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Towards Efficiency: Assessing Productivity Gains in Inland Waterway Transport in Rio Grande do Sul

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Abstract
The state of Rio Grande do Sul (RS) presents a highly concentrated transportation matrix in the road modal with a lack of infrastructure. Given this scenario, this article aims to measure the economic impacts arising from increased productivity resulting from expanding the use of waterways in the state. For this purpose, the computable general equilibrium inter-regional model named TRANSP-RS was developed, providing a detailed analysis of freight transportation. Simulations were conducted, comparing the productivity gains between waterway, road, and a combination of both transports. The results indicated that waterway transportation can offer superior returns compared to road transport in terms of investments. Regionally, the simulations showed an increase in variables such as regional gross product, added value, aggregate employment, income, and household consumption. Ultimately, the most benefited regions in the simulations were the populated arrangement and the rest of RS, highlighting the significance of these areas for transport-dependent sectors such as agriculture and manufacturing.

Keywords: Waterway Transport. Computable General Equilibrium. Regional Economy.

Resumo
O estado do Rio Grande do Sul (RS) apresenta uma matriz de transportes altamente concentrada no modal rodoviário e com carência de infraestrutura. Diante desse cenário, este artigo tem como objetivo mensurar os impactos econômicos advindos do aumento da produtividade decorrente da ampliação da utilização das hidrovias no estado. Para isso, foi desenvolvido o modelo de equilíbrio geral computável inter-regional denominado TRANSP-RS, com uma análise detalhada dos transportes de cargas. As simulações foram realizadas comparando os ganhos de produtividade entre os transportes hidroviário, rodoviário e ferroviário. Os resultados indicaram que o transporte hidroviário pode oferecer retornos superiores aos do transporte rodoviário em termos de investimentos. No contexto regional, as simulações demonstraram um aumento em variáveis como produto regional bruto, valor agregado, emprego agregado, renda e consumo das famílias. Por fim, as regiões mais beneficiadas nas simulações foram o arranjo populacional e o resto do RS, evidenciando a relevância dessas áreas para setores dependentes de transporte, como agricultura e indústria de transformação.

Palavras–chave: Transporte Hidroviário. Equilíbrio Geral Computável. Economia Regional.

Hacia la eficiencia: evaluación de las ganancias de productividad en el transporte fluvial en Rio Grande do Sul

Resumen
El estado de Rio Grande do Sul (RS) presenta una matriz de transporte altamente concentrada en el modo carretero y con carencia de infraestructura. Ante este escenario, este artículo tiene como objetivo medir los impactos económicos derivados del aumento de la productividad derivado de la mayor utilización de las vías fluviales en el estado. Para ello, se desarrolló el modelo de equilibrio general computable interregional denominado TRANSP-RS, con un análisis detallado del transporte de carga. Las simulaciones se realizaron comparando las ganancias de productividad entre el transporte fluvial, carretero y ferroviario. Los resultados indicaron que el transporte fluvial puede ofrecer retornos superiores al transporte carretero en términos de inversiones. En el contexto regional, las simulaciones mostraron un aumento en variables como el producto regional bruto, el valor agregado, el empleo agregado, los ingresos y el consumo de los hogares. Finalmente, las regiones más beneficiadas en las simulaciones fueron el arreglo poblacional y el resto de RS, evidenciando la relevancia de estas áreas para sectores dependientes del transporte, como la agricultura y la industria manufacturera.

Palabras clave: Transporte fluvial. Equilibrio general computable. Economía regional.

1 Introduction

This study aims to analyze the economic impacts resulting from increased productivity in the use of inland waterways in the state of Rio Grande do Sul (RS), with the goal of identifying more effective strategies to enhance the state's competitiveness at both national and global levels. The analysis of waterway transportation is essential due to its lower cost, which enables economies of scale and results in lower carbon emissions (Cunha, 2014).

According to the State Logistics Plan of Rio Grande do Sul (PELT/RS, 2014), the state's transport matrix is heavily concentrated, with road transport accounting for more than 80% of the total freight volume. Data from the Ministry of Transport (MT, 2012) indicate that a significant portion of goods such as grains, frozen meat, and furniture is transported daily via highways, representing about 80% of the cargo handled by the Port of Rio Grande, located in the southernmost part of the state and among the largest in Brazil.

The state's waterway system holds virtually unlimited potential for inland navigation. One viable alternative to reduce dependence on roadways is the utilization of the Lagoa dos Patos, the largest waterway in Brazil, which connects approximately 220 km from the southern region of the state to the metropolitan area of Porto Alegre (ANTAQ, 2016). Furthermore, the PELT-RS (2014), in conjunction with the state port and waterway authority, proposes improvements to Lagoa dos Patos, expanding its navigable area by 300 km to accelerate cargo traffic in this segment. Therefore, in order to minimize economic losses caused by such modal concentration and improve state logistics, the promotion of greater use of waterway transport is being pursued, given its comparatively lower cost per ton-kilometer and reduced environmental impact (MT, 2012).

The assessment of economic impacts resulting from transport improvements can be carried out through various methodologies; however, empirical economic literature has predominantly focused on econometric models and computable general equilibrium (CGE) models. For aggregate-level analyses, the latter proves more suitable, as it captures indirect effects across sectors, as emphasized by Bröcker (2002) and Robson, Wijayaratnadixit, and Dixit (2018). Accordingly, the CGE model applied in this study enables simultaneous evaluation of the policy’s effects on economic activity, income, employment, public finances, exports, sectoral performance, and welfare indicators.

For this reason, CGE models are increasingly employed in analyzing transportation-related issues, incorporating the costs of freight and passenger transport. Robson, Wijayaratnadixit, and Dixit (2018) highlight that CGE models integrate transport networks with time and financial costs across spaces, and can focus on national, regional, or urban scales. This makes it possible to identify a range of effects triggered by such policies, including impacts on economic activity, employment, wages, and the spatial distribution of income. In the international context, several authors have explored this approach, such as Bröcker (2002), Knaap and Oosterhaven (2011), Bröcker and Korzhenevych (2013), Verikios and Zhang (2013), Nieuwkoop (2014), Robson, Wijayaratnadixit, and Dixit (2018), Cai et al. (2023), and Wang and Dixit (2024).

