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Dynamics of Foreign Trade in Brazilian States

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Abstract

This study analyzes the impact of real exchange rate devaluations on the trade balance of Brazilian states by major economic categories (capital goods, intermediate goods, consumer goods, and fuels and lubricants), testing the J-Curve hypothesis and the Marshall-Lerner Condition. A panel autoregressive distributed lag (PARDL) model was applied to annual data from 26 Brazilian states (2000–2020), using Driscoll and Kraay's (1998) robust covariance correction to address cross-sectional and temporal dependence. This correction is robust to general forms of cross-sectional (spatial) or temporal dependence, typically present in data of this nature. The results suggest that real exchange rate devaluations have negative impacts on the trade balance across all sectors analyzed in the short term, followed by a positive and elastic long-term impact in most categories - except for fuels and lubricants, where there is evidence only of the initial phase of the J-curve phenomenon.

Keywords: J-Curve, Marshall-Lerner Condition, Cross-Section Dependence

1. Introduction

The study of exchange rate fluctuations and their impact on the trade balance has been the focus of extensive research in theoretical and empirical literature in recent decades. This is because this indicator is often identified as one of the key determinants of a nation's trade performance, reflecting the country's competitiveness on the global stage and proving relevant for economic policy decision-making.

In traditional international trade theory, real exchange rate devaluations can influence the relative prices of tradable goods, boosting exports over imports and improving an economy's trade balance. Currency devaluation is, therefore, seen as increasing external competitiveness, stimulate exports, and improve the trade balance of economies to promote economic growth (Dash, 2013; Carneiro, 2014; Arize et al., 2017; Nusair, 2017).

Economic theory also emphasizes that currency devaluations can impact short—and long-term horizons differently. More specifically, such devaluations may have negative repercussions on the trade balance in the short term before reverting to the long-term trajectory, where they are expected to result in surpluses (Bahmani-Oskooee & Ratha, 2004).

In this line, several studies have examined to what extent and under what theoretical conditions economies that presented trade deficits could achieve surplus results through exchange rate devaluation. The literature has investigated one focus of this relationship: the empirical regularity of the J-Curve phenomenon and the validity of the Marshall-Lerner Condition (MLC). These concepts would explain the short-term adverse and long-term positive effects of a currency devaluation on net exports.

The underlying hypothesis of the J-Curve phenomenon is associated with the occurrence of a deterioration in the trade balance in the short term, followed by an improvement in the long term in response to a currency devaluation. Authors such as (Xu, Bahmani-Oskooee & Karamelikli, 2022; Sonaglio, Scalco & Campos, 2010) attribute the initial negative effect to certain short-term rigidity in the prices of exports and imports agreed upon in exchange contracts and the necessary gap for adjusting production capacity in response to the lag in the decision-making process of agents. On the other hand, the MLC confirms whether the long-term impact of devaluations in the real exchange rate on the trade balance is positive and statistically significant (Bahmani-Oskooee & Fariditavana, 2015).

Due to the importance of these concepts and their effects on short- and long-term dynamics on the performance of an economy's trade balance, the precise measurement of trade performance has become extremely important for the assessment of trade policy, and several empirical approaches have been used to investigate certain countries that are satisfied or not with those mentioned above. For the Brazilian economy, authors such as Sonaglio, Scalco and Campos (2010), Mortatti, Miranda and Bacchi (2011), Scalco, Carvalho and Campos (2012), Mustafa, Rahman and

Guru-Gharana (2015), Ramos Filho and Ferreira (2016), Arruda, Martins and Castelar (2019), Arruda, Brito and Castelar (2022), present their contributions.

Even with the recent increase in the number of studies on the topic, the literature that addresses these phenomena for the Brazilian economy is far from a consensus, especially from regional and sectoral perspectives. Furthermore, the investigations leave open a gap regarding empirical applications, especially with the use of panel data; that is, although the panel approach presents several advantages compared to pure time series or cross-section models, such as control due to individual heterogeneity, the possibility of information with greater data variation, minimization of aggregation bias, lower collinearity and greater degrees of freedom, the methodology does not seem to have attracted researchers as strongly, having received limited consideration in the investigation of phenomena such as the J-Curve and the MLC.

A first effort regarding regional exercises using state panel data in Brazilian literature can be seen in Arruda and Martins (2020). The authors investigate the phenomena of the trade balance of basic and industrialized goods for a panel containing 10 Brazilian states between 1999 and 2015, with the application of Panel Vector Autoregression (PVAR) models, to test the occurrence of the J phenomenon and the Panel Dynamic Ordinary Least Squares (PDOLS), to investigate the validity of the MLC. The results confirmed the MLC in all analyses and the J phenomenon only for industrialized ones.

In international literature, panel data methods are more commonly employed to investigate the phenomena of the J-curve and the MLC, focusing on analyses of bilateral trade balances between countries without emphasizing regional and sectoral aspects in their analyses.

In recent decades, the literature on dynamic panels has shifted towards studying situations where both the time dimension (T) and the cross-sectional dimension (N) are relatively large. Typically, this is applied to data sets where the cross-section is represented by countries, states, municipalities, or regions within countries (Blackburne & Frank, 2007). However, in many applications, strong assumptions of homogeneity in the estimated relationships persist, along with the use of estimators that assume cross-sectional independence.

Nevertheless, an essential element in this context is the potential occurrence of dependence between the panel units due to the existence of unobservable common factors. In economic terms, these factors can include global events, such as pandemics or economic recessions, spillover effects, such as the diffusion of new products, or technological changes, whose effects simultaneously affect the cross-sectional units. Ignoring this issue in the estimation process can lead to biased results, as these factors generate correlations between the panel units (Hoecley, 2007; Bailey et al., 2015; Pesaran, 2015). Notably, this problem is mainly present in panels with regional and sectoral data. To address these issues, more recent studies on non-stationary dynamic panels have begun to consider estimators that allow for potential heterogeneous effects in the relationships between variables across the panel units and take cross-sectional dependence into account in their dynamics.

In this line, the present study aims to move in this direction by employing panel data in a regional context for Brazilian states, using techniques robust to potential heterogeneity and cross-sectional dependence effects. Specifically, the study utilizes the Panel Autoregressive Distributed Lag (PARDL) framework to estimate short and long-term relationships between currency devaluations and the trade balance of Brazilian states. This is followed by the application of the non-parametric covariance matrix algorithm of Driscoll and Kraay (1998), which produces standard error estimates robust to various forms of cross-sectional (spatial) or temporal dependence - an exercise not yet undertaken for Brazil in regional and sectoral perspectives.

Therefore, this study contributes to the panel data literature investigating the J-Curve and MLC phenomena by applying robust estimators to account for cross-sectional (spatial) or temporal dependence in a regional and sectoral context. This is done by considering information from all 26 Brazilian states and the classification of products into major economic categories (MEC). Specifically, the categories include capital goods, intermediate goods, consumer goods, and fuels and lubricants.

In this way, this research seeks to answer the following research hypotheses: considering large categories of economic goods, is there evidence of a J-curve in Brazilian states? In the long term, also considering large economic categories, is the effect of a currency depreciation compatible with the Marshall-Lerner condition? That is, is the effect of a currency depreciation positive on the trade balance of the capital goods, consumer goods, intermediate goods, and fuels and lubricants sectors? Thus, this article adds to the literature by performing estimations at the subnational level and considering large economic categories, which, to the authors' best knowledge, has not yet been done in the empirical literature of this area.

The continental dimension of the Brazilian economy and the significant economic and productive diversity among its states justify this approach. It is essential to emphasize that Brazilian states interact through trade and are nationally and geographically connected, sharing common histories. Therefore, the various exchange rate policies employed since the

late 1990s in the Brazilian economy, its recent advancement in global trade chains, substantial inter and intraregional disparities, and the vulnerability of emerging economies to internal and external shocks provide additional motivation for studies that develop into the investigation of short and long-term dynamics for foreign trade. This will be addressed within a panel data framework considering the potential effects of interdependence between states.

In summary, the study analyzes the short and long-term relationships between real devaluation in the exchange rate and the trade balance of Brazilian states according to major economic categories. To do so, it utilizes annual data for 26 Brazilian states from 2000 to 2020 and employs the framework of autoregressive models with distributed lags in a panel setting (PARDL) with standard error correction based on Driscoll and Kraay (1998).

In addition to this introduction, the study comprises four additional sections. The subsequent section provides a literature review on J Curve's regularity and the MLC's validity. Following that, methodological aspects are presented, including a description of the database and the trade balance profile of Brazilian states based on major economic categories, along with an outline of the econometric strategy employed. The fourth section is dedicated to the analysis and discussion of the results. Lastly, concluding remarks are offered.

2. Literature Review

The literature examining the issue of this research is extensive. This section is dedicated to conducting a survey of the key works that employ panel techniques to assess the occurrence of the J-curve phenomenon and the MLC.

Investigating the MLC hypothesis for the Swedish economy, Hatemi-J and Irandoust (2005) examine the bilateral elasticities between Sweden and its major trading partners (Denmark, France, Germany, Norway, the United Kingdom, and the USA) for the period from 1960 to 1999. They employ Ordinary Least Squares with Dummy Variables estimator and panel unit root techniques, specifically Levin, Lin, and Chu (2002), Im, Pesaran, and Shin (2003), and cointegration analysis as proposed by Pedroni (1997). The results indicate that the MLC is only confirmed in the bilateral relationship with Germany. Using the same techniques, Irandoust et al. (2006) expanded the previous study by adding Finland and the Netherlands as trading partners to investigate the phenomenon between 1960 and 2001. The empirical results confirm the MLC only in Sweden's bilateral relationship with France and the Netherlands.

