Regional Economic Effects of Port Efficiency Improvements in Brazil

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Abstract:
Port efficiency is a key determinant of economic competitiveness, yet its regional economic effects remain poorly understood, particularly in large and economically heterogeneous countries. This study evaluates how improvements in port efficiency affect regional growth, trade, and sectoral performance in Brazil. A physically grounded productivity indicator is developed from operational microdata provided by the Brazilian National Waterway Transportation Agency (ANTAQ) to characterize the operational heterogeneity of Brazilian ports. The regional economic effects of the productivity targets established in the National Port Logistics Plan (PNLP) 2015 are then evaluated using a dynamic-recursive multiregional computable general equilibrium model. Results indicate positive but spatially uneven impacts, with economically diversified and logistically connected regions capturing the largest gains. The findings show that the economic returns of port modernization depend primarily on regional productive structures rather than throughput volume, supporting spatially informed infrastructure planning.

Keywords: Port Efficiency; Computable General Equilibrium; Regional Spillovers.

Resumo:
A eficiência portuária é um determinante fundamental da competitividade econômica, mas seus efeitos regionais ainda são pouco compreendidos, especialmente em países de grande extensão territorial e elevada heterogeneidade econômica. Este estudo avalia como melhorias na eficiência portuária afetam o crescimento regional, o comércio e o desempenho setorial no Brasil. Para isso, desenvolve-se um indicador de produtividade baseado em microdados operacionais da Agência Nacional de Transportes Aquaviários (ANTAQ) para caracterizar a heterogeneidade operacional dos portos brasileiros. Em seguida, os efeitos econômicos regionais das metas de produtividade do Plano Nacional de Logística Portuária (PNLP) 2015 são avaliados por meio de um modelo de equilíbrio geral computável multirregional dinâmico-recursivo. Os resultados indicam impactos positivos, porém espacialmente desiguais, com regiões economicamente diversificadas e logisticamente integradas concentrando os maiores ganhos. Os achados mostram que os retornos da modernização portuária dependem principalmente das estruturas produtivas regionais, e não do volume movimentado, reforçando a importância de um planejamento da infraestrutura orientado pelas especificidades espaciais.

Palavras-chave: Eficiência Portuária; Equilíbrio Geral Computável; Transbordamentos Regionais.
Classificação JEL: R42; R11; C68.
Área de avaliação: Economia Regional

1. Introduction

The expansion of global value chains has substantially increased the importance of logistics systems in shaping economic performance and international competitiveness. As production processes become increasingly fragmented across countries, firms rely on transport networks capable of moving goods efficiently, reliably, and at competitive costs. In this context, the reduction of traditional trade barriers has shifted attention toward logistics-related frictions, such as transport costs, border procedures, and infrastructure quality, which now represent primary constraints on international trade, acting as hidden non-tariff barriers (Gereffi, 2005; D. Hummels, 2007; D. L. Hummels & Schaur, 2013). Since time delays function as a trade barrier, particularly for high-value goods, maritime transport accounts for nearly 80% of global merchandise trade by volume (UNCTAD, 2021), making ports essential nodes within contemporary production and distribution networks (Lee et al., 2008).

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Rather than serving solely as interfaces between maritime and inland transport, ports have evolved into strategic logistics platforms that influence the organization of production, firms' location decisions, and the competitiveness of entire regions (Notteboom & Rodrigue, 2005; Slack, 2006; D.-W. Song & Panayides, 2008). This evolution aligns with the paradigm of "port regionalization," where maritime gateways are increasingly integrated with regional production systems through transport corridors and inland terminals (Bottasso et al., 2014; Luo et al., 2022; MPA, 2022; Munim & Schramm, 2018). Consequently, improvements in port performance affect not only transport efficiency but also production costs, delivery reliability, firms' market access, and participation in global value chains are beyond the physical boundaries of port facilities (D. Hummels, 2007).

Theoretical perspectives vary on whether ports independently drive regional development or merely reflect pre-existing economic dynamism. On the one hand, ports are frequently viewed as engines of economic growth capable of attracting investment, promoting industrial agglomeration and strengthening regional specialization (Fujita & Mori, 1996; Haddad et al., 2006). On the other hand, some authors argue that port expansion often reflects pre-existing economic dynamism rather than acting as its primary cause (Goss, 1990). Despite this debate, there is broad consensus that port performance and regional development are mutually interconnected through production networks, transport infrastructure and market integration. Consequently, evaluating port efficiency requires moving beyond the analysis of individual facilities to consider how changes in logistics performance spread throughout regional economies.

These characteristics make the assessment of port efficiency particularly challenging in large and economically heterogeneous countries. Because production structures, logistics dependence and market integration vary substantially across regions, identical improvements in port performance may generate markedly different economic outcomes, consistent with broader evidence showing that transport infrastructure generates heterogeneous regional effects depending on local productive structures and agglomeration dynamics (Rocha et al., 2023). Moreover, firms are connected through extensive interregional supply chains, meaning that part of the benefits generated by a more efficient port may be transmitted to regions that do not host the infrastructure itself, while others may experience competitive adjustments resulting from changes in transport costs and trade patterns. These transmission mechanisms highlight the need for analytical approaches capable of representing the economy as an integrated system rather than a collection of isolated regional markets. Rather than generating homogeneous gains, port efficiency tends to reinforce existing productive linkages, causing benefits to propagate unevenly across territories (Gripaios & Gripaios, 1995; Haddad et al., 2010).

The existence of these interregional transmission mechanisms has important methodological implications. Evaluating the economic consequences of port-efficiency improvements requires more than measuring changes in cargo throughput or operational performance at individual terminals. Because production sectors are linked through intermediate input demand, trade flows and factor markets, logistical improvements propagate throughout the economy, affecting regions that may not be directly connected to the port where efficiency gains occur. Consequently, analytical approaches restricted to port-level indicators or partial-equilibrium analyses are unable to capture the broader economic adjustments generated by changes in logistics performance.

These limitations have motivated an increasing body of literature to adopt computable general equilibrium (CGE) models to investigate the economy-wide consequences of transport and logistics improvements. Recent studies have further demonstrated the usefulness of CGE frameworks for evaluating how improvements in logistics performance and trade facilitation alter transport costs, modal choices, trade flows, and broader economic outcomes, reinforcing their suitability for transport policy analysis(Avetisyan & Hertel, 2021). Unlike partial approaches, CGE models explicitly represent the interdependence among sectors, households, governments and external markets, allowing changes in transport efficiency to propagate through production costs, relative prices, trade flows and resource allocation. When extended to a multiregional framework, these models additionally capture domestic trade linkages and spatial spillovers, making it possible to identify how localized infrastructure improvements affect regions with different productive structures and degrees of economic integration (Doi et al., 2001; Haddad et al., 2010; Ishikura, 2020; Junqueira, 2017; Rodrigues, 2022; L. Song & van Geenhuizen, 2014).

This perspective is particularly relevant for Brazil. The country's productive system is characterized by strong regional specialization, long transport distances and an extensive network of interregional trade flows, making logistics performance a fundamental determinant of economic competitiveness. Although maritime transport accounts for more than 90% of Brazil's international trade volume, port infrastructure and operational performance remain highly heterogeneous across the national territory (Antaq, 2023). Major export corridors concentrate agricultural commodities, minerals and energy products, whereas container terminals support the import of capital goods, intermediate inputs and higher value-added manufactures. Consequently, individual ports perform distinct economic functions and connect different regional production systems. Because production and trade linkages vary across Brazillian regions, aggregate performance indicators may conceal significant operational heterogeneity and lead to "spatially blind" policy designs This national port system faces persistent bottlenecks that function as substantial non-tariff frictions, increasing logistics costs and reducing supply-chain reliability.

The strong geographic concentration of Brazilian cargo flows further reinforces the strategic importance of a relatively small number of port complexes. Approximately 45% of national cargo throughput is handled by ports located in the Southeast, while a relatively small number of port complexes, including Santos, Itaguaí, Vitória, Paranaguá, Itaqui and Rio Grande, serve as strategic gateways connecting domestic production with international markets (Antaq, 2023; Brasil, 2015). These port complexes anchor well-established logistics corridors that integrate agricultural frontiers, mining regions and industrial centers across the country. The Port of Santos, for example, supports not only the economy of São Paulo but also significant shares of the foreign trade of inland states such as Minas Gerais, Mato Grosso and Goiás, illustrating how port performance generates effects that extend far beyond administrative boundaries.