In Brazil, the use of CGE models to analyze transportation issues is extensive, with notable contributions from Haddad and Domingues (2001), Almeida (2004), Haddad (2004), Araújo (2006), Domingues et al. (2010), Betarelli Junior (2012), Torres (2013), Vassalo (2015), Campos and Haddad (2016), Gonçalves (2018), Matos, Gonçalves, and Pinto (2022), Pontes et al. (2022), Proque, Betarelli Junior, and Perobelli (2022), and Betarelli Junior, Domingues, and Hewings (2023). Most of these studies employed CGE models to evaluate the impacts of improvements in road transportation, with particular focus on the Southeast and North regions. Thus, this article seeks to address the lack of studies focusing on waterway transport, particularly in the southern states of Brazil.

The model adapted in this study, B-MARIA, is part of the class of interregional computable general equilibrium models, recognized for their ability to capture intersectoral effects within the economy. Since the transport sector can be considered a production cost for all other sectors, a CGE-type model is appropriate to evaluate the impact of a reduction in transport costs. The model disaggregates transport margins into six types, enabling analysis of the effects of different transport modes, particularly waterway transport, on the economy of Rio Grande do Sul.

In the economic literature, several studies based on CGE models highlight that improvements in transport infrastructure significantly influence regional development. In the case of waterway transport, such improvements help reduce freight costs and enhance connectivity between production zones and consumer markets. This process triggers multiplier effects that boost productive chains such as agribusiness, industry, and services, attract new investments, and promote the spatial reorganization of economic activities (Rosik; Wójcik, 2023).

In this context, CGE models, especially those with spatial extensions (SCGE), are suitable analytical tools for measuring the direct, indirect, and interregional effects of enhancements in waterway infrastructure. These models allow for the simulation of shocks associated with reduced transport costs and increased accessibility, affecting economic variables such as output, employment, and regional income. Furthermore, they enable the analysis of spillover effects, whereby logistical gains in one region spread to neighboring territories, fostering greater territorial cohesion and systemic efficiency.

The theoretical foundation of Lösch's Location Theory reinforces this argument by showing that reduced transport costs expand market areas, stimulate competition, lower prices, and intensify income circulation (Almeida et al., 2021). Thus, strengthening waterway infrastructure, when analyzed through CGE models, emerges as a policy with high potential to promote more balanced regional development.

Following this introduction, Section 2 presents a literature review focusing on waterway transport in Rio Grande do Sul. Section 3 outlines the methodological procedures. Section 4 discusses the results. Finally, the concluding remarks are presented in Section 5.

2 Waterway Transport in Rio Grande do Sul

Waterway transport presents distinct structural and operational characteristics compared to rail and road modes, offering significant potential for reducing logistical costs and enhancing productive efficiency. However, its adoption involves technical, environmental, and institutional challenges, especially when creating new navigable channels. Given the high complexity and cost of such interventions, the most economically viable alternative is the requalification and utilization of existing waterways through actions such as sediment dredging and improvements in navigability.

The literature highlights the significant economic advantages of waterway transport. According to Vassalo (2015), the waterborne mode has the lowest cost per ton-kilometer - being 56% more economical than road transport, 20% more advantageous than rail, and 29% cheaper than pipeline transport. In practice, the cost of transporting a load by 1 km on roads is equivalent to transporting the same load by 2.27 km on waterways. Despite this comparative advantage, Brazil still faces major infrastructure bottlenecks. The country ranks 56th globally in transport competitiveness but drops to 114th in terms of infrastructure quality (Vassalo, 2015).

In the context of Rio Grande do Sul, there is a mismatch between the state's hydrographic potential and the actual use of its waterways. According to the *Plano Estadual de Logística de Transporte* (PELT-RS, 2018), approximately 88% of cargo is transported by road, 6% by rail, and only 3% by waterways. This percentage is significantly lower than the national average, which stands at 65% for roads, 16% for waterways, and 15% for railways. This scenario is particularly relevant considering that the state is home to the Port of Rio Grande, one of the largest in the country, with installed capacity and intermodal infrastructure (road and rail) that favor logistical integration.

Betarelli Júnior (2013) emphasizes that improvements in transport infrastructure generate direct effects on accessibility and multiplier effects across other economic sectors, measured through forward and backward linkage coefficients. Expanding waterway capacity, therefore, can stimulate production chains, boost foreign trade, and promote the spatial reorganization of economic activity. Furthermore, by reducing logistics costs, such improvements enhance regional competitiveness and contribute to economic development with lower environmental impact.

In this regard, the underutilization of the waterway mode in Rio Grande do Sul represents a strategic opportunity. With an integrated hydrological system, highlighting the *Lagoa dos Patos* and its connection to the Port of Rio Grande, the state possesses favorable logistical conditions for adopting public policies aimed at expanding waterborne infrastructure as a tool for regional development.

The *Confederação Nacional do Transporte* (CNT) identifies the main obstacles to the development of waterway transport in Brazil as poor infrastructure and regulatory barriers, exacerbated by a lack of investment, absence of proper signaling, and difficulties in constructing new navigable channels. Cunha (2014) supports this analysis by pointing to specific deficiencies in the state of Rio Grande do Sul, such as the lack of navigational aids on the *Lagoa dos Patos* and the discontinuity of dredging operations. Additionally, excessive bureaucracy undermines operational efficiency and discourages the entry of new firms into the sector.

Despite its limitations, the waterway mode remains underutilized, although its greater use could yield significant economic gains for the state. The PELT-RS (2018) highlights the low use of coastal shipping (*cabotagem*) in Rio Grande do Sul, suggesting greater integration of the ports of Rio Grande, Pelotas, and Porto Alegre into the regional logistics network. Considering that approximately 80% of Brazil's GDP is generated in areas located within 200 km of the coast, expanding coastal shipping to link the state with other regions of the federation represents a viable and strategic logistics alternative.

The underutilization of waterways is a nationwide reality. According to Teixeira et al. (2018), although Brazil possesses an extensive hydrographic network, its integration into the transport system occurred mostly during the colonial and imperial periods and was later neglected in favor of other transport modes. In contrast, developed countries continue to invest in the modernization of their waterway transport systems, recognizing their comparative advantages.

The PELT-RS (2018) projects R$ 361.2 million in investments in the state's waterway network by 2024, predominantly from federal resources. However, uncertainties remain regarding the capacity to attract private capital, even with the planned use of concessions and public-private partnerships (PPPs). The plan includes expanding 380 km of navigable routes, maintaining 776 km, constructing or upgrading 13 water terminals, and conducting studies on freight rates, stated demand, traffic, logistical inefficiencies, and operational costs. These actions require coordination with the federal government on regulatory, normative, and financing aspects.

