Railway Concessionaires, Logistics Corridors and Regional Production Systems: Evidence from Brazil[1]

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Abstract

Railway freight corridors play a central role in connecting regional production systems, yet the economic importance of individual railway concessionaires remains unexplored. This study evaluates the role of Brazilian freight railway concessionaires across regional economies by explicitly representing each concessionaire within twenty-seven Brazilian state input-output tables and applying the Hypothetical Extraction Method under both Leontief and Ghosh perspectives. Each concessionaire is individually extracted to assess its backward and forward production linkages and the resulting economy-wide, sectoral, and regional production losses. The results reveal substantial heterogeneity among concessionaires. Demand-side impacts are associated with intermediate input purchases required for railway operations, whereas supply-side impacts reflect the productive specialization of the logistics corridors served. Mining corridors affect iron ore and steel activities, while agricultural corridors affect agribusiness supply chains. These findings highlight the distinct economic functions of railway corridors and provide evidence to support concession management, infrastructure investment, and regional development policies.

Keywords: Railway Concessionaires; Logistics Corridors; Hypothetical Extraction Method; Production Linkages.

Resumo

Os corredores ferroviários de carga desempenham papel central na conexão dos sistemas produtivos regionais, porém a importância econômica das concessionárias ferroviárias permanece inexplorada. Este estudo avalia o papel das concessionárias brasileiras de transporte ferroviário de cargas nas economias regionais por meio de sua representação explícita em vinte e sete matrizes estaduais de insumo-produto e da aplicação do Método de Extração Hipotética sob as perspectivas de Leontief e Ghosh. Cada concessionária é extraída individualmente para avaliar seus encadeamentos produtivos para trás e para frente e as perdas de produção em níveis nacional, setorial e regional. Os resultados revelam heterogeneidade entre as concessionárias. Os impactos pelo lado da demanda decorrem das compras de insumos intermediários para as operações ferroviárias, enquanto os impactos pelo lado da oferta refletem a especialização produtiva dos corredores logísticos. Corredores mineradores afetam atividades ligadas ao minério de ferro e ao aço, enquanto corredores agrícolas afetam cadeias do agronegócio. Os resultados fornecem evidências para subsidiar a gestão das concessões, a priorização de investimentos em infraestrutura e políticas de desenvolvimento regional.

Palavras-chave: Concessionárias Ferroviárias; Corredores Logísticos; Método de Extração Hipotética; Encadeamentos Produtivos.
Classificação JEL: R15; R40; C67.
Área de avaliação: Economia Regional

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1 Introduction

Regional economies are not isolated production systems. Instead, they are interconnected through complex networks of intermediate transactions, final demand, and trade flows that allow firms located in different territories to exchange goods and services (Capello, 2009; Fujita et al., 2001; Isard, 1956; Miller & Blair, 2009). These interactions largely depend on transport systems, which shape accessibility, determine logistics costs, and influence firms' ability to connect with suppliers and consumers. Transport infrastructure extends beyond its traditional role of moving freight and passengers by underpinning the logistics corridors that organize production networks, integrate regional markets, and generate spatial spillovers. The economic relevance of transport infrastructure therefore stems not only from its physical assets but also from the production networks it sustains across regions (Donaldson, 2018; Duranton & Venables, 2018; Lakshmanan, 2011; Melo et al., 2013).

These spatial interactions are materialized through logistics corridors that connect production areas, consumption markets, and export gateways (Rodrigue, 2020). By reducing transport costs and improving accessibility, these corridors facilitate market integration, strengthen interregional trade, and enhance firms' competitiveness (Donaldson, 2018). Among freight transport modes, railways play a particularly important role in sustaining these corridors because of their high transport capacity and lower operating costs over long distances, making them especially suitable for transporting large volumes of agricultural and mineral commodities (Brodzik et al., 2025). Their importance is particularly evident in countries with large territorial extensions and heterogeneous productive structures, where individual railway corridors perform distinct economic functions. This perspective is particularly relevant in Brazil, where continental dimensions, the spatial concentration of agricultural and mineral production, and the long distances separating major producing regions from export ports make freight transportation a critical determinant of regional competitiveness (Assis, Silva, et al., 2017; BRASIL, 2021).

Despite possessing one of the world's largest freight railway networks, Brazil's transport matrix remains heavily concentrated on road transportation, while railways account for only about 15% of total freight transport activity measured in tonne-kilometres (TKU) (BRASIL, 2016). Following the concession reforms of the late 1990s, freight railway operations were organized into concessionaires responsible for geographically distinct logistics corridors (Assis, Marchetti, et al., 2017; Assis, Silva, et al., 2017). Rather than constituting a homogeneous national network, these corridors differ substantially in their regional coverage, commodity specialization, operational scale, network characteristics, and degree of integration with regional production systems (BRASIL, 2024).

The relationship between transport infrastructure and regional development has been extensively examined in the economic literature. An initial body of research emphasizes its role in fostering economic growth by reducing transport costs, increasing productivity, and expanding market access (Esfahani & Ramírez, 2003; Lakshmanan, 2011; Maparu & Mazumder, 2017). A second stream of studies highlights the broader regional effects of transport infrastructure, showing how improved accessibility promotes agglomeration economies, labor mobility, technological diffusion, and spatial spillovers (Allen & Arkolakis, 2022; Donaldson, 2018; Duranton & Turner, 2012). More recently, transport corridors have been recognized as the mechanisms through which these benefits are transmitted across regions by strengthening connectivity, facilitating trade integration, and promoting regional development (Quium, 2019; Taisarinova et al., 2020).

Despite the growing evidence on the economic effects of transport infrastructure and transport corridors, railway research has predominantly examined infrastructure expansion, operational performance, investment programs, freight production, and aggregate relationships between railway activity and economic growth (Guimarães et al., 2023). Input-output studies have advanced this discussion by adopting increasingly disaggregated representations of transport systems, distinguishing transport modes, passenger and freight services to identify heterogeneous sectoral linkages through the Hypothetical Extraction Method (HEM) (Chen et al., 2022; Du et al., 2019). Similarly, HEM has been applied within multiregional input-output frameworks to evaluate the role of individual regions in production networks (Kimura, 2026). Nevertheless, railway freight transportation itself generally remains represented as a single sector, overlooking differences in territorial coverage, commodity specialization, and production linkages among concessionaires operating freight railway corridors. This limitation is especially relevant in Brazil, where concessionaires connect economically distinct regional economies and may therefore perform markedly different economic functions.

