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ORIGINAL ARTICLE

The subnational supply chain and the COVID-19 pandemic: Short-term impacts on the Brazilian regional economy

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Abstract

To control the transmission of coronavirus disease 2019 (COVID-19), Brazilian local governments have adopted partial lockdown measures in economic sectors, thereby triggering transmission shocks along input–output supply chains. The national internal market and territorial disparities favor the formation of subnational production networks within borders, thus increasing the potential effects of lockdown measures on regional integration production networks. Therefore, this study makes hypothetical simulations of COVID-19 mitigation policy decisions to understand the regional impacts on integration in supply chains, considering both domestic and global value chains. The generalized hypothetical extraction method is applied to a Brazilian interregional input–output model with 68 industries and 27 regions, imputing partial removals on intermediate consumption and final demand. The results suggest that richer subnational areas, mainly São Paulo and Rio de Janeiro, are proportionally more impacted by COVID-19 trade shocks. However, the poorer peripheries are doubly affected, either by the foreign shock, which would damage their economic structure, or by the retraction of the subnational demand from core states. The findings highlight that economic shocks are spatially distributed through different industrial structures, thus stressing the need to avoid 'one size fits all' regional policies to mitigate the potential negative effects on exposed regions.

KEYWORDS
COVID-19 outbreak, domestic value chains, hypothetical extraction method, regional effects

JEL CLASSIFICATION
R12; R10

1 | INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic is pushing governments worldwide to apply partial or total lockdown measures to economic sectors as a containment strategy to control the spread of disease transmission. Notwithstanding the consensus on the effectiveness of this type of intervention (Golan et al., 2020; Porsse et al., 2020; Surico & Galeotti, 2020), these contingency measures fundamentally affect interregional linkages, thereby raising doubts about the impacts on the connectivity degree of value chains. Recent literature suggests transmission effects along global value chains (GVCs) at the international level, with a clear tendency to shorten value chain networks in geographically closer networks (Baldwin & Evenett, 2020; Javorcik, 2020). However, the supply and demand shocks associated with COVID-19 lockdowns also affect domestic interregional input–output (IRIO) linkages, which have received considerably less attention. These impacts are particularly relevant in large economies, such as Brazil, which have structural paths that interplay the role of the input–output (IO) production network. First, national participation in GVCs has increased in recent years, as well as the higher share of domestic value-added (DVA) in an evident backward position in low-tech industries (Guilhoto et al., 2015; Lema et al., 2015; Viola & Lima, 2017). Second, the economic geography leads to a heterogeneous industrial composition within borders, thereby favoring domestic value chains (DVCs) (Azzoni & Haddad, 2018; Perobelli et al., 2019). Notably, most of the technology and knowledge economic activities are concentrated in large urban agglomerations in southeastern Brazil, mainly São Paulo and Rio de Janeiro states, while the poorer and peripheral areas are highly dependent on natural resources for both internal and foreign markets (Aroca et al., 2018; Silveira-Neto & Azzoni, 2011).

This study examines the regional impacts on the value chain integration of partial lockdown strategies for mitigating the effects of COVID-19 with an IRIO application for Brazil. The generalized hypothetical extraction method (GHEM) is adopted to measure the differences between the baseline trade in value-added (TiVA) based on the IO model data and the TiVA in a partial lockdown COVID-19 scenario for both interregional and global levels (Dietzenbacher & Lahr, 2013; Giammetti et al., 2020; Haddad, Perobelli, & Araújo, 2020). The contribution of this paper is twofold. First, a multiscalar perspective is adopted, accounting for the impacts on both DVCs and GVCs, and the regional and industrial composition measurements. Second, we calculate the relative loss of TiVA caused by shocks in the intermediate consumption and final demand resulting from COVID-19 partial lockdowns at the industry level (Haddad, Perobelli, & Araújo, 2020).

We conduct an analysis for Brazil by exploring the regional impacts of unexpected recessive shocks on value chain integration, assessing the spatial distribution of losses, and appraising the degree of regional exposure in an economically restricted scenario. This is particularly relevant for forecasting policy decisions to support regions experiencing COVID-19 pandemic-induced crises (Haddad, Perobelli, Araújo, & Bugarin, 2020). We model the main contingency measures adopted by local governments – reducing the economic activity of specific sectors according to the level of risk and social distance (Ferreira dos Santos et al., 2020; Ponce, 2020) – on the IRIO system. Thus, we shed light on the role of production networks at different geographic scales to understand the spatial distribution of economic and trade losses. Our objective is not to quantify the real changes in the regional gross domestic product (GDP)[1] but to identify the potential losses associated with the productive regional structure within Brazil.

This paper is organized into five sections as follows. The next section presents the related literature. The third section details the method for accounting for TiVA changes and exposure levels in a COVID-19 scenario of partial economic lockdowns. The fourth section shows the main regional results. Finally, the last section presents the main considerations and policy implications of the study.

2 | REGIONAL INEQUALITIES AND COVID-19 SYSTEMIC SHOCKS

In this section, we briefly show the structural characteristics of Brazil's supply chain and the main mechanisms that contribute toward explaining the propagation of trade integration effects associated with systemic partial lockdown restrictions.

Brazil has relevant structural characteristics to analyze the degree of exposure and effects of subnational integration on value chains mainly due to its market size (in terms of the territorial area, population, and trade patterns), which favors the creation of complex internal production networks. Internationally, the economy is relatively closed and specialized in the exportation of raw materials (De Backer et al., 2018; Perobelli et al., 2019; Sturgeon, 2016). Furthermore, subnational trade is relevant to national economic development (Atienza, Arias-Loyola, & Phelps, 2020; Atienza, Lufin, & Soto, 2018) and the structural propagation of economic shocks related to COVID-19 mitigation measures. Furthermore, the country is characterized by strong diversity in weather and natural resource endowment and pronounced regional inequalities (Azzoni & Haddad, 2018; Silveira-Neto & Azzoni, 2011) that lead to diverse regional patterns of economic and integration impacts.

The economy and population of the country are concentrated in the largest economic centers in Brazil. Figure 1 shows the spatial distribution of employment (part a) and an index of productive specialization (part b) as indicators of some structural aspects of the country. Large economic centers dominate the Southeast Macroregion, including the states of São Paulo, Rio de Janeiro, Minas Gerais, and Espírito Santo. These four states represented 11% of the national territory, 53% of the national GDP, and 42% of the population in 2017 (IBGE, 2020). The industrial composition of these states is diversified, whereas knowledge bases and local capacities (research and development hubs, financial market, manufacturing industry, and foreign direct investment flows) are also concentrated in this area (Haddad et al., 2017; Iammarino & McCann, 2013). The South Macroregion is the second hierarchical area in terms of economic importance, with 14% of the population and 16% of GDP, and above-average per capita income, education, and labor quality. Conversely, the rest of the country encompasses the poor Northeast Macroregion that covers nine states, 27% of the population, and 15% of GDP in 2017. Finally, the sparsely populated North and Midwest Macroregions have large areas, strongly based on natural resource exploitation.