Despite the strategic importance of these logistics corridors, substantial operational disparities persist across Brazilian ports. Differences in infrastructure quality, cargo composition, equipment availability, governance arrangements and hinterland accessibility translate into significant variations in vessel waiting times, berth productivity and operational efficiency (Antaq, 2023; Fontes & Mello, 2006; P. F. Wanke, 2013). Such heterogeneity implies that aggregate indicators of port performance may conceal important regional differences and underestimate the economic consequences of operational improvements. Consequently, understanding the economic implications of port modernization requires performance measures capable of capturing operational heterogeneity while recognizing the production and trade linkages connecting Brazilian regions.

Recognizing these structural challenges, the National Port Logistics Plan (PNLP) 2015 established explicit productivity targets aimed at narrowing the performance gap between Brazilian ports and international benchmarks (Brasil, 2015). The plan proposed productivity gains of approximately 50% for bulk terminals and 120% for container terminals over a twenty-year horizon, reflecting expected improvements in operational procedures, infrastructure capacity and cargo-handling efficiency. Beyond defining investment priorities, the PNLP provides a consistent policy benchmark for evaluating the broader economic implications of port modernization.

Although a growing literature has examined port efficiency using operational benchmarking, Data Envelopment Analysis (DEA), stochastic frontier methods and econometric approaches (Fontes & Mello, 2006; Wang et al., 2005; P. F. Wanke, 2013), recent empirical evidence suggests that port investments can also generate positive effects on local economic activity, reinforcing the role of maritime infrastructure as a driver of regional development (Karimah & Yudhistira, 2020). Nevertheless, comparatively less attention has been devoted to understanding how localized improvements in port performance propagate through interregional production systems. Most studies focus either on measuring the efficiency of individual ports or on estimating their impacts on local economic outcomes and trade flows, providing limited evidence on how operational gains diffuse across domestic supply chains and reshape broader regional economic interactions. This limitation is particularly relevant in Brazil, where strong interregional production and trade linkages imply that productivity improvements achieved at one port may generate benefits, or competitive adjustments, in regions that do not directly host the infrastructure.

Addressing this gap requires combining a detailed empirical characterization of port operations with an analytical framework capable of capturing the economy-wide transmission of productivity improvements. This study develops a physically grounded measure of port productivity using operational microdata from the Brazilian National Waterway Transportation Agency (ANTAQ). The utilization of approximately 2 million vessel-call observations allows for the construction of cargo-weighted operation times, thereby avoiding the distortions inherent in monetary proxies and capturing the physical dynamics of the vessel turnaround cycle. These productivity indicators are integrated into a dynamic-recursive multiregional computable general equilibrium (CGE) model, the Brazilian Interregional Model and Transport (BIM-T). This framework explicitly represents interregional trade flows and transport margins, allowing the analysis to examine how achieving the productivity targets of the National Port Logistics Plan (PNLP 2015) propagates through production networks and domestic supply chains. The proposed approach identifies how port modernization affects regional growth and sectoral performance. By explicitly considering domestic trade alongside international trade, the study clarifies whether logistical improvements in major hubs generate broad spatial spillovers or reinforce economic concentration. The results provide evidence for "spatially informed" infrastructure policies by identifying both the direct effects on port-hosting regions and the indirect spillover effects transmitted throughout the economy.

Accordingly, the main objective of this study is to quantify how improvements in port efficiency affect regional economic growth, sectoral performance and trade across the Brazilian economy. By combining a detailed empirical characterization of port operations with an economy-wide evaluation of policy-induced productivity improvements, the analysis investigates not only the direct impacts experienced by the states where efficiency gains occur, but also the indirect effects transmitted through domestic production networks and interregional trade linkages.

Collectively, the proposed approach contributes to literature in four main respects. First, it introduces a physically grounded measure of port productivity based on detailed operational microdata, moving beyond conventional aggregate efficiency indicators and providing a richer empirical characterization of the operational heterogeneity of Brazilian ports. Second, it evaluates the economy-wide implications of the productivity targets established in the PNLP 2015 within a dynamic multiregional CGE framework, providing a comprehensive assessment of how policy-driven improvements propagate through production networks, domestic trade and interregional economic linkages. Third, unlike most previous studies, the analysis explicitly considers the role of domestic trade alongside international trade, offering a more complete understanding of how port-efficiency policies affect a continental economy. Finally, the results provide evidence directly relevant for infrastructure planning by identifying where productivity-enhancing investments are most likely to generate broad regional spillovers and the greatest national economic returns.

The remainder of this paper is organized as follows. Section 2 reviews the international experience on port strategies and the institutional evolution of the Brazilian port system. Section 3 describes the construction of the operational productivity indicator, the multiregional CGE model and the simulation design. Section 4 presents the empirical results, while Section 5 discusses their policy implications. Finally, Section 6 concludes.

2. International Port Governance and the Brazilian Port System

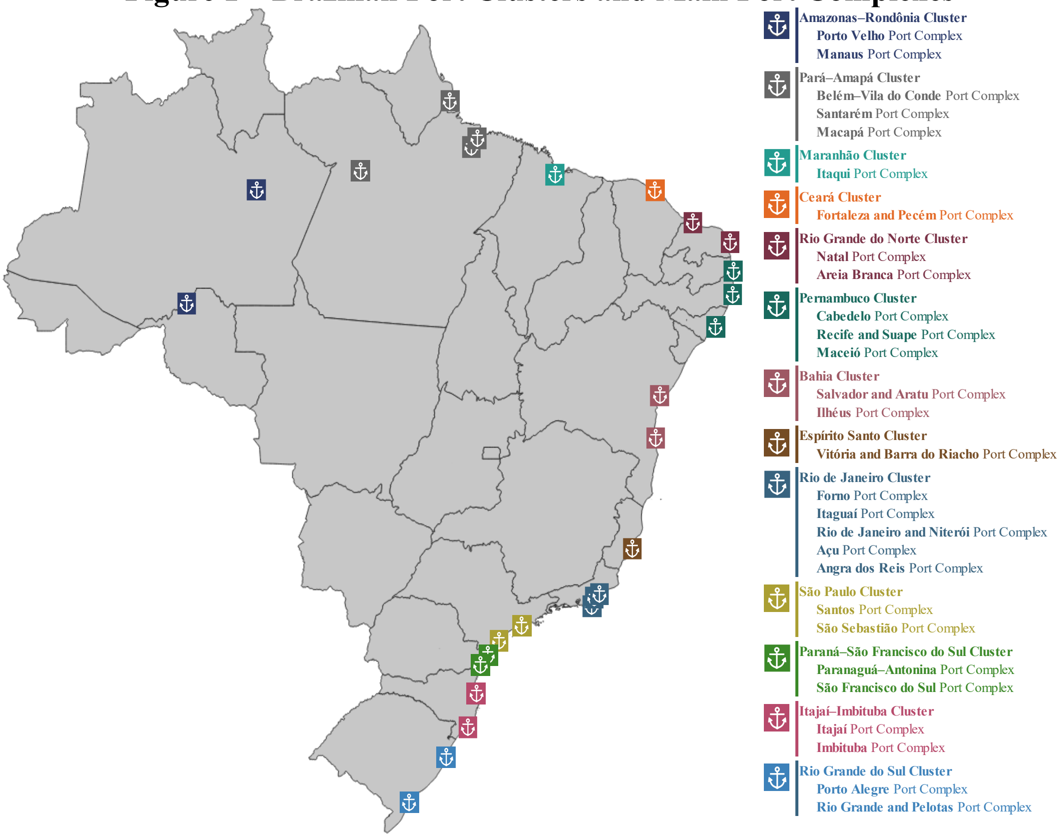
The international experience reveals that port performance is shaped by a combination of governance arrangements, regulatory capacities, and the ability to articulate port strategies with broader territorial and industrial policies. Empirical evidence consistently suggests that governance models, particularly public-private partnerships (PPPs) and private administration, are associated with improved scale and managerial efficiency in ports**.** Ports operate as nodes embedded in complex economic geographies, where coordination failures between municipal authorities, port administrations, and national logistics strategies can generate persistent inefficiencies (Merk & Dang, 2013). While cities tend to prioritize employment, land use, and tax revenues, port authorities focus on throughput, vessel turnaround time, and international competitiveness. Aligning these interests is fundamental for the consolidation of productive clusters and for sustaining long-term logistical modernization.

