{it}$  is still negative, significant at 10% and with a magnitude of about 14, which is in the lower range of the estimates presented in Table 6.

All in all, empirical results reported in Table 6 shows that, in the case of Poisson regressions, once we include at least importer and exporter fixed effects, port infrastructures are positively associated to exports of Brazilian states. As far as the magnitude of the impact is concerned, it is important to note that coefficient of regressors that enter linearly into the Poisson regression equation can be interpreted as semi-elasticities (Wooldridge, 2010). Therefore, we can evaluate the impact of port infrastructure with the following virtual experiment: let us assume that port infrastructures are increased from the median of its distribution (0.0024) to the 75th percentile (0.0299).<sup>18</sup> In this case exports would increase by about 68%<sup>19</sup>: this is a very large effect, probably outside the range one could judge realistic. However, if we consider estimates reported as column 8,<sup>20</sup> the impact would be much smaller and close to 28%. It is important to acknowledge that the change in the stock of port infrastructure considered in this example is indeed a very large change, far bigger than any increase in port infrastructure experienced by a Brazilian state over our sample period.

If we consider the largest port extension in our sample period (which corresponds to an increase in the port infrastructure variable of 0.014), the associated impact on exports could have been as large as 14%, if we consider our most conservative estimate in column 8. Finally, the effect of the stock of roads does not turn out to be very robust: the effect is largely negative, although in general it is not statistically significant. After having discussed the export regressions we now turn to Table 7, where we examine the case of imports of Brazilian states. As we can see, the impact of ports is very small and largely insignificant.<sup>21</sup> Only when we consider the lagged model (column 6, corresponding to column 8 in Table 6), we find a positive and statistically significant effect of port infrastructure. In this case, an increase in the port infrastructure of 0.014 (the largest increase in a given year experienced by a Brazilian state), would be associated to an increase in Brazilian imports of about 11%. Again, as in the case of exports, the effect of roads is not very robust across models, although in a few cases is positive and statistically significantly so.

All in all, our empirical results suggest that, if we estimate a gravity equation by a Poisson pseudo maximum likelihood estimator and we control for a wide set of fixed effects, port infrastructures seem to be positively correlated with trade. Moreover, the effect is large and robust in the case of exports, while it is smaller and less robustly estimated in the case of imports.

A few words should be spent on the way we measure ports in this study. Indeed, one could argue that port infrastructures can be a poor proxy for port activity. In a somewhat extreme scenario, the port facilities could be unutilized: considering a variable that jointly considers port infrastructure, as well as its efficiency of use, might provide a better proxy for port activity. However, modifying our

<sup>14</sup> Results are available from the authors upon request.

<sup>15</sup> For a paper analysing the impact of ports on economic activity using spatial econometric techniques, see Bottasso et al. (2014).

<sup>16</sup> To the best of our knowledge, ours is the only study seeking to estimate the impact of port infrastructure on trade employing the widest set of fixed effects.

<sup>17</sup> In other words, the port infrastructure variable in year  $t$  variable needs to be uncorrelated with the error terms in any year  $s \neq t$ .

<sup>18</sup> Let us recall that the port infrastructure variable is expressed as the length of port piers in a Brazilian state normalized by that state's area. Moreover, about 40% of our observations display a zero level of port infrastructure.

<sup>19</sup> This is derived as follows:  $25 * (0.0299 - 0.0025) * 100$ .

<sup>20</sup> Or the estimates we get when we include lags and leads.

<sup>21</sup> In Table 7 we report fewer regressions with respect to export estimates because in some we experienced convergence problems.

physical proxies with indicators for efficiency and productivity of ports would introduce serious endogeneity concerns, given that any of these indicators would be based on port outputs in each Brazilian state, which surely depends on that state intensity of trade. By way of contrast, the expansion of port infrastructures is less likely to be related to demand developments and trade, and therefore more likely to be exogenous in our setting.