These regional differences tend to amplify the upstream and downstream economic impacts from COVID-19 measures across value chains, as the regions have different positions and roles from a multiscalar perspective. For example, regarding economic size, the southeastern states have a leading position as net exporters for both DVCs and GVCs. Simultaneously, poorer peripheries, mainly the northeastern and northern states, are relatively more connected toward GVCs based on raw material provisions (Guilhoto et al., 2015; Lee et al., 2018; Sturgeon, 2016). The regional connectivity pattern can be seen in the industrial composition of the gross output. Table 1 presents the location quotient for the 20-ISIC industry groups and the five Brazilian administrative macroregions. The southeastern states specialize in a greater industrial pool, revealing their diversity with a more complex integration profile in higher value-added industries. However, there is a resource-based specialization in peripheral states, which is revealed by the highest indexes in primary industries – agriculture, livestock, and mining – to deal with lower value-added levels in production and trade.

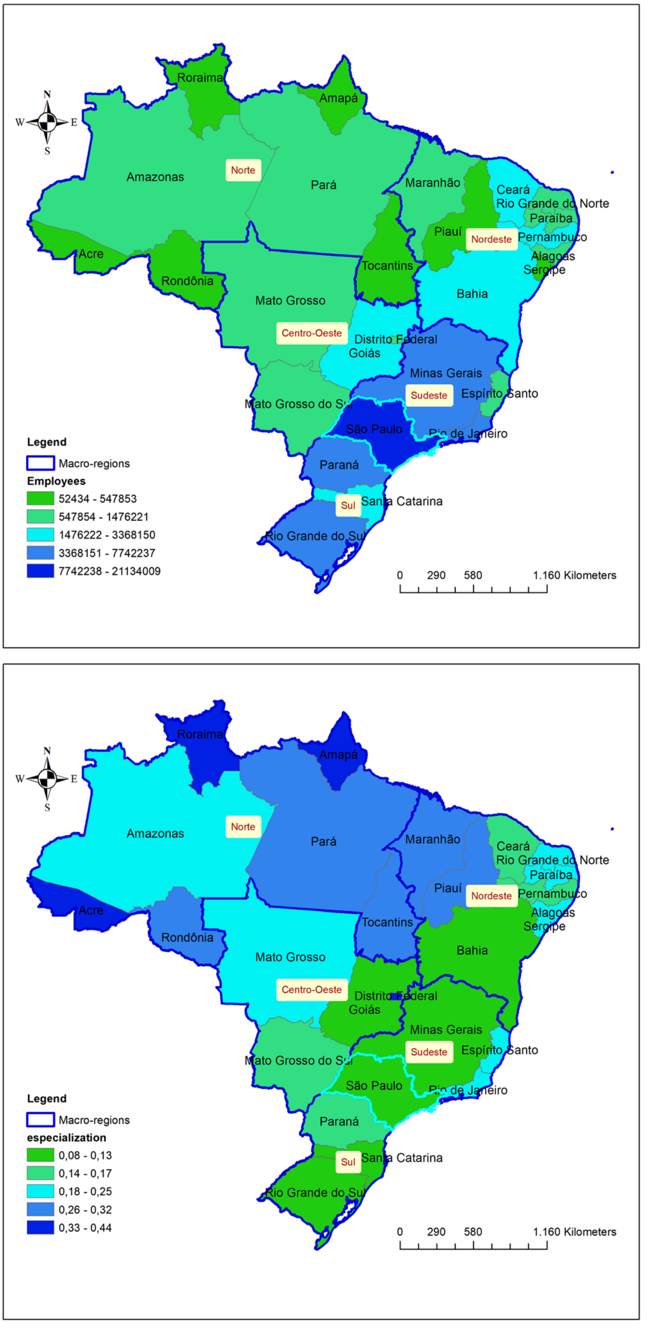


FIGURE 1 Brazilian regional economy
Source: elaborated by the authors based on RAIS (2020)

These structural characteristics are essential for the spatial propagation of COVID-19 mitigation measures (Fernandes, 2020; Haddad, Perobelli, Araújo, & Bugarin, 2020). In Brazil, local governments generally impose partial industry-specific constraints, including closing a business, limiting operating time, or even reducing the number of productive workers (Ferreira dos Santos et al., 2020; Ponce, 2020). Therefore, the regional value-added content

TABLE 1 Location quotient of sectorial gross output at the macroregional level[1]

Industry	Midwest	Northeast	North	Southeast	South
Accommodation and food	0.81	1.38	0.83	1.01	0.82
Administrative activities and complementary services	0.76	0.90	0.57	1.18	0.75
Agriculture, livestock, forest production, fisheries, and aquaculture	2.40	1.33	1.45	0.52	1.49
Arts, culture, sport, and recreation	0.73	0.97	0.42	1.17	0.78
Construction	1.01	1.40	1.38	0.90	0.91
Domestic services	1.05	1.16	1.03	0.99	0.88
Education	1.49	1.40	1.10	0.82	1.03
Electricity and gas	0.98	1.39	1.61	0.81	1.15
Extractive industries	0.21	0.63	2.36	1.36	0.07
Financial, insurance, and related services	1.12	0.51	0.29	1.26	0.64
Human health and social services	0.92	1.40	1.15	0.94	0.89
Information and communication	0.72	0.61	0.36	1.31	0.61
Manufacturing industries	0.62	0.75	0.91	1.04	1.29
Other service activities	1.20	1.01	0.71	0.99	1.01
Professional, scientific, and technical activities	0.60	0.67	0.39	1.25	0.79
Public administration, defense, and social security	2.36	1.55	1.44	0.74	0.62
Real estate activities	1.01	1.14	1.03	0.97	0.97
Trade; repair of motor vehicles and motorcycles	0.98	1.11	0.92	0.95	1.11
Transport, storage, and mail	0.88	0.95	0.83	1.04	1.03
Water, sewage, waste management, and decontamination activities	0.97	1.12	0.45	1.08	0.81

Source: elaborated by the authors, based on Brazilian IRIO 2011.
Note: 1 – macroregional state distribution is shown in Annex.

produced at the local level and traded through IO linkages is potentially affected. This study sheds light on these spatial effects, which are heterogeneous at different geographic scales.