International cases provide clear evidence that port competitiveness depends on coherent state–market interactions. Shanghai's trajectory, marked by strong state coordination, integration with financial services, and industrial clustering policies, illustrates how centralized planning can accelerate port modernization and expand hinterland connectivity (Hong et al., 2013). Singapore's success as a transshipment hub stems from sustained public investment in automation, digitalization, and high-end logistics capabilities (MPA, 2022). European ports such as Rotterdam and Antwerp pursued different but complementary strategies: territorial expansion to mitigate urban constraints, development of dedicated freight corridors (e.g., *Betuweroute*), and adoption of advanced technological solutions such as drones, IoT monitoring, and real-time digital simulations (Merk & Notteboom, 2013; Port of Antwerp Bruges, 2021). These experiences demonstrate that consistent regulatory frameworks, targeted investments, and technological integration can significantly reduce operational bottlenecks and generate productivity gains. Moreover, these strategic gateways increasingly embody the paradigm of “port regionalization”. Under which ports are no longer isolated interfaces but nodes within broader value chains, integrating inland distribution networks and transport corridors to strengthen regional economic systems (Notteboom & Rodrigue, 2005).

Contrasting these strategies with Brazil highlights the structural challenges faced by the national port system. Despite reforms since the 1990s, beginning with the dissolution of PORTOBRÁS and the enactment of the 1993 Port Modernization Law (Brasil, 1993), the country still exhibits high logistical costs, limited intermodal integration, and heterogeneous operational performance across regions. The regulatory restructuring and the creation of ANTAQ in 2001 (Brasil, 2001) improved oversight and transparency. However, persistent fragmentation between public and private governance arrangements continues to constrain the sector's ability to diffuse economic benefits inland. The coexistence of *Companhias Docas*, municipal and state delegations, and private use terminals (TUPs) has produced an institutional mosaic that is more fragmented than leading international benchmarks. This institutional complexity represents a critical gap, as the limited empirical integration of governance structures with spatial-economic models often hinders a comprehensive assessment of regional impacts (World Bank, 2007).

Figure 1 presents the spatial distribution of Brazilian port clusters and their main port complexes, illustrating the geographic concentration of facilities along the coastline and the distinct regional configurations of the national port system. Brazil’s port infrastructure is extensive and heterogeneous, comprising 34 organized public ports and 147 private terminals distributed across more than 8,500 km of coastline and 22,000 km of inland waterways (Antaq, 2023).

Figure 1 – Brazilian Port Clusters and Main Port Complexes



Source: Adapted from Brasil (2015).

Cargo flows remain highly concentrated, with Southeast ports accounting for approximately 45% of national throughput and only ten port complexes handling more than half of the country's total volume. While such centralization can generate economies of scale, it also amplifies regional bottlenecks. The competitive and cooperative interactions among these regional ports, characterized as "coopetition," play a decisive role in shaping regional demand patterns and the long-term strategic positioning of clusters. The Port of Santos exemplifies this duality: it is the country's primary trade platform, serving even landlocked regions such as Minas Gerais and Mato Grosso, yet faces recurrent congestion, limited automation, and insufficient rail integration. Although the port's 2021–2025 Strategic Plan proposes modernization initiatives to address these constraints, progress has been uneven.

Cargo dynamics further illuminate structural inefficiencies. Between 2010 and 2016, cargo volume expanded while operation times decreased, reflecting productivity gains. However, after 2016, this relationship deteriorated: volume continued to grow, yet waiting and berthing times stagnated, signaling that capacity expansion and technological upgrades did not keep pace with demand. These trends mirror international findings that port performance is tightly linked to procedural efficiency, hinterland connectivity, and adequate pricing structures, factors repeatedly emphasized in studies on trade facilitation and maritime logistics (Z. H. Munim & Schramm, 2018; Sánchez et al., 2003). These persistent operational inefficiencies function as substantial non-tariff barriers, analogous to an increase in distance from international markets, which significantly raises maritime transport costs and reduces trade competitiveness (Bottasso et al., 2018; P. Wanke & Barros, 2016).

Brazil's trade composition reinforces these structural vulnerabilities. Exports are dominated by primary commodities, fuels, minerals, seeds, and grains, while imports rely heavily on high value-added manufactured goods, particularly machinery, equipment, and chemical products (Brasil, 2023). Such asymmetry has direct implications for port logistics: bulk facilities face rising pressure from commodity flows, whereas container terminals must handle growing import volumes of higher value-added manufactured goods (Antaq, 2023). This trade structure positions Brazilian ports simultaneously as export gateways for primary commodities and import gateways for manufactured goods, requiring reliable operations across distinct cargo types and logistics chains.

In this context, comparing Brazil to international benchmarks reveals clear gaps in automation, process digitalization, governance cohesion, and integrated planning. At the same time, international experience points to practical pathways for narrowing these gaps through institutional coordination, technological upgrading, and long-term planning. Policies that clearly define investment priorities, streamline regulatory interfaces, and incentivize technological adoption could substantially narrow Brazil's logistical deficit. Improvements in port efficiency, whether operational, institutional, or infrastructural, tend to produce measurable economic effects not only at the local level but through spatial spillovers across the national production system, as shown in previous empirical and CGE-based studies (Haddad et al., 2010; Sant'Anna & Kannebley Júnior, 2018).

Ultimately, the synthesis of international experience and Brazil's institutional evolution suggests that the country's path toward global competitiveness depends on three intertwined dimensions: (i) strengthening regulatory coherence and governance capacity; (ii) adopting technological and organizational innovations aligned with global best practices; and (iii) implementing integrated logistics and industrial policies capable of reducing structural bottlenecks and improving regional connectivity. These elements provide the conceptual bridge for understanding how improvements in port efficiency, particularly those related to waiting times, operational practices, and organizational coordination, can propagate through production networks and influence regional and national economic performance.

3. Methodology

This section presents the methodological framework used to evaluate the regional and sectoral economic effects of improvements in port efficiency in Brazil. The empirical strategy combines detailed operational information from ANTAQ microdata with a dynamic multiregional computable general equilibrium model (BIM-T). The analysis proceeds in two stages. First, operational microdata are used to characterize the heterogeneity of port performance and construct a physically grounded productivity indicator. Second, productivity improvements consistent with the targets established in the National Port Logistics Plan (PNLP 2015) are evaluated through policy simulations in the CGE model, allowing their economy-wide effects to be traced across production networks, interregional trade flows and transport-cost interactions.