For the Chinese economy, Wang, Lin, and Yang (2012) estimate the short and long-term relationships of real exchange rate devaluations in bilateral balances between China and its 18 most significant trading partners, including Brazil. They use a monthly panel dataset covering 2005 to 2009 and employ the Panel Fully Modified Ordinary Least Squares (PFMOLS) and the Panel Error Correction Model (PECM) estimators. The results reveal indications of an incomplete J-curve phenomenon, where, after a currency devaluation, there is a short-term negative effect that does not reverse in the long term. This phenomenon is observed only in relations with the United States, Japan, and the United Kingdom, indicating the absence of the MLC in any of the bilateral trade relationships in the study.

Using panel data from 33 countries, including Brazil, Yazgan and Ozturk (2018) test the occurrence of the J-curve and MLC hypothesis for bilateral trade flows of each of these countries vis-à-vis their major trading partners. The authors employ techniques to accommodate heterogeneous effects in the response of bilateral balances to changes in the real exchange rate and potential interdependence effects among trading partners. They use a Panel Error Correction Model (PECM) and Common Correlated Effects Mean Group (CCEMG) estimators to infer short-term effects and the pooled version, assuming coefficient homogeneity, to investigate long-term effects. The long-term analysis reveals that, for most countries, a real devaluation of the national currency has favorable effects on the country's trade balance, validating the MLC. However, no short-term evidence in favor of the J-curve was observed.

Ebadi (2020) examines the validity of the MLC hypothesis using panel data from two groups of countries. The first group comprises 22 OECD countries, and the second group comprises 10 Asian countries, covering the period from 2000 to 2017. The author adopts the econometric strategy of heterogeneous dynamic panels using Pooled Mean Group (PMG) estimations to obtain the best long-term elasticities in export and import demand models. The results indicate the occurrence of the MLC only for the 10 Asian countries.

Kaya (2021) tests whether the MLC hypothesis holds for Turkey's bilateral trade balances after the Customs Union by analyzing the effects of the real exchange rate on bilateral trade balances between Turkey and its top 25 trading partners. The study employs heterogeneous panel techniques and estimators, including Common Correlated Effects Mean Group (CCEMG) and Augmented Mean Group (AMG). The results indicate that the MLC is valid at the bilateral level for the United States, Belgium, Spain, Switzerland, Romania, and Russia.

For the Turkish economy, Gözen and Bostanci (2021) examine the J-curve phenomenon using a panel with annual data on bilateral balances between Turkey and its major trading partners from 1995 to 2018. The authors employ the Panel Dynamic Ordinary Least Squares (PDOLS) estimator for group means, along with preliminary techniques for unit root presence, structural break, and cointegration, following the approach of Westerlund (2007). For each country, the estimation results via PDOLS do not provide any evidence in favor of the occurrence of the J-curve phenomenon.

Investigating these phenomena for a panel of 10 selected Sub-Saharan African countries between 1970 and 2020, Abille and Meçik (2023) employ the panel ARDL framework using (PMG – ARDL) and Mean Group (MG-ARDL) estimations. The conclusions of the PMG-ARDL model reveal the occurrence of the complete J-curve only in Cameroon, Burkina Faso, and Gambia. In the remaining countries, real exchange rate devaluations do not lead to a short-term deterioration but only a positive long-term effect, thus validating only the MLC. In the MG-ARDL estimations, the complete J-curve phenomenon is observed only in Ghana and Cameroon.

Thus, the review presented above clearly reveals the absence of studies of this nature for panel data from a regional and sectoral perspective, especially in exercises for Brazil, an economy with continental dimensions and significant regional differences.

In this context, Moraes et al. (2015) conducted a study for Rio Grande do Sul, considering the total balance, basic products, and industrialized products, using monthly data from January 1999 to May 2014 and the Vector Error Correction Model (VECM). The results do not confirm the occurrence of the J-curve phenomenon. Employing the same methodological framework for the state of Ceará, Arruda and Martins (2016) confirm the J-curve only for aggregate net exports and industrialized products.

Arruda, Castelar, and Martins (2019) examine the validity of the MLC hypothesis for the trade balance of the Southern region of Brazil using monthly data from 1999.1 to 2013.7 and Vector Error Correction Models (VECM). The results confirm the occurrence of the MLC with elasticities of the real exchange rate ranging between 2.76 and 5.55.

Arruda and Martins (2020) investigate the long-term impacts of currency devaluations on total net exports and basic and industrialized products for a panel with information from 10 Brazilian states using Panel Dynamic Ordinary Least Squares (PDOLS) and monthly data from 1999 to 2015. The evidence indicates the validity of the MLC in all considered models, with estimated elasticities concerning the real exchange rate ranging between 1.01 and 1.57, between 0.28 and 0.99 concerning external income, and between -0.19 and -0.25 concerning domestic income.

Recently, Souza (2022) analyzed the J-curve phenomenon for the aggregate trade balance of the Northeast region with the rest of the world using Vector Error Correction Models (VECM) and impulse response functions, finding no evidence of the phenomenon for this region. Through ARDL techniques, Seibert et al. (2023) assess the J-curve and MLC phenomena for the agricultural trade balance of the Midwest between 1999 and 2019. The authors do not find consistent evidence supporting the validity of either phenomenon.

In summary, despite the mentioned contributions, there is a noticeable scarcity of studies examining the J-curve and the validity of the MLC in a regional context, especially from sectoral perspectives. For Brazil, it is evident that a significant portion of the associated literature has predominantly used pure time series frameworks to investigate these phenomena, leaving a gap for other econometric approaches, such as panel data, which offer the opportunity to examine these phenomena within a regional perspective by considering states, municipalities, or regions along their individual trajectories over time. Although panel econometrics is more widely employed in international literature, the focus has primarily been on analyzing bilateral balances between countries, with limited emphasis on regional aspects. In this line, this study innovates by investigating the phenomena of the J-Curve and the validity of the MLC from a regional and sectoral perspective, using a panel data framework that allows for estimators to accommodate heterogeneous dynamics and mitigate possible violations arising from cross-sectional dependence among the units of the study.

3. Methodology

3.1 Data Source and Descriptive Analysis of Variables

In this work, the trade balance of Brazilian states will be analyzed according to the Major Economic Categories (MEC), developed and made available by the Ministry of Development, Industry, and Foreign Trade (MDIC).

According to this classification, the exported and/or imported products are hierarchically organized based on the destination and use of the goods produced into six economic groups: capital goods, intermediate goods, consumer goods, including durable consumer goods, semi-durable consumer goods, and non-durable consumer goods, fuels and Lubricants, and Unspecified Goods. Chart 1 outlines the structure of the categories and subcategories of the MEC (Ministry of Development, Industry, and Foreign Trade [MDIC], 2016).

The panel contains annual information for the 26 Brazilian states between 2000 and 2020. Chart 2 presents a summary of the variables used and their respective sources. The trade balance indicator or net exports is given by the logarithm of the ratio between exports and imports, constructed by taking the values of exports and imports for the Brazilian Federative Units (excluding the Federal District) for the sectors according to the MEC. The information was extracted from the Foreign Trade Secretariat of the Ministry of Development, Industry and Foreign Trade (MDIC, 2016).

Chart 1. Classification by Major Economic Categories

Capital Goods

- Capital goods, except industrial transport equipment
- Industrial transport equipment

Intermediate Goods

- Basic foods and beverages, mainly intended for industry
- Elaborate foods and beverages, mainly intended for industry
- Basic industrial inputs
- Elaborate industrial inputs
- Parts and accessories for capital goods
- Parts and accessories for transport

Consumer Goods

- **Durable consumer goods**
  - Durable consumer goods – except transport equipment
  - Passenger cars
  - Non-industrial transport equipment
  - **Semi-durable and Non-Durable Consumer Goods**
  - Semi-durable consumer goods
  - Non-durable consumer goods
  - Basic foods/beverages, mainly intended for domestic consumption
  - Prepared foods/beverages intended mainly for domestic consumption

Fuels and Lubricants

- Basic fuels and lubricants
- Elaborate fuels and lubricants
  - Gasoline for cars
  - Fuels and lubricants prepared except gasoline for automobiles

Source: Prepared by the authors.

The exchange rate measure used in this study is the real effective exchange rate (REER), employed as a gauge of the level of external competitiveness of an economy, available in the Time Series Generator System of the Central Bank of Brazil (BCB-SGS). The indicator is based on the Wholesale Price Index - Internal Availability (IPA-DI), as it only assesses tradable goods. The proxy for state economic activity (or state domestic income) is represented by the Gross Domestic Product (GDP) of the Brazilian states, developed and provided by the Brazilian Institute of Geography and Statistics (IBGE). The indicator was deflated using the Wholesale Price Index - Internal Availability (IGP-DI) from the Getúlio Vargas Foundation (FGV). Finally, the proxy for foreign income, or global demand, is represented by the value of total world imports in current dollars (CIF - Cost, Insurance, and Freight), compiled by the Direction of Trade Statistics (DOTS) and published by the International Monetary Fund (IMF). The values were appropriately deflated using the Index of Prices for Total World Imports, available in the Federal Reserve Economic Data of St. Louis (FRED).