Three main aspects can be used at least to explain the diverse regional impacts of COVID-19 partial lockdowns. First, the results depend on the sectoral linkages. Idiosyncratic shocks in companies or sectors can spread to other companies (or sectors) through a network of IO linkages, which leads to considerable regional and national impacts (Giammetti et al., 2020; Inoue & Todo, 2020; Porsse et al., 2020). Regionally, industrial composition plays a governance role in value chains and is responsible for the magnitude of local impacts (Bonet-Morón et al., 2020). Second, the interplay of different geographical integration scales further induces different paths to transmit shocks through IO linkages. Regional economies are affected by changes in interregional and global interflows beyond borders (Acemoglu et al., 2020; Lee, 2019). Third, the industrial diversification of integration into value chains can be used to determine how a region is affected in the short term (Mau, 2016; Modrego, Canales, & Bahamonde, 2020). Moreover, economic diversification allows for the evaluation of how they can recover, especially given their role in the functioning of production networks (Cuadrado-Roura & Maroto, 2016; Santos, Orsi, & Bond, 2009). Diversification of production and exports can protect local economies against adverse trade shocks, thus offsetting local revenues and goods (Lee, 2019). Notably, the relatively closed Brazilian economy (Perobelli et al., 2019) can be an important aspect toward understanding how the country can deal with the COVID-19 crisis in value chains.

Therefore, the set of restrictive measures adopted by policymakers to mitigate the effects of the COVID-19 outbreak can affect regional economies in different ways. The growing literature on COVID-19 effects has focused on sectoral output (Bonet-Morón et al., 2020; Porsse et al., 2020), employment (Maria del Rio-Chanona et al., 2020), value-added (Giammetti et al., 2020), and international trade (Guan et al., 2020; Ivanov, 2020) effects across different case studies. However, supply and demand imbalances from contingency measures potentially affect the subnational architecture of value chains, whose literature has received less attention. Furthermore, this study contributes toward understanding the potential relationships between the industrial structure and the regional impact related to integration into value chains. We explore the transmission of internal and external shocks through IO linkages and value-added trade, which are highly dependent on trade and internal spatial governance. The next section details the methodological strategy used.

3 | DATA AND METHODS

In this section, we elucidate the empirical strategy in two parts. Initially, we show the partial GHEM and the assumptions of partial lockdowns of final demand and intermediate consumption. Subsequently, we explain the TiVA measures for both the DVCs and GVCs based on the GHEM.

3.1 | Modeling strategy

The following analysis suggests a strategy for applying a framework developed for the ex ante impact assessment of COVID-19 in a regional systemic context. The objective is to explore the model's interdependencies to examine the potential effects on the bilateral TiVA embedded in multiscalar value chains, accounting for both DVCs (interregional value-added trade) and GVCs (value-added in regional exports). However, systemic mitigation responses are not within the scope of our application. Notably, our empirical findings intend to identify the potential economic losses associated with the productive regional structure, but do not intend to quantify the real changes in regional GDP due to the COVID-19 pandemic. An analysis of that nature would require information on the results of changes in production and the demand–supply dynamics of companies and their relationship with foreign companies. Moreover, it would require assumptions about industrial and spatial standards of substitution regarding the origin of the inputs incorporated into the value chains (Chen et al., 2018).

In COVID-19 response modeling, partial lockdown measures are industry-specific and applied to the Brazilian IRIO model. Based on the methodology proposed by Haddad, Perobelli, and Araújo (2020), the GHEM is used to measure the impact of reducing intersectoral relations on bilateral TiVA. The GHEM method is suitable for this empirical exercise as it allows quantifying how much the total production of the economy with n sectors and r regions changes if a particular sector is partially contracted in this interregional system. Particularly, the application enables us to analyze the relative importance of a region and its set of economic activities, which are fundamentally dependent on the existing linkages with the rest of the economy, thus providing relevant insights regarding the systemic impact in regional and industry-level terms (Haddad, Perobelli, Araújo, & Bugarin, 2020). The technique provides ex ante evidence for policymakers to restrict economic activity with the total linkages structure, being feasible to measure the spread of effects on subnational outcomes. The regional approach to the extraction method was initially proposed by Dietzenbacher et al. (1993), and the complete taxonomy can be found in Miller and Blair (2009).

In this regard, we follow the theoretical assumptions proposed by Dietzenbacher et al. (1993), Miller and Lahr (2001), and Dietzenbacher and Lahr (2013). In general, the GHEM assumes there are a few industries with identical establishments, one of which ceases to exist to reduce the industry's capacity. Imbalances are then introduced into the IRIO system to internalize COVID-19's simulated lockdown measures through the IO intermediate output and final demand (Bonet-Morón et al., 2020). These simultaneous changes in the supply and demand side lead to the need to redefine the general equilibrium of the economic system, thus justifying the GHEM technique (Dietzenbacher & Lahr, 2013). A similar simulation strategy has been recently adopted in COVID-19 economic cost studies, such as Bonet-Morón et al. (2020) for the Colombian case following the strategy proposed by Haddad, Perobelli, and Araújo (2020), and Giammetti et al. (2020) to analyze the locked value-added (LVA) in Italy. Moreover, the flexibility of the GHEM within an IRIO system allows us to extend the analytical scope and include the bilateral TiVA at different geographical scales.

3.2 | Scenario of COVID-19 lockdown measures

Policymakers often block the activities of economic industries during pandemics. Therefore, we attribute iterations that partially constrain the intermediate supply and final demand from the IRIO system as a representative of a simulated scenario of COVID-19 contingency measures applied by the government.

