Determinants of Brazilian exports by levels of technological intensity: a gravity model analysis using the PPML estimator

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Abstract

The objective of this study is to analyze the determinants of Brazilian exports by levels of technological intensity in the period 2000-2015. Gravity models were estimated for total of the exports and for each type of exports by levels of technological intensity, using the PPML-estimator developed by Silva and Tenreyro (2006). The results of this study indicate that it is a process of concentration of Brazilian exports in low technology and medium-low technology products, at the same period in which China's share of total Brazilian shipments abroad grew. Estimates of empirical gravity models have shown that the income and size of the consumer market of Brazil's trading partners seem to have the greatest positive influence on the Brazilian exports. In this sense, indications of this study are that the Brazil should continue to diversify its trading partners to minimize the impacts of a possible reduction of the economic growth of large trading partners (such as China and the US) on its exports and increase its exports of products with greater technological intensity. The results also highlight the need for Brazil to make greater efforts to increase its competitiveness in the international market to reduce the negative impacts of transport costs on the final prices of products exported by the country.

Keywords: Brazilian exports; technological intensity; gravity models; PPML-estimator.

Resumo

O objetivo deste estudo é analisar os determinantes das exportações brasileiras por níveis de intensidade tecnológica no período 2000-2015. Foram estimados modelos gravitacionais para as exportações totais e para cada tipo de exportações por níveis de intensidade tecnológica, utilizando-se o estimador *Poisson Pseudo-Maximum-Likelihood* (*PPML*), desenvolvido por Silva e Tenreyro (2006). Os principais resultados do trabalho apontam que está em curso um processo de concentração das exportações brasileiras em produtos de baixa e média-baixa tecnologia, ao tempo em que tem crescido a participação da China no total dos embarques brasileiros para o exterior. As estimações dos modelos empíricos evidenciaram que a renda e o tamanho do mercado consumidor dos parceiros comerciais do Brasil parecem exercer as maiores influências positivas sobre as exportações do país. Nesta linha, as indicações são de que o país deve continuar diversificando seus parceiros comercias, de modo a minimizar os impactos de uma possível redução do crescimento econômico de grandes parceiros comerciais (como a China e os EUA) sobre suas exportações e a aumentar suas exportações de produtos de maior intensidade tecnológica. Os resultados do trabalho também conferem relevância à necessidade de o Brasil envidar maiores esforços para aumentar sua competitividade no mercado internacional, de modo a reduzir os reflexos negativos dos custos de transportes sobre os preços finais dos produtos exportados pelo país.

Palavras-Chave: Exportações brasileiras; intensidade tecnológica; modelos gravitacionais; estimador *Poisson Pseudo-Maximum-Likelihood* (*PPML*).

JEL Classification: F10, F14, C23.

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1. Introduction

The growth of Brazilian exports has been very uneven when analyzed in its levels of technological intensity. In recent years, exports of products of lower technological intensity have grown much faster than those of more exports of technologically intensive products, causing significant changes in the country's export agenda.

This disharmonious movement of exports in levels of technological intensity may generate undesirable long-term effects on the performance of the Brazilian trade balance because the process of innovation and imitation creates a new configuration that can result in a redistribution of the trade flow between countries and in an international division of labor (GUERRIERI, 1991)[3]. Although the conditions for its generation and diffusion are different for each economic activity, the new technologies lead to the differentiation of products and increase the country's international competitiveness (BERNARD *et al.*, 2003; MARQUES-RAMOS, 2007). And in its capacity for the generation and diffusion of new technologies lie the explanations for its advantages (comparative and/or absolute) acquired by many countries in the field of foreign trade and in its position in terms of the international standard of trade.

In this sense, the changes in the Brazilian export agenda in recent years require new studies on the determinants of these exports with updated data, since the advantages acquired in foreign trade by firms or countries concerning technological issues are temporary, lasting only enough for imitators to incorporate new technical skills that overcome the technological gap that existed in their productive processes (GUERRIERI, 1991).

In Brazil case, in addition to the changes in levels of technological intensity of exported products, the studied period (2000-20015) captures the repositioning of China between the trade partners of the country, overcoming United States as the main destination of Brazilian products. Moreover, in the Brazilian literature on international trade although some empirical research has been made by using gravity equations none has focus on levels of technological intensity, just as it was done in this study[4].

In this sense, the objective of this study is to analyze the determinants of Brazilian exports in its levels of technological intensity in the period 2000-2015 with the use of gravity models. That is, the study seeks to explain the differentiated performance of Brazilian exports in its levels of technological intensity by means of gravity variables, such as market size, transport costs, customs tariffs, common borders and trade agreements.

Gravity models were estimated for total exports and for each type of exports in the level of technological intensity. In all estimations, we used the Poisson Pseudo-Maximum-Likelihood (PPML) estimator, developed by Silva and Tenreyro (2006). This method has proved to be effective in the presence of heteroscedasticity, which makes estimations biased and inconsistent when gravity models are estimated by method that request linear transformation (SILVA; TENREYRO, 2006).

The use of gravity models has become increasingly frequent in international trade studies, mainly because of its empirical applicability and its flexible structure, which favors the quantification of the effects of trade with great foresight in a realistic gravity environment, with multiple countries, several sectors and even several companies, adapting to many general equilibrium international trade theories (YOTOV; PIERMARTINI; MONTEIRO; LARCH, 2016).

Initially criticized for having no theoretical basis, the gravity equations were applied in the bundle of Ricardian models (EATON; KORTUM, 2002, HELPMAN; MELITZ; RUBINSTEIN, 2008) in the Heckscher-Ohlin structure (BERGSTRAND 1985 and 1989; DEARDORFF, 1995) and also in models of imperfect competition (HELPMAN; KRUGMAN, 1985; HELPMAN; MELITZ; RUBINSTEIN, 2008).

To develop all these questions, this study has been divided into five sections. The first and the last sections concern the introduction and conclusion; the second section presents the microeconomic basis of

[3] Not coincidentally, a variable was inserted in the models estimated in this study that seeks to capture if the main trade partners of the country in the analyzed period have or not patterns of income and technologies similar to those of Brazil.

[4] Castilho (2001) conducted estimations of Brazilian exports using the two and four-digit disaggregation of the Standard International Trade Classification (STIC) and Sarmento (2012) made estimations in productive stage (primary goods, intermediate goods and final goods), but without highlighting the issue of technological differences among exported products.

gravity models and the Brazilian empirical literature on the subject; the third section covers the empirical model, the estimation strategy and the data used in this study; and the fourth section contains the results of empirical models estimated.

2. Gravity models for export determination

2.1. The microeconomic fundamentals of gravity models

Tinberg (1962), Poyhonen (1963) and Linnemann (1966) were the first to use the gravity model for analysis in the international trade theory in the 1960s. As we know, the basic equation used by Tinberg (1962) originates from the Law of Universal Gravitation by Isaac Newton, which states that the gravity force between two bodies is positively attracted by the product of their masses and negatively influenced by the square distance between them, as shown in equation 1, below.

$$F_{ij} = G\frac{M_i M_j}{D_{ij}^2} \qquad (1)$$

From Equation (1), *Fij* is gravity force between bodies *i* and *j*; *Mi* indicates the mass of the body *i*; M_j is the mass of the body *j*; $D^2{}_{ij}$ is the square of the distance between the bodies *i* and *j*; and *G* is a constant. In Tinberg's equation (1962), the trade flow between two countries is directly related to the size of its markets (which has GDP as a proxy) and inverse to the distance between countries (parameter for transport costs). The equation (2), below, reproduces the equation of Tinberg (1962), where X_{ij} indicates the value of exports between countries *i* and *j*; *Y* denotes the nominal GDP value; D_{ij} is the geographic distance between countries *i* and *j*; *k* is a constant; α and β are parameters with positive signs and θ is a parameter with negative sign. The GDP is a proxy for the size of the economy of each country *i* and *j* and the proxy for transport costs is attributed to the geographical distance between these countries.

$$X_{ij} = k\frac{Y_i^{\alpha} Y_j^{\beta}}{D_{ij}^{\theta}} \qquad (2)$$

Over time, other variables were incorporated into Equation (2), such as the population of countries, trade agreements, colonization relationship, common language, natural and artificial barriers to trade, borders and territorial contiguity.

Despite its applicability, the gravity model initially suffered resistance because it did not have a solid theoretical basis. It was Anderson (1979) who elaborated the first theoretical basis for the gravity model, starting from the development of a gravity equation based on a demand function of imports with constant elasticity of substitution (CES), in which each country produces and sells differentiated products and, therefore, imperfect substitutes in the international market, impressing microeconomic foundations to the model.