Chart 2. Description of the Variables

Variable	Proxy	Period	Source
Real Exchange Rate $_{it*}$ (REER)	Natural logarithm of the real effective exchange rate of state *i* in year *t*	2000–2020	BCB-SGS
Domestic Income$_{it}$	Natural logarithm of GDP in state *i* in year *t*	2000–2020	IBGE
Foreign Income$_{it*}$	Natural logarithm of the value of total world imports in current dollars	2000–2020	DOTS-FMI
Trade Balance of Capital goods$_{it}$ (TBK)	Natural logarithm of the balance of capital goods of state *i* in year t	2000–2020	MDIC
Trade balance of Intermediate Goods$_{it}$ (TBI)	Natural logarithm of the balance of intermediate goods of state *i* in year t	2000–2020	MDIC
Trade balance of Consumer Goods$_{it}$ (TBC)	Natural logarithm of the balance of consumer goods of state *i* in year t	2000–2020	MDIC
Trade balance of Fuel and Lubricants (TFL)	Natural logarithm of the Fuel and Lubricants balance of state *i* in year *t*	2000–2020	MDIC

Source: Prepared by the authors. Note. * The external income and real exchange rate variables are the same for all units in the panel.

It is important to highlight that the REER and Foreign Income variables are common to all states in the sample and, therefore, some local variations are not captured by these proxies. For example, changes in the income of a country that is relatively more important to the trade balance of a given state will not be properly captured by the proxy for external income used.

Table 1 summarizes the descriptive statistics for the set of variables[1] used in the study based on sample information from the 26 Brazilian states between 2000 and 2020. In summary, each variable in the panel consists of 546 observations, except for the trade balance of fuels and lubricants, which had fewer observations due to missing values for some Brazilian states over the analyzed years.

Table 1. Descriptive Statistics of the Series Used in the Study

Variable	Mean	Standard Deviation	Minimum	Maximum
Capital Goods	-243,15	810,12	-6.417,94	4.822,73
Intermediate Goods	908,06	5.489,86	-24.812,93	31.695,05
Consumer Goods	331,74	1.025,06	-2.903,09	7.595,24
Fuel and Lubricants	-89,37	2.155,76	-9.146,33	17.467,71
Real Exchange Rate	99,54	22,35	68,36	148,35
Foreign Income	95,45	11,70	74,95	112,34
Domestic Income	207.322,50	385.077,30	6.780,08	3.464.724,69

Source: Prepared by the authors. Notes: The variables of trade balance and foreign income are in millions of dollars. Domestic income is in millions of reais, 2019 values. Except for the fuel and lubricants sector, with 507 observations, the other variables correspond to 546 observations each.

In general terms, the average trade balance of Brazilian states by MEC showed a surplus for intermediate and consumer goods while reporting a negative average balance for the capital goods and fuels and lubricants sectors. The trade balances of the intermediate goods and fuels and lubricants sectors exhibit the most comprehensive ranges, while the capital goods sector reported a lower dispersion. The average domestic income observed in Brazilian states was R$ 207.32 billion, with a standard deviation of 385.07 billion, highlighting the significant economic disparity among Brazilian states.

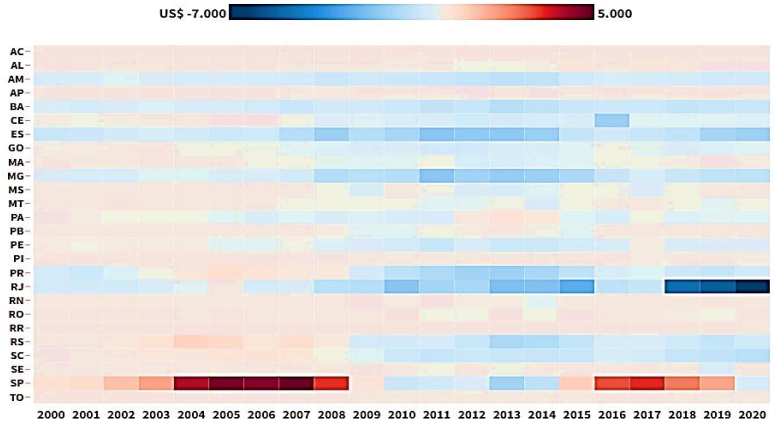


Figure 1. Trade Balance of Brazilian states by Capital Goods FOB (Million US$)

Figures 1 to 4 describe the trajectory of trade balances for the federative units through heatmaps, providing an overview of the trade flows for the 26 Brazilian states according to the MEC. These heatmaps highlight, through a performance scale, the states' trade results in each MEC sector.

Considering the capital goods sector in Figure 1, it is noticeable that the state of São Paulo stands out, showing a surplus in most of the sample, with a significant highlight between 2000 and 2009. However, it started to exhibit a trade deficit, returning to contribute surpluses for the sector in 2015. On the other hand, the worst trade result in the sector can be observed in the trade balance of Rio de Janeiro, which showed a deficit in all periods of the sample, with a higher magnitude between 2017 and 2020.

A similar analysis can be conducted for the intermediates sector, as shown in Figure 2, where the most significant positive contributions come from the states of Minas Gerais, Espírito Santo, and Pará, presenting a positive balance throughout the series. Minas Gerais stands out, particularly between 2008 and 2015, when it intensified these gains. On the other hand, the largest deficits in the sector are recorded in the trade balances of the states of São Paulo and Amazonas, with São Paulo experiencing more intense deficits between 2008 and 2015.

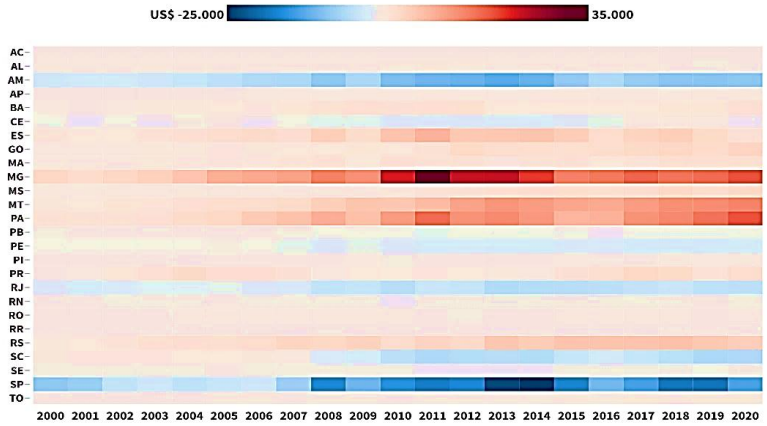


Figure 2. Trade Balance of Brazilian states by Intermediate Goods FOB (Million US$)

Figure 3 illustrates the state-level trade flows for Consumer Goods, where the states of São Paulo, Paraná, and Rio Grande do Sul stand out with more intense and persistent surpluses during the analyzed period. On the other hand, the most significant deficits are recorded in the trade balances of the states of Rio de Janeiro, Espírito Santo, and Goiás, particularly between 2008 and 2015.

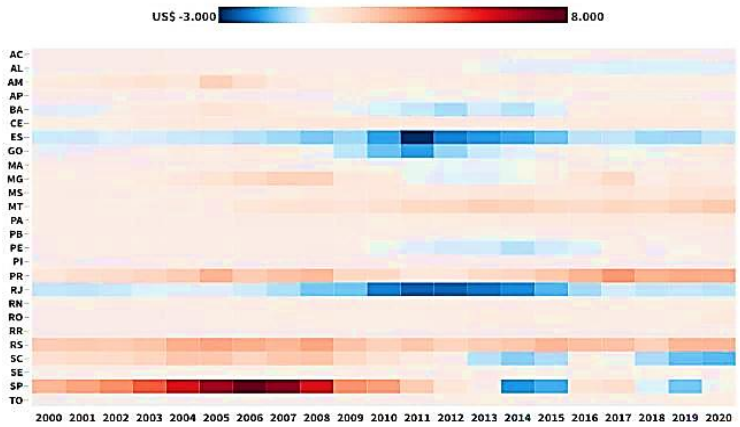


Figure 3. Trade Balance of Brazilian states by Consumer Goods FOB (Million US$)

Considering the trade balance of Fuel and Lubricants in Figure 4, the heatmaps indicate a surplus trajectory in the trade balance of the state of Rio de Janeiro for most periods, with more significant gains from 2006 onwards. Observing the trade deficits, the most significant impacts can be seen in the trade balances of the states of São Paulo, Minas Gerais, Mato Grosso do Sul, and Maranhão between 2007 and 2011 and between 2010 and 2015.

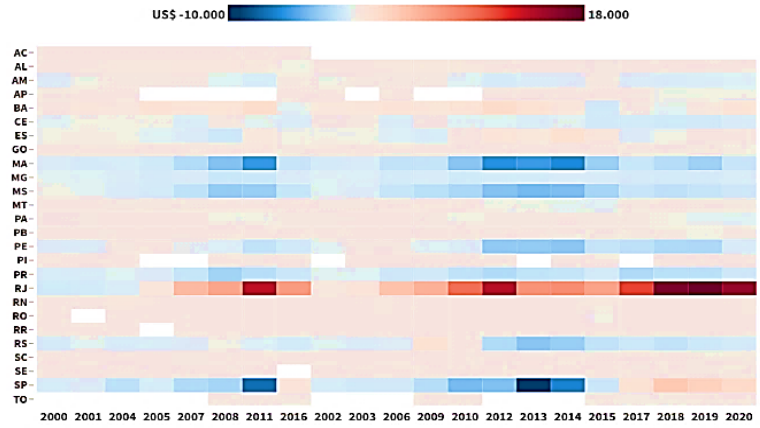


Figure 4: Trade Balance of Brazilian states by Fuels and Lubricants FOB (Million US$)

Finally, Figures 5 to 8 provide a geographical perspective comparison between the first and last years of the sample. In general terms, the most significant changes were found in the sectors of consumer goods and fuels and lubricants.