3.2.1 | Intermediate consumptions changes

Changes in the intermediate output are simulated while assuming the partial closure of the Leontief production function of industry-identified companies (regardless of the region).[2] For each industry *s*, a risk factor, $0 < \alpha^s < 1$, represents the proportion wherein each industry is affected by lockdown measures. Values close to zero indicate industries that are proportionally more affected by restrictive measures, while values close to unity represent economic activities that are less affected by contingency measures. The α values are similar to Bonet-Morón et al. (2020),[3] implying imbalances in the IRIO system. For example, the health sector has a value of 1.0 (S64), assuming that 100% of the intermediate supply is maintained, while the hotel and food sector (S47), as well as entertainment (S66), presents values close to zero (see Section 3.4 for details). Thus, for a sales (industry *s*) and purchasing (industry *t*) intermediate relationship, the α value is set as follows:

$$\alpha^{s,t} = \begin{cases} \alpha^s, \text{ if } \alpha^s < \alpha^t \\ \alpha^t, \text{ if } \alpha^s > \alpha^t \end{cases}, \tag{1}$$

where $\alpha^{s,t}$ is a risk factor between supply industry *s* and demand industry *t*, for all regions ($n = 1,\ldots,n$). A matrix $\mathbf{f^a} = [\alpha^{s,t}]$ is premultiplied by the intermediate consumption matrix $\mathbf{A}$, excluding the diagonal for each region (Los, Timmer, & De Vries, 2016). Thereafter, a new set of constrained technical intermediate coefficients equals $\overline{a}^{st} = \frac{\overline{z}^{s,t}}{x^t} = \left(\frac{\overline{a}^{s,t} z^{s,t}}{x^t}\right) = \alpha^{s,t} z^{s,t}$ is set. Consequently, there is a new matrix $\overline{\mathbf{A}} = \mathbf{f^a}\mathbf{A}$, as well as a Leontief inverse representing the COVID-19 scenario, $\overline{\mathbf{L}} = \left(\mathbf{I} - \overline{\mathbf{A}}\right)^{-\mathbf{1}}$.

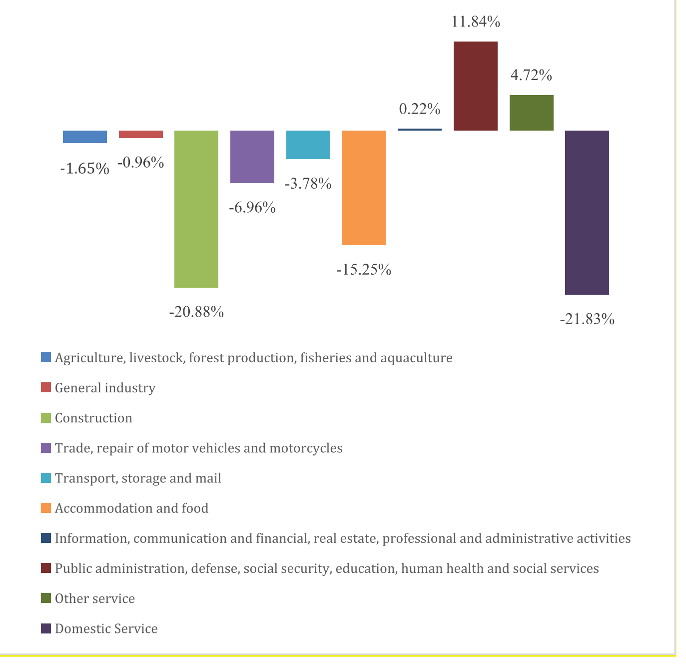
Based on the properties of the Leontief production function, we can then consider penalties at the industry and regional levels, thereby ensuring new general equilibrium balances of the IRIO system (Ferreira dos Santos et al., 2020) and allowing us to measure the impacts in bilateral TiVA through the value chains. Notably, all the results are strongly dependent on α, which directly and indirectly determines how systemically the effects are spilled through linkage networks. Notwithstanding being a relevant limitation of the analytical scope, the effects across production networks are easily captured in an IO general equilibrium.

3.2.2 | Final demand changes

Let $\mathbf{y^u}\ \forall\ u = \{HH, GOV, INV, EXP\}$, the final demand components (*HH*: household consumption; *GOV*: government expenditures; *INV*: investments; and *EXP*: exports). Based on secondary data, our COVID-19 scenario considers relative changes in *HH* and *EXP*, maintaining that *INV* and *GOV* are constant in the short term. The final demand shocks are annualized based on the temporal constant production function (Haddad, Perobelli, & Araújo, 2020).

Thus, to avoid overestimations, relative changes in *HH* ($\Delta y_n^{u=HH}$) for each region *n* are based on the relative variation of the following regional level data: (1) the difference in the expected wage level for the first half of 2020, calculated as a linear projection based on the wage levels of the same period between 2012 and 2019, with data from the four-monthly National Continuous Household Survey (Pesquisa Nacional de Amostra Domiciliar; PNAD) compatibilized with regional and sectoral setting in IRIO table; and (2) the average change in intermediate consumption given by the matrix $\mathbf{f}^a$ for the region of origin (note that $\mathbf{f}^a$ is a column matrix with the average of the $\overline{\mathbf{A}}$ matrix rows) (Giammetti et al., 2020). The wage bill data of the first four mounts of 2020 for aggregated industries from the PNAD survey are used, as shown in Figure 2. Concerning simulated *HH* shocks, it is important to clarify two relevant aspects. First, PNADC data are aggregated at the industry and national level, implying a limitation of the nature of industry-specific final demand variations. Second, PNADC sectoral aggregation has fewer sectors than the SCN, implying that the regional and subsectoral breakdown took into account the official data from the Annual Social Information Report (RAIS) of the Ministry of Economy, which considers the SCN structure.[4] Furthermore, regional structural differences are considered in the IRIO table.

Thereafter, export changes ($\Delta y_n^{u=EXP}$) in region *n* are calculated as the industry and regional average between the following: (1) the relative change from the forecast industry exports (as a linear function of the total sectoral exports for the same period between 2015 and 2019 based on monthly data from the Secretariat of Foreign Trade of the Ministry of Economy; SECEX) and (2) the relative change in partial extractions of the intermediate use given by the matrix $\mathbf{f}^a$ for the region of origin (average of $\overline{\mathbf{A}}$ rows) (Dietzenbacher & Lahr, 2013; Giammetti et al., 2020). The average values of the relative variations in the final demand are presented in Annex.



Source: PNAD (2020).

Note: 1 – Compared to the same period of the last three years.

FIGURE 2 Variation in the wage bill1 (first quarter of 2020)
Source: PNAD (2020).
Note: 1 – compared with the same period of the last 3 years

3.3 | Measurement of the impact on bilateral TiVA based on HEM

The GHEM allows us to measure how much of the regional value-added is potentially blocked by changes in the IO system, thus providing relevant analytical elements on how interregional and global value chains are ex ante affected by partial lockdown measures. We assume that the effect of hypothetical constraint measures in the economic system can be measured by partially removing them from an IRIO table and rebalancing the general equilibrium on the set of accounts (Dietzenbachen & Lahr, 2013). This technique has three main advantages: (1) it allows for the measurement of the effect of changes in the intermediate output within a Leontief structure; (2) it applies to the estimation of the effects of the partial closure of a group of companies; and (3) it extends to measure effects on trade in an IRIO system.