To address this limitation, this study explicitly represents individual Brazilian freight railway concessionaires in the Brazilian input-output model rather than treating railway transportation as a homogeneous transport sector. This representation preserves the geographic scope of operation, commodity specialization, and intersectoral production linkages of each concessionaire. The HEM is then applied under both the demand-driven (Leontief) and supply-driven (Ghosh) perspectives to evaluate the systemic importance of each concessionaire and their backward and forward production linkages (Cella, 1984; Dietzenbacher et al., 1993). This analysis is particularly relevant in Brazil following the renewal of long-term railway concessions and the expansion of public and private investments in freight infrastructure (Assis, Marchetti, et al., 2017; BRASIL, 2021). Identifying which railway concessionaires, and the logistics corridors they operate, are most relevant for sustaining regional economic activity provides valuable evidence for concession policies, infrastructure planning, and place-based regional development strategies.

Against this background, this paper evaluates the economic importance of Brazilian railway concessionaires across state economies using the HEM. The analysis is conducted independently for each of the twenty-seven Brazilian state input-output tables, where railway transportation is explicitly represented by nine freight railway concessionaires. Within each state table, each concessionaire is individually extracted under both the demand-driven (Leontief) and supply-driven (Ghosh) perspectives to evaluate its backward and forward production linkages.

This study makes four main contributions to the literature. First, it explicitly represents all Brazilian freight railway concessionaires within state input-output tables, replacing the conventional representation of railway transportation as a single aggregated sector. Second, it evaluates the economic role of each concessionaire across the twenty-seven Brazilian state economies, revealing the spatial heterogeneity of railway production linkages that aggregate analyses conceal. Third, by combining demand-driven (Leontief) and supply-driven (Ghosh) hypothetical extraction procedures, it provides complementary evidence on the backward and forward production linkages associated with each concessionaire. Finally, the results generate policy-relevant evidence for railway concession management, infrastructure investment prioritization, and regional development strategies by identifying the concessionaires, and the logistics corridors they operate, that play the greatest role in sustaining productive activity across Brazilian state economies.

The remainder of the paper is organized as follows. Section 2 provides an overview of the Brazilian freight railway system and the spatial distribution of railway concessionaires. Section 3 describes the database and methodological framework. Section 4 presents and discusses the empirical results. Finally, Section 5 concludes and discusses the main policy implications.

2 Literature Review

The relationship between transport infrastructure and regional economic performance has been documented in the empirical literature ((Donaldson, 2018; Lakshmanan, 2011; Melo et al., 2013). Rather than generating uniform benefits across space, transport investments generally produce heterogeneous economic effects that depend on regional productive structures, trade specialization, network connectivity, and the position of regions within logistics systems (Allen & Arkolakis, 2022). Consequently, recent studies have progressively shifted their focus from evaluating infrastructure in aggregate terms toward understanding how specific transport networks and logistics corridors shape regional development (Quium, 2019; Rosik & Wójcik, 2022).

A broad empirical literature shows that improvements in transport infrastructure promote economic growth by reducing logistics costs, increasing accessibility and facilitating market integration. However, the magnitude of these effects varies substantially across regions. Studying Indian states, Kaur and Puri (2023) find that transport investment positively affects regional GDP, with railway accessibility exerting significant effects only after approximately two years, suggesting that firms and households require time to reorganize production and logistics decisions in response to infrastructure improvements. Their results also indicate that regional characteristics condition infrastructure returns, implying that investment policies should account for local productive structures rather than relying on uniform strategies. Similar conclusions are reported for Saudi Arabia, where transport investment generates positive impacts on regional output after one year, whereas railway accessibility requires a longer adjustment period before producing measurable economic gains (Alotaibi et al., 2022).

Evidence from China further reinforces the existence of substantial regional heterogeneity. Liang et al. (2020) finds that the Guangdong–Guangxi–Guizhou High-Speed Railway did not generate a uniform corridor effect but produced stronger economic gains in less-developed counties and in locations farther from major urban centers, with impacts operating mainly through investment attraction and structural transformation. Likewise, Chen and Haynes (2017) shows that high-speed rail contributed to reducing regional disparities in China, although the magnitude of its effects differed considerably across regions according to both railway density and accessibility improvements. These findings suggest that transport infrastructure does not affect all territories equally but interacts with existing regional economic conditions.

Another important strand of research emphasizes that transport infrastructure generates significant spatial spillovers beyond the regions where investments are located. Using spatial econometric models for Chinese provinces, Yin et al. (2024) demonstrates that transport infrastructure produces positive direct and indirect effects on regional economic growth, with spillovers being strongest among geographically proximate regions. Jiang et al. (2016) similarly finds that transportation investment generates positive spillovers between economically similar provinces, whereas regions connected through strong transport networks but characterized by large development gaps may experience weaker or even negative spillover effects due to factor migration toward more developed economies. Comparable evidence is reported for Iran, where improvements in railway infrastructure generate positive spillover effects on neighboring provinces, indicating that diffusion effects outweigh agglomeration forces (Dehghan Shabani & Safaie, 2018). Together, these studies consistently show that transport infrastructure operates through interregional production networks rather than affecting regions in isolation.

Beyond the aggregate relationship between transport infrastructure and economic growth, an expanding literature has increasingly examined logistics corridors as functional economic systems connecting production areas, export gateways and consumption markets. Rather than viewing transport infrastructure simply as physical capital, this perspective emphasizes the role of corridors in organizing regional production networks and facilitating trade integration. Quium (2019) argues that well-functioning transport corridors generate broader socioeconomic benefits by reducing transport costs, improving logistics efficiency, attracting productive investment and strengthening regional integration. At the same time, the author highlights that these benefits are unevenly distributed and depend on complementary institutional conditions, governance arrangements and local productive capacities. Consequently, transport corridors should be understood not only as transport infrastructure but also as mechanisms through which regional development processes are organized.

Brazilian evidence likewise highlights the heterogeneous role of freight transport across regional economies. Moralles et al. (2019) shows that transport infrastructure generates significant spatial spillovers across Brazilian regions, although their magnitude depends on local productive structures, economic specialization and regional connectivity. Complementing this perspective, Betarelli Junior et al. (2011) demonstrate, using a hybrid input-output framework, that transport production linkages vary substantially according to export destinations and commodity specialization. Railway transport exhibits stronger production linkages with exports directed to Mercosur and ALADI, whereas maritime transport becomes the dominant mode for exports to China, NAFTA and the European Union. The authors further show that iron ore exports to China generate approximately 9,788 tonnes of additional railway demand for each additional R$1 million exported, with nearly 75% of these requirements arising through indirect production linkages. Evidence from the North-South Railway similarly indicates that freight rail investments strengthen market integration and stimulate productive activity in municipalities directly connected to the corridor (Vieira & Oliveira, 2020). At the firm level, Victorino and Bertussi (2023) report substantial differences in operational efficiency across Brazilian railway concessionaires, reflecting heterogeneity in infrastructure quality, network characteristics and cargo specialization. Collectively, these studies indicate that freight rail systems perform distinct economic functions across Brazilian regions rather than constituting a single, undifferentiated railway sector.