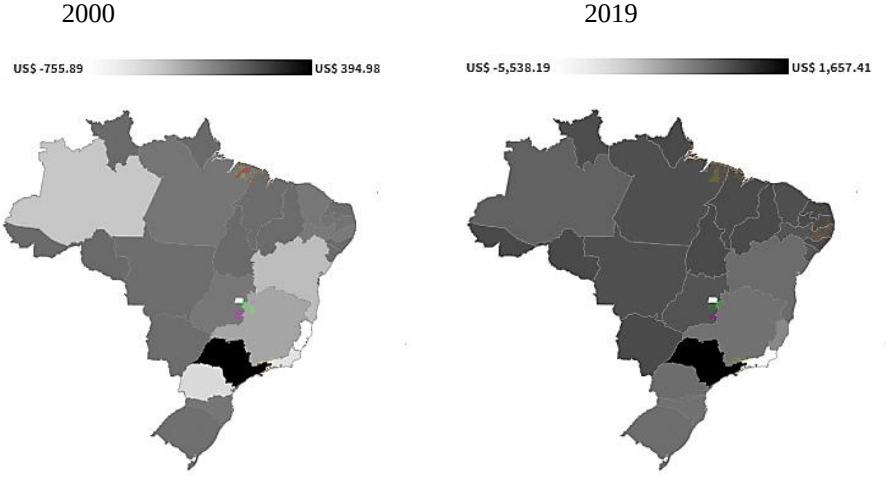


Figure 5. Geographic Comparison of Capital Goods Balance, 2000-2019, FOB Million US$

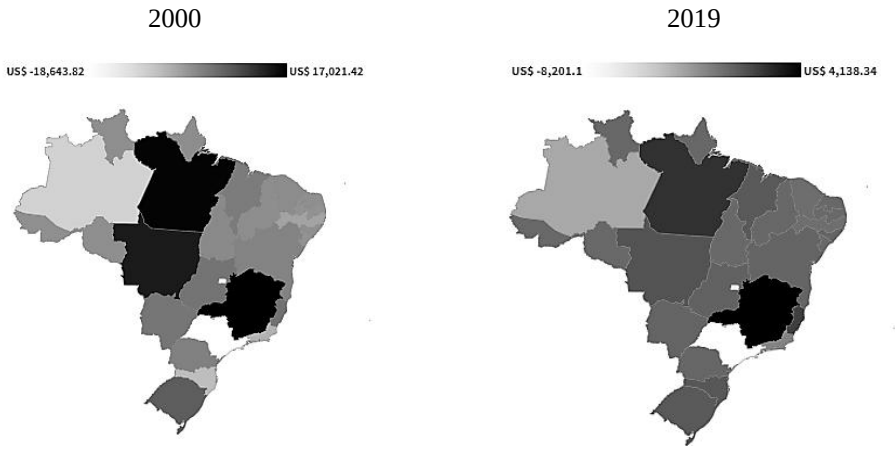


Figure 6. Geographical Comparison: Intermediate Goods Balance, 2000-2019, FOB Million US$

Regarding the capital goods account, the state of São Paulo stands out with a higher balance in both periods. As for intermediate goods, Minas Gerais is among the states with a higher balance in both periods, but Mato Grosso and Pará followed it in the last year.

As for consumer goods, initially, the states of São Paulo and Rio Grande do Sul lead the statistics, but in the last year, São Paulo is surpassed by Rio Grande do Sul, Paraná, and Mato Grosso.

Finally, there are thematic maps for fuels and lubricants. In this case, significant changes are observed. While most of the country had a positive balance in this category in 2000, in the last year, only the state of Rio de Janeiro had a balance greater than zero.

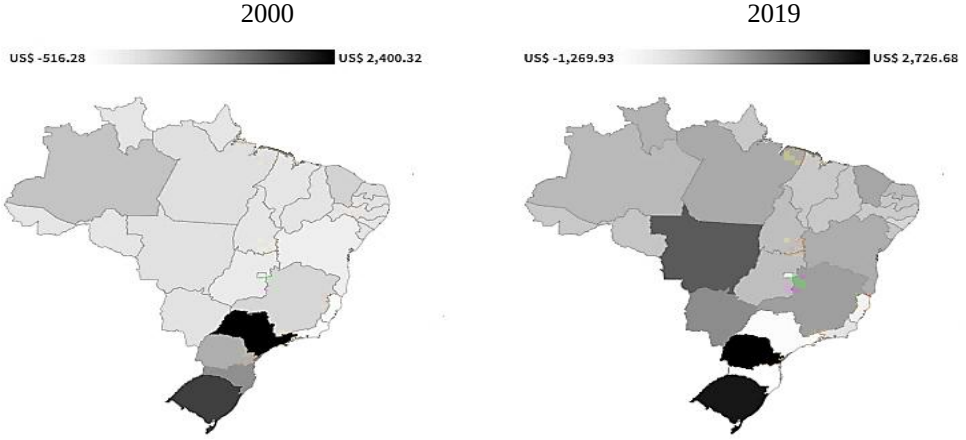


Figure 7. Geographical Comparison of Consumer Goods Balance, 2000-2019, FOB Million US$

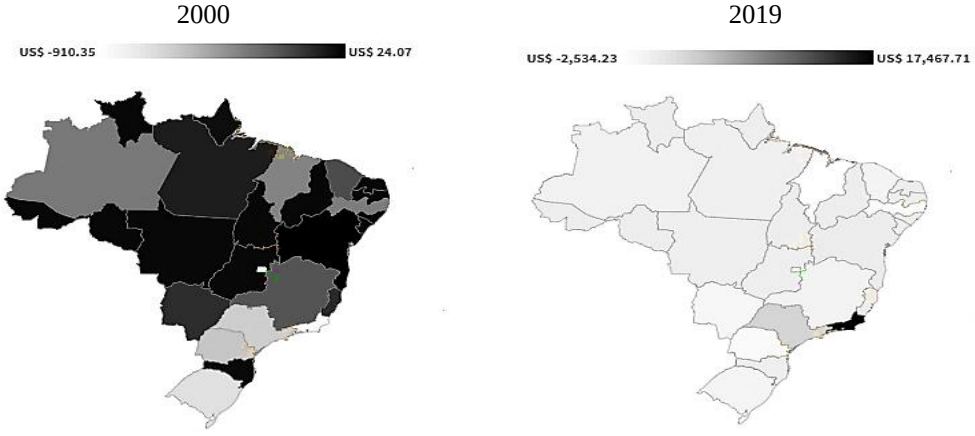


Figure 8. Geographical Comparison of Lubricants Balance, 2000-2019, FOB Million US$

3.2 Econometric Strategy: Panel ARDL with Driscoll-Kraay Robust Standard Errors

To investigate the validity of the J-curve and MLC hypotheses, the trade balance indicator is used, defined as the logarithm of the ratio between the values of exports and imports for the sectors considered as a function of a covariate vector X composed of the real effective exchange rate, REER, domestic income, Y, and foreign income, Y*.

Two specifications with panel data will be considered to model the trade balance of Brazilian states, according to the MEC. The first is in terms of disaggregated trade balances by sectors of the MEC, that is, for the sectors of capital goods, intermediate goods, consumer goods, and fuels and lubricants, totaling four models. The second consists of a model for stacked MEC sectors, encompassing all information in a single panel. Therefore, five models will be estimated to infer the analyzed phenomena from regional and sectoral perspectives.

This study employs a new generation of robust techniques for heterogeneous panel data in the presence of cross-sectional dependence. The importance of econometric methods considering cross-sectional dependence has grown, as ignoring its presence influences the adopted methodological strategy and produces unreliable inferences. As mentioned earlier, unobservable common factors (or shocks) that may cause interdependence effects between panel units should be considered, as variables or residuals resulting from cross-sectional dependence can persist.

In this context, with the increase in the temporal dimension of the information, the focus on large-dimensional panel data has evolved to consider the importance of techniques that consider the assessment of non-stationary, cointegration, and the possibility of heterogeneous dynamics in short and long-term relationships, as well as general forms of cross-sectional dependence.

A methodology that allows for exploring the properties of non-stationary time series in a panel data structure, considering all these potential data characteristics, is the framework of Panel Autoregressive Distributed Lag (PARDL) models. The PARDL has proven to be robust for studying dynamic relationships in cointegrated series, regardless of the presence of endogenous or exogenous regressors and the order of integration of the underlying variables, whether they are stationary at the level in first difference or a combination of both, as long as they are below the second order of integration. Additionally, this methodology distinguishes short- and long-term effects. If a set of variables is cointegrated, its reparametrized form through an Error Correction Model (PARDL-ECM) is commonly used in estimating non-stationary panel data. This allows the analysis of short and long-term dynamics between variables simultaneously, as well as the speed of adjustment to the long-term equilibrium, which is quite convenient for the objectives of this research. In addition, the model is robust in selecting the best lags for the variables in the specification to be estimated, helping to mitigate potential problems related to endogeneity and serial correlation (Pesaran, Shin & Smith, 1999).