Subsequently, Bergstrand (1985) worked with a gravity equation that would be the reduced form of a partial equilibrium subsystem, which originates from a general equilibrium model of international trade, with differentiated products for each country. The equation of the export demand for each country is obtained by maximizing a constant substitution elasticity function (CES) and the supply equation is the maximization of a profit function of the exporting company, based on a function of constant elasticity of transformation (CET). Bergstrand's (1989) study is an extension of the previous one (with capital and labor as factors of production, differentiated products and increasing returns of scale), with the expansion of the micro-foundations of the gravity equations under the Heckscher-Ohlin model.

Helpman and Krugman (1985) have also given important theoretical support to the gravity model, establishing a scheme with differentiated products and scale economies, within the scope of monopolistic competition. The authors have imposed a framework on the model that combines characteristics of

Theory of Comparative Advantage with imperfect competition. The old theory would be the reason for the inter-industrial trade and the new one of the intra-industry trade practiced by the countries.

Deardorff (1995) developed gravity equations with Cobb-Douglas and CES type preferences to show that these equations are consistent with the Heckscher-Ohlin model. The author worked with two extreme cases of bilateral trade (one without barriers and with homogeneous products and the other with barriers and differentiated products) seeking to find a general result that supported the use of gravity equations to explain foreign trade due to differences in resource endowments between countries.

Eaton and Kortum (2002) proposed a Ricardian Model of International Trade, which therefore incorporates differences in technological levels between countries as well as natural and artificial geographical barriers. The gravity model employs a probabilistic formulation of technological heterogeneity (which seeks to measure the comparative advantages of each country), along with the geographical barriers that inhibit foreign trade in the context of a general equilibrium analysis. The specialization of countries in products where they have the greatest comparative advantage is determined not only by differences in productivity among them but also by the geographical barriers that determine the cost of international transport.

Anderson and van Wincoop (2003) developed a gravity model in an attempt to solve the "border puzzle", which indicates that borders reduce the level of exchange between countries. The study had as its starting point McCallum's (1995)[5] model, in which bilateral trade between two countries depends on the production of both, their bilateral distance and if they are separated by a border. The fundamental difference between Anderson and van Wincoop (2003) compared to McCallum's (1995) was the addition of some terms to correct the bias caused by the omission of variables in the gravity equation. These terms characterize multilateral trade resistance (the name given to all variables that create multilateral trade barriers), such as exchange costs, the presence of trade barriers, and the distances between countries. An increase in multilateral trade resistance, for example, between country *j* and its other trading partners, other than country *i*, increases the latter's exports to *j*, given a particular trade barrier between these two countries.

More recently, Helpman, Melitz and Rubinstein (2008) developed a model of international trade with heterogeneous firms. In the gravity model, the products are differentiated, the firms have fixed and variable export costs and their productivities are different. The profitability of exports varies, depending on their destination, being bigger when they go to countries with higher demand, for which the fixed and variable costs of exports are lower. Only the most efficient and therefore more productive firms earn profits on exports.

It is noticeable that over time there has been an evolution of theories in an attempt to adapt more and more to the reality of modern economy. The gravity models were provided with economic fundaments, which involved not only the traditional international trade theories (with Ricardian models and based on the Heckscher-Ohlin structure) but also in the New Trade Theory, incorporating variables to measure scale economies, product differentiation and heterogeneity of exporting companies in the context of imperfect competition.

Based on this theoretical framework, gravity equations were estimated to verify the determinants of trade flow of several countries. This was the case, for example, of Rahman (2003) for Bangladesh; Sohn (2005) for South Korea; Batra (2006) for India; Marquez-Ramos (2007) for African countries; Eita (2008) for Namibia; Collins (2008) for the USA; Rahman (2009) for Australia; Hatab, Romstad and Huo (2010) for agricultural exports in Egypt; Binh, Duong and Cuong (2011) for Vietnam; Roy and Rayhan (2011) Bobkova' (2012) for Bangladesh; for the Czech Republic and for Germany Hippolyte (2012) for Barbados; Iwasaki and Suganuma (2013) for Russia; Yeshineh (2014) for Ethiopia; Karamuriro and Karukuza (2015) for Uganda; Spinelli and Miroudot (2015) for the OECD countries; Brodzicki (2015) for Poland; Kahfi (2016) for exports of manufactured goods in Indonesia; Dlamini, *et al.* (2016) for

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[5] The model of McCallum (1995) takes into account the export of country *i* to country *j* (dependent variable), GDP of country *i*, GDP of country *j*, distance between countries *i* and *j* and an equal dummy variable 1 if there is interprovincial trade and equal 0 if trade is between an American state and a Canadian province.

Swaziland's sugar exports; Wang and Badman (2016) for Peru; Didier and Koenig (2016) for China; and Hussain (2017) for Pakistan.

In general, the gravity models estimated in these studies depend on the trade flow between two countries (exports plus imports) or exports from one country to another. The Main Independent Gravity Variables (called MIGV) used are the GDP of each of the exporting countries and of the importing countries, the distance between them and dummies for colonial past, common language and contiguity (frontier). The country's GDP is used as a proxy for the exports offer and the GDP of the importing country as a proxy for demand; the population is used as a measurement of the market size for each country; the geographic distance is a proxy for the transportation cost; being aided by other trade barrier proxies, such as the colonial past, the common language and contiguity. The basic equation that reflects the use of these variables is the following:

$$lnX_{ij} = \alpha_1 + \alpha_2 lnY_i + \alpha_3 \ln Y_j + \alpha_4 N_i + \alpha_5 N_j + \alpha_6 \ln D_{ij} + \alpha_7 Z_{ij} + \varepsilon_{ij} \qquad (3)$$

Where *i* is the exporting country; *j* the importing country; *ln* is the natural logarithm; *X* represents exports; *Y* the GDP; *N* the population; *D* the geographic distance; *Z* is the dummies vector variable for colonial past, common language and contiguity; ε_{ij} is the error term.

Regarding the estimation of gravity models, some authors opt for the Ordinary Least Squares (OLS) method, mainly due to the simplicity of its application, but the effectiveness of this method is constantly questioned because of the bias of the estimators found[6]. An increasing number of papers have used the panel data technique[7], with an emphasis on fixed effects panels, because of their ability to capture unobserved factors specific to each country that are constant over time. More recently, there have been methods that deal with the absence of trade flow between countries in a given period (zero trade flows) and which are more robust in the presence of heteroscedasticity, which is common in the data used in gravity models. In this line, one of the most used methods is the Poisson Pseudo-Maximum-Likelihood (PPML) estimator[8].

We bring next the Brazilian empirical literature with the main studies that used gravity models in the estimations of models that also aimed to investigate the determinants of Brazilian foreign trade.

2.2 The use of gravity models to explain trade determinants and the Brazilian empirical literature

The Brazilian empirical literature that applied gravity equations to analyze the trade determinants is relatively recent. Initially, Piane and Kume (2000) used a gravity model to investigate the evolution of bilateral flows of international trade among 44 countries, in order to capture the effects of preferential agreements of six economic blocks in the period between 1986 and 1997.

Castilho (2001) sought to analyze the products of 98 sectors from Mercosur[9] to verify if the exports of these sectors would be stimulated in the case of a bilateral liberalization between this economic block the European Union (EU)[10]. Mercosur was also the target in Azevedo (2004), who examined its effects on intra-block trade and total exports and imports of the block in the period 1987-1998. Azevedo, Portugal and Barcellos Neto's (2006) study is similar to that of Azevedo (2004), including the variables

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6 *See* Castilho (2001); Azevedo (2004); Azevedo, Portugal and Barcellos Neto (2006); Sohn (2005); Batra (2006); Marquez-Ramos (2007); Roy and Rayhan (2011; Sarmento (2012); Hippolyte (2012).

7 *See* Rahman (2003); Bosworth and Collins (2008); Eita (2008); Hatab, Romstad and Huo (2010); Binh, Duong and Cuong (2011); Roy and Rayhan (2011); Iwasaki and Suganuma (2013); Yeshineh (2014); Karamuriro and Karukuza (2015); Dlamini, et al. (2016); Kahfi (2016); Wang and Badman (2016).

8 *See* Daumal and Zignago (2005); Bobkova´(2012); Iwasaki and Suganuma (2013); Spinelli and Miroudot (2015); Brodzicki (2015); Pereira and Almeida (2015); Cordeiro and Rodrigues Jr (2016); Didier and Koenig (2016); Hussain (2017).

9 Mercosur is a South American trade bloc established by the Treaty of Asunción in 1991 and Protocol of Ouro Preto in 1994. Its full members are Argentina, Brazil, Paraguayand Uruguay. Venezuela is a full member but has been suspended since December 1, 2016. Associate countries are Bolivia, Chile, Peru, Colombia, Ecuador and Suriname.

10 The European Union (EU) has 28 member states that are located primarily in Europe, with estimated population of over 510 million.

used, except that instead of dealing with Mercosur, he investigated the effects of the creation of the FTAA[11] on the trade flow in a group of countries that would be part of this block.