The use of input-output models has further expanded the analysis of transport systems by incorporating intersectoral production linkages into the evaluation of transport infrastructure. Previous studies have progressively increased the level of sectoral and spatial disaggregation, distinguishing transport modes, freight services and regional production networks to identify heterogeneous backward and forward linkages (Chen et al., 2022; Du et al., 2019; Kimura, 2026). Hypothetical extraction applications have similarly demonstrated the usefulness of evaluating the systemic importance of individual sectors or regions within production networks (Cella, 1984; Dietzenbacher et al., 1993; Kimura, 2026). Nevertheless, railway freight transportation continues to be represented almost exclusively as a single aggregated sector. Consequently, existing studies are unable to distinguish the economic role performed by individual concessionaires operating geographically distinct logistics corridors with different productive specializations, territorial coverage and regional production linkages.

This study addresses this gap by explicitly representing each Brazilian freight railway concessionaire within state input-output tables and evaluating its systemic importance through the Hypothetical Extraction Method under both demand-driven (Leontief) and supply-driven (Ghosh) perspectives. By preserving the production linkages associated with each concessionaire, the analysis moves beyond the traditional representation of railway transportation as a homogeneous sector and provides new evidence on how individual railway corridors contribute to sustaining regional productive systems across Brazilian states.

3 Methodology and Data

This section presents the methodological framework adopted to assess the economic importance of Brazilian railway concessionaires across Brazilian state economies. It first introduces the input–output model, followed by the Hypothetical Extraction Method (HEM). The final subsection describes the construction of the analytical database, including the disaggregation of the railway freight transportation sector into nine concessionaires, the estimation procedures, and the regionalization of the national input–output database used in the empirical analysis.

3.1 Input–Output Model

The input–output model, developed by Leontief (1936) describes interindustry interdependencies through the flows of goods and services used as intermediate inputs and allocated to final demand (Guilhoto, 2011; Miller & Blair, 2009). The economy is represented by n industries, with the total output of industry i (x_i) allocated as follows:

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{1}$$

where z_{ij} denotes intermediate sales from industry i to industry j, and f_i represents final demand for the output of industry i. The direct technical coefficients (a_{ij}) are defined as $a_{ij} = \frac{z_{ij}}{x_j}$. Substituting these coefficients into Equation (1) yields the standard input-output system:

$$x_i = \sum_{j=1}^{n} a_{ij}x_j + f_i \tag{2}$$

In matrix notation, it is expressed as:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \tag{3}$$

where $\mathbf{A}$ is the matrix of direct technical coefficients (a_{ij}), while $\mathbf{x}$ and $\mathbf{f}$ are the $n \times 1$ vectors of total output and final demand, respectively. Treating the technical coefficient matrix and final demand vector as given, the solution of the system is:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \equiv \mathbf{L}\mathbf{f} \tag{4}$$

where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse, or total requirements matrix. Each element l_{ij} measures the direct and indirect effects of a one-unit change in the final demand for industry j on the output of industry i (Guilhoto, 2011; Miller & Blair, 2009).

Alternatively, Ghosh (1958) proposed a formulation based on the distribution of output across industries. In matrix notation:

$$\mathbf{x}' = \mathbf{i}'\mathbf{Z} + \mathbf{v}' \tag{5}$$

where $\mathbf{x}'$ and $\mathbf{v}'$ denote the transposed vectors of total output and value added, respectively. While the Leontief inverse relates industry output to final demand, the Ghosh formulation relates industry output to changes in primary inputs (value added). The allocation coefficient matrix ($\mathbf{B}$) is obtained by row-normalizing the intermediate transactions matrix ($\mathbf{Z}$) (Ghosh, 1958; Miller & Blair, 2009):

$$\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z} \tag{6}$$

where $\hat{\mathbf{x}}$ is the diagonal matrix of total industry output, and each element b_{ij} of matrix $\mathbf{B}$ is $b_{ij} = \frac{z_{ij}}{x_i}$.

Rewriting Equation (6) as $\mathbf{Z} = \hat{\mathbf{x}}\mathbf{B}$ and substituting it into Equation (5) yields:

$$\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}' \tag{7}$$

Given the allocation coefficient matrix ($\mathbf{B}$) and the value-added vector ($\mathbf{v}'$), the solution of the system is:

$$\mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} \equiv \mathbf{v}'\boldsymbol{G} \tag{8}$$

where $\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1}$ is the Ghosh inverse. Each element g_{ij} represents the total output generated in industry j as a result of a one-unit change in the primary inputs (value added) of industry i (Miller & Blair, 2009).

In this study, the Leontief and Ghosh input-output models are applied independently to each of the twenty-seven Brazilian state input-output tables. Each table is disaggregated to explicitly identify nine freight railway concessionaires while preserving the original interindustry production structure, enabling the application of the HEM at the concessionaire level.

3.2 Hypothetical Extraction Method (HEM)

The HEM evaluates the economic importance of an industry by measuring the change in total output resulting from its hypothetical removal (Miller & Blair, 2009). In this study, the method is applied under both the demand-driven (Leontief) and supply-driven (Ghosh) perspectives to evaluate the systemic importance of each freight railway concessionaire (Dietzenbacher, 1997; Miller & Blair, 2009).

Under the demand-driven formulation, the HEM is implemented by replacing with zeros the column corresponding to the railway concessionaire in the technical coefficient matrix, yielding the modified matrix $\overline{\mathbf{A}}_{(cj)}$. The economy's output after the extraction is given by:

$$\overline{\mathbf{x}}_{(cj)} = \left(\mathbf{I} - \overline{\mathbf{A}}_{(cj)}\right)^{-1}\mathbf{f} \tag{9}$$

where $\overline{\mathbf{x}}_{(cj)}$ denotes the output vector after the hypothetical extraction of the railway concessionaire. The corresponding output losses are calculated as:

$$\boldsymbol{\Delta}\mathbf{x}_{\boldsymbol{cj}} = \mathbf{x} - \overline{\mathbf{x}}_{(cj)} \tag{10}$$

Each element of the vector $\boldsymbol{\Delta}\mathbf{x}_{\boldsymbol{cj}}$ represents the reduction in industry output resulting from the extraction of the railway concessionaire.