Compared with traditional trade measures, TiVA provides a more detailed picture of not only direct but also indirect interactions between regions and regional and international partners (Meng, Fang, Guo, & Zhang, 2017; Meng, Wang, & Koopman, 2013). Following Haddad, Mengoub, et al. (2020), let us consider a single economy with n subnational regions, s industries,[5] and foreign destinations $m = \{RoW\}$. The national gross output can be expressed as follows:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{Ly}. \tag{2}$$

The actual DVA of a subnational region $n = 1$ needed to meet their final demand is given by the following:

$$\mathbf{GDP}_1 = \mathbf{v_1}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}\boldsymbol{i}, \tag{3}$$

where $\mathbf{v_1}$ is a row matrix with the first element equal to the ratio between value-added and gross output in industries of region 1 and zeros elsewhere like $\mathbf{v_1} = [\tilde{\mathbf{v}}_\mathbf{1}\ 0 \cdots 0]$, and $\boldsymbol{i}$ is a summation vector of ones. Other regions are set to zero because we are interested in 1's regional value in its trade with other regions or exports (other countries).

The GHEM allows us to compute the difference between the current gross output and the simulated scenario, according to the partial constraints in the economic system explained in the previous section. Considering $\overline{\mathbf{A}}$ as the matrix associated with restricted intersectoral trade flows (intermediate consumption) due to the partial lockdown and $\overline{\mathbf{f}}$ as the lockdown-related final demand, the restricted gross output is given by the following:

$$\overline{\mathbf{x}} = \left(\mathbf{I} - \overline{\mathbf{A}}\right)^{-1}\overline{\mathbf{y}}, \tag{4}$$

where $\overline{\mathbf{A}}$ and $\overline{\mathbf{y}}$ represent the new matrices of the COVID-19 restriction scenario. In this case, Equation 2 can be rewritten as follows:

$$\overline{\mathbf{GDP}}^*_{1,\mathrm{n}} = \mathbf{v_1}\left(\mathbf{I} - \overline{\mathbf{A}}^*_{\mathbf{1,n}}\right)^{-1}\overline{\mathbf{y}}^*_{\mathbf{1,n}}\boldsymbol{i}. \tag{5}$$

Notably, the COVID-19 scenario suggests an LVA for subnational region 1 as the difference between $\mathbf{GDP_1}$ and $\overline{\mathbf{GDP_1}}$, which consequently implies systemic changes in the composition of bilateral TiVA flows. Consequently, the decrease in intermediate and final deliveries sold by each industry and region alters the coefficients. This implies changes in the TiVA across networks according to the new general equilibrium. Meanwhile, instead of assuming that the subnational region $n = 1$ does not trade with region n (as in the traditional HEM technique), the intermediate consumption and final demand are considered to be partially changed by α, as shown in Equation 1. Subsequently, we apply the GHEM to determine the extent to which the subnational value-added traded inside the country changes as the difference in the amount of value-added in the baseline and counterfactual COVID-19 scenario. The difference between Equations 5 and 3 results in bilateral TiVA between subnational regions 1 and n as a result of the value-added decomposition (Miroudot & Ye, 2020). The aggregate measure of annual loss in bilateral value-added flows across the DVC is given by the following:

$$\overline{\mathbf{TiVA}}_{1,\mathrm{n}} = \mathbf{GDP_1} - \overline{\mathbf{GDP}}^{*}_{\mathbf{1,n}} \forall\, n = \{1,\ldots,n\}, \tag{7}$$

where $\overline{\mathbf{TiVA}}$ represents the decrease in trade if the output associated with the lockdown measures is partially removed from region 1 to *n*. In other words, it is the total value-added traded between the two subnational regions with which such activities are associated. By extending the accountability of the value-added traded between subnational regions to the GVC, we consider the difference between Equation 3 and the DVA in exports, which is given as follows:

$$\overline{\mathbf{GDP}}^{*}{}_{\mathbf{1,m}} = [\tilde{\mathbf{v}}_{\mathbf{1}} \;\; \mathbf{0}] \begin{bmatrix} (\mathbf{I}-\mathbf{A_{11}})^{-1} & \cdots & (\mathbf{I}-\mathbf{A_{1,n}})^{-1} \\ \vdots & \ddots & \vdots \\ (\mathbf{I}-\mathbf{A_{n1}})^{-1} & \cdots & (\mathbf{I}-\mathbf{A_{n,n}})^{-1} \end{bmatrix} \begin{bmatrix} \mathbf{y_{11}} & \cdots & \mathbf{y}_{1,n} & \overline{\mathbf{y}}_{\mathbf{1m}} \\ \vdots & \ddots & \vdots & \vdots \\ \mathbf{y_{n1}} & \cdots & \mathbf{y_{nn}} & \mathbf{y_{nm}} \end{bmatrix}. \tag{8}$$

Note that it is assumed that export destination is exogenous and that only the α factor is applied to the final demand, as in Haddad, Perobelli, Araújo, and Bugarin (2020), Bonet-Morón et al. (2020), and Ferreira dos Santos et al. (2020). This ensures that the difference is calculated based on the same economic structure as the baseline, with the original Leontief matrix. To complete the trade cycle, we incorporate the gross imports conducted by each region and industry of the interregional system. By not adopting a global multiregional database, we assume that the imports generate regional value-added with the same local production technology, which seems produced in Brazil. This allows us to incorporate foreign markets from the perspective of purchase and value-added sales (Haddad, Mengoub, et al., 2020).

As in Chen et al. (2018), the level of regional exposure to value-added flows from the GHEM results is calculated. Specifically, we are interested in how much of the regional LVA is allocated to attend both DVCs and/or GVCs, considering the indirect effects in the IRIO system. Thereafter, the ratio between the value-added traded between regions 1 and *n* in relation to the total GDP of region 1 indicates how much each region is exposed to multiscalar value chains, as follows:

$$\overline{\mathbf{GDP}}^{\mathbf{exp}}_{\mathbf{1,n}} = \frac{\sum \overline{\mathbf{TiVA}_{1,n}}}{\mathbf{GDP_1}} \forall n = \{1,\ldots,n\}, \overline{\mathbf{GDP}}^{\mathbf{exp}}_{\mathbf{1,m}} = \frac{\sum \overline{\mathbf{TiVA}_{1,m}}}{\mathbf{GDP_1}} \forall m = \{RoW\}. \tag{9}$$

This measurement reflects how productive linkages are potentially affected by the imbalances imposed by the COVID-19 scenario.