Table 1 – PELT-RS Investment Plan: Implementation Costs of Waterway Infrastructure Projects by Route and Project Horizon (in R$)

Jurisdiction	**2019**	**2024**	**Total**
State-level Investments	113.700.000	-	113.700.000
Number of State-level Interventions	2	-	2
Federal Investments	119.900.000	-	119.900.000
Number of Federal Interventions	2	-	2
Investments in State Terminals / PPPs	50.000.000	35.200.000	85.200.000
Number of State Terminals	3	6	9
Jurisdiction	**2019**	**2024**	**Total**
Investments in Federal Terminals / PPPs	-	20.000.000	20.000.000
Number of Federal Terminals	-	2	2
Investments in Uruguayan Terminals	-	22.400.000	22.400.000
Number of Terminals in Uruguay	-	2	2
Total	283.600.000	77.600.000	361.200.000
Total Number of Interventions	7	10	17

Source: Adapted from PELT-RS (2018).

Table 1 summarizes the investment plan outlined in the *Plano Estadual de Logística de Transporte do Rio Grande do Sul* (PELT-RS), detailing the allocated amounts and the number of interventions by jurisdiction and time horizon. These figures demonstrate the planned effort to revitalize the waterway infrastructure, although the allocated resources remain modest when compared to investments in other transport modes.

Beyond operational concerns, there are also geographical challenges. Cunha (2014) notes that many Brazilian waterways lack direct access to the ocean, requiring integration with other modes of transport to complete the logistics chain. Collaziol (2003) emphasizes the importance of coordinated actions for modernizing logistical infrastructure, ranging from equipment upgrades and management training to the requalification of navigation channels, particularly with regard to dredging and nighttime signaling.

The restructuring of the waterway system in Rio Grande do Sul is expected to yield benefits such as freight cost reductions, decreased expenditures on highway construction and maintenance, and potentially lower accident rates, given that waterways statistically present fewer incidents. Regulatory reform may also mitigate negative impacts on logistics operations, considering the current lack of regulatory clarity, overlapping responsibilities among government agencies, and the presence of conflicting guidelines (Collaziol, 2003).

According to the same author, around 90% of ports in Rio Grande do Sul came under private administration after 1997. However, the state's port system lacks competitiveness, resembling an oligopolistic structure with limited competition among terminals. This configuration has led to a decline in competitiveness over time, the displacement of cargo to road transport, and stagnation in the waterway sector. These outcomes stem from various factors, most notably the prioritization of road transport in public policy, the demobilization of the shipbuilding industry, and corporatism in port management.

Gonçalves (2018) and data from PELT-RS highlight the lack of efficient interregional connections via waterways and railways, reinforcing the predominance of road transport in the state's logistics matrix. The heterogeneous geography of Rio Grande do Sul also contributes to regional disparities, as constructing transport infrastructure is more costly in areas with rugged terrain. Cross-border trade with Uruguay may be conducted via inland waterways or coastal routes. Moreover, there is already a partially operational route between Porto Alegre and Argentina, covering approximately two-thirds of the journey.

The state's most important waterway complex consists of a network of rivers and lakes that connect to the Atlantic Ocean through the *Barra do Rio Grande*, integrating industrial, agro-industrial, and agricultural zones, including the Porto Alegre Metropolitan Region, which accounts for approximately 80% of the state's GDP (PELT-RS, 2015). Despite this potential, coastal shipping (*cabotagem*) remains underutilized. Considering that the majority of Brazil's GDP is generated in areas located within 200 km of the coastline, the ports of Rio Grande, Pelotas, and Porto Alegre could be more effectively leveraged for interstate cargo transportation.

The *Secretaria de Infraestrutura e Logística*, through the PELT-RS, presents projects focused on expanding and modernizing the waterway network. These include technical, economic, and environmental feasibility studies for implementing waterways in regions such as the *Uruguai River Basin*, as well as the construction of new water terminals in strategic municipalities. In the short term, notable actions include the river transport of timber from Pelotas to the industrial terminal in Guaíba, with an estimated volume ranging between 1.0 and 2.0 million tons annually. This alternative offers significant economic advantages, as its per-kilometer transport cost is lower than that of other modes. Increasing the share of waterway transport in the regional logistics matrix contributes to reducing systemic costs, boosting domestic production, and generating positive externalities for the economy of Rio Grande do Sul.

According to PELT-RS (2018), only 3% of the total cargo transported in the state is carried via waterways. This low share is associated with a lack of adequate infrastructure, including appropriate draft levels for commercial navigation and effective signaling systems - factors that undermine the safety and regularity of operations, as noted by Cunha (2014). Despite the state's natural geographic advantages, significant structural barriers persist. Rio Grande do Sul is divided into three distinct hydrographic regions:

1. The coastal region, with six river basins;
2. The Guaíba Lake region, with nine basins;
3. The Uruguay River region, also with nine basins.

These areas comprise ten commercially navigable segments. The longest segment is the one connecting Itapuã to the Port of Rio Grande, extending 267 km with a 5.2-meter draft. The shortest segment connects the river mouth (*foz*) to the BR-116 highway, stretching just 3 km, also with a 5.2-meter draft. The shallowest recorded draft in the state's waterways is 2.5 meters, which limits the navigability of larger vessels and, consequently, reduces the competitiveness of the mode.

Table 2 – Commercially Navigated Waterways in Rio Grande do Sul

Waterway	Route	Draft (m)	Length (km)
Rio Jacuí	Cachoeira do Sul – Charqueadas	2,5	174
Rio Jacuí	Charqueadas – Porto Alegre	4,0	54
Rio Taquari	Triunfo – Estrela	2,5	86
Rio Caí	Foz – Montenegro	2,5	56
Rio dos Sinos	Foz – São Leopoldo	2,5	48
Rio Gravataí	Foz – BR-116	5,2	3
Delta do Jacuí	Porto Alegre – Polo Petroquímico	5,2	28
Lago Guaíba	Porto Alegre – Itapuã	5,2	48
Lagoa dos Patos	Itapuã – Rio Grande	5,2	267
Canal São Gonçalo	Lagoa dos Patos – Porto de Pelotas	5,2	12

Source: Adapted from PELT-RS (2018).