Under the supply-driven formulation, the HEM is implemented by replacing with zeros the row corresponding to the railway concessionaire in the allocation coefficient matrix, yielding the modified matrix $\overline{\mathbf{B}}_{(lj)}$. The economy's output after the extraction is given by:

$$\overline{\mathbf{x}}'_{(\boldsymbol{lj})} = \mathbf{v}'\left(\mathbf{I} - \overline{\mathbf{B}}_{(lj)}\right)^{-1} \tag{11}$$

where $\overline{\mathbf{x}}'_{(\boldsymbol{lj})}$ denotes the output vector after the hypothetical extraction of the railway concessionaire. The corresponding output losses are calculated as:

$$\boldsymbol{\Delta}\mathbf{x}'_{\boldsymbol{lj}} = \mathbf{x}' - \overline{\mathbf{x}}'_{(\boldsymbol{lj})} \tag{12}$$

The elements of the vector $\boldsymbol{\Delta}\mathbf{x}'_{\boldsymbol{lj}}$ represent the reductions in industry output resulting from the elimination of intermediate sales by the railway concessionaire. The procedure is repeated independently for each railway concessionaire in each of the twenty-seven state input-output tables.

3.3 Development of the Railway Input–Output Database

The database employed in this study is based on the 2015 Brazilian Input–Output Table (IOT) published by the Brazilian Institute of Geography and Statistics (IBGE, 2015), originally comprising 127 products and 67 industries. As a starting point, we adopted the extended IOT developed by Betarelli (2017), in which the original land freight transportation sector was disaggregated into railway, road, and pipeline freight transportation. Building upon this framework, the railway freight transportation sector was further disaggregated into the nine freight railway concessionaires operating in Brazil: MRS Logística (MRS), Ferrovia Centro-Atlântica (FCA), Estrada de Ferro Vitória a Minas (EFVM), Estrada de Ferro Carajás (EFC), Rumo Malha Paulista (RMP), Rumo Malha Norte (RMN), Rumo Malha Oeste (RMO), Rumo Malha Sul (RMS), and Ferrovia Tereza Cristina (FTC), using information from the National Land Transport Agency (ANTT, 2023b, 2023a) and the Annual Survey of Services (IBGE, 2017). Following the methodology proposed by (Betarelli, 2017), the revenue structure of each concessionaire was estimated from railway freight revenues calculated as the product of transport distance and the corresponding reference tariff for each commodity (R$/tonne, R$/m³, or R$/container) (CNT, 2007). This procedure resulted in an extended product-by-industry database, which was subsequently transformed into an industry-by-industry input–output matrix through the diagonalization of the production matrix. The remaining productive activities were then aggregated, yielding a final analytical database with 78 industries while preserving the individual identification of the nine railway concessionaires and maintaining the accounting consistency of the original Brazilian input–output table.

The railway disaggregation adopted in this study builds upon a broader research agenda aimed at extending the Brazilian input–output database to represent transportation activities in greater detail (Betarelli Junior, 2022, 2023; Betarelli Junior et al., 2022). Consequently, the analytical database employed here is not an ad hoc construction developed specifically for the hypothetical extraction exercise, but rather a previously developed and validated framework that is applied to evaluate the economic importance of individual railway concessionaires. The initial stage of the disaggregation consisted of reallocating transport margins across road, railway, and waterway freight transportation, including the supplementary tables associated with domestically produced and imported goods. According to the Brazilian System of National Accounts (IBGE, 2000), transport margins correspond to freight services that are separately identified whenever transportation costs are borne by the purchaser, regardless of the transport provider. This accounting principle provides the basis for reallocating freight services across transport modes before the railway sector is decomposed into individual concessionaires.

Waterway transport margins were allocated according to the distribution structure proposed by (Betarelli, 2017) using detailed cargo movement statistics from the ANTAQ Waterway Statistical Yearbook (ANTAQ, 2020). Railway transport margins were estimated using tonne-kilometres transported (TKU) by concessionaire (ANTT, 2015) combined with the official tariff schedules published by ANTT. Because actual freight tariffs are confidential, the maximum tariffs established by the regulatory agency were weighted according to observed transport routes to derive allocation coefficients consistent with the effective revenues reported in the concessionaires' financial statements (ANTT, 2024). Tariffs originally expressed per container were converted into values per tonne, while the identification of transported commodities relied on detailed port statistics and the operational connections between ports and railway concessionaires available from ANTAQ (2020). These procedures generated a product-specific allocation structure consistent with the Brazilian National Accounts classification, allowing transport margins to be distributed among the nine railway concessionaires. The remaining transport margins were subsequently assigned to road freight transportation by residual, ensuring consistency with the aggregate transport margins reported in the 2015 Brazilian National Accounts (IBGE, 2022).

After transport margins had been estimated, the supply and use of land freight transportation services were further disaggregated among railway, road, and pipeline transportation while preserving the original treatment of waterway transport adopted in the 2015 Brazilian IOT (IBGE, 2022). The allocation of transport services across productive activities followed the distribution structure developed by the National Accounts Directorate of IBGE (Montoya & Martins, 2021). Railway services were subsequently allocated among the nine concessionaires according to the estimated revenue-sharing coefficients and a product-specific market-share matrix, whose elements represent the participation of each concessionaire in the production of the commodities transported by rail. The final demand components were allocated using household expenditure information from the Household Budget Survey (POF 2008–2009) (IBGE, 2010), whereas service exports were estimated from SISCOSERV statistics compiled by the Ministry of Development, Industry and Foreign Trade.

Gross Output was defined by the estimated transport margins and basic-price use, while Intermediate Consumption was estimated using concessionaires' financial statements(ANTT, 2024) and the Annual Survey of Services (IBGE, 2018). Cost items were subsequently mapped into the National Accounts input classification to ensure consistency with the original accounting structure. Particular attention was devoted to diesel consumption, which represents the largest variable operating cost of railway transportation. Concession-specific fuel expenditures were estimated using physical diesel consumption, operational indicators such as Useful Tonnes (TU) and Tonne-Kilometres (TKU), and unit fuel prices reported by (ANTT (2015, 2024), with specific estimation procedures adopted for concessionaires lacking complete accounting information. Value Added was subsequently obtained as the difference between Gross Output and Intermediate Consumption, preserving the accounting identities of the Brazilian National Accounts. The complete estimation procedures, validation exercises, and resulting concession-specific cost structures are documented in Rodrigues (2026), whose database provides the cost structure adopted in this study. Finally, the consistency between estimated Intermediate Consumption and the original input–output totals was restored through the biproportional RAS adjustment procedure (Miller & Blair, 2009).

The resulting national database was subsequently regionalized through the bottom-up gravity procedure proposed by (Horridge, 2006), generating interregional input–output matrices for the 27 Brazilian states. The regionalization combined information on gross output, final demand, imports, regional production, population, and interregional distances with complementary information from ANP (2022), (IBGE, 2022, 2025), RAIS (RAIS, 2026), and COMEX Stat (BRASIL, 2023) to estimate interregional trade flows while preserving the national accounting identities. To facilitate the hypothetical extraction analysis and emphasize the productive activities most closely associated with railway freight transportation, the regional database was finally aggregated into 78 industries while maintaining the explicit identification of the nine railway concessionaires, which constitute the analytical units evaluated throughout the hypothetical extraction exercises.