We believe it might be important to relate our findings to the previous literature. As discussed in the introduction, only few papers sought to assess the impact of transportation infrastructure on trade; moreover, port infrastructures were generally considered as parts of more aggregate indicators, thereby making a direct comparison with our paper extremely difficult. We can only mention three papers that are more amenable to a direct comparison with ours. The first is the study by [Wilson et al. \(2005\)](#), who show that composite indicators of port and air transport facilities (mixed together) of both importers and exporters are positively correlated with bilateral trade in a large sample of countries: however, their empirical models are estimated by OLS and authors fail to jointly control for importer and exporters fixed effects. In turn, [Bensassi et al. \(2015\)](#) estimate a gravity equation for a panel of Spanish regions in order to evaluate the impact of both transport infrastructure and the logistics system on trade. In some regression specifications authors find that the efficiency of the port industry (measured as regional ports productivity) or, alternatively, the extent of regional port facilities (measured as the percentage of sea traffic in a region over total traffic in Spain) is positively correlated with trade. However, their model does not include neither Spanish regions-by-year fixed effects, nor regions-country fixed effects. Finally, [Marquez-Ramos \(2016\)](#) estimated gravity equations for a set of Spanish regions and found evidence that ports facilities in a region as well as in neighbourhood ones are positively correlated with exports.

## 5. Conclusion

This study focuses on an important issue such as the relation between trade and transport infrastructure, mainly considering port infrastructure endowment. Our estimates of a gravity equation on a panel of Brazilian states observed over the period 2009–2012 confirm the links between international trade, GDP, population and distance, but they also show the capability of port endowment to foster international trade flows. The positive impact of port infrastructure on trade is found to be higher for export flows with respect to imports: in particular, estimates suggest that maritime infrastructure investments realized over the sample period have generated an increase of about 14% for export and 11% for import flows. This result might be connected to the different logistics services – and related transport organization – that "export oriented" activities (e.g. soy, fuel, and iron ore) need in comparison with "import related" flows. Moreover, the presence of the biggest Brazilian firms in all main bulk exporting sectors (e.g. Vale for the iron one, Petrobras for oil) that are often acting also as integrated transport companies (e.g. investing in terminal facilities) might have increased the positive effects of export related activities on local economies.

Another interesting result of this study is related to spillover effects: estimates provide evidence in favor of the existence of positive spillover effects of ports, although such effect is imprecisely estimated. The possible existence of spillovers underlines the link between port infrastructure and other landlocked regions and suggest the possibility to foster their international trade through more efficient connections among main production/consumption points and ports.

Our empirical results do not provide evidence in favor of a positive effect of roads infrastructure endowments on international trade flows. Such result might be associated to the out-of-date status of many internal roads that in some cases can generate extra costs and might negatively affect trade operations. This aspect is also underlined by the previous literature that investigated the Brazilian logistics system (e.g. [Ng et al., 2013](#); [Wanke, 2013](#)).

Although the analysis might be improved from different points of view, we believe that overall results provide support in favor of the implementation of policy intervention aimed at the expansion of port infrastructure. Moreover, it seems that the positive impact of such investments on trade flow might be reinforced by complementary investments designed at improving and developing other transport infrastructure, like roads. Such investments, by increasing connectivity and reducing transport costs, might be able to reinforce and amplify spillover effects between maritime and non-maritime regions. Indeed, these results are in line with other studies (e.g. [Galvão et al., 2017](#); [Wanke et al., 2011](#)) that suggest the need of improving Brazilian port efficiency (and endowment).

Limitations of the model do not allow us to identify possible specific trade patterns (or commodities) that might generate the main benefits, weakening the possibility to suggest specific interventions for main Brazilian policy makers. Nevertheless, our analysis underlines the clear contribution of the Brazilian port system to the national economic growth and how potential improvements in the port transport and logistics system could generate major benefits for the local economies.

In order to increase the quality of the proposed research, future developments will focus on comparing different realities and trade patterns, investigating the role of the overall transport system on the Brazilian trade structure and on specific regions.

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