3.4 | Data

In this study, the 2011 Brazilian IRIO is used, including 68 industries and 27 subnational regions (federative units), representing the country's productive structure.[6] The IO table is built by the Regional and Urban Economics Lab at the University of São Paulo (NEREUS-USP), and it is the latest public IRIO available online (the database is available from Haddad et al., 2017). Evidence in the IO suggests that tables represent interregional and interindustry dependence on the economic structure, which tends to maintain stability over time. This is shown by Timmer et al. (2016), indicating that the fragmentation of production has modest changes over time, thereby facilitating the assumption that the economic structure is not considerably different.

To apply the GHEM, we define the α values as industry-level constraint adjustments, similar to those proposed by Bonet-Morón et al. (2020). This setting is based on the general aspect of partial lockdowns applied by state governments in Brazil and reflects sectors vulnerable to COVID-19 contamination. Table 2 details the 68 values imposed on IRIO relations. The values of $\mathbf{f^a}$ (average of $\overline{\mathbf{A}}$ rows) are based on intersectoral relations, according to Equation 1. Moreover, the relative changes in final demand are given by the differences between the expected values (as a linear projection) and the observed value in the first quarter of 2020 (details in Annex). Further, for comparison purposes and to capture price level changes, we deflate the monetary values for December 2019 according to the IPCA price index (Brazilian Institute of Geography and Statistics, IBGE).

4 | RESULTS

Section 4.1 describes the spatial distribution of the LVA results while considering the partial constraints related to the COVID-19 scenario. The details of the changes in value-added allow us to understand the regional patterns of regional content changes in trade. Section 4.2 details the changes in bilateral TiVA flows and value-added content exposure across interregional and global networks.

4.1 | LVA results

This section provides a measurement of the potential changes in GDP by assuming partial restrictions in intermediate use, **A**, and the interregional final demand, **y**. Figure 3 shows the regional distribution of the LVA. The results indicate that all the value-added is hypothetically removed from the Brazilian economy; the four states of the Southeast Macroregion are concentrated with 60% of the losses in terms of national GDP. These states have the main large urban and industrial structures in the country and are responsible for most of the interregional supply and demand of intermediates so that potential losses generate effects upstream and downstream along with the subnational production networks.

As presented in Section 3, we assume a hypothetical partial lockdown measure at the industry level along the regions to provide empirical evidence on DVCs and GVCs. Notably, the national cost of the pandemic depends on regional production structures (Fernandes, 2020; OECD, 2020; Ruiz-Estrada, 2020). At the subnational level, the degree of concentration (and diversification) of industries in space is a relevant component for understanding the changes induced by exogenous shocks on the IRIO system. As the wealthiest states have more complex productive linkages networks, they are proportionally more affected by lockdown measures, given their more diversified and interconnected economic activity.

Figure 4 shows the relationship between the values of α and LVA, considering the entire economy. The sectors are affected by different magnitudes and are not always accompanied by different values of α. It is evident that the primary industries, such as agriculture and livestock, are highly dependent on demand from other more advanced sectors in the production chain, with the potential to be affected by both changes in DVCs and GVCs. However, in the short term, the potential for relative losses is not so high, given the lower sectorial capacity to incorporate value into production and because they have relatively high values of α (0.9 for agriculture and livestock, and 0.8 for forest production industry), which is related to the low risk of exposure of workers in these sectors to COVID-19.

At the industry level, in the mining activities – even with relatively higher α values (with relative restrictions) – the productive chains imply more significant relative losses for the GDP in these sectors. As they are sectors with a predominant backward linkage pattern, they become sensitive to economic activity variations in other industries, which require inputs based on natural resources. Simultaneously, extractive activities tend to incorporate more outstanding value-added than other primary industries, such as agriculture and livestock. Manufacturing, in general (industries S12 to S36), despite having heterogeneous partial block levels (α varies from 0.60 to 0.80), shows negative variations with an average of 2.3% value-added losses. Tertiary and service activities (industries S38–S68) show GDP reductions ranging from 0.10% (for example, real estate activities – S42) to 2.79% (food and accommodation),

TABLE 2 Partial constraints (values of α) at the industry level (SCN IRIO industries)

Sector	SCN	ISIC-group	α
S1	Agriculture, including support for agriculture and post-harvest	Agriculture, livestock, forest production, fisheries, and aquaculture	0.90
S2	Livestock, including support for livestock	Agriculture, livestock, forest production, fisheries, and aquaculture	0.90
S3	Forest production; fisheries and aquaculture	Agriculture, livestock, forest production, fisheries, and aquaculture	0.80
S4	Extraction of mineral coal and nonmetallic minerals	Extractive industries	0.80
S5	Oil and gas extraction, including support activities	Extractive industries	0.80
S6	Iron ore extraction, including beneficiation and agglomeration	Extractive industries	0.80
S7	Extraction of nonferrous metallic minerals, including processing	Extractive industries	0.80
S8	Slaughter and meat products, including dairy and fishery products	Manufacturing industries	0.60
S9	Sugar manufacture and refining	Manufacturing industries	0.75
S10	Other food products	Manufacturing industries	0.75
S11	Beverage manufacturing	Manufacturing industries	0.75
S12	Manufacture of tobacco products	Manufacturing industries	0.75
S13	Manufacture of textile products	Manufacturing industries	0.65
S14	Manufacture of clothing artifacts and accessories	Manufacturing industries	0.65
S15	Manufacture of footwear and leather goods	Manufacturing industries	0.65
S16	Manufacture of wood products	Manufacturing industries	0.65
S17	Manufacture of cellulose, paper, and paper products	Manufacturing industries	0.65
S18	Printing and playback of recordings	Manufacturing industries	0.65
S19	Oil refining and coking plants	Manufacturing industries	0.90
S20	Manufacture of biofuels	Manufacturing industries	0.85
S21	Manufacture of organic and inorganic chemicals, resins, and elastomers	Manufacturing industries	0.90
S22	Manufacture of pesticides, disinfectants, paints, and various chemicals	Manufacturing industries	0.90
S23	Manufacture of cleaning products, cosmetics/perfumery, and personal hygiene	Manufacturing industries	0.90
S24	Manufacture of pharmaceutical chemicals and pharmaceutical products	Manufacturing industries	0.90
S25	Manufacture of rubber and plastic products	Manufacturing industries	0.80
S26	Manufacture of nonmetallic mineral products	Manufacturing industries	0.80
S27	Production of pig iron/ferroalloys, steel, and seamless steel tubes	Manufacturing industries	0.80
S28	Nonferrous metal metallurgy and metal casting	Manufacturing industries	0.80
S29	Manufacture of metal products, except machinery and equipment	Manufacturing industries	0.80
S30	Manufacture of computer equipment, electronic, and optical products	Manufacturing industries	0.80
S31	Manufacture of electrical machinery and equipment	Manufacturing industries	0.80