Porto and Canuto (2004) investigated the impact of Mercosur on the trade flow of the Brazilian macro-regions (Central-West, North, Northeast, South and Southeast), having as explained variable the total exports from each state to another state or country. Two other studies also used state exports as explained variable: Daumal and Zignago (2005) sought to analyze the border effect on the exports of each Brazilian state and Pintor, Schneider and Porto (2017) had as research focus the state's total exports in Paraná, a state of southern Brazil.

Salles *et al.* (2011) studied the determinants of Brazilian cellulose and paper exports between 1997 and 2005. These exports were also the explained variable used in the Pereira and Almeida (2015) model, whose objective was to study the impacts of technical measurements on the sector's exports of cellulose and paper in Brazil.

Sarmento (2012) examined the trade flows of the Latin American Integration Association (LAIA) in order to verify if the preferential agreements promoted between the member countries stimulate some articulation or productive integration among the different countries. Vianna (2014) used gravity models to verify the determinants of the Brazilian trade flow with 106 countries, with emphasis on the "border puzzle" analysis (McCallum Puzzle), which was also inserted in the Brazilian foreign trade model estimated by Prates and Pereira (2015).

Cordeiro and Rodrigues Jr (2016) studied the trade creation and trade diversion caused by Mercosur over the sectors of agriculture and industry in the 1990s. The trade creation and trade diversion were also the central concern of Miranda (2017), who evaluated the effects of Brazil's trade agreements with seven countries between 1981 and 2013.

The analysis of Table 1 evidence that the most commonly used estimation methods were the Ordinary Least Squares (OLS), Pooled OLS, Fixed-effects and random-effects models and the Poisson Pseudo-Maximum-Likelihood (PPML) estimator. One of the central concerns of these studies was the analysis of the effects of Mercosur on the flow of foreign trade in Brazil. In fact, the impacts of other economic blocks and/or preferential trade agreements on the Brazilian trade flow seem to be the fundamental motivation for the use of gravity models in Brazilian studies. In addition to Mercosur, the dummy variables were included for ASEAN[12], LAIA, BRICS[13], Andean Community[14], FTAA and the EU. Among the studies in Table 1, only those of Daumal and Zignago (2005) and Salles *et al.* (2011) did not estimate models with explanatory variables related to economic blocks and preferential agreements.

Furthermore, most of the aforementioned studies had models with practically all the main independent gravity variables (GDP of each of the exporting country and the importing country, distance between them and dummies for colonial past, common language and contiguity, group which was defined above as MIGV). In relation to the dependent variable, the predominance in the studies is the trade flow and bilateral trade (either in imports or exports), but there are more specific cases, such as that of Salles *et al.* (2011) and Pereira and Almeida (2015), who worked with paper and cellulose exports, and Castilho (2001), whose analysis rested on bilateral imports from 98 sectors from Mercosur to the EU.

In this aspect, it should be noted that in none Brazilian study has the focus to examine the relation between the exports and the technological question, contrary to what happens in the present study, which intends to examine the determinants of Brazilian exports by intensity of technological intensity. Besides this, as will be seen in section 4, in studied period (2000-2015), China ended up taking place of US as the biggest importer of Brazilian products. Although it does not raise the causes of this fact, this study indicates that the growth of China's participation on total of Brazilian exports coincide to reduction of

[11] The Free Trade Area of the Americas (FTAA) was a proposed agreement to eliminate or reduce the trade barriers among all countries in the Americas, excluding Cuba.

[12] The Association of Southeast Asian Nations (ASEAN) is a regional intergovernmental organization comprising ten Southeast Asian countries.

[13] BRICS is the acronym for an association of five major emerging national economies: Brazil, Russia, India, China and South Africa. Originally the first four were grouped as "BRIC" (or "the BRICs"), before the induction of South Africa in 2010.

[14] The Andean Community is a customs union comprising the South American countries of Bolivia, Colombia, Ecuador, and Peru.

exports of products of higher technology intensity. All that, distinguishes this work form another's that use gravity models to estimate determinants of Brazilian international trade and therefore reinforces the relevance of its realization.

Table 1: National Studies that Estimated Gravity Models to Study the Determinants of Brazilian Foreign Trade

Author	Dependent Variable	Independent variables	Estimation Method	Period
Piane and Kume (2000)	Trade flow (sum of exports and imports).	MIGV, GDP per capita, degree of country openness, relative distance and dummies for the Andean Community, Asean, Mercosur, NAFTA and EU15.	Undefined.	1986-1997.
Castilho (2001)	Bilateral imports from 98 sectors.	MIGV (without contiguity and colonial past), GDP per capita, customs tariffs, non-tariff barriers and dummies for preferential agreements between Mercosur and the EU.	Ordinary Least Squares (OLS).	1996-1997.
Porto and Canuto (2004)	Exports from each state to another state or country.	MIGV (without common language), population, and dummies for island, Mercosur, NAFTA and EU and NAFTA.	Pooled OLS, fixed-effects model and first differences model.	1990-2000.
Azevedo (2004)	Bilateral trade, whether in nominal imports or exports or the sum of both.	MIGV, population, territorial area, relative distance, counterfactual value of the logarithm of imports, real exchange rate and dummies for trade between MERCOSUR countries.	OLS weighted least squares and tobit estimator.	1987-1998.
Daumal and Zignago (2005)	Exports from Brazilian states to other states of the country and to other countries.	GDP and geographical distance, a dummy for trade between states, another for trade between one state and another, and fixed effects for exports and for imports.	Poisson Pseudo-Maximum-Likelihood (PPML) and tobit estimator.	1991-1999.
Azevedo, Portugal and Barcellos Neto (2006)	Bilateral trade, whether in nominal imports or exports or the sum of both.	PLGI, population, territorial area, relative distance, counterfactual value of the logarithm of imports, real exchange rate and dummies for island and NAFTA, Mercosur and Andean Community.	OLS weighted least squares and tobit.	Different periods between 1987 and 1998.
Salles *et al.* (2011)	Exports of paper and cellulose.	GDP, GDP per capita and distance between countries.	OLS.	1997-2005.
Sarmento (2012)	Imports or exports by stage of production.	MIGV, difference between GDP per capita and dummy preferential agreements (ALADI).	OLS and Poisson estimator.	1995-2011.
Vianna (2014)	Trade flow (sum of exports and imports).	MIGV, frontier effect, exchange rates and dummies for Mercosur, ALADI, NAFTA and BRICS.	Pooled OLS, Least Squares Dummy Variables, and randomly matched panels.	1993-2011.
Pereira and Almeida (2015)	Exports of paper and cellulose.	MIGV (no colonial past) and dummies for Mercosur, ALADI, NAFTA and BRICS.	Fixed-effects and random-effects models, PPML estimator and the Kyriazidou panel data estimator.	1997-2012.
Prates and Pereira (2015)	Trade flow (sum of exports and imports).	MIGV (no colonial past) and dummies for the countries' participation in economic blocks, with special emphasis on Mercosur.	Pooled OLS, Least Squares Dummy Variables, and random effects model.	2000-2012.
Cordeiro and Rodrigues Jr (2016)	Imports	MIGV, population and dummies for the countries' participation in economic blocks, with special emphasis on Mercosur.	Fixed-effects and random-effects models and PPML estimator.	1990s.
Miranda (2017)	Imports	GDP, population and dummies for trade creation and diversion.	PPML estimator.	Between 1981 and 2013.
Pintor, Schneider e Porto (2017)	Exports in the state of Paraná	MIGV (no colonial past and common language), territorial extension of international commodity prices and dummy variables for the years 2008, 2009 and 2010 for China, NAFTA, Europe and MERCOSUR	Random-effects model.	2000-2012.

Source: Authors' elaboration.

3. Methodology

3.1 Data sources

All data used in the study refer to the period 2000-2015. The GDP per capita (in current US$) and population (in number of inhabitants) are based on the World Bank Indicators; the distance between Brazil and the main destinations of its exports refers to distances (in kilometers) between the capitals of these countries, raised through the "Distance between Cities" website, which presents such distances calculated by API - Application Programming Interface Google Maps; the borders are based on the Center d'Etudes Prospectives et d'Informations Internationales (CEPII) database; the territory of each country was obtained in the Channel Countries @, from the Brazilian Institute of Geography and

Statistics - IBGE; and the trade agreements that Brazil signed with other countries were raised on the website of the Brazilian Ministry of Industry and Foreign Trade (MDIC).

Exports refer to the value exported by Brazil to its fifteen trading partners. The definition of these countries was made by surveying the average share of each of them in total exports from Brazil in the period 2000-2015 and its result presented in Table 5 (section 4). The disaggregated export data were taken from the UN Commodity Trade Statistics (UN Comtrade). These exports were grouped according to the technological intensity of the products, followed by the methodology developed by the OECD[15], which divides them into high technology, medium-high technology, medium-low technology and low-technology products. Table 2, below, details the products that fall into each of these levels of technological intensity.