3.1. Port Productivity Indicator

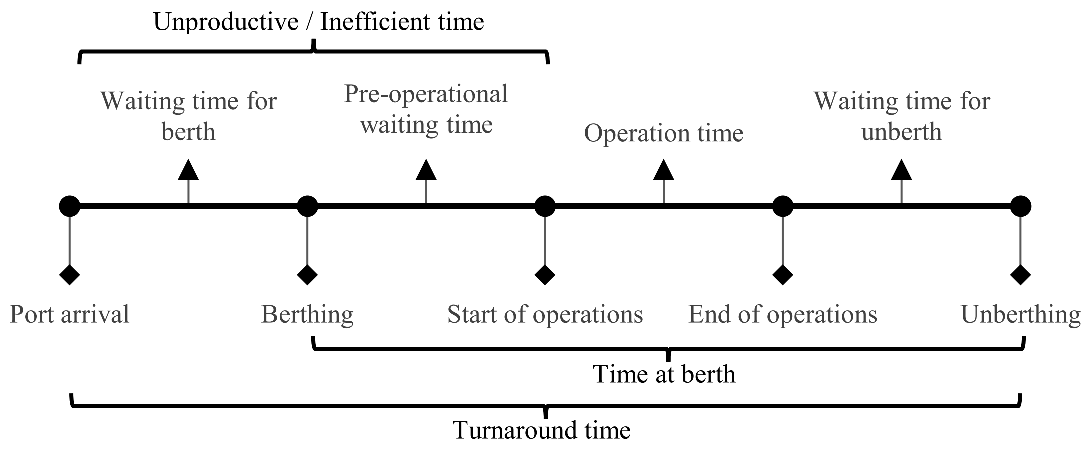
The empirical analysis relies on operational microdata from the Brazilian National Waterway Transportation Agency (Antaq, 2023), specifically the Vessel Docking, Cargo and Containerized Cargo databases. Together, these datasets provide detailed information on vessel movements, cargo volumes and operational timestamps, allowing port activity to be reconstructed at a high level of granularity. The sample covers the period from 2015 to 2022 and includes only long-haul navigation, which concentrates the cargo flows associated with Brazil's international trade. By utilizing granular microdata to construct a measure of "tons per day of effective operation," this study provides a standardized response to the lack of consensus on standard efficiency indicators. Unlike conventional aggregate efficiency indicators, this measure avoids the distortions inherent in monetary proxies and directly reflects the speed at which port facilities convert operational time into cargo throughput, preserving differences in infrastructure and operational practices across Brazilian ports.

Each observation corresponds to an individual long-haul vessel call associated with Brazil's international trade, recording the origin and destination ports together with the exact timestamps of arrival, berthing, cargo-handling operations and departure. After integrating the operational databases, harmonizing identifiers and applying consistency filters, the final panel comprises approximately 2 million vessel-call observations covering the 2015–2022 period. This level of detail provides a highly disaggregated representation of port operations, strengthening the empirical basis for the productivity indicator developed in this study.

To harmonize the databases, vessel docking and cargo-handling records were linked using their common identifiers. Observations with missing or inconsistent timestamps were removed, and only long-haul vessel movements were retained. The resulting integrated database provides, for each port call, information on cargo volumes, vessel characteristics and the duration of each stage of the port turnaround cycle, ensuring comparability across states and establishing a consistent basis for constructing the productivity indicator.

Because the database records the exact timing of each operational stage, total port stay can be decomposed into distinct operational and non-operational components. Although the chronology illustrated in Figure 2 follows the sequence typically observed in import operations, the same time components are also applicable to exports, differing only in the ordering of cargo-handling activities rather than in the underlying operational stages.

Figure 2 – Timeline of Port Operations (Import Perspective)



Source: Adapted from Sant’Anna & Kannebley Júnior (2018).

Based on this operational sequence, three time indicators were calculated for each state: waiting time before berthing, operation time and total port stay. To ensure that larger facilities exert proportionally greater influence on state-level performance measures, all indicators were computed as cargo-weighted averages. The productivity indicator was then defined as the ratio between the total cargo volume handled and the corresponding operation time, providing a physically grounded measure of cargo-handling performance. Unlike conventional aggregate efficiency indicators, this measure directly reflects the speed at which port facilities convert operational time into cargo throughput while preserving differences in infrastructure, cargo composition and operational practices across Brazilian ports.

Tables 1 and 2 summarize the resulting operational patterns and the spatial distribution of port activity. The descriptive statistics reveal substantial heterogeneity in both port performance and trade integration across Brazilian states. While states such as Pernambuco and Espírito Santo exhibit relatively high operational productivity, others, including Maranhão and Pará, continue to display long waiting and operation times, suggesting persistent infrastructure and operational bottlenecks. At the same time, cargo flows remain highly concentrated in a limited number of maritime gateways. In 2019, ports located in the Southeast accounted for nearly half of Brazil's exports and imports, with Santos alone handling approximately 35% of exports and 40% of imports. Inland production centers, including Minas Gerais and Mato Grosso, depend heavily on these coastal gateways through well-established interstate logistics corridors. Taken together, these descriptive patterns highlight the pronounced operational heterogeneity of the Brazilian port system and justify concentrating the subsequent simulations on the thirteen states responsible for approximately 98% of national port throughput. More importantly, they reinforce the expectation that improvements in port productivity will generate spatially differentiated economic effects, motivating the use of a multiregional CGE framework capable of capturing interregional spillovers and economy-wide adjustment mechanisms.

Table 1 – Port Stay, Operational Times, and Productivity by State (2015–2022)

State (UF)	Port Stay (days)			Operation Time (days)			Waiting Time (days)			Operation Productivity (million tons/day)		
	2015	2022	Var.	2015	2022	Var.	2015	2022	Var.	2015	2022	Var. %
AM	2.52	2.71	0.19	2.12	2.36	0.24	0.39	0.35	-0.05	2.47	2.84	14.82
BA	2.01	1.83	-0.17	1.69	1.50	-0.19	0.31	0.34	0.02	9.70	15.44	59.14
CE	2.10	2.18	0.08	1.94	1.87	-0.07	0.17	0.31	0.14	3.29	3.93	19.34
ES	2.07	2.31	0.23	1.63	2.03	0.40	0.44	0.28	-0.17	103.95	47.71	-54.10
MA	3.15	3.15	0.00	2.79	2.80	0.01	0.36	0.35	-0.01	52.47	70.78	34.89
PA	2.61	2.78	0.18	2.21	2.30	0.09	0.39	0.48	0.09	11.81	17.16	45.32
PE	1.29	1.76	0.47	1.03	1.45	0.42	0.26	0.31	0.05	7.15	6.08	-15.00
PR	1.26	1.50	0.24	1.02	1.26	0.24	0.24	0.24	0.00	38.47	40.13	4.32
RJ	1.29	1.36	0.07	0.93	1.05	0.12	0.36	0.31	-0.05	155.00	175.67	13.34
RN	2.40	2.79	0.39	2.16	2.55	0.39	0.24	0.24	0.00	0.78	0.78	0.97
RS	1.68	1.59	-0.09	1.41	1.30	-0.11	0.26	0.29	0.03	23.69	24.99	5.51
SC	1.46	1.55	0.08	1.24	1.27	0.03	0.22	0.28	0.06	22.52	28.13	24.88
SP	1.58	1.75	0.17	1.17	1.40	0.23	0.41	0.35	-0.06	85.59	95.15	11.17
BR	2.00	2.10	0.11	1.63	1.78	0.15	0.37	0.32	-0.04	445.00	460.69	3.53

Note: Operational productivity measures how much cargo a port handles per day of effective operation, directly reflecting its physical efficiency.
Source: ANTAQ (2023); BRASIL (2023).

Table 2 – Port Shares in State-Level Import and Export Operations (2019)