TABLE 2 (Continued)

Sector	SCN	ISIC-group	α
S32	Manufacture of machinery and mechanical equipment	Manufacturing industries	0.80
S33	Manufacture of cars, trucks, and buses, except parts	Manufacturing industries	0.80
S34	Manufacture of parts and accessories for motor vehicles	Manufacturing industries	0.80
S35	Manufacture of other transport equipment, except motor vehicles	Manufacturing industries	0.80
S36	Manufacture of furniture and products from different industries	Manufacturing industries	0.80
S37	Maintenance, repair, and installation of machinery and equipment	Manufacturing industries	0.80
S38	Electric power, natural gas, and other utilities	Electricity and gas	0.95
S39	Water, sewage, and waste management	Water, sewage, waste management, and decontamination activities	0.95
S40	Construction	Construction	0.50
S41	Trade and repair of motor vehicles and motorcycles	Trade; repair of motor vehicles and motorcycles	0.40
S42	Wholesale and retail trade, except motor vehicles	Trade; repair of motor vehicles and motorcycles	0.40
S43	Ground transportation	Transport, storage, and mail	0.40
S44	Water transportation	Transport, storage, and mail	0.40
S45	Air transport	Transport, storage, and mail	0.40
S46	Storage, auxiliary transport, and mail activities	Transport, storage, and mail	0.70
S47	Accommodation	Accommodation and food	0.20
S48	Food	Accommodation and food	0.40
S49	Editing and editing integrated with printing	Information and communication	0.50
S50	Television, radio, cinema, and sound/image recording/editing activities	Information and communication	0.40
S51	Telecommunications	Information and communication	0.85
S52	Development of systems and other information services	Information and communication	0.55
S53	Financial intermediation, insurance, and private pension	Financial, insurance, and related services	0.90
S54	Real estate activities	Real estate activities	0.45
S55	Legal, accounting, consulting, and corporate headquarters activities	Professional, scientific, and technical activities	0.45
S56	Architectural, engineering, technical testing/analysis, and R & D services	Professional, scientific, and technical activities	0.45
S57	Other professional, scientific, and technical activities	Professional, scientific, and technical activities	0.45
S58	Non-real estate rentals and management of intellectual property assets	Administrative activities and complementary services	0.45
S59	Other administrative activities and complementary services	Administrative activities and complementary services	0.40

(Continues)

TABLE 2 (Continued)

Sector	SCN	ISIC-group	α
S60	Surveillance, security, and investigation activities	Administrative activities and complementary services	0.85
S61	Public administration, defense, and social security	Public administration, defense, and social security	0.85
S62	Public education	Education	0.75
S63	Private education	Education	0.75
S64	Public health	Human health and social services	1.00
S65	Private health	Human health and social services	1.00
S66	Artistic, creative, and entertainment activities	Arts, culture, sport, and recreation	0.25
S67	Membership organizations and other personal services	Other service activities	0.40
S68	Domestic services	Domestic services	0.40

Source: elaborated by the authors, 2021.

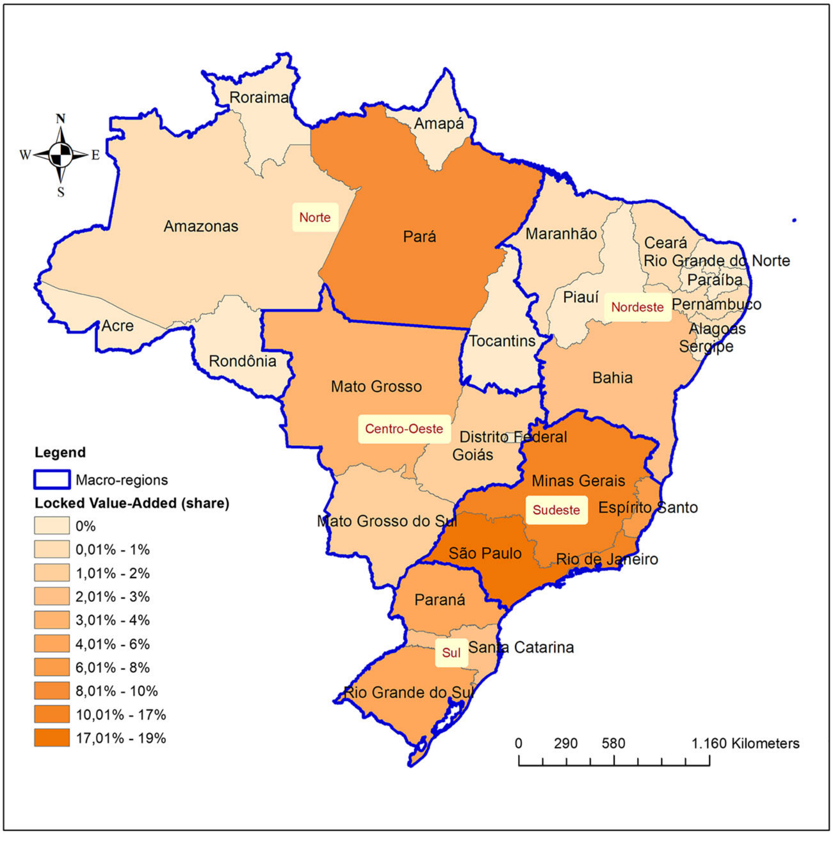
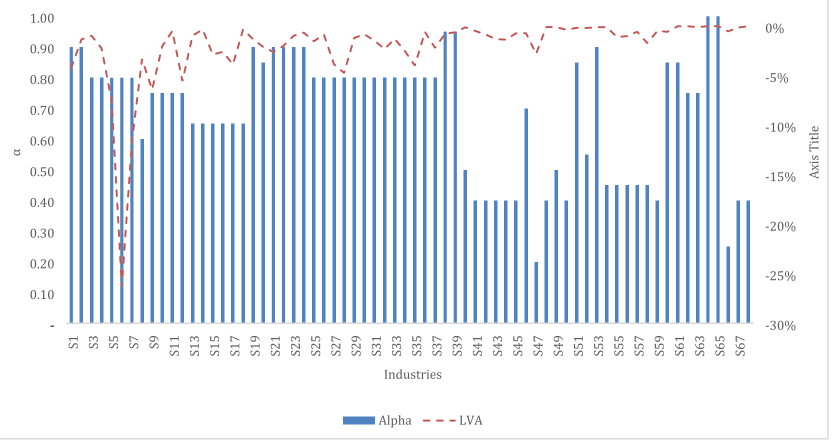


FIGURE 3 Regional distribution of national reduction in GDP
Source: elaborated by the authors, 2021



Source: Elaborated by the authors, 2021.