Table 2 - Classification of Technological Intensity according to the OECD Disaggregation

OECD Classification	Products
High tech	Aerospace products and equipment; office and computer supplies; radio, television and communication equipment; medical instruments, optics and precision; and pharmaceuticals.
Medium-high technology	Scientific instruments; motor vehicles; electric machinery and equipment; Chemicals; machinery and mechanical equipment.
Medium-low technology	Rubber and plastic products; shipbuilding; manufactures, metal products; non-metallic mineral products; refined petroleum products and other fuels.
Low technology	Textile products leather and footwear; food, beverages and tobacco; wood, furniture, cellulose and paper; manufactured goods and recycled goods.

Source: Authors' elaboration. For more details, see Hatzichronoglou (1997).

3.2 The empirical model

The gravity model estimated in this study is based on the gravity equation proposed by Anderson and van Wincoop (2003), as shown below:

$$lnX_{ij} = \alpha_1 + \alpha_2 lnY_i + \alpha_3 \ln Y_j + \alpha_4 \ln D_{ij} + \alpha_5 \delta_{ij} + \varepsilon_{ij} \qquad (4)$$

From Equation (4), X_{ij} is the exports s from i to j; Y_i is the GDP for country i; Y_j is the GDP for country j; D_{ij} is the distance between country i and country j; and δ_{ij} is the dummies vector of variable representing the multilateral trade barriers. Anderson and van Wincoop (2003) worked with the consumption function $(\Sigma\ \beta_i\ ^{(1\text{-}\sigma)/\sigma} c_{ij}{}^{(1\text{-}\sigma)/\sigma})\ ^{\sigma/(1\text{-}\sigma)}$, in which β_i is a parameter, $\sigma > 1$ is a constant substitution elasticity between different product types and c_{ij} is the consumption of products of region i in region j. This equation is maximized by consumers, who are subject to the budget constraint given by $\Sigma p_{ij} c_{ij} = Y_j$, where p_{ij} is the price of the product of region i sold in region j. This last equation ensures that the total spending of consumers in country j is equal to the total of their consumption of different goods coming from all countries, including j. Thus $p_{ij} = p_i t_{ij}$, where p_i is the price received by the exporter and t_{ij} is the bilateral cost of trade (c_{ij}) between countries i and j. Prices differ between different locations where a product is marketed because of external trade costs, which are generally not directly observed. Assuming that these costs are incorporated in the price received by the exporter, the nominal value of the exports is given by $x_{ij} = p_{ij} c_{ij}$ and the total nominal value of the trade in the region is given by $Y_i = \Sigma x_{ij}$.

The nominal demand of the products from country i by the consumers in country j is: $X_{ij} = \left(\frac{\beta iPi\ tij}{Pj}\right)^{(1-\sigma)} Y_i$, where $P_j = [\Sigma j(\beta i\ pi\ tij)^{1-\sigma}]^{\frac{1}{1-\sigma}}$. We can find the equilibrium proposed by Anderson and van Wincoop (2003), and we arrive at the gravity equation of the model described as, $Xi = \frac{YiYj}{Y^w}\left(\frac{tij}{PiPj}\right)^{1-\sigma}$.

Having said that, the gravity model for that this paper used to estimate the determinants of Brazilian exports looks like the following:

[15] See Hatzichronoglou (1997).

$$EXP_{ijt} = \alpha + \beta_1 lnGDPPC_{it} + \beta_2 lnGDPPC_{jt} + \beta_3 lnN_{it} + \beta_4 lnN_{jt} + \beta_5 lnDIFGDPPC_{ijt} + \beta_6 lnDIST_{ij} + \beta_7 lnRELDIST_{ijt} + \beta_8 lnTARIF_{jt} + \beta_9 lnTERR_J + \beta_{10} BORDER_{ij} + \beta_{11} TRADEAGRE_{ij} + \beta_{12} CRISIS2007 + \beta_{13} CRISIS2008 + \varepsilon_{ij} \qquad (5)$$

From Equation (5),

- *i* the exporting country, Brazil, in the case of this study;
- *j* each of Brazil's main trading partners;
- α is the constant term;
- EXP_{ijt}[16] Brazilian exports to all its trading partners, in US$ in period *t*;
- $lnGDPPC_t$ the natural logarithm of GDP per capita, in US$, in period *t*;
- lnN_t the natural logarithm of the country's population in period *t*;
- $lnDIFGDPPC_{ijt}$ the natural logarithm of the absolute difference between Brazil's GDP per capita and the GDP per capita of each importing country in period *t*;
- $lnDIST_{ij}$ the natural logarithm of the geographical distance between the capital of Brazil and the capital of the importing country, in kilometers;
- $lnRELDIST_{ijt}$ the natural logarithm of relative distance, which refers to the inverse of the distance between the capital of Brazil and the capital of the importing country, weighted by the share of GDP in the world GDP in period *t*, given by $lnRELDIST_{ijt} = \sum_{j\neq i} 1/(Dist_{ij}/\frac{PIB_j}{PIBw})$.
- $lnTARIF_{jt}$ the natural logarithm of the tariffs imposed on Brazilian exports by each of its trading partners in period *t*;
- $lnTERR_j$ natural logarithm territorial area of the country *j*;
- $BORDER_{ij}$ a dummy variable that assumes the value 1 if Brazil borders the importing country and 0 if Brazil does not border the importing country;
- $TRADEAGRE_{ij}$ a dummy variable that assumes the value 1 if Brazil has a trade agreement with country j and 0 if it does not have one;
- $CRISIS2007$ a dummy variable that assumes the value 1 if the 2007/2008 International Financial Crisis affected Brazil's exports in the year 2007 and 0 if it has not affected them;
- $CRISIS2008$ a dummy variable that assumes the value 1 if the international financial crisis affected the exports of Brazil in the year 2008 0 if it has not affected them; and
- ε_{ij} the term for error.

Regarding the variables that are on the right side of the equation (5), the GDP per capita ($lnGDPPC_t$) will be used as a proxy of the capacity of the country *i* to offer and of the country *j* to demand the exported goods. With a higher GDP per capita, the exporting country is expected to be more able to invest in innovations and infrastructure, becoming more productive and prone to export. On the side of importing countries, a higher GDP per capita implies a higher purchasing power and, consequently, an increase in their demand for imports. Therefore, this variable is expected to have a positive coefficient.

In the case of population (lnN_t), this variable could mean that the country's market is large (or small), with positive impact (or negative) on the demand for goods and services. The growth of the population of the importator country can elevate Brazilian export, while the larger domestic population can reduce this exports, once low the export excess of the country[17]. Thus, this variable is expected have a positive coefficient of importator country population (lnN_{jt}) and negative to population of Brazil (lnN_{it}).

[16] The value for dependent variable is taken without log in PPML- Estimator technique.

[17] From the point of view of the factors of production, the population coefficient can be positive or negative: positive if it is considered that a larger population makes it possible to increase the division of labor in the domestic economy, increasing its

The absolute difference between the exporting country GDP per capita and the importing country GDP per capita ($lnDIFGDPPC_{ijt}$) has been added to the gravity model as a proxy for the differential development between these two countries and is used to try to identify trade patterns and also to measure the economic and technological inequalities between countries engaged in foreign trade[18]. Their coefficient can be positive or negative, depending on two basic hypotheses: the first is Linder's hypothesis, according to which countries with similar per capita income patterns have similar tastes and preferences, stimulating intra-industry trade among them, based on the exchanges of differentiated products[19]. The second is the Heckscher-Ohlin hypothesis, which assumes that the greater the difference between countries' per capita incomes, the greater will be the differences between their productive resource endowments, stimulating productive specialization between them and interindustrial trade; on the other hand, a smaller difference between those incomes would lead to a reduction in foreign trade, unlike Linder's hypothesis. In this line, the negative sign of the coefficient of absolute difference between the GDP per capita supports the Linder hypothesis, whereas the positive one bases the Heckscher-Ohlin hypothesis.

Regarding the geographical distance between the exporting country and the importing country ($lnDIST_{ij}$), this variable concerns a proxy for the cost of transport between these two countries. The greater the distance, the higher the transportation cost, which raises the price of a good in the importing country, thus reducing its demand. Therefore, the distance coefficient must be negative.

One of the problems associated with the use of geographic distance between countries as a proxy for transport costs is that trade between countries with large economies can sometimes distort the results of this variable[20]. Considering the significant participation of large economies such as China and the US in total Brazilian exports, the relative distance ($lnRELDIST_{ijt}$) was added in the model estimated in this study. The formula used to calculate this variable was suggested by Head and Mayer (2014). For these authors, this variable is also a good proxy for multilateral resistance, proposed by Anderson and van Wincoop (2003), but it is not directly observable[21]. Like for the geographical distance, the negative sign is expected for the relative distance.