4 Results and Discussions

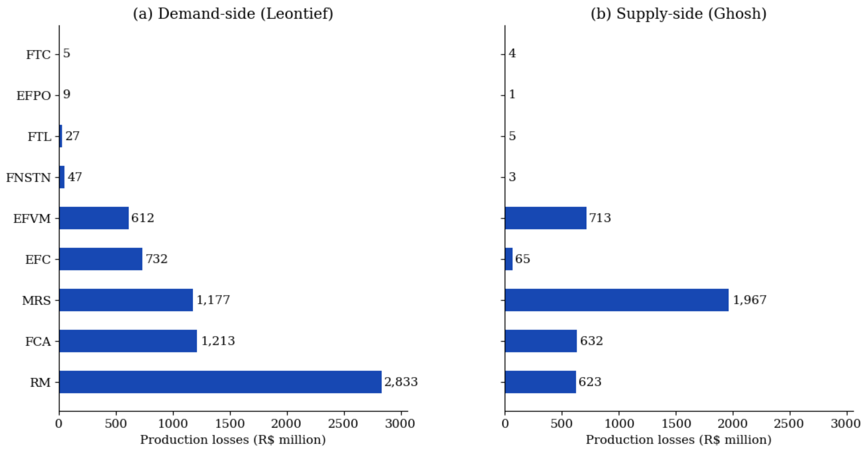
This section presents the results of the hypothetical extraction analysis from an aggregate to a regional perspective. Economy-wide production losses are first examined under the demand-side and supply-side approaches, followed by their sectoral and spatial distribution across Brazilian states. The findings are then discussed to highlight the different economic roles played by Brazilian railway concessionaires.

4.1 Economic importance of railway concessionaires across Brazilian state economies

The HEM reveals heterogeneity in the economic importance of Brazilian freight railway concessionaires. The analysis adopts both the demand-side (Leontief) and supply-side (Ghosh) perspectives using an input-output specification with explicit trade and transport margins, which means they are treated as service inputs supplied by the trade and transportation sectors rather than remaining embedded in purchasers' prices, thereby modifying the interindustry transaction structure (Miller & Blair, 2009). The estimated impacts vary across concessionaires, reflecting differences in the types of freight transported and in their integration with the

Brazilian production system. Figure 1 summarizes the resulting economy-wide production losses.

Figure 1. Aggregate production losses (R$ million)



Source: Authors' calculations.

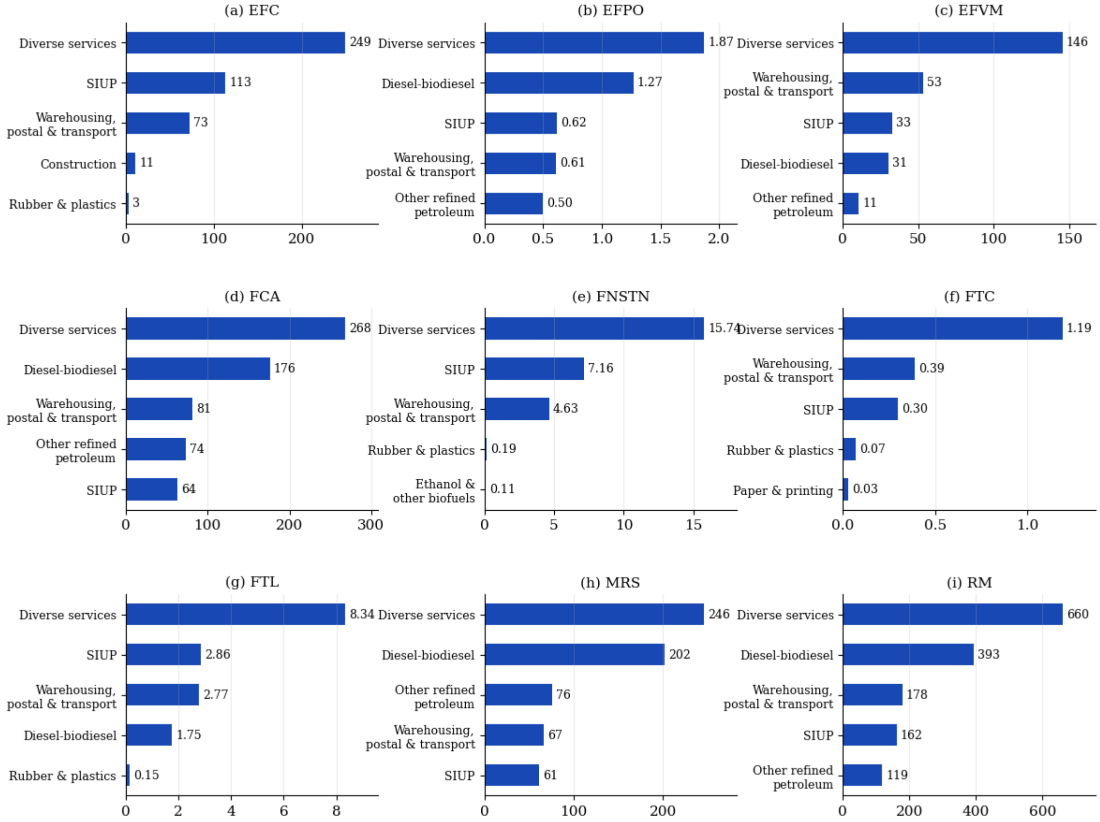
The demand-side results indicate that RM generates the largest economy-wide production losses (R$ 2,833 million), followed by FCA (R$ 1,213 million) and MRS (R$ 1,177 million). While the supply-side results identify MRS as the concessionaire associated with the largest production losses (R$ 1,967 million), followed by EFVM (R$ 713 million) and FCA (R$ 632 million). Differences between the demand- and supply-side rankings reflect differences in the interindustry linkages captured by each formulation (Dietzenbacher et al., 2019). Under the Leontief model, impacts depend primarily on intermediate input purchases as well as on the economic importance of the supplying industries, whereas under the Ghosh model they depend on the industries relying on railway transport services, as well as on their interindustry linkages.

The heterogeneous ranking observed in Figure 1 reinforces an important conclusion emerging from the transport economics literature: transport infrastructure should not be interpreted as a homogeneous production factor. Instead, its economic importance depends on the productive systems connected to each transport network and on the industries relying upon it (Allen & Arkolakis, 2022; Quium, 2019). While previous studies generally evaluated infrastructure at an aggregate level, the present results demonstrate that this heterogeneity also exists within the railway sector itself, where concessionaires operating different logistics corridors exhibit markedly different levels of systemic importance.