Therefore, to study the phenomena of the J-curve of the MLC, a panel autoregressive structure with distributed lags in its error correction form (PARDL-ECM) is employed. The general form of a dynamic panel ARDL$(p, q_1, q_2, \dots, q_k)$ is defined as:

$$ln\ ln\left(\frac{EXP_{ijt}}{IMP_{ijt}}\right) = \sum_{m=1}^{p} \lambda_{ijm} y_{ij,t-m} + \sum_{m=0}^{q} \delta_{ijm}^{'} X_{ij,t-m} + \mu_{ij} + \varepsilon_{ijt} \quad (1)$$

where, $i = 1,2 \dots, N$, indicates the states belonging to the panel; $j = 1,2 \dots, W$ identifies the sectors; $t = 1,2, \dots, T$ reflects the time dimension; X_{it} is a vector $(kx1)$ of independent variables; λ_{it} are scalars for the lags of the dependent variables; δ_{it} represents a vector $(K\ x\ 1)$ containing the coefficients of lagged explanatory variables; μ_i denotes the group-specific effect, p e q are the orders of lags associated with the regressand and explanatory variables, respectively, and ε_{it} is the stochastic error term. The variable $ln\ ln\left(\frac{EXP_{ijt}}{IMP_{ijt}}\right)$ is the natural logarithm of the net exports the state i, in category j, in year t. The covariate vector X is composed of $ln\ ln\,(Y_t)$, the natural logarithm of the proxy of domestic income of state i in year t; $ln\ ln\,(TXCER_t)$ is the natural logarithm of the Brazilian real effective exchange rate; $ln\ ln\,(Y_t^*)$ is the natural logarithm of the proxy for foreign income.

Once the cointegration relationship between the variables has been verified, the equation above can be conveniently rewritten in its error correction form to establish the long-term equilibrium relationship of the variables and their short-term adjustment dynamics, as follows:

$$\Delta\, ln\, ln\left(\frac{EXP_{ijt}}{IMP_{ijt}}\right) = \phi_{ij}\left(ln\, ln\left(\frac{EXP_{ijt-1}}{IMP_{ijt-1}}\right) - \beta'_{ij}X_{ijt}\right) + \sum_{m=1}^{p-1}\lambda^*_{ijm}\Delta\, ln\, ln\left(\frac{EXP_{ijt-1}}{IMP_{ijt-1}}\right) + \sum_{m=0}^{q-1}\delta'^*_{ijm}\,\Delta X_{ij,t-m} + \mu_{ij} + \varepsilon_{ij,t} \quad (2)$$

where, $\phi_{ij} = -\left(1 - \sum_{m=1}^{p}\lambda_{ij,m}\right)$, $\beta_{ij} = \frac{\sum_{l=0}^{q}\delta_{ij,m}}{(1-\sum_l \lambda^*_{ij,m})}$, with $\lambda^*_{ijm} = -\sum_{l=m+1}^{p}\lambda_{ijl}$, $m = 1,2,\dots,p-1$ e $\delta^*_{ijm} = -\sum_{l=m+1}^{q}\delta_{ijl}$, $m = 1,2,\dots,q-1$.

The error correction term $\left(ln\left(\frac{EXP_{ijt-1}}{IMP_{ijt-1}}\right) - \beta'_{ij}X_{ijt}\right)$ constitutes the long-term relationship between the regress and the explanatory variables; $\phi_{ij}$is the speed of adjustment of the specific unit i. It is expected that this parameter is not null; otherwise, there will be no evidence for a long-term relationship. It is also expected that this parameter is negative and statistically significant, assuming that the long-term relationship between the variables is stable. The vector β'_{ij} contains the slope coefficients or long-term elasticities, while the parameters λ^*_{ij} and δ'^*_{ij} provide the short-term dynamic coefficients of the regress and the explanatory variables, respectively.

Thus, if a cointegration relationship is established, the underlying hypothesis of the J-Curve phenomenon will be supported if the short-term dynamic effect of a real exchange rate devaluation is negative or statistically insignificant, while its long-term counterpart is positive and statistically significant, as suggested by the MLC (Bahmani-Oskooee & Fariditavana, 2016).

3.2.1 Specification Tests

When dealing with a dataset like the one in this study, it is standard in literature to conduct tests that allow the identification of phenomena such as heterogeneity of coefficients among cross-sectional units, cross-sectional dependence, the presence of unit roots, and cointegration. These tests are necessary to verify if the specification and methodological strategy employed are appropriate.

To verify whether the series used in the study are cointegrated from a panel perspective, their integration order is initially tested using unit root tests proposed by Maddala and Wu (1999) – Fisher ADF –, Im, Pesaran, and Shin (2003) – IPS –, and Pesaran (2007) – CIPS, all of which share the null hypothesis of the presence of a unit root in the panel. The alternative hypothesis for these tests is that only a fraction is stationary. Regarding cointegration, the Westerlund (2007) procedure is adopted, encompassing four test statistics, two in the Group-Means version (Ga e Gt) and two in the Panel-Tests version (Pa e Pt). Both sets of test statistics are constructed under the null hypothesis of no cointegration in the series for all cross-sectional units of the panel. On the other hand, the alternative hypothesis for the Group-Means statistics is cointegration in at least one panel unit, during the Panel-Tests versions test cointegration for the entire panel.

Next, to address the possibility of heterogeneous effects on the dynamics of short and long-term coefficients for the specification in (2), three estimators are considered: the Dynamic Fixed Effects (DFE) estimator, the Mean Group (MG) estimator, and the Pooled Mean Group (PMG) estimator.

In the DFE approach, the data for each model are grouped, and the coefficients for short and long terms are restricted to be equal, allowing only the intercept to vary between cross-sectional units. However, if the slope coefficients are not similar, the DFE approach generates inconsistent results, potentially misleading. Alternatively, the model could be adjusted for each group separately, and then a simple arithmetic average of the coefficients could be calculated, obtaining the average estimate for the group. This is the MG (Mean Group) approach, which allows heterogeneity in the coefficients for short and long terms in the specific units of the panel. Despite this estimator providing consistent long-term estimates, they are inefficient in the presence of homogeneity between the coefficients. Finally, the PMG (Pooled Mean Group) estimator incorporates characteristics of both previous approaches, allowing the coefficients for

short terms to differ between groups (as with the MG estimator) but restricting the coefficients on the long-term of the cointegration vector to be equal (as with the DFE estimator).

When there is no a priori information to reject the hypothesis of homogeneity in coefficients – such as a theoretical justification, for example, the Hausman test (1978) can be conducted to decide which estimator would be more appropriate based on these estimators' consistency and efficiency properties. However, the MG, DFE, and PMG estimators assume cross-sectional independence in the presence of common factors and may produce unreliable results. Especially for panel datasets that contain interdependent states, common macroeconomic shocks or repercussions that can affect states together and cause cross-sectional dependence issues should be considered. Ignoring this phenomenon in the econometric procedure can lead to unreliable results.

On the other hand, as long as the unobserved common factors are uncorrelated with the explanatory variables, coefficient estimates based on standard panel estimators remain consistent. However, standard covariance matrix estimation techniques for the errors are biased, and therefore, statistical inference based on such standard errors is invalid (Hoechle, 2007). In this case, various possibilities arise for estimating the covariance matrix of errors, such as choosing to correct the estimated standard errors using robust standard errors[2].

In this line, Driscoll and Kraay (1998) – DK – propose a non-parametric approach for correcting errors in the presence of cross-sectional (spatial) or temporal dependence based on Newey-West (1987). In broad terms, the DK strategy consists of first adjusting the standard errors of the model via ordinary least squares (OLS) to address the issue of cross-sectional dependence and then applying a Newey-West type correction to the sequence of cross-sectional means of the time series moment conditions. The standard error estimates, thus adjusted, ensure that the covariance matrix estimators are consistent in heteroscedasticity and autocorrelation and are robust to general forms of cross-sectional (spatial) or temporal dependence. Additionally, the DK algorithm can equally apply to balanced and unbalanced panel data sets. It can effectively handle missing values without restricting viability, regardless of the panel's temporal (T) and cross-sectional (N) dimensions.

The CD test, proposed by Pesaran (2015), is applied to ascertain the presence of cross-sectional dependence. The test's null hypothesis is that weak dependence exists, while the alternative hypothesis is strong dependence. The CD test utilizes pairwise correlation coefficients between the OLS residuals of individual regressions in the panel model under the null hypothesis of weak cross-sectional dependence, being robust to various situations such as non-normality of errors, non-stationarity, presence of structural breaks, and coefficient heterogeneity. The test is defined as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=1+1}^{N}\hat{\rho}_{ij}\right)} \quad (3)$$

Weak cross-sectional dependence implies that the estimated correlation (ρˆ_ij) between an observation from unit i and unit j at each point in time (T) converges to zero as the number of cross-sectional units (N) tends to infinity. On the other hand, under strong cross-sectional dependence, the correlation between the units converges to a constant different from zero. Pesaran (2015) asserts that, in this context, only weak dependence is required to obtain consistent estimates, rather than the more restrictive assumption of cross-sectional independence, because the correlation among a small number of cross-sectional units in the analysis does not affect the estimates.

In summary, the econometric strategy of the present study can be summarized as follows: Initially, the order of integration of the series is analyzed through unit root tests of IPS, CIPS, and Fisher-ADF type. Then, a cointegration analysis is conducted, following Westerlund's (2007) approach, using four test statistics. Once cointegration is verified, a panel error correction model (PARDL-ECM) is specified, and the Hausman test is conducted to identify which estimator among the MG, DFE, and PMG approaches would be most suitable based on the presence or absence of heterogeneous coefficients among panel states. Next, to investigate the issue of cross-sectional dependence in the residuals of the selected best PARDL-ECM specifications, the Pesaran (2015) CD test is applied. If the test indicates the presence of common factors, the DK correction is employed. Finally, to verify if the adopted technique was robust in mitigating problems associated with cross-sectional dependence, the CD test is again applied to the residuals of the estimated equations.

4. Analysis of the Results

To compare the relationships examined in the present study, panel unit root tests by Maddala and Wu (1999), Fisher ADF –, Im, Pesaran, and Shin (2003) – IPS –, and Pesaran (2007) – CIPS were initially employed to assess the integration order of the variables used. The results are presented in Table 2 and indicate that the series exhibits a

combination of stationary and non-stationary properties. However, in all applied tests, the series were stationary in the first difference, consistent with the panel ARDL specification.