The tariffs applied by countries to imported products ($lnTARIF_{jt}$) are barriers that hinder international trade. The higher the tariff, the lower the import level of the country that applies it and vice versa. It is, therefore, a variable whose expected sign for the coefficient is negative.

The coefficient of the territorial area ($lnTERR_j$) of the countries is also expected to have a negative sign. This variable is used in gravity models as a proxy for the availability of natural resources in the country. It is reasonable to assume that a country with a large territorial area has less need to import natural resource-intensive goods than another country with a small territorial area.

The dummy variable border ($BORDER_{ij}$), on the other hand, is expected to have a positive sign. A common geographical border increases bilateral trade, facilitating access for consumers and businesses to goods and services across the border and reducing the cost of transportation.

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foreign trade opportunities; and negative if a high population is considered to have a large labor supply capable of producing a wide range of goods internally and reducing their propensity for international trade.

[18] Two hypotheses were tesded in Batra (2006); Rahman (2003 and 2009); Wang and Badman (2016); Karamuriro and Karukuza (2015).

[19] Linder (1961) presupposes that the similarity of income between countries leads to internal demands with approximate structures and that the presence of increasing returns of scale makes each of these countries specialize in the production of a good. This hypothesis was revisited in Chow and Yochanan (1999) and in Choi (2002) with results that corroborated it.

[20] See Polak (1996).

[21] As a proxy for this variable, Feenstra (2003) proposes the use of fixed effects for exporters and importers for cross section estimates, while Olivero and Yotov (2012) suggest the exporter-year and importer-year form for estimates made by the data method on panel. In other works, such as those of Wei (1996) and Helliwell (1998), the multilateral resistance is presented as the geographic distance between the countries *i* and *j* and each of its commercial partners, weighted by the share of GDP of these countries on world GDP. Head (2003) and Head and Mayer (2014) suggest that this latter form of approach to multilateral resistance be changed by dividing its result by unity so as to prevent its value from becoming too large in the case of many countries distant geographically and with small economies.

Brazil is a signatory of trade agreements through which tariff preferences are applied to several of its exports. When countries form a trade agreement, they not only apply lower tariffs but also cooperate in a number of other areas with policies that reduce the overall costs of their bilateral trade and remove other trade barriers besides tariffs. The coefficient of the dummy $TRADEAGRE_{ij}$ variable is therefore expected to be positive, in order to illustrate the importance of these arrangements for domestic exports.

In order to capture the effect of the international financial crisis on Brazilian exports in the period analyzed in the study, two dummy variables were inserted, one for 2007 ($CRISIS2007$) and another one for 2008 ($CRISIS2008$), both with a negative expected sign.

Regarding the explanatory variable, the model presented in this study (Equation 5) will be estimated for total exports, exports of high technology goods, exports of medium-high technology, exports of medium-low technology and exports of low technology, as presented by the OECD export disaggregation methodology.

3.3 Estimation strategy

The estimates of the empirical model proposed in this study will be performed by the Poisson Pseudob-Maximum-Likelihood (PPML) estimator. This estimator was developed by Silva and Tenreyro (2006) use of the level of trade flow (rather than log of trade flows) as a left-hand side variable also permits to keep the zeroes in regressions and to correct heteroscedasticity problems, which are usually found in the series used in gravity models. Silva and Tenreyro (2006) point out that, in the presence of heteroscedasticity, the model estimates in the logarithm form are severely biased, distorting interpretations of their results. The authors indicate that a resolution for this problem is replacing log-linearized estimator with a multiplicative form.

Silva and Tenreyro (2006) carried out Monte Carlo simulations to defend the idea that the PPML estimator is consistent to estimate gravity models, with robust empirical results taking into account not only basic models such as those introduced by Tinbergen (1962), but also those that rely on a multilateral resistance proxy in the gravity equation, replicating the idea that was developed by Anderson and van Wincoop (2003).

Yotov *et al.* (2016) summarize the reasons for the use of the PPML estimator space in the estimations of gravity models: i) it can be applied in a gravity equation in its multiplicative form, with the elimination of possible inconsistencies caused by heteroscedasticity; ii) it deals effectively with the presence of null values in trade flows; iii) its additive property ensures that the fixed effects of its gravity equation are identical to the corresponding structural terms; and iv) it can be used to calculate the effects of trade policies consistent with general equilibrium theories.

Head and Mayer (2014) also performed Monte Carlo simulations that indicated that there are important components of robustness in the PPML estimator. In this same line, Bobkova´ (2012) carried out a study to analyze the efficiency of the estimation of gravity models based on logarithmic transformations and recommended the use of this estimator.

4. Results

All exports were analyzed in the light of the Organization for Economic Cooperation and Development (OECD) methodology for disaggregating these exports[22] . Considering this methodology, we can see that, between 2000 and 2015, Brazilian low-tech exports grew 316.87% and medium-low-tech exports grew 289.87%. These results boosted the country's total exports, whose growth in the period was 244.87%, well above the advances in high technology and medium-high technology exports that were, respectively, 48.23% and 151.64 % (TABLE 3).

[22] For more details on this methodology, see Hatzichronoglou (1997).

As a result, the Brazilian export agenda underwent significant changes in the period 2000-2015, with an increase in the participation of low and medium-low technology products and a reduction in the share of high and medium-high technology products in the total exports of the country. The combined share of the latter types of products fell from 34.15% in 2000 to 22.63% in 2015, while the combined share for the first two types increased from 65.85% to 77.37% in the same period (TABLE 4).

Table 3 – Nominal Rate of Growth of Brazilian Exports by Levels of Technological Intensity (%) – Selected Periods

OECD Classification	2000-2005	2006-2010	2011-2015	2000-2015
High tech	73,12%	9,03%	-21,47%	48,23%
Medium-high technology	104,34%	24,44%	-1,03%	151,64%
Medium-low technology	149,47%	111,30%	-26,04%	289,87%
Low technology	107,85%	74,23%	14,92%	316,18%
Total	115,68%	69,48%	-5,65%	244,87%

Source: Authors' elaboration based on data from the UN Comtrade Data.

Table 4 - Share of Exports by Degree of Technological Intensity in Total Exported by Brazil (%) - Selected Periods

OECD Classification	2000	2008	2015
High tech	7,64%	3,94%	3,28%
Medium-high technology	26,51%	18,44%	19,35%
Medium-low technology	27,42%	39,54%	30,99%
Low technology	38,43%	38,07%	46,38%

Source: Authors' elaboration based on data from the UN Comtrade Data.

As Table 5 shows, countries such as Argentina and the US have remained important destinations for shipments of Brazilian products abroad, but the main highlight in the period analyzed in the study was China, which surpassed the US as the largest importer of Brazilian products. In the first year of the 2000s, Brazil sent to Argentina and the United States, respectively, 11.39% and 23.84% of its total exports, while China's share in this total was only 1.98%; in 2010, China had already become the main market for Brazilian exports with 15.37% while the US and Argentina shares were 9.51% and 9.21%; in 2015, the US participation increased slightly to 12.71%, but Argentina's share fell to 6.78% and was China further consolidated in the first position, being responsible for 18.86% of the total exports.

Table 5 - Fifteen Main Destinations of Brazilian Exports by Degree of Technological Intensity (%) - Selected Years