This distinction also helps explain why previous empirical studies have consistently reported heterogeneous economic returns from transport infrastructure. Rather than reflecting infrastructure availability alone, part of this heterogeneity appears to arise from differences in regional productive structures and economic specialization. This interpretation is consistent with evidence showing that infrastructure effects vary according to local economic characteristics (Kaur & Puri, 2023), regional accessibility conditions (Liang et al., 2020), and the productive composition of Brazilian regions (Moralles et al., 2019).

The demand-side decomposition reveals a sectoral pattern across concessionaires. Diversified services rank first in every case, followed by diesel and biodiesel, public utility services and petroleum refining products, whose relative order varies across concessionaires. This consistency reflects the common intermediate inputs required to provide railway transport services. Because the Leontief model captures backward production linkages arising from intermediate input purchases (Miller & Blair, 2009), the economy-wide impacts of extracting a concessionaire depend primarily on the scale of these purchases rather than on the composition of the freight transported (Figure 2).

Figure 2. Five most affected productive sectors in the Brazilian economy in the demand-side (R$ million)

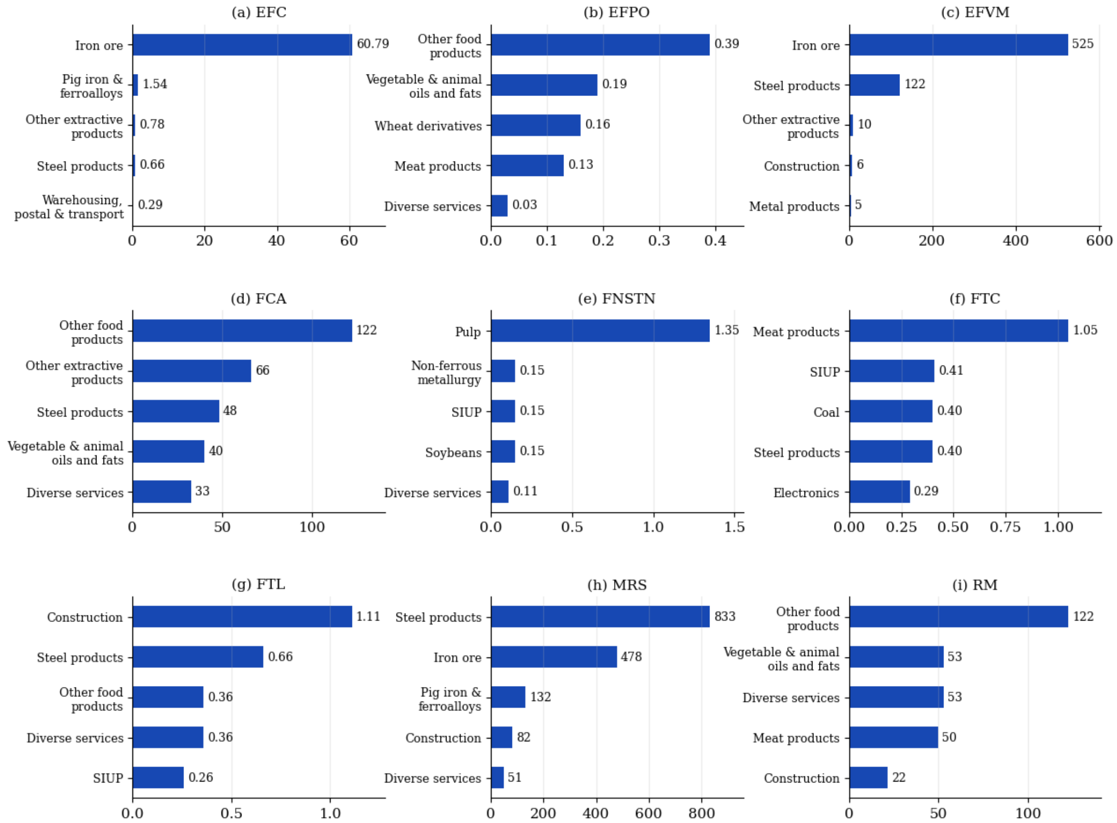


Source: Authors' calculations.
Note: Margins were excluded from the rankings to emphasize linkages with the productive sectors of the economy. These exclusions, however, do not alter the hypothetical extraction results.

The relative similarity of the affected supplier sectors contrasts sharply with the heterogeneity observed under the supply-side approach. This finding suggests that railway concessionaires share a broadly comparable operational input structure despite serving economically distinct freight markets. Consequently, differences in their systemic importance arise less from railway production itself than from the productive activities connected to each logistics corridor.

The supply side, by contrast, does not exhibit a common pattern in production losses. Because forward linkages depend on the industries purchasing railway transport services, and because each concessionaire serves a distinct corridor with its own production base and cargo profile (BRASIL, 2024), the sectoral composition of impacts diverges sharply across concessionaires. For MRS and EFVM, which constitute Brazil's principal iron ore export corridors and serve a substantial share of the country's integrated steel industry (Fiuza & Tito, 2015), forward impacts are concentrated in iron ore, pig iron, and semi-finished steel. By contrast, FCA and RM are more closely linked to agricultural production and food supply chains: FCA transports a diversified mix of agricultural and industrial commodities (Tribunal de Contas da União, 2025), whereas RM plays a central role in grain exports (Péra et al., 2024). Consequently, their forward impacts are concentrated in food products, vegetable oils, and meat processing. Outside the mining and agricultural corridors, forward impacts decline sharply. EFC remains strongly associated with the mining production chain, whereas FNSTN, FTC, FTL, and EFPO generate comparatively smaller and more dispersed impacts (Figure 3).

Figure 3. Five most affected productive sectors in the Brazilian economy in the supply-side (R$ million)



Source: Authors' calculations.
Note: Margins were excluded from the rankings to emphasize linkages with the productive sectors of the economy. These exclusions, however, do not alter the hypothetical extraction results.

These results closely resemble the corridor perspective proposed by Quium (2019), who argues that logistics corridors function as economic systems linking specific production bases to markets rather than merely providing transport services. In the Brazilian case, concessionaires associated with mining corridors predominantly affect extractive and steel industries, whereas concessionaires operating agricultural corridors primarily influence food-processing and agribusiness activities. Productive specialization therefore emerges as one of the main determinants of forward production linkages.