State (UF)	Share (%)	Main Ports of Entry (Imports)				Share (%)	Main Ports of Exit (Exports)			
RO	0,6	Manaus - AM	(21,1%)	Santos - SP	(19,0%)	0,6	Santos - SP	(34,2%)	Manaus - AM	(33,7%)
AC	0,0	Manaus - AM	(70,0%)	Itaguaí - RJ	(12,6%)	0,0	Manaus - AM	(49,2%)	Paranaguá - PR	(24,8%)
AM	4,6	Manaus - AM	(85,1%)	Itaguaí - RJ	(7,8%)	0,3	Manaus - AM	(62,5%)	Santos - SP	(25,4%)
RR	0,0	Manaus - AM	(61,6%)	Itaguaí - RJ	(26,1%)	0,0	Manaus - AM	(99,9%)	Salvador - BA	(0,1%)
PA	0,9	Belém - PA	(72,2%)	Santos - SP	(6,4%)	10,0	São Luís - MA	(77,6%)	Belém - PA	(18,7%)
AP	0,1	Maceió - AL	(78,8%)	Santana - AP	(5,7%)	0,0	Santana - AP	(81,3%)	Belém - PA	(18,3%)
TO	0,1	São Luís - MA	(33,9%)	Salvador - BA	(13,2%)	0,6	São Luís - MA	(71,1%)	Santos - SP	(15,1%)
MA	2,7	São Luís - MA	(98,1%)	Santos - SP	(0,8%)	1,9	São Luís - MA	(96,6%)	Santos - SP	(2,1%)
PI	0,2	Santos - SP	(43,1%)	Salvador - BA	(26,5%)	0,3	São Luís - MA	(80,5%)	Salvador - BA	(7,6%)
CE	1,7	Fortaleza - CE	(56,4%)	Santos - SP	(21,8%)	1,2	Fortaleza - CE	(87,9%)	Santos - SP	(6,4%)
RN	0,1	Natal - RN	(44,2%)	Suape - PE	(24,4%)	0,2	Fortaleza - CE	(40,1%)	Natal - RN	(35,4%)
PB	0,4	Maceió - AL	(34,9%)	Suape - PE	(28,6%)	0,1	Salvador - BA	(29,9%)	Suape - PE	(26,4%)
PE	4,4	Suape - PE	(87,1%)	Recife - PE	(4,5%)	0,8	Suape - PE	(67,4%)	Santos - SP	(10,9%)
AL	0,5	Itaguaí - RJ	(26,4%)	Maceió - AL	(23,6%)	0,2	Maceió - AL	(89,7%)	Suape - PE	(2,8%)
SE	0,5	Salvador - BA	(40,2%)	Aracaju - SE	(32,0%)	0,0	Salvador - BA	(86,6%)	Santos - SP	(12,1%)
BA	4,9	Salvador - BA	(86,8%)	Santos - SP	(5,4%)	4,3	Salvador - BA	(63,6%)	Santos - SP	(13,0%)
MG	5,4	Santos - SP	(57,1%)	Rio de Janeiro - RJ	(22,1%)	12,8	Santos - SP	(35,8%)	Vitória - ES	(21,9%)
ES	3,3	Vitória - ES	(58,5%)	Santos - SP	(34,3%)	4,0	Vitória - ES	(76,0%)	Santos - SP	(15,5%)
RJ	7,8	Rio de Janeiro - RJ	(41,1%)	Itaguaí - RJ	(33,7%)	13,9	Itaguaí - RJ	(42,3%)	Niterói - RJ	(16,6%)
SP	31,9	Santos - SP	(94,0%)	São Sebastião - SP	(3,6%)	19,3	Santos - SP	(87,9%)	S. Sebastião - SP	(4,0%)
PR	9,4	Paranaguá - PR	(93,9%)	S. F. do Sul - SC	(3,7%)	8,1	Paranaguá - PR	(77,9%)	S. F. do Sul - SC	(10,3%)
SC	10,7	Itajaí - SC	(56,7%)	S. F. do Sul - SC	(37,2%)	4,3	Itajaí - SC	(63,6%)	S. F. do Sul - SC	(27,3%)
RS	5,9	Rio Grande - RS	(65,0%)	Porto Alegre - RS	(26,7%)	1,0	Itajaí - SC	(50,4%)	Santos - SP	(17,7%)
MS	0,7	Santos - SP	(44,7%)	Paranaguá - PR	(39,7%)	2,8	Santos - SP	(47,6%)	Paranaguá - PR	(27,5%)
MT	1,4	Santos - SP	(38,9%)	Paranaguá - PR	(27,0%)	9,5	Santos - SP	(52,2%)	Belém - PA	(14,4%)
GO	1,6	Santos - SP	(67,4%)	Paranaguá - PR	(19,5%)	3,7	Santos - SP	(68,6%)	Vitória - ES	(18,9%)
DF	0,1	Santos - SP	(67,7%)	Rio de Janeiro - RJ	(13,3%)	0,0	Santos - SP	(46,7%)	Vitória - ES	(37,0%)
BR	100.0	Santos - SP	(39,6%)	Paranaguá - PR	(10,5%)	100,0	Santos - SP	(35,2%)	São Luís - MA	(10,9%)

Note: “Share” refers to the participation of each state (UF) in the national total. The percentages in parentheses following each port name correspond to the share of that specific port in the state’s total imports (entry) or exports (exit).
Source: BRASIL (2023).

3.2. The CGE Model

The regional and sectoral economic impacts of improvements in port efficiency are evaluated using the Brazilian Interregional Model with Transport (BIM-T), a dynamic-recursive multiregional computable general equilibrium (CGE) model specifically developed to represent production, consumption, interregional trade and transport interactions. This framework provides a quantitative response to the sparse analysis linking hinterland logistics infrastructure and multimodal connectivity directly to port efficiency and regional outcomes. BIM-T follows the Johansen (1960) tradition, in which the economic system is expressed as a set of linearized equations and solved in annual percentage changes. Its theoretical structure is closely related to the Australian TERM family of models (Horridge et al., 2005), while its multiregional specification explicitly represents domestic trade flows, transport margins and spatial price differentials among Brazilian states (Andrade et al., 2021; Betarelli Junior & Domingues, 2013; Dixon et al., 2002).

Consistent with the standard CGE framework, producers minimize production costs while representative households maximize utility through nested optimization structures. Regional industries combine intermediate inputs, labor, capital and land using a hierarchical production technology. At the first level, constant elasticity of substitution (CES) functions govern the substitution between domestic and imported inputs as well as among primary factors. At higher levels, intermediate inputs are combined through fixed-proportion Leontief technologies, while producers allocate output between domestic and export markets according to a constant elasticity of transformation (CET) specification. Household demand follows a combined CES/Klein-Rubin preference structure, giving rise to a Linear Expenditure System (LES), whereas investment demand is represented by a CES-Leontief structure composed of domestic and imported capital goods.

The dynamic-recursive specification links successive periods through capital accumulation. Capital stocks evolve according to past investment net of depreciation, while investment allocation responds to expected rates of return relative to their long-run equilibrium values. This mechanism allows productivity shocks to generate gradual adjustments over time rather than instantaneous equilibrium responses, capturing both short-run and long-run effects of improvements in port efficiency.

A distinctive feature of BIM-T is its explicit representation of transport margins and interregional trade flows. Goods produced in one state may be consumed, processed or exported through another, allowing the model to distinguish the region of production from the region through which exports leave the country. By explicitly modeling interstate logistics corridors, the model internalizes the role of hinterland connectivity as a mediator of port-related economic effects, addressing the gap in understanding how interior connectivity facilitates or constrains the diffusion of benefits inland. To better represent the productive structure associated with port activities, the database was aggregated into 22 economic sectors while preserving the 27 Brazilian Federative Units as the regional dimension of the model. The sectoral aggregation distinguishes activities directly related to port operations, including the port sector, water transport and other transport services, as well as the principal commodity-producing and manufacturing sectors responsible for Brazilian foreign trade. This aggregation preserves the productive specialization of the regions while reducing the dimensionality of the model, making it suitable for the policy simulations developed in this study.

Table 3 – Regional and Sectoral Aggregation

Regions				Sectors			
1	Acre (AC)	15	Paraíba (PB)	1	Agriculture	12	Misc. Industry
2	Alagoas (AL)	16	Paraná (PR)	2	Chemicals	13	Misc. Services
3	Amapá (AP)	17	Pernambuco (PE)	3	Coal	14	Oil & Gas
4	Amazonas (AM)	18	Piauí (PI)	4	Construction Materials	15	Other Extractives
5	Bahia (BA)	19	Rio de Janeiro (RJ)	5	Electronics & Communications	16	Other Transport Services
6	Ceará (CE)	20	Rio Grande do Norte (RN)	6	Food Industry	17	Port Sector
7	Distrito Federal (DF)	21	Rio Grande do Sul (RS)	7	Iron Ore	18	Pulp & Wood
8	Espírito Santo (ES)	22	Rondônia (RO)	8	Land Transport	19	Refining & Biofuels
9	Goiás (GO)	23	Roraima (RR)	9	Livestock & Forestry	20	Steel
10	Maranhão (MA)	24	Santa Catarina (SC)	10	Machinery & Vehicles	21	Water Transport
11	Mato Grosso (MT)	25	São Paulo (SP)	11	Metal Products	22	Wholesale & Retail
12	Mato Grosso do Sul (MS)	26	Sergipe (SE)				
13	Minas Gerais (MG)	27	Tocantins (TO)				
14	Pará (PA)						

Source: Authors' elaboration

The database underlying BIM-T is based on the 2015 Brazilian Interregional Input-Output System, constructed from the most recent benchmark input-output tables available for Brazil at the time of this study, published by the Brazilian Institute of Geography and Statistics (IBGE, 2018), and complemented by the transport-sector disaggregation developed in previous applications of the BIM-T framework (Andrade et al., 2021; Betarelli Junior & Domingues, 2013). The original database comprises 136 products, 67 industries, five final-demand components (household consumption, government consumption, investment, exports and inventories), three primary production factors (labor, capital and land), transport and trade margins, taxes and interregional trade flows linking the 27 Brazilian states.