The Port of Rio Grande, as one of the largest in the country, stands out as a key hub for waterborne transport via the *Lagoa dos Patos*, serving as a strategic route to reach the state capital, Porto Alegre. Cunha (2014) suggests that the maintenance costs of this route would be considerably lower compared to those of road infrastructure.

Another point of great interest is the potential of the *Vale do Jacuí*, located in Cachoeira do Sul. This valley encompasses approximately 600 km of potential navigable routes that still require detailed studies to assess critical project parameters. The exploitation of this resource has attracted the attention of exporting firms due to the potential reduction in transportation costs, which could significantly enhance the state's economic efficiency. Furthermore, the *Rio Jacuí* plays a vital role in transporting bulk cargo and biodiesel between the northeastern region of Brazil and the Port of Rio Grande.

3 Methodology and Data

3.1 The TRANSP-RS Model and Data

This section addresses the technical structure of the adapted CGE model, in which the main models employed were: (i) B-MARIA and (ii) B-MARIA-27. Additional details regarding the TRANSP-RS model can be found in Matos, Gonçalves e Pinto (2022). The structure of the TRANSP-RS model is built upon microeconomic definitions of supply and demand from the agents that compose the economic system under conditions of perfect competition. The definition of the equations corresponds to the specification of functional forms, the objectives of the agents, and their respective constraints. Equilibrium conditions are then established to solve the agents' optimization problems, either through maximization or minimization. The model is, therefore, micro-founded and structured in blocks that represent: production input demands, investment demand, household and government demand, foreign demand, demand for transport margins, among other components.

The coding of the equations, database construction, behavioral assumptions of the agents in the economic system, model implementation, and productivity shocks were carried out using the *General Equilibrium Modelling PACKage* (GEMPACK, version 12.1). Thus, the TRANSP-RS model is based on the version of B-MARIA adapted by Haddad (2004). Structurally, the model includes several modules of equations: a core block for production, consumption, and market equilibrium; a labor market and regional migration module; a public finance module; capital accumulation and investment equations; and additional specifications. In summary, the model features 22 sectors[1], 6 final demand agents (producers, investors, households, exporters, governments, both federal and regional, and inventories), 2 productive factors (labor and capital), 5 sources of intermediate inputs (main municipality, population arrangement, rest of the state, rest of Brazil, and rest of the world), and 7 margin components (one for trade and six for transport).

The core of the model is composed of blocks of equations related to the demand for production inputs, investment demand, household and government demand, external demand, and demand for trade and transport margins. Market equilibrium is achieved through microeconomic and macroeconomic assumptions,

1 The 26 sectors represented in the model are: Agriculture, Livestock, Food Products, Machinery and Equipment, Other Industries, Electricity, Water, Construction, Trade, Road Transport, Waterway Transport, Rail Transport, Air Transport, Other Transport Services, Accommodation, Communication, Financial Activities, Asset Management, Scientific Activities, Administrative Activities, Public Administration, Education, Health, Arts and Culture, Other Services, and Domestic Services.

and within this block, aggregate variables such as GDP, trade balance, investment, private consumption, and public consumption are established. A distinguishing feature of the B-MARIA family of models is the integration of economic data with demographic variables. In this regard, Porsse (2005) highlights that, in the labor market and regional migration module, the population in each region is determined through the interaction of demographic variables, including interregional migration, establishing a connection between regional population and labor supply. Thus, the labor market operates under the assumption that labor supply can be influenced by interregional differences in wages or regional unemployment rates, along with demographic variables, which are typically defined exogenously (PORSSE, 2005). Additionally, a major advantage of the B-MARIA model applied in this study is the ability to simulate transport margin shocks differentiated by type of agent: producers (intermediate consumption) and final demanders (households and investors).

The construction of the database was based on the *Matriz Insumo-Produto Inter-Regional do Arranjo Populacional de Porto Alegre* estimated by Haddad, Araújo e Perobelli (2020), as well as on demographic and social data (population, regional and interregional migration, and regional labor supply and demand) from IBGE (2020). Table 3 presents the list of regions used in the database and provides a summary of the input-output matrix for the Porto Alegre population arrangement.

Table 3 – List of Regions

ID	Name of Region / Metro Area	Municipalities	GDP (2015)	GDP (%)	Population (2015)	Population (%)
1	Municipality of Porto Alegre	1	68.132.502	1,14%	1.476.867	0,72%
2	Porto Alegre Population Arrangement	11	51.744.774	0,86%	1.590.496	0,78%
3	Remaining Rio Grande do Sul	485	262.115.314	4,37%	8.180.609	4,00%
4	Rest of Brazil	5.073	5.613.794.408	93,63%	193.202.077	94,50%
	BRAZIL (Total)	5.570	5.995.786.998	100,00%	204.450.049	100,00%

Source: Haddad, Araújo e Perobelli (2020).

Additionally, elasticities and other parameters were obtained from the national empirical literature. Transport margins were disaggregated by region using data from the *Ministério dos Transportes*, the 2015 national input-output matrix, the *Relação Anual de Informações Sociais* (RAIS-2015), and the *Plano Estadual de Logística do Rio Grande do Sul* (PELT-RS). From an economic perspective, the simulations carried out in this study are based on the following equation:

$$P1(i,s,j) = | BAS1(i,,s,j) + \sum_{n=1}^{N} MAR1(i,s,j,n) + TAX1(i,s,j) \} \setminus BAS1(i,s,j) \qquad (1)$$

From an economic perspective, the simulations carried out in this study are based on the following equation, in which base-year prices and quantities are defined so as to satisfy the conditions of the adapted model, demonstrating that:
(2) Quantity demanded of product *i* = Quantity supplied of product *i*

(3) Value of production in industry *j* = Value of inputs js plus production taxes
(4) Market prices = Basic prices plus trade and transport margins and sales taxes
Margins can be understood as:

$$X1MAR(i,s,j,r) = X1(i,s,j) * A1MARG(i,s,j,r). \tag{2}$$

Onde $X1MAR(i,s,j,r)$ é a utilização de margem mercadoria r (por exemplo, o transporte hidroviário) para facilitar o fluxo de insumo intermediário i de fonte s (doméstica ou importada) para indústria j $X1(i,s,j)$ é o uso do bem i fonte s para indústria j como insumo intermediário $A1MAR(i,s,j,r)$ é a utilização de margem mercadoria r por unidade de fluxo de insumo intermediário (i,s) para a indústria j.