Table 2. Unit Root Test

Variable	Test	Fisher-ADF	IPS	CIPS	Order of Integration (Fisher/ IPS/ CIPS)
ln ($REER_{it}$)	Level	-0.49 [0.69]	1.63 [0.94]	-2.61 [-2.15]	I (1) /I (1)/I (0)
	First Difference	3.77 [0.00]	-9.07 [0.00]	-5.6 [-2.20]	
ln ($Foreign\ Income_{it}$)	Level	-0.44 [0.32]	-3.93 [0.00]	-2.44 [-2.15]	I (1)/ I (0)/ I (0)
	First Difference	1.94 [0.00]	-7.8 [0.00]	-5.55 [2.20]	
ln($Domestic\ Income_{it}$)	Level	-4.83 [0.97]	4.09 [0.96]	-2.48 [-2.15]	I (1) /I (1)/I (0)
	First Difference	4.61 [0.00]	-9.42 [0.00]	-4.75 [-2.20]	
ln (TBK_{it})	Level	0.2 [0.41]	-6.06 [0.00]	-2.85 [-2.15]	I (1) / I (0)/ I (0)
	First Difference	3.55 [0.00]	-20.07 [0.00]	-5.12 [-2.20]	
ln (TBI_{it})	Level	0.58 [0.27]	-3.61 [0.00]	-2.46 [-2.15]	I (1)/ I (0)/ I (0)
	First Difference	4.17 [0.00]	-15.86 [0.00]	-4.69 [-2.20]	
ln (TBC_{it})	Level	1.58 [0.05]	-2.37 [0.00]	-2.85 [-2.15]	I (1)/ I (0)/ I (0)
	First Difference	1.78 [0.00]	-11.83 [0.00]	-5.14 [-2.20]	
ln (TFL_{it})	Level	1.25 [0.10]	N. A		I (1)
	First Difference	2.37 [0.00]			
ln (TBA_{it})	Level	0.71 [0.21]	N. A		I (1)
	First Difference	11.02 [0.00]			

Source: Prepared by the authors. Note. P-values of the test at the 5% significance level are expressed in brackets, except for the CIPS test, which does not have a standard normal distribution, and therefore, critical values are reported based on tabulated values for N, T = (26,21) at the 5% significance level. NA - Test not available for the unbalanced panel.

Next, cointegration analysis was conducted following the approach of Westerlund (2007), utilizing its four test statistics, two of which are in the Group Means version and the other two in the Panel-Tests version. Both sets of statistics test the null hypothesis of no cointegration for the panel. However, while the former tests the alternative hypothesis of cointegration in at least one panel unit, the latter examines cointegration for the entire panel. Westerlund's test statistics are normally distributed, and the robustness of their results against cross-sectional dependence is achieved through bootstrap replications. The results are presented in Table 3 and demonstrate that the null hypothesis of no cointegration is rejected for groups of units and the entire panel, confirming a long-term relationship among the variables.

Table 3. Westerlund's cointegration test

Westerlund Statistic		Sectoral Models		
		TBK	TBI	TFL
Gt	Test value	-3.51	-3.02	-3.24
	P-value	[0.00]	[0.00]	[0.00]
	Robust P-valor	[0.00]	[0.00]	[0.00]
Gα	Test value	-10.4	-9.18	-12.26
	P-value	[0.00]	[0.00]	[0.00]
	Robust P-valor	[0.02]	[0.06]	[0.00]
P_t	Test value	-15.92	-13.63	-15.94
	P-valor	[0.00]	[0.00]	[0.00]
	Robust P-valor	[0.00]	[0.01]	[0.01]
Pα	Test value	-10.54	-9.87	-8.85
	P-value	[0.00]	[0.03]	[0.13]
	Robust P-valor	[0.03]	[0.04]	[0.02]

Source: Prepared by the authors. Note. For the Westerlund test, the optimal number of lags and leads for each series was determined according to the Akaike Information Criterion (AIC); the optimal Bartlett kernel window was defined as the number of bootstraps set at 400 for all models. Since the Westerlund test (2007) is not feasible for unbalanced panels, the Kao test (1999) was considered for the panel with the aggregate of sectors and fuels and lubricants.

In this context, the Hausman test is employed to initially test the null hypothesis that the MG model is inefficient against the alternative that the PMG is consistent. Subsequently, the test is conducted to verify the null hypothesis that the DFE is inefficient and that the PMG estimator would be most appropriate. If, in all cases, the null hypothesis is rejected and the DFE is found to be inefficient compared to the PMG model, the test is employed again, this time to determine whether the MG is inefficient and the DFE would be the most appropriate. Table 4 summarizes the results and indicates the rejection of the more flexible models, MG and PMG, in all considered cases, concluding that the DFE estimator provides consistent and efficient estimates, being the most suitable for the panels used in the study.

Table 4. Hausman Test

Test	Test Statistic	Sectoral Models				TBA
		TBK	TBI	TFC	TFL	
MG X PMG	$\chi^2_{(3)}$	7.79 [a]	0.71 [a]	0.15 [a]	N. A	N. A
	Prob>χ^2	[0.06]	[0.87]	[0.98]		
DFE X PMG	$\chi^2_{(3)}$	82.30 [b]	86.19 [b]	78.85 [b]	N. A	N. A
	Prob > χ^2	[0.00]	[0.00]	[0.00]		
MG X DFE	$\chi^2_{(3)}$	0.13 [c]	0.01 [c]	0.35 [c]	1.69 [c]	0.95 [c]
	Prob > χ^2	[0.98]	[0.99]	[0.95]	[0.63]	[0.95]

Source: Prepared by the authors. P-Value within brackets. PMG estimate for comparison in the test is not available. [a] PMG is a more efficient estimator than MG. [b] PMG is a more efficient estimator than DFE. [c] DFE is a more efficient estimator than MG. NA - Test not available for the unbalanced panel.

Despite the PARDL-DFE specification being particularly appealing in contexts where a certain regularity in the short-term dynamics and long-term equilibrium, the estimator DFE assumes cross-sectional independence and, if used, can lead to unreliable results. This is because the existence of common factors or unobserved shocks may be reflected in the estimation residuals, generating a correlation among the different states associated with the panel under study. Therefore, when employing a panel of states, it is essential to consider all forms of cross-sectional dependence that may arise.

Therefore, to investigate the presence of cross-sectional dependence in the residuals of PARDL-DFE estimations, the cross-section dependence (CD) test proposed by Pesaran (2015) was conducted. The null hypothesis of this test is weak cross-sectional dependence, against the alternative hypothesis of strong dependence. As mentioned earlier, it is desirable for the test not to reject H0, as weak dependence means that in the limit, as N and T grow – cross-section dependence will disappear, and thus the estimator is consistent. Additionally, robustness tests for heteroscedasticity and autocorrelation in the residuals of the estimations in each of the estimated models were performed. To test for heteroscedasticity, the modified Wald test was used, with the null hypothesis being homoscedasticity, while to test for autocorrelation, the Wooldridge test was employed, with the null hypothesis being the absence of autocorrelation. However, as shown in Table 5, the null hypothesis of all three tests is rejected for all estimated PARDL-DFE models.

Table 5. Pesaran (2015) Cross-sectional Dependence Test, Heteroskedasticity, and Autocorrelation in PARDL-DFE Residuals

Test	Test Statistic	Sectoral Models				Aggregate Model
		TBK	TBI	TBC	TFL	TBA
Pesaran (2015)	CD	3.26	4.65	2.41	1.91	7.78
	P-valor	[0.00]	[0.00]	[0.01]	[0.03]	[0.00]
Modified Wald for Heteroskedasticity	χ^2	14050.42	5418.16	6139.35	4178.12	3455.03
	P-valor	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Wooldridge Autocorrelation Test (2001).	F-Statistic	46.26	83.97	41.32	28.04	83.2
	P-valor	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Source: Prepared by the authors.

Thus, to measure the short and long-term impacts of currency devaluation on the foreign trade of Brazilian states according to the MEC, the PARDL-DFE panel approach with non-parametric covariance matrix correction as proposed by Driscoll and Kraay (1998) was employed to verify the existence of the J-curve phenomenon and the validity of the MLC. Table 6 summarizes the results.

In general terms, the long-term evidence points to the validity of the MLC for all sectors except for fuels and lubricants; that is, the results indicate that the long-term effect of currency devaluation is positive and statistically significant on the net exports of Brazilian states. This result aligns with both the literature on the Brazilian economy and the broader international research on the MLC. In the Brazilian context, several studies have explored this relationship (Moura & da Silva, 2005; Scalco et al., 2012; Moraes et al., 2015; Arruda & Martins, 2020; Arruda, Brito & Castelar, 2022). Similarly, some international studies have validated the MLC condition using different methodologies, including purely time series models (Arora, Bahmani-Oskooee & Goswami, 2003; Bahmani-Oskooee & Ratha, 2004; Mustafa, Rahman & Guru-Gharana, 2015) and bilateral panel data approaches (Wang et al., 2012; Yazgan & Ozturk, 2018; Ebadi, 2020; Kaya, 2021; Abille & Me ̧ik, 2023).

Considering the sectoral models by MEC, the long-term elasticities with respect to the exchange rate indicate that a 1% real devaluation in this indicator leads to an improvement in the trade balance of 4.89% in capital goods, 1.48% in intermediate goods and 5.17% in consumer goods. In the aggregated MEC model, the improvement in the trade balance of Brazilian states amounts to approximately 1.92%. The sector of fuels and lubricants reported a statistically null long-term elasticity.