Behavioral parameters, including Armington substitution elasticities, CES substitution elasticities and CET transformation elasticities, follow the calibration adopted in previous applications of BIM-T and related Brazilian multiregional CGE models (Andrade et al., 2021; Betarelli Junior & Domingues, 2013). Using the same parameterization adopted in the established BIM-T literature ensures consistency with previous empirical applications and provides a robust basis for evaluating the regional and sectoral impacts of port-efficiency improvements under the policy scenarios analyzed in this study.

3.3. Simulation Design

The simulation strategy follows a recursive dynamic framework consisting of a baseline trajectory and a policy scenario. The baseline reproduces the expected evolution of the Brazilian economy in the absence of policy interventions and serves as the counterfactual against which the effects of port-efficiency improvements are evaluated. Because BIM-T is calibrated on the 2015 Brazilian Interregional Input-Output System, historical macroeconomic variations observed between 2016 and 2022 are introduced as exogenous shocks to update the database, while the prospective period (2023–2040) assumes an average annual GDP growth rate of 2.2%, providing a consistent long-run reference path for the simulations.

Policy experiments evaluate the productivity targets established in the National Port Logistics Plan (PNLP 2015). Following the plan's projections, port productivity is assumed to increase by 50% for bulk terminals and 120% for container terminals over a twenty-year horizon. When weighted according to the observed cargo composition between 2015 and 2022, these targets correspond to an aggregate productivity gain of 57.81%, equivalent to an average annual increase of 2.31%. Rather than being introduced as a one-time productivity shock, this annual improvement is applied sequentially throughout the prospective simulation period (2024–2040), representing a gradual implementation of the PNLP targets over time. These productivity gains are introduced as technical-change shocks in the port-services sector through the variable $atot_{i,d}$. Because the model is expressed in monetary values whereas port productivity is measured in physical units, regional shocks are weighted by each state's share of national cargo throughput, ensuring consistency between the operational productivity targets and the economic structure represented in the CGE model.

Two sets of policy experiments are performed. The first applies productivity shocks individually to the thirteen states responsible for approximately 98% of Brazil's port throughput, allowing the identification of regional differences in the transmission of port-efficiency gains. The second applies proportional productivity improvements simultaneously across all states, representing the nationwide implementation of the PNLP targets and providing a benchmark for aggregate, sectoral and regional comparisons. This approach integrates institutional and governance variables into the spatial-economic framework, as the simulated technical gains represent the expected outcomes of the reforms, public-private partnerships, and managerial improvements discussed qualitatively in the literature. By converting policy targets into quantitative shocks, the study moves beyond traditional operational benchmarking to provide a forward-looking evaluation of how planned productivity improvements propagate through production networks and domestic supply chains. Within the recursive dynamic framework, annual productivity improvements generate cumulative adjustments in investment, production, prices and interregional trade flows, allowing both the direct impacts on port-hosting states and the indirect spillover effects transmitted through domestic production networks to be evaluated.

4. Economic Effects of Port Efficiency Improvements

This section examines how port-efficiency gains propagate through the Brazilian economy within the recursive-dynamic CGE framework. The policy shock is introduced as a permanent reduction in the technical requirement of port services per unit of traded goods. In the model, this reduction lowers the quantity of port services required for handling imports and exports, thereby releasing labor and capital previously tied to the port sector and reducing the production costs of traded composites. Because primary factors are mobile across activities and regions, these efficiency improvements generate a sequence of interrelated adjustments in prices, output, investment, and trade. All results are presented as accumulated deviations from the baseline for the 2024–2040 period.

4.1 Macroeconomic and Regional Effects

Port-efficiency improvements generate widespread macroeconomic expansion, although both the magnitude and the spatial distribution of the gains vary considerably across scenarios and regions. Under the nationwide efficiency scenario, the cumulative effect is a 0.57% increase in Brazil's GDP, equivalent to approximately R$ 3.4 trillion over the 2024–2040 period. However, these results reveal highly asymmetric regional outcomes, confirming that logistical gains tend to concentrate in regions with pre-existing industrial density, potentially reinforcing established territorial disparities if not accompanied by regional integration policies. Table 4 summarizes the principal macroeconomic outcomes across the regional and national policy scenarios.

The simulated scenarios indicate that economic returns depend not only on the volume of cargo handled but on the density of productive linkages connected to each gateway. São Paulo and Rio de Janeiro generate the largest absolute gains because their ports are embedded in diversified industrial economies. This provides quantitative evidence for the "port regionalization" paradigm, where major hubs act as the primary engines of the national economy by integrating maritime gateways with extensive regional production systems through logistics corridors. By contrast, Maranhão produces comparatively smaller macroeconomic gains despite handling a substantial share of national throughput. This suggests that the capacity of a port to induce regional growth is constrained in commodity-specialized regions where production chains have fewer backward and forward linkages within the domestic economy, mirroring the infrastructure underutilization often noted in less developed areas.

Table 4 – Macroeconomic impacts across scenarios (accumulated deviations from 2024 to 2040)

Scenario[a]	Δ Regional GDP[1] (%)	Δ Regional GDP[1] (R$ billions)	Δ National GDP (%)	Δ National GDP (R$ billions)	Main Spillover Region	Most Affected Sectors
São Paulo (C_SP)	0.52	9.83	0.22	1340.17	Southeast and Central-West	Machinery, Vehicles, Electronics
Rio de Janeiro (C_RJ)	0.61	3.98	0.11	717.4	Minas Gerais and São Paulo	Oil and Gas
Espírito Santo (C_ES)	1.61	1.81	0.06	371.48	Minas Gerais	Steel, Mining
Maranhão (C_MA)	0.57	0.44	0.01	78.36	Piauí, Tocantins	Agribusiness
National (C_BR)	–	–	0.57	3417.6	Southeast and Amazonas	Port-intensive sectors

Note: Results represent accumulated percentage change relative to the baseline scenario;
[a] Refers to each of the selected policy scenarios. [1] Regional GDP = GDP in the region that received the port productivity shock.
Source: Research results.

These outcomes are consistent with the adjustment mechanisms embedded in the recursive-dynamic CGE framework. In the short run, lower port-service requirements release productive resources that are gradually reallocated toward more competitive activities. As investment responds to higher expected returns, capital accumulation reinforces the initial productivity gains, allowing the economy to converge toward a new equilibrium characterized by higher output and greater productive capacity. The long-run gains therefore emerge not only from lower logistics costs but also from the cumulative expansion of investment and production over time.

Figure 3 reinforces an important feature of the simulations: the benefits of port-efficiency improvements are transmitted far beyond the regions where the productivity shocks originate. While São Paulo and Rio de Janeiro retain a substantial share of the national gains owing to their diversified economic structures, they also generate significant spillover effects through their extensive production and logistics linkages with the Central-West and Southeast regions. Conversely, efficiency improvements in Maranhão remain more geographically concentrated because the state's export profile is dominated by bulk commodities, whose production chains are comparatively less integrated into the broader Brazilian economy. These findings indicate that the economic relevance of a port depends not only on its operational scale but also on the density of the regional production networks connected to its hinterland.