Posteriormente, são realizadas simulações que mensuram ganhos de produtividades nos setores de transporte do Rio Grande do Sul, buscando realizar um comparativo do custo-benefício por tipo de transporte.

Where $X1MAR(i,s,j,r)$ represents the use of margin commodity *r* (e.g., waterway transport) to facilitate the flow of intermediate input *i* from source *s* (domestic or imported) to industry *j*; j $X1(i,s,j)$ is the use of good *i* from source *s* as an intermediate input by industry *j*; and $A1MAR(i,s,j,r)$ denotes the use of margin commodity *r* per unit of intermediate input flow *i, s* to industry *j*.

Subsequently, simulations are performed to measure productivity gains in the transport sectors of Rio Grande do Sul, aiming to conduct a cost-benefit comparison across transport modes.

3.2 Description of the Simulations

The literature shows that infrastructure, regulatory issues, and tax burdens are important factors in determining transportation prices (as well as the prices of other goods and services). In this study, different proposals for improving waterway transport are compared with each other and with improvements in other modes of transport, in order to assess their relative utility for society. As previously discussed, Rio Grande do Sul has a transport matrix heavily dependent on the road mode. It is important to consider that waterway transport can be considerably cheaper due to better economies of scale, but that infrastructure and regulatory issues create significant disadvantages for this mode.

According to *Fundação Dom Cabral* (FDC, 2018), in a survey conducted with 130 companies representing 15.4% of Brazilian GDP, 22.3% of which are headquartered in the southern region of Brazil, logistics costs account for 12.37% of total company expenditures (an increase compared to 11.19% in 2014). Of these 12.37% dedicated to logistics costs, 40.1% are related to long-distance transport, 23.4% (2.87118%) to urban distribution, 9.9% (1.21473%) to port-related costs, and 26.6% (3.26382%) to other logistical expenses.

Based on these considerations, six scenarios were developed to simulate productivity shocks in the economy aimed at improving waterway transport. These scenarios also include comparisons with improvements in other transport modes, using both short-run and long-run closures within the B-MARIA model framework.

Table 1 – Transport Policy and Effects on the Reduction of Transport Costs

Scenario	Type of Shock	Region of Implementation
1) Margin shocks in waterway transport	10% reduction in technical margin and final demand	Porto Alegre Population Arrangement and rest of the state of RS
2) Capital productivity shock in the waterway sector	10% increase in capital productivity	Porto Alegre Population Arrangement and rest of the state of RS
3) Tariff power shock in waterway transport	10% reduction in tariff power	Arranjo populacional de Porto Alegre e restante do estado do RS
4) Capital productivity shock in the road transport sector	10% increase in capital productivity	Porto Alegre Population Arrangement and rest of the state of RS
5) Capital productivity shock in the rail transport sector	10% increase in capital productivity	Porto Alegre Population Arrangement and rest of the state of RS
6) Capital productivity shock in the road, rail, and waterway sectors	10% improvement in capital productivity	Municipality of Porto Alegre

Source: Prepared by the authors.

With regard to the scenarios developed, the increase in capital productivity can be used as a way to simulate improvements in transport infrastructure. After all, better infrastructure implies higher productivity with the same level of investment (although there is a cost associated with such improvement), whereas a reduction in tariff power represents a direct incentive for the use of a specific transport mode.

4 RESULTS

After the construction of the database and the programming of the model, a homogeneity test was performed as the initial procedure. The application of a 10% shock to the exchange rate (*natphi*) indicated that the model was in equilibrium. In addition, several robustness tests were conducted by modifying the elasticities, and the results demonstrated the model's robustness in relation to parameter sensitivity.

4.1 National Results

The results obtained, presented in Table 4, provide an overview of the macroeconomic impacts at the national level for both short-run and long-run simulations under each scenario. One notable observation is the reduction in the unemployment rate across all scenarios, except for Scenario 3 in the short run. Conversely, real household consumption increases in almost all scenarios, with the exception of Scenario 3 in the short run. Consistent with the literature, real GDP and the level of economic activity increase in all simulated scenarios. Haddad (2004) had already pointed out that improvements in transport infrastructure have a positive effect on GDP.

The reduction in transportation costs is reflected in the decrease of product prices indexed to GDP in most scenarios. A relevant finding is the increase in import volume in most long-run scenarios, while export volume tends to decrease over the same period. This shift suggests that improvements in transport infrastructure do not necessarily imply an improvement in the trade balance in the long run. However, in the short run, where government spending and investments are treated as exogenous, the impact is predominantly positive on exports and negative on imports.

When analyzed quantitatively, in Scenario 1, a 10% reduction in waterway transport margins results in a real national GDP increase of 0.002761% in the short run and 0.005861% in the long run. In the short run, household real consumption increases by 0.003483%, employment rises by 0.003308%, export volume by 0.004338%, and economic activity level by 0.001649%. In the long run, the corresponding increases are 0.011318% in household consumption, 0.000288% in employment, and 0.003589% in economic activity.

Table 4 – Macroeconomic Results

Macroeconomic Variables	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Unemployment rate	-0.003055	-0.000062	-0.001049	-0.000018	0.003090	-0.000004
Household real consumption	0.003483	0.011318	0.001181	0.003658	-0.003328	0.003818
Employment	0.003308	0.000288	0.001136	0.000083	-0.003346	0.000018
Export volume	0.004338	-0.005987	0.001294	-0.002021	0.027038	0.030549
Real GDP	0.002761	0.005861	0.000958	0.001948	-0.002932	0.002609
Import volume	0.001062	0.009283	-0.000401	0.002184	-0.005832	-0.001442
Aggregate employment (wage-weighted)	0.003146	0.000086	0.001085	0.000024	-0.003363	0.000002
Nominal wages paid by producers	0.000413	0.020240	-0.000339	0.006066	-0.025342	-0.019844
Investment at indexed prices	-0.000975	0.008960	-0.000809	0.002365	-0.020861	-0.019422
Consumer price index	0.000413	0.009231	-0.000339	0.002512	-0.025342	-0.023630

Exports at indexed prices	-0.002786	0.003646	-0.000911	0.001168	-0.016950	-0.020847
GDP deflator	-0.000119	0.010659	-0.000520	0.002953	-0.027050	-0.025096
Relative price of capital and labor	-0.002175	0.016921	-0.000822	0.005406	-0.009362	-0.000980
Economic activity index	0.001649	0.003589	0.000569	0.001190	-0.001763	0.003537
Interregional trade at indexed prices	-0.000468	0.008784	-0.000901	0.002103	-0.022282	-0.021955