The foreign demand indicator also proved to be statistically significant in most of the considered specifications and with the expected sign; that is, an increase in the external income indicator appears to translate into an increase in demand for domestic exports, which, ceteris paribus, improves the trade balance of Brazilian states, confirming the theoretical prediction. From a sectoral perspective, this impact was higher for capital goods, followed by consumer goods, with

elasticities of 6.61% and 2.93%, respectively, in response to a 1% increase in external demand. The aggregated model reported an elasticity of approximately 1.70%. The sectors of intermediates, fuels and lubricants presented statistically insignificant results.

Table 6. Elasticities of Long and Short Run for PARDL-DFE Models with Driscoll-Kraay Robust Standard Errors

MODEL	Capital Goods	Intermediate Goods	Consumer Goods	Fuel and Lubricants	Aggregate Model
I. Long-term elasticities					
ln(REER)	4.89 [0.00]	1.48 [0.00]	5.17 [0.00]	-3.16 [0.15]	1.92 [0.00]
ln(Foreign Income)	6.61 [0.00]	1.11 [0.13]	2.96 [0.00]	1.29 [0.77]	1.7 [0.00]
ln(Domestic Income)	3.02 [0.00]	0.71 [0.21]	3.19 [0.00]	1.65 [0.00]	2.58 [0.00]
II. Short-term elasticities					
Δln*(REER)*	-3.08 [0.00]	-0.89 [0.00]	-1.42 [0.00]	-3.79 [0.01]	-1.62 [0.00]
Δln(REER)t-1	-0.93 [0.24]	-0.53 [0.13]	-0.22 [0.00]	-1.37 [0.33]	-0.3 [0.31]
Error Correction term (ϕ_i)	-0.68 [0.00]	-0.45 [0.00]	-0.28 [0.00]	-0.42 [0.00]	-0.5 [0.00]
III. Statistics and Robustness Tests					
Observations	494	494	494	335	1.817
Number of Groups	26	26	26	23	101
F-Statistic	66.93	73.73	78.16	66.21	18.83
Prob > F	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
within R^2	0.36	0.27	0.23	0.24	0.28
máx. number of lags	2	2	2	2	2
Pesaran's CD test (2015)	-0.42 [0.672]	-1.41 [0.264]	-2.06[a] [0.039]	-0.22 [0.823]	-2.06 [0.559]

Source: Prepared by the authors. Note. [a] Not reject H0 at 1%.

Regarding the effects of domestic income, the results reveal positive and elastic impacts in most models, suggesting the importance of these sectors for state economies, except for the intermediate goods sector, whose elasticity was statistically null. The models for the capital goods sector, consumer goods, and the aggregated model reported the highest estimated elasticities, 3.09%, 3.19%, and 2.58%, respectively. Arora, Bahmani-Oskooee and Goswami (2003) argue that a positive impact of domestic income on the trade balance can occur if this indicator reflects an expansion in the production of substitutes for imports.

The results for the proxy of foreign income and domestic income support the findings in the studies by Moraes et al. (2015), in a study on the trade balance of industrialized and basic sectors in the Southern region of Brazil; Sonaglio, Scalco and Campos (2010) for selected sectors of the Brazilian manufactured goods trade balance; Scalco, Carvalho and Campos (2012), and Arruda, Castelo Branco and Brito (2022), both for the trade balance of Brazilian agriculture; Ramos Filho and Ferreira (2016) for some sectors of the manufacturing industry, and Arruda, Brito, and Castelar (2022) in an analysis of the trade balance of durable and non-durable goods.

Once the validity of the MLC was not rejected in the majority of the considered models, the occurrence of the J-curve phenomenon was examined, that is, the effect on the short-term dynamics of a devaluation of the real exchange rate on the trade balance, before its improvement in the long term. From Table 6, it is observed that both the sectoral models and the aggregated model present short-term exchange rate elasticities with negative and elastic signs, indicating that real devaluation of the exchange rate results in an initial deterioration of the trade balance of Brazilian states. The highest magnitude elasticities, in absolute terms, were observed in the fuels and lubricants sector, -3.79%, and in the capital goods sector, -3.08%.

Therefore, the short-term and long-term effects investigated here attest to the temporary deterioration in net exports followed by their long-term improvement in response to a real exchange rate devaluation in most of the considered models, confirming the occurrence of the complete J-curve. The exception was the model for the fuels and lubricants sector, whose result only indicates the initial phase of the J phenomenon since the MLC was not satisfied in the long

term. The results align with the main studies in the national literature that, like this one, address sectoral trade balances (Moura & da Silva, 2005; Arruda & Martin, 2016; Scalco, Campos, & Sonaglio, 2012; Arruda, Brito & Castelar, 2022; Arruda, Castelo Branco & Brito, 2022).

The error correction term (ϕ_i) exhibited a coefficient with negative and statistically significant signs in all analyzed models. These coefficients indicate the speed at which the trade balance of Brazilian states adjusts to long-term equilibrium after short-term shocks in the explanatory variables, thus signaling adequate convergence and stability in the relationship between variables in the long-term specification. Across the five models, the reversal of the trade balance to its long-term equilibrium is relatively faster within one year for the capital goods sector (67%), followed by the aggregated model (50%), the intermediate goods sector (45%), fuels and lubricants (42%), and the consumer goods sector (27%).

Finally, the statistics from Pesaran's CD test (2015) reveal a substantial decrease in residual correlation between cross-sectional units after applying the Driscoll-Kraay method in the PARDL-DFE specifications, thus demonstrating that the non-parametric correction was effective in mitigating cross-sectional dependence in all estimated models.

4. Concluding Remarks

This study examined the short and long-term impacts of real exchange rate devaluation on the trade balance of Brazilian states according to the MEC, aiming to infer the J-curve phenomenon and the validity of the MLC. To support this analysis, a panel framework was employed containing annual data for the 26 Brazilian states from 2000 to 2020, using the PARDL-DFE strategy with Driscoll and Kraay's (1998) standard errors, robust to general forms of cross-sectional dependence.

In general, the long-term results indicate positive and elastic responses of Brazilian states' trade balances to real exchange rate devaluations, thus validating the MLC for the majority of the sectors considered, with the exception of fuels and lubricants. The positive response to the trade balance was more pronounced for the consumer goods and capital goods sectors.

The results for the proxies of foreign income and domestic income are also in line with theoretical predictions in most models, except for intermediate goods, whose long-term elasticities in relation to these indicators were not statistically significant, and for the fuels and lubricants sector, which showed statistically null external demand elasticity. Authors such as Moraes et al. (2015); Scalco, Carvalho and Campos (2012); Ramos Filho and Ferreira (2016); and Arruda, Castelo Branco and Brito (2022) also observed effects of this nature in their sectoral analyses for external income, while Arora, Bahmani-Oskooee, and Goswami (2003) point to a possible substitution effect as justification for positive effects of domestic income on net exports.

The short-term evidence indicated that the Brazilian states' trade balance response to a real devaluation in the exchange rate is negative and elastic, indicating that the initial deterioration phase of the trade balance is present in all sectors of the MEC. The negative impact was most pronounced in the fuels and lubricants and capital goods sectors, respectively. Combining this result with the validity of the MLC, it is concluded that the complete J-curve phenomenon was observed in most sectors, except for fuels and lubricants, where there is only evidence of its initial phase.

In this regard, the evidence found reinforces the importance of adopting exchange rate policies by the monetary authority to maintain the real exchange rate at competitive levels since currency devaluations have contributed to improving the trade balance of Brazilian states in most sectors of the MEC, both in the short and long term. Additionally, it is recommended that actions and policy strategies be implemented to promote greater integration of Brazil and its states into global trade chains, given that external demand has also been favorable for improving the trade balance at the regional level in most of these sectors.

In summary, the present study supports the main empirical evidence regarding the J-curve phenomenon and the Marshall-Lerner Condition for the Brazilian trade balance, even in a regional and sectoral context, utilizing a panel econometric methodology that mitigates problems associated with cross-sectional dependence, which is generally present in data of this nature. However, the discussions in this study could be expanded in future research to include both a panel approach of Brazilian states that considers a higher level of sectoral disaggregation and possible nonlinear or asymmetric effects in the relationships between the real exchange rate and the trade balance of these states.

One potential limitation of this research concerns the fact that the econometric methodology employed does not completely mitigate concerns associated with endogeneity bias arising from simultaneity. Therefore, an interesting future research agenda would be to reproduce the econometric exercise of this article, but with methodologies that allow controlling for this type of problem, such as instrumental variable estimators and/or GMM.

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Authors' contributions

Prof. Elano Ferreira Arruda and Prof. Antonio Clecio de Brito were responsible for the study design and critical revision of the manuscript. Prof. Felipe de Sousa Bastos conducted the data collection and performed the estimations. Prof. Antonio Clecio de Brito drafted the manuscript, and Prof. Felipe de Sousa Bastos revised it. All authors read and approved the final version of the manuscript.

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Data sharing statement

No additional data are available.

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References

Abille, A. B., & Meçik, O. (2023). The exchange rate, income, trade openness, and the trade balance: Longitudinal panel analysis for selected SSA countries. *International Trade, Politics, and Development*, *7*(2), 138-153. https://doi.org/10.1108/ITPD-04-2023-0007

Arize, A. C., Malindretos, J., & Igwe, E. U. (2017). Do exchange rate changes improve the trade balance: An asymmetric nonlinear cointegration approach. *International Review of Economics and Finance, 49,* 313-326. https://doi.org/10.1016/j.iref.2017.02.007

Arora, S., Bahmani-Oskooee, M., & Goswami, G. (2003). Bilateral J-curve between India and her trading partners. *Applied Economics*, *35*(9), 1037-1041. https://doi.org/10.1016/S0313-5926(13)50034-8

Arruda, E. F., & Martins, G. (2016). Curva J e condição de Marshall-Lerner: Evidências para as exportações líquidas cearenses. *Revista Economia e Desenvolvimento*, *15*(1), 40-59.