Figure 3 – National cumulative variation (2024–2040) in GDP, exports, and imports, by scenario

Scenario[a]	GDP Change (R$ bilions)	GDP Change (%)	GDP Intra/Interregional Proportion	Exports Change (R$ bilions)	Exports Change (%)	Exports Intra/Interregional Proportion	Imports Change (R$ bilions)	Imports Change (%)	Imports Intra/Interregional Proportion
C_AM	102.7	0.02		8.7	0.01		8.0	0.01	
C_BA	166.3	0.03		13.0	0.02		10.4	0.01	
C_CE	68.3	0.01		5.1	0.01		3.9	0.00	
C_ES	371.5	0.06		29.1	0.04		31.0	0.04	
C_MA	78.4	0.01		6.2	0.01		5.3	0.01	
C_PA	70.5	0.01		5.7	0.01		4.6	0.01	
C_PE	212.3	0.03		16.4	0.02		13.2	0.02	
C_PR	286.1	0.05		26.7	0.04		25.4	0.03	
C_RJ	717.4	0.11		50.7	0.07		54.9	0.07	
C_RN	22.2	0.00		1.4	0.00		1.0	0.00	
C_RS	234.2	0.04		20.6	0.03		18.4	0.02	
C_SC	307.2	0.05		27.5	0.04		27.0	0.03	
C_SP	1,340.2	0.22		183.9	0.21		149.2	0.18	
C_BR	3,417.6	0.57		345.2	0.45		311.0	0.37	

Note: Results represent accumulated percentage change relative to the baseline scenario;
[a] Refers to each of the selected policy scenarios.
Source: Research results.

To further examine the spatial transmission of these gains, Table 5 reports the three states experiencing the largest increases in GDP, exports and imports under each regional policy scenario.

Table 5 – Intra-regional percentage effects (2024–2040) on regional macroeconomic variables, by scenario

Scenario[a]	GDP			Exports			Imports		
	1º	2º	3º	1º	2º	3º	1º	2º	3º
C_AM	AM (0.67%)	RR (0.09%)	AC (0.06%)	AM (0.23%)	DF (0.17%)	GO (0.1%)	RR (0.07%)	AM (0.06%)	MT (0.03%)
C_BA	BA (0.43%)	TO (0.03%)	PI (0.03%)	DF (0.39%)	MG (0.16%)	GO (0.14%)	BA (0.09%)	SE (0.03%)	AL (0.03%)
C_CE	CE (0.35%)	PI (0.02%)	RN (0.02%)	DF (0.22%)	CE (0.14%)	PI (0.1%)	CE (0.06%)	RN (0.02%)	AM (0.01%)
C_ES	ES (1.61%)	MG (0.09%)	RR (0.06%)	MG (0.62%)	DF (0.46%)	GO (0.18%)	ES (0.19%)	MG (0.09%)	MS (0.06%)
C_MA	MA (0.57%)	PI (0.06%)	TO (0.04%)	DF (0.33%)	GO (0.14%)	PI (0.14%)	MA (0.04%)	AP (0.02%)	AM (0.02%)
C_PA	PA (0.34%)	AP (0.05%)	TO (0.03%)	DF (0.23%)	GO (0.1%)	TO (0.08%)	AP (0.06%)	PA (0.05%)	RR (0.03%)
C_PE	PE (0.92%)	PB (0.15%)	RN (0.09%)	DF (0.57%)	GO (0.22%)	MG (0.22%)	PE (0.23%)	AL (0.09%)	PB (0.09%)
C_PR	PR (0.5%)	MS (0.05%)	MG (0.03%)	DF (0.24%)	MG (0.15%)	GO (0.13%)	PR (0.12%)	MS (0.04%)	MG (0.03%)
C_RJ	RJ (0.61%)	RR (0.11%)	MG (0.1%)	RJ (0.34%)	MG (0.29%)	DF (0.23%)	RJ (0.15%)	MG (0.1%)	MG (0.1%)
C_RN	RN (0.21%)	PB (0.01%)	-	RN (0.11%)	DF (0.04%)	GO (0.02%)	RN (0.03%)	PB (0.01%)	CE (0.01%)
C_RS	RS (0.41%)	MS (0.04%)	AC (0.03%)	DF (0.24%)	GO (0.14%)	MG (0.12%)	RS (0.08%)	SC (0.04%)	AM (0.03%)
C_SC	SC (0.8%)	MS (0.04%)	MG (0.04%)	DF (0.33%)	MG (0.19%)	GO (0.18%)	SC (0.13%)	PR (0.05%)	RS (0.04%)
C_SP	SP (0.52%)	MG (0.15%)	AC (0.15%)	SP (0.63%)	MG (0.24%)	DF (0.24%)	SP (0.24%)	RO (0.18%)	MG (0.18%)

Note: Results represent accumulated percentage change relative to the baseline scenario;
[a] Refers to each of the selected policy scenarios.
Source: Research results.

A critical contribution of this analysis is the identification of spatial spillovers, which clarifies how hinterland connectivity mediates port efficiency. Minas Gerais consistently emerges among the principal secondary beneficiaries of improvements implemented in Rio de Janeiro and Espírito Santo, reflecting the strong integration of mining and steel production across these neighboring states. Similarly, productivity gains in São Paulo propagate toward Goiás, Mato Grosso and the Federal District, illustrating the importance of São Paulo's logistics corridors for connecting inland production with international markets. Rather than spreading uniformly across the national territory, the gains follow existing production and trade networks, reinforcing the view that port investments generate their largest economic returns when embedded within dense regional supply chains.

These findings are consistent with the international literature emphasizing that the economic effects of ports extend well beyond their immediate areas of operation and depend fundamentally on the productive structure connected to their hinterlands. The Brazilian case, however, highlights an additional dimension: because domestic trade flows link geographically distant production regions to a relatively small number of export gateways, improvements achieved at strategically connected ports can generate substantial spillovers even in regions located far from the coastline. This reinforces the importance of adopting multiregional analytical frameworks capable of explicitly representing interstate production networks and domestic trade interactions.

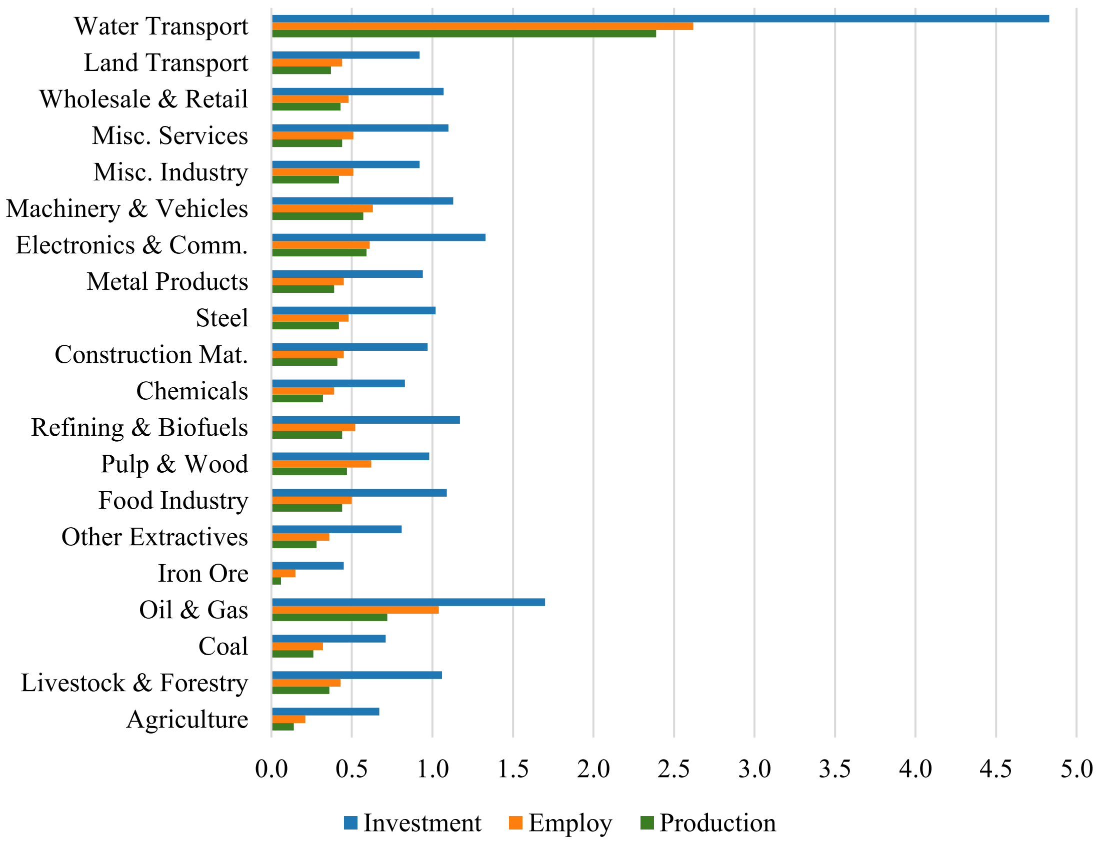
4.2 Sectoral Responses and Production Dynamics

Port-efficiency improvements reshape the sectoral composition of the Brazilian economy by altering the relative costs of production and trade. The productivity shock creates a clear hierarchy of sectoral responses, demonstrating that port modernization acts as a catalyst for structural transformation in sectors with high value-added. Because ports mediate a substantial share of imported intermediate inputs and exported goods, reductions in port-service requirements improve the competitiveness of industries that are more deeply integrated into international markets or more dependent on logistics-intensive supply chains. The resulting adjustments are therefore not uniform across sectors but reflect differences in production technology, input structure and exposure to domestic and international trade.