Macroeconomic Variables	**Scenario 4**		**Scenario 5**		**Scenario 6**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Unemployment rate	-0.001672	-0.000121	-0.001245	-0.000024	-0.000128	-0.000006
Household real consumption	0.002094	0.012683	0.001410	0.004315	0.000121	0.000736
Employment	0.001810	0.000558	0.001348	0.000112	0.000139	0.000034
Export volume	0.009427	0.000737	0.001367	-0.002448	0.000521	-0.000268
Real GDP	0.003258	0.008323	0.001106	0.002269	0.000185	0.000470
Import volume	-0.008292	0.002105	-0.000336	0.002702	-0.000410	0.000181
Aggregate employment (wage-weighted)	0.001520	0.000157	0.001280	0.000034	0.000181	0.000098
Nominal wages paid by producers	-0.004925	0.016960	-0.000262	0.007240	-0.000260	0.000988
Investment at indexed prices	-0.006406	0.004007	-0.000785	0.002905	-0.000378	0.000202
Consumer price index	-0.004925	0.005005	-0.000262	0.003052	-0.000260	0.000289
Exports at indexed prices	-0.005319	-0.000176	-0.000964	0.001449	-0.000334	0.000177
GDP deflator	-0.005709	0.006032	-0.000457	0.003589	-0.000318	0.000368
Relative price of capital and labor	-0.007449	0.014942	-0.001013	0.006355	-0.000285	0.000923
Economic activity index	0.000797	0.004673	0.000671	0.001406	0.000095	0.000310
Interregional trade at indexed prices	-0.005865	0.003978	-0.000891	0.002597	-0.000334	0.000228

Source: Prepared by the authors.

These results are consistent with recent literature that employs Computable General Equilibrium (CGE) models to assess the impacts of shocks in the transport sector, as evidenced by Proque, Betarelli Júnior e Perobelli (2022), Betarelli Júnior, Domingues e Hewings (2023), and Cai et al. (2023).

4 Regional Results and Comparisons Across Transport Modes

The regional simulation results, presented in Table 5, show that tariff revenue gains represent aggregate gains. Considering that investment in transport infrastructure constitutes public expenditure, it is relevant to analyze the fiscal return of such investments for public finances. The results indicate that, in the long run, tariff gains are positive in almost all regions and most scenarios, except Scenario 3, which simulates a tariff exemption.

In Scenario 1, the region most positively affected is the rest of the state (*Restante do Estado*), with an increase of 0.021414% in the short run and 0.049284% in the long run. In Scenario 2, the rest of the arrangement (*Restante do Arranjo*) benefits the most, with increases of 0.007761% in the short run and 0.018041% in the long run. However, Scenario 3 shows no favorable outlook for tariff revenue, with the main municipality (*Município Principal*) registering the largest losses, approximately -0.79% in both the short and long run.

In Scenario 4, only short-run decreases are observed, affecting mainly the main municipality with a reduction of -0.046959%. In the long run, results are more favorable, with the rest of the arrangement experiencing the most significant gain - 0.046622%. Scenario 5 impacts primarily the rest of the arrangement, with increases of 0.006887% in the short run and 0.020265% in the long run. As anticipated, Scenario 6 affects mainly the main municipality (Porto Alegre), registering growth of 0.005012% in the short run and 0.020472% in the long run.

Table 5 – Gross Regional Product (GRP)

Region	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Munic_Princ	0.005174	0.022332	0.001241	0.006456	-0.002032	0.002033
Rest_Arranj	0.015427	0.045356	0.005204	0.017214	-0.002247	0.004942
Restante_UF	0.020110	0.048374	0.004324	0.012721	-0.002168	0.004992
Restante_BR	0.001817	0.003334	0.000772	0.001271	-0.002959	0.002546
Region	**Scenario 4**		**Scenario 5**		**Scenario 6**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Munic_Princ	0.008831	0.047618	0.002014	0.009242	0.008754	0.024579
Rest_Arranj	0.053079	0.133245	0.008408	0.023962	0.001427	0.003401
Restante_UF	0.036547	0.095877	0.006671	0.017172	0.000490	0.001673
Restante_BR	0.001308	0.002814	0.000784	0.001316	0.000064	0.000104

Source: Prepared by the authors.

The data presented in Table 5 reveal significant variation across the affected regions. In Scenarios 1, 2, and 5, the short-run impacts are greater in the rest of the state (0.080394%, 0.011302%, and 0.013286%, respectively), while in the long run, the rest of the arrangement experiences stronger effects (0.166336%, 0.031472%, and 0.037519%). In Scenario 3, there are short-run losses followed by long-run gains, with an eventual effect of 0.004992% in the rest of the state. Scenarios 4 and 6 primarily affect the rest of the arrangement and Porto Alegre, respectively. In the long run, Scenario 4 generates an increase of 0.180182% in the rest of the arrangement, whereas Scenario 6 results in a 0.040499% increase in the main municipality.

The results shown in Table 6 indicate a positive impact on the value added of production across all scenarios, supporting the findings of Araújo (2006), who emphasized the propagation of shocks between regions, even when applied to a specific area. Contrary to the theory proposed by Araújo (2006), however, this model shows that the regions directly affected by the shock experience a more pronounced increase in production. This outcome may be related, as suggested by Haddad (2004), to the application of the shock to transport margins without a compensatory investment.

In Scenario 1, the rest of the state (*Restante do Estado*) is the most impacted region, with a long-run increase of 0.043456%. In Scenario 2, the rest of the population arrangement (*Restante do Arranjo Populacional*) registers a long-run increase of 0.016939%. Scenario 3 presents a short-run decline, with negative effects of -0.001847% in the main municipality, but long-run increases of up to 0.006372% in the rest of the state. In Scenario 4, the most significant short-run impact occurs in the rest of the state (0.020813%), while in the long run, the rest of the arrangement shows the highest increase (0.102856%). Scenario 5 primarily affects the rest of the arrangement, with a long-run increase of 0.022516%, whereas Scenario 6 has its greatest impact on the main municipality, reaching 0.024833% in the long run.