Arruda, E. F., & Martins, G. (2020). Taxa de câmbio e exportações líquidas: Uma análise para os estados brasileiros. *Nova Economia*, *30*(1), 111-142. https://doi.org/10.1590/0103-6351/4180

Arruda, E. F., Brito, A. C., & Castelar, P. U. C. (2022). Exchange rate and trade balances in Brazil: A disaggregated analysis by major economic categories. *International Journal of Economics and Finance, 14,* 62-76. https://doi.org/10.5539/ijef.v14n6p62

Arruda, E. F., Castelar, P. U. C., & Martins, G. (2019). The J-curve and the Marshall-Lerner condition: Evidence for net exports in the Southern region of Brazil. *Planejamento e Políticas Públicas*, *52*(1), 17-48.

Bahmani-Oskooee, M., & Fariditavana, H. (2015). Nonlinear ARDL approach, asymmetric effects, and the J-curve. *Journal of Economic Studies*, *42*(3), 519-530. https://doi.org/10.1108/JES-03-2015-0042

Bahmani-Oskooee, M., & Karamelikli, H. (2022). Is there a J-curve effect in the U.S. service trade? Evidence from asymmetric analysis. *International Journal of Finance and Economics*. (Forthcoming). https://doi.org/10.1002/ijfe.2624

Bahmani-Oskooee, M., & Ratha, A. (2004). Dynamics of the U.S. trade with developing countries. *The Journal of Developing Areas*, *37*(2), 1-11. https://doi.org/10.1353/jda.2004.0020

Bahmani-Oskooee, M., & Ratha, A. (2004). The J-curve: A literature review. *Applied Economics*, *36*, 1377-1398. https://doi.org/10.1080/0003684042000201794

Bahmani-Oskooee, M., Harvey, H., & Hegerty, S. W. (2013). Empirical tests of the Marshall-Lerner condition: A literature review. *Journal of Economic Studies*, *40*(3), 411-443. https://doi.org/10.1108/01443581311283989

Blackburne, E. F., III, & Frank, M. W. (2007). Estimation of nonstationary heterogeneous panels. *Stata Journal*, *7*, 197-208. https://doi.org/10.1177/1536867X0700700204

Carneiro, F. L. (2014). *A influência da taxa de câmbio sobre os fluxos de comércio exterior*. Discussion Papers (No. 1967), Instituto de Pesquisa Econômica Aplicada (IPEA).

Dash, A. K. (2013). Bilateral J-curve between India and her trading partners: A quantitative perspective. *Economic Analysis and Policy*, *43*(3), 315-338. https://doi.org/10.1016/S0313-5926(13)50034-8

Ditzen, J. (2018). Estimating dynamic common-correlated effects in Stata. *The Stata Journal*, *18*(3), 585-617. https://doi.org/10.1177/1536867X1801800306

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, *80*(4), 549-560. https://doi.org/10.1162/003465398557825

Ebadi, E. (2020). Comparison of the Marshall-Lerner condition in OECD and Asian countries: New evidence from pooled mean group estimation. *Economics Bulletin*, *40*(2), 1332-1348.

Gözen, M. Ç., & Bostancı, F. C. (2021). Validity of J-curve for Turkey and its main external trade partners: An application of a panel data approach. *Sosyoekonomi*, *29*(50), 149-168. https://doi.org/10.17233/sosyoekonomi.2021.04.08

Hatemi, J. A., & Irandoust, M. (2005). Bilateral trade elasticities: Sweden versus her major trading partners. *American Review of Political Economy*, *3*(2), 38-49. https://doi.org/10.38024/arpe.88

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, *46*, 1251-1271. https://doi.org/10.2307/1913827

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The Stata Journal*, *7*(3), 281-312. https://doi.org/10.1177/1536867X0700700301

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53-74. https://doi.org/10.1016/S0304-4076(03)00092-7

Irandoust, M., Ekblad, K., & Parmler, J. (2006). Bilateral trade flows and exchange rate sensitivity: Evidence from likelihood-based panel cointegration. *Economic Systems*, *30*(2), 170-183. https://doi.org/10.1016/j.ecosys.2005.12.001

Kaya, A. I. (2021). Real exchange rate and trade balance in Turkey: Evidence from heterogeneous panel data. *Panoeconomicus*, *68*(5), 1-23. https://doi.org/10.2298/PAN161208007K

Maddala, G. S., & Wu, S. (1999). Comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*, 631-652. https://doi.org/10.1111/1468-0084.0610s1631

Ministério do Desenvolvimento, Indústria e Comércio Exterior (MDIC). (2016). *Classificação da Secretaria de Comércio Exterior por grandes categorias econômicas – CGCE* (Nota metodológica DEAEX/SECEX/CGET nº 001). Retrieved from www.mdic.gov.br/balanca/metodologia/Nota_CGCE.pdf

Moraes, B. M., Tristão, P. A., Diallo, I., & Bender Filho, R. (2015). Evidências da curva J para a balança comercial do estado do Rio Grande do Sul (1999-2014). *Revista de Economia*, *41*(2), 123-150.

Mortatti, C. M., De Miranda, S. H. G., & Bacchi, M. R. P. (2011). Determinantes do comércio Brasil-China de commodities e produtos industriais: Uma aplicação VECM. *Economia Aplicada*, *15*(2), 311-335. https://doi.org/10.1590/S1413-80502011000200007

Moura, G., & Da Silva, S. (2005). Is there a Brazilian J-curve? *Economics Bulletin*, *6*(10), 1-17.

Mustafa, M., Rahman, M., & Guru-Gharana, K. K. (2015). Brazil-US trade balance and exchange rate: Dynamic empirics. *The Journal of Developing Areas*, *49*(3), 151-164. https://doi.org/10.1353/jda.2015.0166

Newey, W., & West, K. (1987). A simple positive semi-definite, heteroscedasticity and autocorrelation consistent covariance matrix. *Econometrica*, *50*, 703-708. https://doi.org/10.2307/1913610

Nusair, S. A. (2017). The J-curve phenomenon in European transition economies: A nonlinear ARDL approach. *International Review of Applied Economics*, *31*(1), 1-27. https://doi.org/10.1080/02692171.2016.1214109

Pedroni, P. (1997). *Fully modified OLS for heterogeneous cointegrated panels and the case of purchasing power parity*. Department of Economics, Indiana University. (Mimeo).

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 653-670. https://doi.org/10.1111/1468-0084.0610s1653

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series with an application to the PPP hypothesis. *Econometric Theory*, *20*(3), 579-625. https://doi.org/10.1017/S0266466604203073

Pesaran, H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, *68*, 79-113. https://doi.org/10.1016/0304-4076(94)01644-F

Pesaran, H., Shin, Y., & Smith, R. (1999). Pooled mean group estimation and dynamic heterogeneous panels. *Journal of the American Statistical Association*, *94*, 621-634. https://doi.org/10.1080/01621459.1999.10474156

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*, 265-312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*, 1089-117. https://doi.org/10.1080/07474938.2014.956623

Ramos Filho, H. S., & Ferreira, M. E. P. (2016). A taxa de câmbio e os ajustes no saldo da balança comercial brasileira: Uma análise setorial da Curva J. *Nova Economia*, *26*(3), 887-907. https://doi.org/10.1590/0103-6351/2471

Scalco, P. R., Carvalho, H. D., & Campos, A. C. (2012). Choques na taxa de câmbio real e o saldo da balança comercial agropecuária brasileira: Evidências da curva J entre 1994 e 2007. *Revista de Economia e Sociologia Rural*, *54*(3), 595-610. https://doi.org/10.1590/S0103-20032012000400001

Sonaglio, C. M., Scalco, P. R., & Campos, A. C. (2010). Taxa de câmbio e a balança comercial brasileira de manufaturados: Evidências da J-curve. *Economia*, *11*(3), 711-734.

Souza, B. G. (2022). *Estudo do fenômeno da curva J na balança comercial nordestina*. Monografia (Graduação em Ciências Econômicas), Faculdade de Economia, Administração e Contabilidade, Universidade Federal de Alagoas, Maceió.

Vasconcelos, C. R. F. (2010). *Dinâmica de curto e longo prazo da balança comercial brasileira: A validade da hipótese da curva J*. Texto para Discussão, 7. Programa de Pós-graduação em Economia, FE/UFJF.

Wang, C. H., Lin, C. H. A., & Yang, C. H. (2012). Short-run and long-run effects of exchange rate change on trade balance: Evidence from China and its trading partners. *Japan and the World Economy, 24*(4), 266-273. https://doi.org/10.1016/j.japwor.2012.07.001

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709-748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Notes

Note 1. We chose to use level variables in the calculation of descriptive statistics to facilitate the reader's understanding of the meaning of the statistics found. In the estimated models, we used the natural logarithm of these variables, a monotonic transformation that allows us to interpret the estimated coefficients as elasticities and is suitable for the purposes of this research since we are studying the J-curve hypothesis and the Marshall-Lerner condition.

Note 2. Chudik and Pesaran (2015) propose the Common Correlated Effects (CCE) estimator to model cross-sectional dependence in panel data. This method includes augmented cross-sectional ARDL regressions to control for common factors explicitly. However, the method is not applicable when the same variable in the panel repeats across different sampled cross-sectional units and, therefore, could not be considered in the present study. For details, see Ditzen (2018).