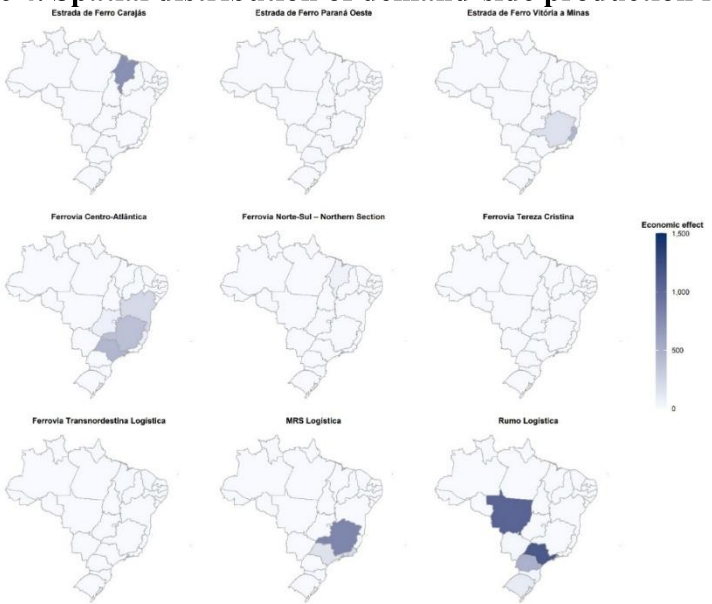
The findings also complement the evidence reported by Betarelli Junior et al. (2011). Whereas their hybrid input-output analysis demonstrated that railway transport requirements vary according to commodity composition and export destination, the present study shows that these differences are also observable across individual railway concessionaires. Rather than behaving as a single railway sector, concessionaires exhibit distinct production linkages reflecting the specialization of the logistics corridors they operate.

Overall, demand-side impacts are driven mainly by the scale of intermediate input purchases, whereas supply-side impacts reflect the productive specialization of the freight corridors served by each concessionaire. Because these aggregate results do not reveal the spatial distribution of production losses, the next section examines their regional dimension.

4.2 Regional distribution of production losses

National estimates provide limited information on how the economic consequences of railway disruptions are distributed across space. Figures 4 and 5 map the state-level production losses generated by the hypothetical extraction of each railway concessionaire under the demand-side and supply-side approaches, respectively. Demand-side production losses are geographically concentrated, although the affected states vary across concessionaires. RM generates the broadest regional impacts, with production losses extending across Mato Grosso, São Paulo, and Paraná, whereas EFVM's losses are concentrated in Espírito Santo and EFC's in Maranhão. FCA exhibits a more dispersed pattern, with production losses distributed across São Paulo, Minas Gerais, and Bahia (Figure 4).

Figure 4. Spatial distribution of demand-side production losses



Source: Authors' calculations.
Note: Economic effect represents production losses (R$ million) from the hypothetical extraction.

The spatial concentration of production losses further reinforces the regional heterogeneity documented in previous transport studies. Rather than generating uniform economic impacts across space, railway concessionaires primarily affect the regional economies located along their operational corridors, consistent with evidence reported for China (Liang et al., 2020), Iran (Dehghan Shabani & Safaie, 2018), and Brazil (Moralles et al., 2019).

Table 1 reports the ten productive sectors[6] with the largest demand-side production losses in the three states experiencing the largest production losses following the hypothetical extraction of RM, FCA, and MRS. Diversified services, diesel and biodiesel, and warehousing, postal and auxiliary transport activities rank among the most affected sectors across nearly all concessionaire-state combinations, indicating that the regional differences observed in Figure 4 are driven primarily by the scale of production losses rather than by differences in their sectoral composition.

This result further suggests that demand-side production losses are primarily associated with the intensity of regional production linkages rather than with fundamentally different railway technologies. In other words, concessionaires tend to purchase similar intermediate inputs, but the magnitude of these purchases depends on the scale and economic importance of the regional production systems they support. inputs, but the magnitude of these purchases depends on the scale and economic importance of the regional production systems they support.

[6] Minor deviations from the common sectoral pattern reflect differences in regional productive structures. In Mato Grosso, sugarcane (R$ 2.09 million) and soybeans (R$ 1.26 million) would replace refined petroleum products and oil and natural gas among the ten most affected sectors. In Paraná, paper and printing (R$ 1.76 million) and gasoline (R$ 2.07 million) would replace oil and natural gas and ethanol (R$ 0.90 million) in the top-ten ranking.

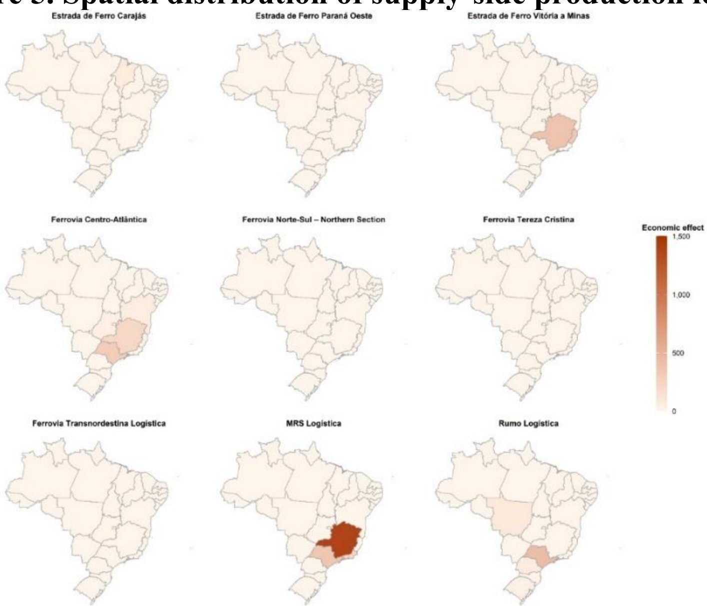
Table 1. Ten productive sectors with the largest demand-side production losses by concessionaire and state (R$ million)

Sector	RM-SP	RM-MT	RM-PR	FCA-SP	FCA-MG	FCA-BA	MRS-MG	MRS-RJ	MRS-SP
Diversified services	261.69	257.85	107.77	100.65	84.8	43.11	159.66	54.1	32.11
Diesel and biodiesel	186.45	126.15	61.25	77.2	51.28	43.83	143.65	22.94	35.67
Warehousing, postal and auxiliary transport activities	72.35	64.29	33.27	27.7	22.85	17.44	42.19	15.88	8.57
Other petroleum refining products	87.88	0	23.95	36.22	17.96	19.4	49.83	9.72	16.52
Public utility services	45	72.93	35.39	17.24	23.09	12.08	42.75	13.22	5.35
Auto parts and accessories	21.39	1.5	7.74	8.17	7.17	1.98	13.32	0.89	2.54
Rubber and plastic	15.03	4.87	5.01	5.74	2.90	2.46	5.39	2.76	1.79
Oil and natural gas	12.41	0.17	0	5.11	0.02	3.37	0.04	8.86	2.32
Ethanol	11.28	10.43	0.9	4.58	1.99	0.84	4.88	0.58	1.95
Civil construction	6.21	7.29	3.03	2.37	2.95	1.72	5.47	1.57	0.73
Other sectors	429.99	504.52	215.46	166.51	171.78	77.8	332.02	84.95	54.45
Total loss	1149.68	1049.99	493.77	451.49	386.78	224.01	799.2	215.49	162

Source: Authors' calculations.
Note: Margins were excluded from the rankings to emphasize linkages with the productive sectors of the economy. These exclusions, however, do not alter the hypothetical extraction results.