Table 6 – Value Added of Production

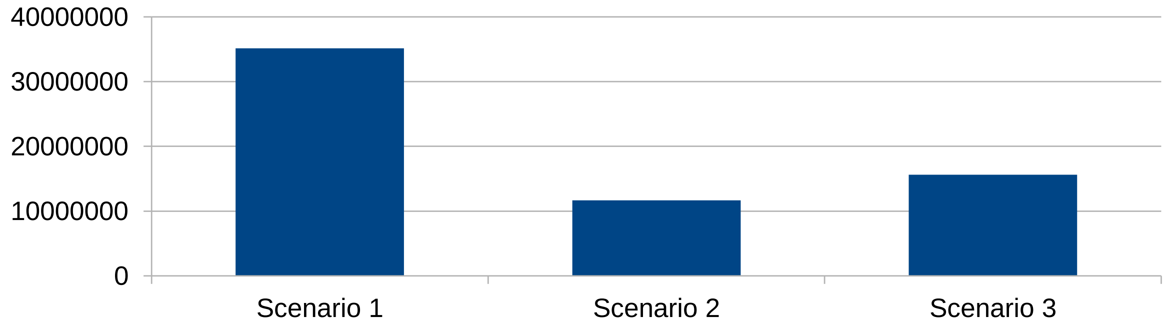
Region	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Munic_Princ	0.003144	0.019934	0.000902	0.005876	-0.001847	0.001882
Rest_Arranj	0.011495	0.041329	0.004979	0.016939	-0.000850	0.005740
Restante_UF	0.013715	0.043456	0.004186	0.012828	-0.000402	0.006372
Restante_BR	0.000957	0.001127	0.000351	0.000431	-0.001836	0.003400
Region	**Scenario 4**		**Scenario 5**		**Scenario 6**	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Munic_Princ	-0.000676	0.038070	0.001290	0.008334	0.007783	0.024833
Rest_Arranj	0.019924	0.102856	0.006758	0.022516	-0.000391	0.001740
Restante_UF	0.020813	0.085422	0.005639	0.016770	0.000041	0.001283
Restante_BR	-0.000324	-0.000507	0.000369	0.000392	0.000009	-0.000048

Source: Prepared by the authors.

The following charts provide a comparative synthesis of the results. In Figure 3, it is evident that Scenario 1 (10% reduction in transport margins) delivers the most favorable outcomes in terms of GDP growth and the highest gains in tariff revenue. This scenario simulates an intervention designed to facilitate trade, including exports.

With respect to Scenario 3, a positive impact on GDP is observed in the long run, particularly in the regions representing the rest of the arrangement and the rest of the state. This result was anticipated, as the scenario simulates a direct tariff reduction as an incentive for greater use of waterway transport, leading to a long-term positive effect. Comparatively, the results suggest that tariff reduction policies may produce more robust effects than productivity gains alone in the context of waterway transportation.

Figure 3 – Comparison of Investments in Waterway Transport (GDP)

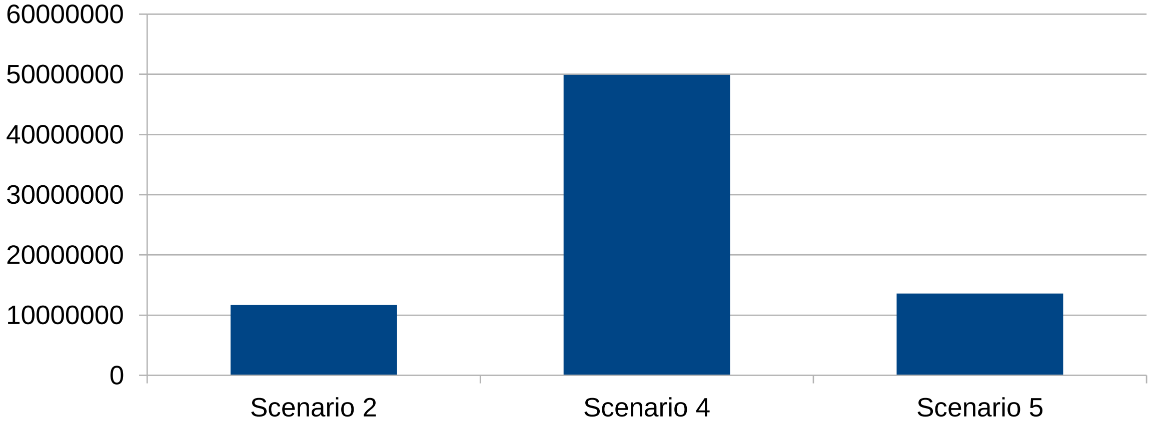


Source: Prepared by the authors.

Figure 4 highlights that Scenario 4 offers the best outcome in terms of GDP impact. This result was expected, as the scenario simulates a 10% improvement in road transport, the most widely used mode in the state. However, because road transport is so extensively employed, the associated development costs would also be considerably higher. Taking into account the volume of cargo transported by each mode and the investment required for such interventions, waterway transport shows the highest return, given its potentially superior cost-benefit ratio when compared to other modes.

When comparing GDP returns between road and rail transport, considering their respective usage in the state, rail transport demonstrates a greater gain. Nevertheless, as noted by Cunha (2014), waterway transport is considered less polluting than its competitors.

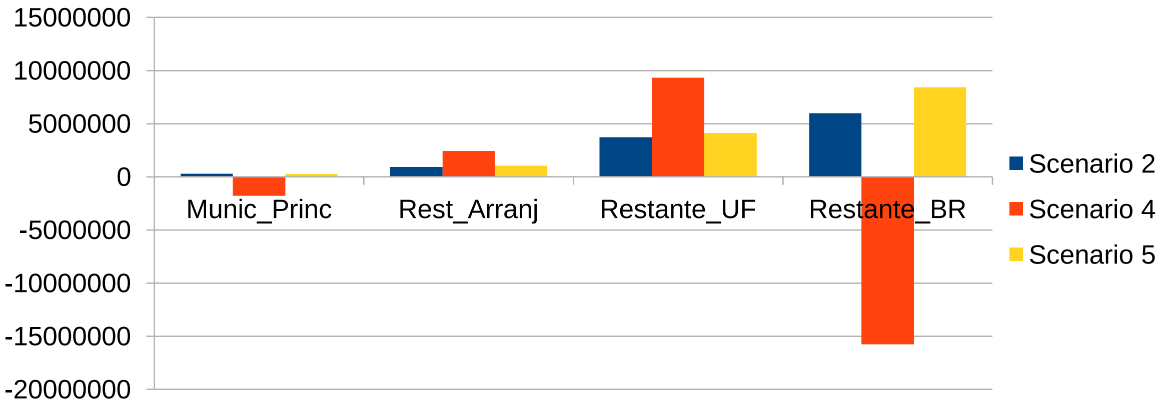
Figure 4 – Comparison of Investments by Transport Mode (GDP) Real GDP under long-run closure, in absolute values[2]



Source: Prepared by the authors.