Country	2000					2010					2015				
	Total	High Tech	Medium-high tech	Medium-low tech	Low tech	Total	High Tech	Medium-high tech	Medium-low tech	Low tech	Total	High Tech	Medium-high tech	Medium-low tech	Low tech
Germany	4,58%	2,68%	3,72%	4,51%	5,60%	4,04%	4,36%	5,04%	3,88%	3,69%	2,74%	4,11%	2,33%	2,31%	3,10%
Argentina	11,39%	25,86%	16,41%	9,46%	6,44%	9,21%	25,84%	25,97%	6,36%	2,34%	6,78%	15,98%	19,96%	5,30%	1,62%
Belgium	3,26%	0,54%	0,80%	4,26%	4,78%	1,74%	0,69%	0,94%	1,17%	2,81%	1,56%	0,82%	0,59%	1,38%	2,14%
Chile	2,28%	3,08%	3,34%	2,09%	1,52%	2,11%	4,70%	3,87%	2,37%	0,72%	2,11%	3,79%	2,84%	3,08%	1,03%
China	1,98%	0,61%	0,66%	2,68%	2,67%	15,37%	1,73%	2,08%	23,88%	14,38%	18,86%	4,18%	3,69%	21,89%	24,20%
Spain	1,84%	1,17%	0,45%	1,78%	2,98%	1,94%	1,06%	2,25%	1,48%	2,36%	1,57%	0,69%	0,38%	1,69%	2,06%
United States	23,84%	30,75%	31,76%	21,87%	18,41%	9,51%	11,30%	11,97%	10,63%	6,97%	12,71%	17,45%	23,07%	14,51%	6,86%
France	3,27%	0,61%	3,78%	2,32%	4,13%	1,79%	1,43%	1,42%	1,59%	2,20%	1,20%	1,72%	0,73%	0,93%	1,55%
Netherlands	5,11%	1,00%	1,40%	4,05%	9,24%	5,11%	1,10%	3,29%	4,58%	6,95%	5,32%	0,60%	3,51%	6,54%	5,60%
Italy	3,92%	1,26%	4,28%	3,43%	4,55%	2,11%	1,18%	1,12%	1,84%	2,95%	1,73%	0,82%	0,83%	1,21%	2,51%
Japan	4,52%	2,62%	2,22%	7,21%	4,57%	3,56%	0,14%	1,53%	5,48%	2,91%	2,57%	0,29%	1,09%	3,33%	2,83%
Mexico	3,13%	4,15%	7,53%	1,99%	0,70%	1,83%	3,86%	5,98%	1,05%	0,42%	1,90%	6,23%	5,01%	1,25%	0,73%
United Kingdom	2,72%	0,92%	2,56%	0,90%	4,48%	1,87%	0,52%	2,16%	1,32%	2,44%	1,17%	0,85%	0,87%	0,81%	1,55%
Russia	0,77%	0,02%	0,01%	0,05%	1,97%	2,07%	0,07%	0,11%	0,11%	5,28%	1,31%	0,14%	0,35%	0,14%	2,57%
Venezuela	1,38%	4,35%	1,88%	1,00%	0,71%	1,93%	4,96%	1,92%	0,70%	2,89%	1,58%	3,04%	1,38%	0,52%	2,27%
Main Countries	74,00%	79,62%	80,81%	67,61%	72,74%	64,18%	62,93%	69,64%	66,45%	59,30%	63,11%	60,70%	66,65%	64,89%	60,61%
Other Countries	26,00%	20,38%	19,19%	32,39%	27,26%	35,82%	37,07%	30,36%	33,55%	40,70%	36,89%	39,30%	33,35%	35,11%	39,39%
World	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Source: Authors' elaboration based on data from the UN Comtrade Data.

It is interesting to note that the Asian country gained participation in almost all levels of exports by technological intensity, but the process was more accentuated for exports of lower technology. By 2015, China's share of total exports of low-tech was 9.0 times higher than it was in 2000; of medium-low technology 8.2 times; high-tech technology 6.8 times; of medium-high technology 5.5 times (TABLE 5).

Regarding the results of the estimations, all models presented have high R^2 adjustment. The lowest one was verified in the estimation of the low technology export equation, for which 60.34% of the export variation is explained by the independent variables included in the model (TABLE 6). In the estimations of total exports, high technology, medium-high technology, and medium-low technology, the independent variables explain, respectively, 79.10%, 90.16%, 91.26% and 84.18% of the change in exports.

Table 6 - Estimates with the PPML Estimator

Variables	Total Exports	High tech Exports	Medium-high technology Exports	Medium-low technology Exports	Low technology Exports
$lnGDPPC_{it}$	-1.2089***	0.5148	-1.3194*	-0.3185	-0.3393
	(0.2961)	(.09429)	(0.7998)	(0.8345)	(0.6896)
$lnGDPPC_{jt}$	8.0292***	7.9137*	13.4883***	13.5483***	5.0310*
	(1.5729)	(4.6421)	(3.7185)	(3.4861)	(2.9704)
lnN_{it}	-27.6709***	-59.0694***	-60.1008***	-62.0376***	-18.2083
	(7.6123)	(25.4865)	(20.0262)	(18.0743)	(16.1908)
lnN_{jt}	6.8611***	8.0124*	12.8463***	10.5394***	2.8684
	(1.6288)	(4.6082)	(3.6196)	(3.4307)	(2.9033)
$lnDIFGDPPC_{ijt}$	-0.0945*	0.26262**	0.0284	-0.1912	-0.1217**
	(0.0538)	(0.1373)	(0.1059)	(0.1650)	(0.0483)
$lnDIST_{ij}$	-7.6860***	-9.17171**	-13.9373***	-11.1275***	-3.2090
	(1.6541)	(4.6710)	(3.6376)	(3.6231)	(2.9064)
$lnRELDIST_{ijt}$	-6.7901***	-7.1020	-11.6999***	-10.3854***	-3.5990
	(1.6126)	(4.6432)	(3.6572)	3.4569)	(2.9090)
$lnTARIF_{ijt}$	-73.6973	2.4592	11.8850**	4.8453	0.0326***
	(79.6433)	(3.4626)	(5.0813)	(5.4577)	(0.0105)
$lnTERR_j$	0.1623***	-0.0122	-0.2796	0.1795	0.5330***
	(0.0737)	(0.1522)	(0.1738)	(0.1716)	(0.0740)
$BORDER_{ij}$	0.3790***	1.1609***	0.1165	-0.6481**	0.9705***
	(0.1313)	(0.2101)	(0.2232)	(0.2900)	(0.1507)
$TRADEAGRE_{ij}$	0.1919	1.3863***	2.2777***	3.0211***	-0.6512**
	(0.2808)	(0.3227)	(0.6337)	(0.6885)	(0.3234)
CRISIS2007	-0.2650*	-0.3798	-0.5208***	-0.5686**	-0.1330
	(0.1551)	(0.2844)	(0.2219)	(0.2341)	(0.1961)
CRISIS2008	-0.2548	-0.5125	-0.8462***	-0.8895***	-0.1744
	(0.1713)	(0.4016)	(0.3194)	(0.3009)	(0.2516)
CONST	130.3399	308.1315***	294.0925***	303.4987***	84.2093
	(33.6459)	(117.9729)	(93.1031)	(84.7316)	(70.1766)
Nº. Obs.	152	103	102	102	103
R^2	0.7910	0.9016	0.9126	0.8418	0.6034

Robust standard error in parentheses

*** $p < 0.01$ ** $p < 0.05$ *$p < 0.1$

Source: Authors' elaboration.

With regard to the coefficients of the explained variables, we highlight the significant impact that the GDP per capita of the importing countries (*lnGDPPC*$_{jt}$) has on all the analyzed types of exports. The coefficients of this variable come with expected signs, with statistical significance in all the estimated models. This variable was the one that had the greatest positive impact in practically all types of exports analyzed, except for exports of high technology products, whose greatest positive impact came from the population of the importing country. For the total exports, the elasticity found was 8.02 and for the export equations by technological intensity, the two largest ones were the exports of medium-low technology and medium-high technology, with elasticities of 13.54 and 13.48 (TABLE 6).

Brazil's GDP per capita (*lnGDPPC*$_{it}$) had statistically significant results only for total exports and for exports of medium-high technology. As can be seen from Table 6, the signs presented by the coefficients of this variable were negative, contrary to what was expected. These results may be derived from the relatively low growth rates that have been observed in Brazil over the period analyzed, taking into account that the GDP per capita of the exporting country is a proxy for its ability to invest and increase its export capacity.

The population of the importing country (*lnN*$_{jt}$) did not have a statistically significant result only in the case of exports of low technology products. For all others, the estimated coefficient was of relevant magnitude and presented the expected sign. As already mentioned, this variable is a proxy for the size of the importing country's market, from which a positive impact on exports is expected. As with the GDP per capita variable, the elasticities of medium-low technology and medium-high technology exports were the highest among those estimated in the study.

Together, GDP per capita and population show the extent of the positive impact of the importing country's consumer market on Brazilian exports. In this line, the US and China should be specially mentioned, since they are the two largest destinations for Brazilian exports. Data from the World Bank Indicators show that these two countries had the first and third largest populations in the world in 2015[23] . The same data show that, among the OECD countries, the USA is the one that owns the fifth largest GDP per capita - behind only Luxembourg, Norway, Switzerland and Ireland - and that China has presented the highest growth rate of this variable among the countries with the largest share of world GDP, with a geometric growth rate of 13, 61% between 2000 and 2015[24].

In relation to the population of the exporting country (*lnN*$_{it}$), all the results found were of great magnitude and only the one related to exports of low technology products is not statistically significant. All these results had coefficient with a negative sign. One possible explanation for this result is that the size of the Brazilian population can reduce the country's exportable surplus, generating a negative impact on its exports.

The results found for the absolute difference between the GDP per capita of the exporting country and the GDP per capita of the importing country (*lnDIFGDPPC*$_{ijt}$) were statistically significant in the estimations of models for total exports, high technology exports and low technology exports. For total exports and for low-tech exports, the results suggest that Brazil has been exporting predominantly to countries with similar patterns of income and technological development, which may stimulate intra-industry trade, as is assumed by the Linder hypothesis. For exports of high technology products, the result found indicates that there is a trade in the Heckscher-Ohlin standard under which they would be subjected to. One possible explanation for this latter result is the significant weight the US has in total Brazilian exports of high technology products. As Table 5 shows, the US was the main destination for Brazilian shipments of this type of product over the period analyzed.