Figure 4 summarizes these adjustments under the national efficiency scenario. Rather than affecting all industries proportionally, the productivity shock generates a clear hierarchy of sectoral responses. The largest gains occur in activities directly linked to international trade and in manufacturing industries with intensive use of imported intermediate inputs. These sectors are able to convert lower logistics costs into stronger investment incentives, higher output and improved competitiveness, reinforcing their position within domestic production networks and global value chains.

The strongest direct effects are observed in water transport, where the productivity shock is introduced, resulting in substantial investment expansion and increased productive capacity. However, the broader economic gains arise primarily through indirect transmission mechanisms. Technologically intensive manufacturing sectors, including electronics and communication equipment, machinery and vehicles, refining and biofuels, and chemicals, display the largest increases in production and investment. Their dependence on imported intermediate goods makes them particularly sensitive to reductions in port-related trade costs, allowing improvements in operational efficiency to translate into lower production costs, higher profitability and accelerated capital accumulation.

Figure 4 – Sectoral effects under the national port-efficiency scenario: investment, employment, and production



Note: Results represent accumulated percentage change relative to the baseline scenario.
Source: Research results.

Conversely, extractive industries like iron ore exhibit comparatively smaller responses despite being the primary users of port infrastructure. This result indicates that while efficiency gains lower non-tariff barriers for all commodities, the systemic economic return is maximized in industries characterized by stronger integration into domestic and global value chains. Commodity-producing industries generally operate with lower domestic value added and fewer backward and forward production linkages, reducing the extent to which logistics improvements propagate throughout the broader economy. Consequently, while these sectors benefit directly from more efficient port operations, their capacity to induce secondary effects on production and investment remains comparatively limited.

Employment expands across most activities but at a slower pace than investment and output, indicating that capital accumulation becomes the dominant adjustment mechanism following improvements in port productivity. As firms respond to lower logistics costs by expanding productive capacity, productivity growth outpaces labor demand, particularly in industries characterized by higher technological intensity and stronger participation in global value chains. This pattern is consistent with the recursive-dynamic nature of the model, in which investment gradually reinforces the initial competitiveness gains generated by the productivity shock.

Regional simulations further demonstrate that sectoral responses depends on the productive specialization of each state. São Paulo exhibits widespread gains across technologically intensive manufacturing activities, reflecting its diversified industrial base and strong integration with national supply chains. Rio de Janeiro concentrates benefits in energy-related industries, where lower trade costs enhance the competitiveness of oil and gas activities, while Espírito Santo displays stronger responses in steel and mining due to its specialization in mineral-export logistics. These differences indicate that the economic effects of port-efficiency improvements are shaped not only by the location of the infrastructure itself but also by the productive composition of the regional economy connected to each port.

Taken together, the sectoral evidence indicates that port-efficiency improvements extend far beyond operational cost savings. By modifying relative production costs, stimulating investment and strengthening the competitiveness of logistics-intensive industries, port modernization contributes to a gradual reallocation of productive resources toward sectors with greater integration into domestic and international production networks. The results therefore reinforce the view that the economic relevance of port investments depends not only on their capacity to increase cargo throughput, but also on their ability to strengthen productive linkages and support structural transformation across the broader economy.

Ultimately, the sectoral and regional evidence suggests that port modernization should be viewed as a regional development strategy rather than a mere infrastructure program. Without coordinated planning to strengthen hinterland connectivity and peripheral productive capacity, the superior efficiency of major hubs may exacerbate spatial concentration. Therefore, infrastructure investments should be prioritized based on their potential to generate broad regional spillovers and support a more balanced spatial distribution of economic activity.

5. Final Remarks

Port efficiency is widely recognized as an important determinant of international competitiveness. However, the results of this study indicate that its economic relevance extends well beyond reducing logistics costs or accelerating cargo handling. In a country characterized by strong regional specialization and extensive domestic supply chains such as Brazil, improvements in port productivity propagate through production networks, influencing investment decisions, regional competitiveness and the spatial distribution of economic activity. Consequently, port modernization should not be viewed solely as an infrastructure policy, but also as a regional development strategy capable of reshaping economic interactions across the national territory.

The simulations show that achieving the productivity targets established in the National Port Logistics Plan (PNLP 2015) generates positive macroeconomic effects through lower production costs, higher investment and stronger export competitiveness. Nevertheless, these gains are distributed unevenly across regions. States with diversified productive structures, dense hinterland connections and greater integration into domestic and international markets, particularly São Paulo, Espírito Santo and Rio de Janeiro, capture a disproportionate share of the benefits. This finding provides empirical support for the "port regionalization" paradigm, suggesting that the economic returns of port investments depend fundamentally on the integration of maritime gateways with inland distribution corridors and regional productive capabilities.

This result has important implications for public policy. Expanding berth capacity alone is unlikely to maximize national economic returns. The effectiveness of these investments depends on coordinated governance and complementary policies that strengthen hinterland connectivity and intermodal transport systems. Furthermore, the evidence supports a transition toward "spatially informed" infrastructure planning, where investments are prioritized according to their potential to generate broad regional spillovers through interregional linkages, rather than focusing exclusively on localized throughput.

The heterogeneous regional responses also suggest that productivity-enhancing policies may unintentionally reinforce pre-existing territorial disparities. Regions already integrated into major logistics corridors are naturally better positioned to capture the direct benefits of efficiency gains, while peripheral regions may experience only limited impacts despite improvements in the national logistics system. This does not diminish the importance of port modernization; rather, it highlights the need for coordinated regional development policies capable of broadening the diffusion of these gains across the country. From a policy perspective, prioritizing investments exclusively according to port throughput may not necessarily maximize long-term national development if complementary investments in regional connectivity and productive capacity are neglected.

An important contribution of this study is the explicit integration of the productivity targets established in the PNLP 2015 with a dynamic multiregional computable general equilibrium framework. By combining detailed operational evidence derived from port microdata with economy-wide simulations, the analysis moves beyond traditional port-efficiency assessments focused exclusively on operational indicators. Instead, it provides a forward-looking evaluation of how planned productivity improvements translate into regional growth, sectoral restructuring and changes in domestic and international trade. This perspective offers useful evidence for supporting the prioritization of infrastructure investments according to their expected regional spillovers and aggregate economic returns.

Despite these contributions, some limitations provide avenues for future research. The simulations focus on technical productivity gains but do not explicitly quantify the costs of corruption or regulatory ambiguity, which remain significant but underexplored determinants of port performance in developing economies. Additionally, while the analysis captures recursive dynamic effects, future longitudinal research utilizing Malmquist indices could further clarify how technological progress and institutional evolution shape efficiency over extended periods. Future studies should also incorporate environmental and social indicators into integrated evaluation frameworks to ensure that port modernization aligns with sustainable development goals.

Overall, the evidence suggests that improving port efficiency has the potential to generate substantial economic gains for Brazil. However, the magnitude and distribution of these benefits ultimately depend on how modernization policies are designed and coordinated with broader transport, industrial, and regional strategies. Port efficiency should therefore be understood as an instrument for fostering productivity growth and a more competitive, integrated, and territorially balanced Brazilian economy.

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