In Figure 5, it is observed that tariff revenue gains in Scenario 4 are positive for the directly affected region but negative for the surrounding regions. In contrast, the outcomes of Scenarios 2 and 5 are positive across all regions. These findings are critical for the design of federal policies aimed at national development, as they demonstrate that investments in road and rail transport yield more widespread benefits for the rest of Brazil, while road transport improvements primarily benefit state-level public finances.

Figure 5 – Comparison of Transport Investments by Mode and Region Absolute values



Source: Prepared by the authors.

2 Valores absolutos são obtidos multiplicando os ganhos encontrados nos resultados macroeconômicos por valores correspondentes na MIP.

In summary, the regional simulation results reinforce the relevance of the computable general equilibrium (CGE) approach for understanding the spatial and distributive effects of transport policies. As highlighted by Betarelli Júnior, Domingues e Hewings (2023) and Campos e Haddad (2016), CGE models with regional disaggregation allow for capturing the direct and indirect effects of logistical shocks on variables such as output, value added, and public tariff revenue, while accounting for productive and commercial interdependencies among regions.

The differentiated behavior between directly impacted regions and adjacent areas underscores the importance of regional spillover effects, frequently emphasized by authors such as Robson, Wijayaratnadixit e Dixit (2018) and Rosik e Wójcik (2023). The more significant gains observed in inland regions and in population arrangements connected to the waterway axis demonstrate that localized improvements can generate positive spatial rebalancing, fostering greater territorial cohesion and reducing regional disparities.

Additionally, the results are consistent with the theory proposed by Bröcker e Korzhenevych (2013), according to which investments in logistical infrastructure enhance spatial connectivity and reduce barriers between regional markets, thus favoring long-term productive specialization and increased regional competitiveness. This effect tends to be more significant when lower-cost transport modes, such as waterways, are involved.

The stronger performance of the waterway investment scenarios - compared to other transport modes - in terms of value added and regional GDP aligns with the findings of Proque, Betarelli Júnior e Perobelli (2022), who emphasize that selecting the appropriate transport mode is a central element in regional development strategies. Waterway transport, by combining low operational costs, reduced environmental impact, and high cargo capacity, presents a substantial competitive advantage, especially in states with hydrographic potential such as Rio Grande do Sul.

Another aspect to consider, as argued by Araújo (2006), is that the regional effects of shocks in waterway transport are not limited to directly benefited areas. However, the results observed in this study indicate that impacts are concentrated in regions where costs were directly reduced (waterway margins), suggesting the need for complementary policies on logistical coordination and modal integration to maximize benefits throughout the entire state territory.

In conclusion, by highlighting the differences among transport modes and their respective economic and spatial returns, the regional results provide empirical support for prioritizing public policies aimed at modernizing the waterway infrastructure in the state of Rio Grande do Sul, with emphasis on leveraging the *Lagoa dos Patos* and strengthening the connection between the Port of Rio Grande and the Metropolitan Region of Porto Alegre.

5 Final Considerations

This study aimed to evaluate the economic and regional impacts of improvements in waterway transport in the state of Rio Grande do Sul by employing a computable general equilibrium (CGE) model with regional disaggregation. Through the simulation of different scenarios, the research sought to understand the effects of policies related to the reduction of logistical costs and infrastructure investments on macroeconomic and spatial variables such as gross domestic product, value added, employment, public tariff revenue, and household consumption. The choice of the waterway mode is justified not only by its low operational cost but also by its potential to induce systemic gains in competitiveness and territorial cohesion.

The results indicate that, even with its limited share in the state's transport matrix, waterway transport generates significant returns, especially in the regions directly affected by policy shocks. The reduction of transport margins positively affects variables such as aggregate output and public revenues, demonstrating the importance of logistics for the regional productive structure. In addition, spillover effects were observed in adjacent regions, confirming that the benefits arising from infrastructure improvements in one territory can spread to other economically integrated areas. This finding is consistent with recent literature on regional development and infrastructure, as noted by authors such as Rosik and Wójcik, Betarelli Júnior, Domingues and Hewings, and Bröcker and Korzhenevych.

The comparison between transport modes also yields relevant insights. Although road transport is the most widely used mode in the state, its operational and environmental costs are higher when compared to inland waterway transport. The simulations showed that waterway transport is capable of generating similar or even superior gains in terms of value added and regional output. This reinforces its potential as a structuring axis for a sustainable territorial development policy. Furthermore, as emphasized by Cunha, it is the mode with the lowest carbon emissions per ton transported, making it a strategic choice in the context of the transition to a low-carbon economy and Brazil's international climate commitments.

The CGE model adopted proved suitable for capturing the direct and indirect effects of logistical interventions in a regionalized context. It allowed the identification of production linkages and intersectoral impacts that are relevant for the design of public policies. However, the model presents some limitations, such as the low sectoral disaggregation in strategic sectors like agriculture and manufacturing, and the absence of an explicit representation of the intermodal transport network, which restricts a more robust analysis of spatial interactions. These limitations point to directions for future research that may incorporate such dimensions through the use of more detailed datasets and complementary methodological approaches.

Public policies aimed at expanding and modernizing the inland waterway infrastructure in the state of Rio Grande do Sul, especially in the *Lagoa dos Patos* region and its connection to the Port of Rio Grande and the Metropolitan Region of Porto Alegre, should be prioritized. The low usage of the waterway mode in the state, despite its installed capacity and strategic location, suggests a historical imbalance in transport investment allocation, traditionally concentrated in road infrastructure. Moreover, strengthening coastal shipping (*cabotage*) and inland navigation requires the removal of regulatory barriers, the encouragement of new logistics operators, and the revitalization of the domestic shipbuilding industry.

In summary, the results presented offer solid empirical support for the formulation of integrated transport and regional development policies. By highlighting the economic, spatial, and environmental advantages of the waterway transport mode, this study contributes to advancing a more balanced and sustainable logistical planning agenda, aimed at promoting economic growth, reducing territorial inequalities, and rationalizing the allocation of public resources.

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