In relation to the population of the exporting country (*lnN*$_{it}$), all the results found were of great magnitude and only the one related to exports of low technology products is not statistically significant. All these results had coefficient with a negative sign[25]. One possible explanation for this result is that the

[23] The population of China in 2015 was 1.371 million people and the US population was 320.8 million. The second largest population in the world was India, with 1.309 million inhabitants. Data from the World Bank Indicators are available at https://data.worldbank.org/indicator.

[24] *See World Bank Indicators.*

[25] The negative sign for this variable was also found by Azevedo, Portugal and Barcellos Neto (2006); Cordeiro and Rodrigues Jr (2016); and Miranda (2017).

size of the Brazilian population can reduce the country's exportable surplus, generating a negative impact on its exports[26].

The results found for the absolute difference between the GDP per capita of the exporting country and the GDP per capita of the importing country ($lnDIFGDPPC_{ijt}$) were statistically significant in the estimations of models for total exports, high technology exports and low technology exports. For total exports and for low-tech exports, the results suggest that Brazil has been exporting predominantly to countries with similar patterns of income and technological development, which may stimulate intra-industry trade, as is assumed by the Linder hypothesis[27]. For exports of high technology products, the result found indicates that there is a trade in the Heckscher-Ohlin standard under which they would be subjected to. One possible explanation for this latter result is the significant weight the US has in total Brazilian exports of high technology products. As Table 5 shows, the US was the main destination for Brazilian shipments of this type of product over the period analyzed.

In the case of the absolute distance between Brazil and the destinations of its exports ($lnDIST_{ij}$), only the result of the export model of low technology products did not present statistical significance. As for the relative distance ($lnRELDIST_{ijt}$), there was not a statistical significance only for the models referring to exports of high technology and low technology products. In general, the results we found are in agreement with the one assumed by the gravity models, indicating that the transport cost has a relevant negative impact on exports. The higher the cost of transportation, the higher the final price of products for consumers living in importing countries and the lower the volume exported by Brazil. Out of the products exported by the country, the ones that seem to be most sensitive to the variation of transport costs are those of medium-high technology and medium-low technology, among which are included, for example, transport equipment, machinery and mechanical equipment, iron ore, petroleum, iron, steel and non-ferrous minerals.

The tariffs ($lnTARIF_{ijt}$) only had significant results for the models related to medium-high technology exports and low technology exports, but the signs for the elasticities were not the ones we expected. Similarly, the territorial area variable ($lnTERR_j$) had significant results for total exports and for exports of low technology products, but also did not show the expected signs.

On the other hand, the results of the frontier variable ($BORDER_{ij}$) had coefficients with the expected signs and presented statistical significance (except for the exports of products of medium-high technology products) indicating that the proximity of Brazil with its trading partners is important to stimulate its exports, be it because of the smaller geographic distance, or even the greater ease of communication and/or other factors that facilitate the access of importers to Brazilian products.

Trade agreements ($TRADEAGRE_{ij}$) also appear to be important in stimulating Brazilian exports, especially those with greater technological intensity, whose elasticities showed an expected sign and were larger than the unity. The results of this variable for total exports (without statistical significance) and for low-tech exports (with coefficient with different sign than expected) appear to have been more influenced by China and the US, which are Brazil's two largest trading partners and do not have any kind of trade agreement with the country.

Regarding the dummies variables that represent the international financial crisis of 2007/2008 (*CRISIS2007* and *CRISIS2008*), the results indicate that the total Brazilian exports were negatively impacted by the aforementioned crisis in 2007, these results did not present statistical significance for the year of 2008. Exports of medium-high and medium-low-tech products had a negative impact caused by the crisis in 2007 and 2008, while the results of high technology and low technology exports were not significant in either of these two years.

[26] By 2015, Brazil had the fifth largest population in the world, according to World Bank Indicators.
[27] A similar result for Brazil's total exports was found by Sarmento (2012).

5. Conclusion

The analysis of exports by levels of technological intensity suggests that there is a process of increasing concentration of Brazilian exports in low technology and medium-low technology products. These exports showed much higher growth than those of high technology and medium-high technology in the period analyzed in this study.

At the same time, China has increased its share of total Brazilian shipments abroad, especially those related to low-technology and medium-low technology products. This movement gives indications that the increase of Brazilian exports to China has to do with the concentration of these exports in products of lower technological intensity.

The results of the estimations showed that the variables of income and size of the consumer market of Brazil's trading partners seem to have the greatest positive influences on the country's exports. This signs two important aspects: the first is that one way to further increase Brazilian exports would be to seek preferential trade agreements with countries with potentially high consumer markets, such as China, the US and the European Union; in this sense, the results of the absolute difference between the GDP per capita of the exporting country and the GDP per capita of the importing country variable ($lnDIFGDPPC_{ijt}$) and the trade agreements variable ($TRADEAGRE_{ij}$) suggest such initiatives may contribute to increase Brazilian exports of products with greater technological intensity. The second aspect concerns the importance of Brazil continuing to diversify its trading partners in order to minimize the impacts of a possible reduction in the economic growth of large trading partners (such as China and the US) on its exports. Again, the variables $lnDIFGDPPC_{ijt}$ e $TRADEAGRE_{ij}$ become relevant as they give evidence that Brazil can increase its exports through the conclusion of preferential trade agreements with countries with levels of income and technological development similar to its own, in addition to reducing the concentration of these exports in a relatively small group of trading partners, that movement can contribute to stimulate the exports of high-tech and medium-high technology as well.

The negative impacts of the international financial crisis on Brazilian exports also suggest that the country should have as one of its goals in the external scenario the diversification of markets for these exports. This measure can act as a counterpoint to international crises, bearing in mind that the impact of these crises hardly affects all countries.

The negative coefficients of the absolute distance and relative distance gravity variables ($lnDIST_{ij}$ and $lnRELDIST_{ijt}$) and the positive ones of that which determines the effects of the existence of a common border between Brazil and the importers of its products ($BORDER_{ij}$) give relevance to the transport costs in the explanation of Brazilian exports. These results highlight the need for the country to make efforts to increase its competitiveness in the international market, since transport costs have a direct impact on the final prices of the country's products adding to that the consumers residing in the destination countries of its exports. Microeconomic measures that increase the productivity of the country are welcome to increase the country's competitiveness in both the domestic and the external scenario. Judging from the performance of exports of products with a higher technological intensity vis-à-vis products with a lower technological intensity, it is also proposed that any measures to stimulate exports should be associated with others that stimulate process and product innovations in the country.

This may end up generating a virtuous cycle, since these measures can contribute to increase the intra-industry trade between Brazil and other trading partners that have development patterns similar to its own, further stimulating the innovations and increasing the participation of the products of greater technological intensity in the total exported by the country.

6. References

ANDERSON, James. A Theoretical Foundation for the Gravity Equation. **American Economic Review**, v. 69, n.1, p. 106-116, 1979.

ANDERSON. J.; WINCOOP, E. Gravity with Gravitas: A Solution to the Border Puzzle. **The American Economic Review**, v. 93, n.1, p. 170-192, mar. 2003.

AZEVEDO, A. O efeito do Mercosul sobre o comércio: uma análise com o modelo gravitacional, **Pesquisa e Planejamento Econômico**, v.34, n. 2, p.307-339, 2004.

AZEVEDO, A.; PORTUGAL, M. S.; BARCELLOS NETO, P. C. F. de. Impactos comerciais da Área de Livre Comércio da Américas: uma aplicação do modelo gravitacional, **Revista de Economia Contemporânea**, Rio de Janeiro, v.10, n.2, p.237-267, 2006.

BATRA, Amita. India's global trade potential: The gravity model approach. **Global Economic Review**, v. 35, n. 3, p. 327-361, 2006.

BERGSTRAND, J. H. The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence. **The Review of Economics and Statistics**, n.67, p.474-481, 1985.

BERGSTRAND, J. H. The Generalized Gravity Equation, Monopolistic Competition and the Factor-Proportions Theory in International Trade. **Review of Economics and Statistics**, n. 71, p. 143-153, 1989.

BERNARD, Andrew B. *et al.* Plants and productivity in international trade. **American Economic Review**, v. 93, n. 4, p. 1268-1290, 2003.

BINH, Dinh Thi Thanh; DUONG, Nguyen Viet; CUONG, Hoang Manh. Applying Gravity model to analyze trade activities of Vietnam. *In*: **Forum for Research in Empirical International Trade Working Paper**, 2011.

BOBKOVA´, B. **Gravity model estimation using panel data** - is logarithmic transformation advisable? (Master’s thesis, IES FSV), Charles University, Prague, 2012.