As shown in Figure 5, supply-side production losses exhibit distinct spatial patterns across concessionaires. MRS generates the largest state-level impact, with production losses concentrated in Minas Gerais, whereas EFVM and FCA display production losses distributed primarily between Minas Gerais and Espírito Santo and between São Paulo and Minas Gerais, respectively. RM's impacts are concentrated mainly in São Paulo and Paraná, while the remaining concessionaires generate comparatively small production losses that are more evenly distributed across states.

Figure 5. Spatial distribution of supply-side production losses



Source: Authors' calculations.
Note: Economic effect represents production losses (R$ million) from the hypothetical extraction.

Table 2 reports the ten productive sectors with the largest supply-side production losses in the three most affected states for MRS, EFVM and FCA[7]. For both MRS and EFVM, the sectoral composition of production losses follows a pattern across states. Semi-finished steel products, iron ore, and pig iron and ferroalloys dominate the rankings, with their relative importance varying according to whether the affected state has a stronger mining or steel-producing specialization. By contrast, FCA exhibits a much more diversified sectoral composition. In São Paulo and Bahia, production losses are concentrated in food processing, vegetable and animal oils, construction, and services, whereas in Minas Gerais mining and steel-related activities become more prominent. These results indicate that the economic effects of supply-side railway disruptions are shaped primarily by the productive structure connected to each railway network rather than by the operational characteristics common to railway concessionaires.

These findings are consistent with previous evidence indicating that the economic effects of transport infrastructure depend on regional productive specialization rather than on infrastructure provision alone (Kaur & Puri, 2023; Moralles et al., 2019). However, the present results extend this literature by demonstrating that such heterogeneity is also observed within the railway sector itself. Even concessionaires operating under the same institutional framework exhibit markedly different economic roles because they connect distinct productive systems and logistics corridors.

Overall, the results indicate that the economic importance of Brazilian railway concessionaires cannot be explained solely by network size or freight volume. Instead, systemic relevance emerges from the interaction between corridor specialization, regional productive structures and intersectoral production linkages. By explicitly distinguishing concessionaires within the input-output framework, the analysis reveals a level of economic heterogeneity that remains concealed when railway transportation is represented as a single aggregated sector.

[7] For EFVM, only two states are reported: following its hypothetical extraction, production losses outside Minas Gerais and Espírito Santo are close to zero across all sectors.

Table 2. Ten productive sectors with the largest supply-side production losses by concessionaire and state (R$ million)

	MRS				EFVM			FCA		
Sector	MG	SP	RJ	Sector	MG	ES	Sector	SP	MG	BA
Semi-finished steel products	651.54	115.05	66.52	Iron ore	225.76	299.61	Other food products	68.42	30.16	9.57
Iron ore	348.79	2.88	126.22	Semi-finished steel products	94.08	28.25	Other mining and quarrying products	6.95	41.91	8.22
Pig iron and ferroalloys	127.96	4.45	0.02	Pig iron and ferroalloys	18.47	1.11	Semi-finished steel products	12.38	32.9	0.55
Civil construction	44.23	29.26	8.05	Other mining and quarrying products	6.01	4.4	Vegetable and animal oils	18.13	12.11	4.12
Other mining and quarrying products	42.99	2.37	2.45	Civil construction	5.29	0.97	Diversified services	21.96	6.2	1.93
Metal products	34.55	34.83	4.49	Metal products	4.78	0.63	Civil construction	15.34	10.25	3.26
Diversified services	19.88	23.83	7.17	Diversified services	2.87	0.76	Wheat and milling products	8.2	4.09	4.78
Automobiles and light vehicles	19.26	14.83	0.28	Automobiles and light vehicles	2.55	0	Iron ore	0.25	15.82	0.07
Auto parts and accessories	12.1	17.27	0.23	Auto parts and accessories	1.6	0.01	Meat products	9.99	4.88	1.14
Mechanical machinery and equipment	9.43	19.52	1.29	Mechanical machinery and equipment	1.26	0.09	Non-ferrous metallurgy	8.08	6.04	1.19
Other sectors	69.36	86.63	19.28	Other sectors	9.87	4.93	Other sectors	128.84	48.96	20.83
Total	1380.1	350.94	236.02	Total	372.55	340.76	Total	298.54	213.33	55.65

Source: Authors' calculations.

Note: Margins were excluded from the rankings to emphasize linkages with the productive sectors of the economy. These exclusions, however, do not alter the hypothetical extraction results.

5 Final Remarks

This paper evaluated the economic importance of Brazilian freight railway concessionaires across the twenty-seven Brazilian state economies by explicitly representing each concessionaire within state input-output tables and applying the Hypothetical Extraction Method under both demand-driven (Leontief) and supply-driven (Ghosh) perspectives.

The results show that Brazilian railway concessionaires perform heterogeneous economic functions within regional production systems. While demand-side impacts are largely associated with the scale of intermediate input purchases required to sustain railway operations, supply-side impacts are primarily determined by the productive specialization of the logistics corridors served by each concessionaire. Consequently, the hypothetical extraction of individual concessionaires generates distinct sectoral and regional production losses, reflecting differences in territorial coverage, commodity specialization and production linkages rather than simply differences in railway operating scale.

These findings contribute to the literature by showing that heterogeneity is not limited to transport infrastructure across regions but also characterizes the railway sector itself. Rather than constituting an undifferentiated transport activity, Brazilian freight railway concessionaires sustain distinct logistics corridors that connect different productive structures and therefore occupy different positions within the national production network. By explicitly representing concessionaires instead of an aggregated railway sector, this study reveals differences in systemic importance that remain concealed in conventional input-output applications.

From a policy perspective, the results suggest that railway concession policies and infrastructure investment strategies should account for the distinct economic roles performed by individual freight corridors. Since concessionaires support different regional production systems, prioritizing investments exclusively according to operational criteria may overlook their broader economic relevance. Incorporating production linkages into investment appraisal may therefore contribute to more efficient concession management and place-based regional development policies.

This study is limited to evaluating the systemic importance of concessionaires within separate state input-output tables. Future research may extend the analysis to an interregional input-output framework, allowing hypothetical extraction to capture production dependencies and spillovers transmitted across state borders through interregional trade flows. Such an extension would provide a more integrated assessment of how individual railway concessionaires support production networks across the Brazilian economy.

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