BOSWORTH, Barry; COLLINS, Susan M. Determinants of US Exports to China. **Asian Economic Papers**, v. 7, n. 3, p. 1-26, 2008.

BRODZICKI, Tomasz *et al*. **Extended gravity model of Polish trade. Empirical analysis with panel data methods**, Instytut Rozwoju, Institute for Development, 2015.

CASTILHO, M. **Acesso das exportações do Mercosul ao Mercado Norte-Americano**. Rio de Janeiro: IPEA, 2001. (Texto para discussão nº 851).

CHOI, Changkyu. Linder hypothesis revisited. **Applied Economics Letters**, v. 9, n. 9, p. 601-605, 2002.

CHOW, Peter; YOCHANAN, Mitchell Kellman. A test of the Linder hypothesis in Pacific NIC trade 1965-1990. **Applied Economics**, v. 31, n. 2, p. 175-182, 1999.

CORDEIRO, Bruno Ferreira *et al.* **Os impactos do Mercosul sobre o comércio: uma abordagem gravitacional**. Universidade de São Paulo (FEA-USP), 2016.

DAUMAL, Marie; ZIGNAGO, Soledad. The border effects in brazil. **CEPII**, v. 9, 2005.

DEARDORFF, A. **Determinants of Bilateral Trade: Does Gravity Work in a Classical World?** National Bureau of Economic Research, n. 5.377, 1995.

DIDIER, Laurent; KOENIG, Pamina. Has China Replaced Colonial Trade ?. **PSE Working Papers** n. 2016-23. 2016.

DLAMINI, Sotja G. *et al.* Determinants of Swaziland's Sugar Export: A Gravity Model Approach. **International Journal of Economics and Finance**, v. 8, n. 10, p. 71, 2016.

EATON, Jonathan; KORTUM, Samuel. Technology, geography, and trade. **Econometrica**, v. 70, n. 5, p. 1741-1779, 2002.

EITA, J.H. **Determinants of Namibian Exports: A Gravity Model Approach**. Paper presented at the 13th African Econometric Conference, University of Pretoria, South Africa, Jul, 2008.

FEENSTRA, R. **Advanced International Trade**: theory and evidence, Princeton University Press, 2003.

GUERRIERI, Paolo. **Technology and International Trade Performance in the Most Advanced Countries**. UCAIS Berkeley Roundtable on the International Economy, UC Berkeley, 1991.

HATAB, Assem Abu; ROMSTAD, Eirik; HUO, Xuexi. Determinants of Egyptian agricultural exports: A Gravity model approach. **Modern Economy**, v. 1, n. 03, p. 134, 2010.

HEAD, Keith. **Gravity for beginners, University of British Columbia**. mimeo, 2003.

HEAD, Keith; MAYER, Thierry. Gravity equations: Workhorse, toolkit, and cookbook. *In*: **Handbook of international economics**. Elsevier, 2014. p. 131-195.

HELPMAN, E., MELITZ, M., RUBINSTEIN, Y. Estimating Trade Flows: Trading Partners and Trading Volumes. **Quarterly Journal of Economics**, n.123, v.2, p.441–487, 2008.

HIPPOLYTE, Rommell. **Determinants of Barbados Exports: Preliminary Analysis using a Gravity Model Approach**, 2012. (MPRA_paper_75557).

HUSSAIN, Mubashir. Globalization and Gravity Model of Trade of Pakistan"- A PPML Estimator Analysis. **Management and Administrative Sciences Review**, v. 6, n. 1, p. 15-27, jan. 2017.

IWASAKI, Ichiro; SUGANUMA, Keiko. A gravity model of Russian trade: the role of foreign direct investment and socio-cultural similarity. **RRC Working Paper Series 40**, Russian Research Center, Institute of Economic Research, Hitotsubashi University, 2013.

KAHFI, Ahmad Sohibil. Determinants Of Indonesia's Exports Of Manufactured Products: A Panel Data Analysis. **Buletin Ilmiah Litbang Perdagangan**, v. 10, n. 2, p. 187-202, 2016.

KARAMURIRO, Henry Tumwebaze; KARUKUZA, Wilfred Nahamya. Determinants of Uganda's Export Performance: a gravity model analysis. **International Journal of Business and Economic Research**, v. 4, n. 2, p. 45-54, 2015.

KYRIAZIDOU, E. Estimation of a panel data sample selection model. **Econometrica**, n.65, v,6, p.1335–1364, 1997.

LINDER, S. B. **An Essay on Trade and Transformation**, New York: John Wiley and Sons, 1961.

LINNEMANN, H. **An econometric study of international trade flows**. Amsterdam: NorthHolland Publishing Co., 1966.

MÁRQUEZ-RAMOS, Laura. Understanding the determinants of international trade in African countries: An empirical analysis for Ghana and South Africa. **Instituto de Economía Internacional**, 2007.

MCCALLUM, J. National Boarders Matter. **American Economic Review**. v. 85, n. 3, p. 667-699, 1995.

MIRANDA, Rebeca Gouget Sérgio. **Impacto dos acordos comerciais do Brasil: aplicação do modelo gravitacional.** 117f. (tese de doutorado). Universidade de Brasília, 2017.

MIROUDOT, Sébastien; SHEPHERD, Ben. **Regional Trade Agreements and Trade Costs in Services**, 2015.

PEREIRA, Franciele de Oliveira; ALMEIDA, Alexandre Nunes de. O impacto das medidas técnicas sobre as exportações brasileiras de papel e celulose. **Revista de Economia e Agronegócio**, v. 12, n. 1, 2, 3, 2015.

PIANI, Guida; KUME, Honório. **Fluxos bilaterais de comércio e blocos regionais: uma aplicação do modelo gravitacional**, Ipea, 2000 (Texto para discussão n. 749).

PINTOR, Geisiane Michelle Zanquetta de; SCHNEIDER, Mirian Beatriz; PORTO, Paulo Costacurta Sá. O Impacto da Crise Financeira de 2008-2009 Sobre as Exportações Paranaenses: uma aplicação do modelo gravitacional. **Orbis Latina**, v. 6, n. 1, 2017.

POLAK, J. Is APEC a natural trading bloc? A critique of the gravity model of international trade. **World Economy**, v.19, 1996.

PÖYHÖNEN, P. A Tentative Model for the Volume of Trade between Countries, **WeltwirtschaftlichesArchiv**, n. 90, v. 1, p. 93-99, 1963.

PRATES, Rodolfo Coelho; PEREIRA, Heliara Pacheco. Análise dos fatores determinantes do comércio internacional brasileiro: uma análise do modelo gravitacional. **Reflexões Econômicas**, v. 1, n. 1, p. 105-129, 2015.

RAHMAN, Mohammad Mafizur. Australia's global trade potential: evidence from the gravity model analysis. In: **Proceedings of the 2009 Oxford Business and Economics Conference (OBEC 2009)**. Oxford University Press, 2009. p. 1-41.

RAHMAN, Mohammad Mafizur. A panel data analysis of Bangladesh’s trade: the gravity model approach. *In*: **Proceedings of the 5th Annual Conference of the European Trade Study Group (ETSG2003)**. European Trade Study Group, 2003.

ROY, Mili; RAYHAN, M. I. Trade flows of Bangladesh: A gravity model approach. **Economics Bulletin**, v. 31, n. 1, p. 950-959, 2011.

SARMENTO, Karla. OS ACORDOS DA ALADI ESTIMULAM A INTEGRAÇÃO PRODUTIVA? **Prêmio Jovens Economistas, documento**, v. 1, 2012.

SILVA, JMC Santos; TENREYRO, Silvana. The log of gravity. **The Review of Economics and statistics**, v. 88, n. 4, p. 641-658, 2006.

SOHN, Chan-hyun; YOON, Jinna. Does the gravity model fit Korea's trade patterns?. **Seoul: Korean Institute of Economic Policy**, 2001.

TINBERGEN, J. **Shaping the World Economy: Suggestions for an International Economic Policy**, New York: The Twentieth Century Funds, 1962.

VIANNA, André Coelho. **Uma análise empírica do comércio exterior brasileiro por meio da equação da gravidade**. 2014. 76 f., il. Dissertação (Mestrado em Economia do Setor Público) - Universidade de Brasília, Brasília, 2014.

WANG, Xu; BADMAN, Ryan P. A Multifaceted Panel Data Gravity Model Analysis of Peru's Foreign Trade. **arXiv preprint arXiv:1612.01155**, 2016.

WEI, Shang-Jin. **Intra-national versus international trade: how stubborn are nations in global integration?** National Bureau of Economic Research, 1996.

YESHINEH, Alekaw Kebede. **Determinants and Potential of Foreign Trade in Ethiopia**: A Gravity Model Analysis, 2014.

YOTOV, Y. *et. al*. An Advanced Guide to Trade Policy Analysis: The Structural Gravity Model. **World Trade Organization,** Genebra, 2016.