FIGURE 4 Hypothetical locked value-added (LVA) at the industry level
Source: elaborated by the authors, 2021

which are dependent on regional production structures, given their concentration potential. The industries with the lowest relative LVA (as public and private health activities) are less directly affected by the use of intermediate inputs in the IRIO system.

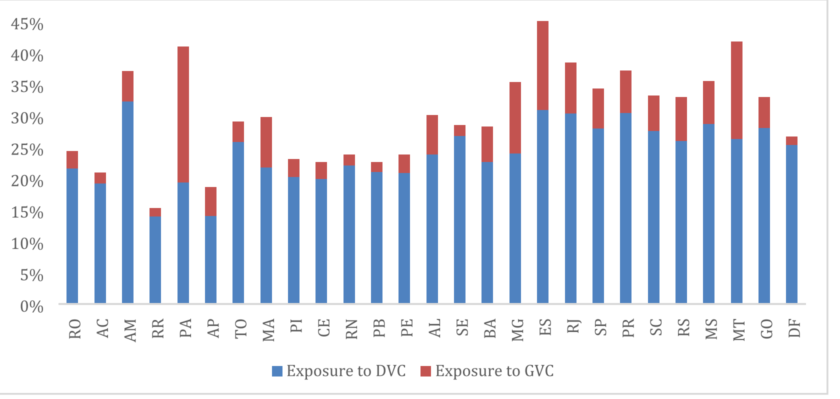
It is important to consider, however, that despite the partial lockdowns were eventually lifted, social distance (both voluntary and selective) implies considerable changes in productive and intersectoral relationships that are not necessarily reflected in our estimations. In this section, regional and industrial LVA losses are the result of simulating the COVID-19 scenario. Assuming that the regional DVA is locked, the next section details the implications for the architecture of value chains at different spatial scales.

4.2 | Connectivity effects on DVCs and GVCs

In this section, we discuss two questions: (1) How does the restrictive scenario related to COVID-19 affect the different regions of Brazil having their integration profile in value chains? (2) Which regions have the structural potential to better face the simultaneous supply and demand shocks of intermediaries? Given that all these issues are uncertain, we follow Chen et al. (2018) and identify regions and sectors exposed to changes in production and trade integration.

Figures 5 and 6 show the regional-level exposure ratio to measure how much TiVA is supplied to DVCs and GVCs, according to Equation 9. It becomes evident that partial restrictions on interindustry activity depend on how the subnational economy connects through trade relationships. Some subnational areas specialized in resource-based industries are highly exposed to GVCs in a partial lockdown COVID-19 scenario – the states of Pará (Northern macroregion of Brazil), Espírito Santo (Southeast), Mato Grosso (Midwest), and Minas Gerais (Southeast) stand out. It is important to consider that all these states have a historical export-based profile, and the dependency on foreign demand imbalances is evident. Regarding DVCs, the wealthier states (Southeast and South) are heavily dependent on the subnational linkages network, implying that the shocks that occur in the internal economy generate negative effects (losses) of value-added traded domestically. Notably, states with simpler economic structures also have a high degree of exposure to DVCs, with their productive potential dependent on interregional demand, especially from the core areas.

The major engine of Brazilian growth is concentrated on the industrial development of the richer states, which can coordinate DVCs through the upstream and downstream chains that tend to generate effects that drive the



Source: Elaborated by the authors, 2021.

FIGURE 5 Exposure of states for DVC and GVC (share of total GDP)
Source: elaborated by the authors, 2021

dynamics of peripheral areas. The unequal endowments of territorial capacities (regional output, innovation systems, and/or development path (Atienza, Arias-Loyola, & Phelps, 2020)) within Brazilian networks play a relevant role in determining the regional distribution of effects. In this sense, structural disparities seem to further increase the impact of COVID-19 from the perspective of integration into markets (Bolwig et al., 2010; Golan et al., 2020; Ivanov, 2020). Therefore, considering the level of exposure of each state to DVCs, Figure 7(a) shows these spatial heterogeneities. These differences reveal that the degree of subnational integration and its extent may be sensitive to changes in the interregional structure. Regions that potentially provide intermediate inputs for interregional demand are identified. The spatial extent of the pandemic lockdown measures is driven by trading patterns, revealing the relevant mechanisms whereby regional growth can be disturbed by removing IO linkages. Southeastern states, extending to the states of the south macroregions and the Amazon, which has the industrial pole of Manaus, show themselves as potentially most affected by variations in the value chains in the short term, given their higher degree of DVC exposure. More peripheral states, mostly in the North and Northeast macroregions, are less exposed to subnational chains, indicating less DVC connectivity.

These results suggest that the most connected and asymmetrically connected sectors can spread throughout the economy, generating specific regional disturbances. However, the size and spread of the shock are strongly dependent on the regional position within the production network of the affected sectors and how it connects with other sectors and regions (Acemoglu et al., 2020; Haddad, Perobelli, Araújo, & Bugarin, 2020; Lee, 2019). Losses in production and value-added trade become greater as the impact of the production network's central nodes increases, basically in the southeastern and southern states. Generally, in Brazil, partial lockdowns are industry-specific (and selective); local governments impose restrictions on the criteria of COVID-19 vulnerability, socioeconomic essentiality, and public health (Ferreira dos Santos et al., 2020; Ponce, 2020). Consequently, these findings shed light on the relevance of sectors within value chains and the differences in geographical scales of integration.

Moreover, Figure 6(b) shows the state-level exposure as the share of value-added embedded in exports and the total restricted state's GDP (as in Equation 9). During the COVID-19 pandemic, it is evident that multiple shocks at a global level spread through production networks. Our results reveal that export-dependent regions may be negatively affected in their local economic basis, given their high degree of exposure to external demand. The effects of changes in the global supply chain tend to have a negative impact with a higher intensity in areas that are relatively disconnected from DVCs. The losses tend to be more sensitive in these states, given the complexity of international networks in integrating these regions at the subnational level (Mudambi & Puck, 2016).

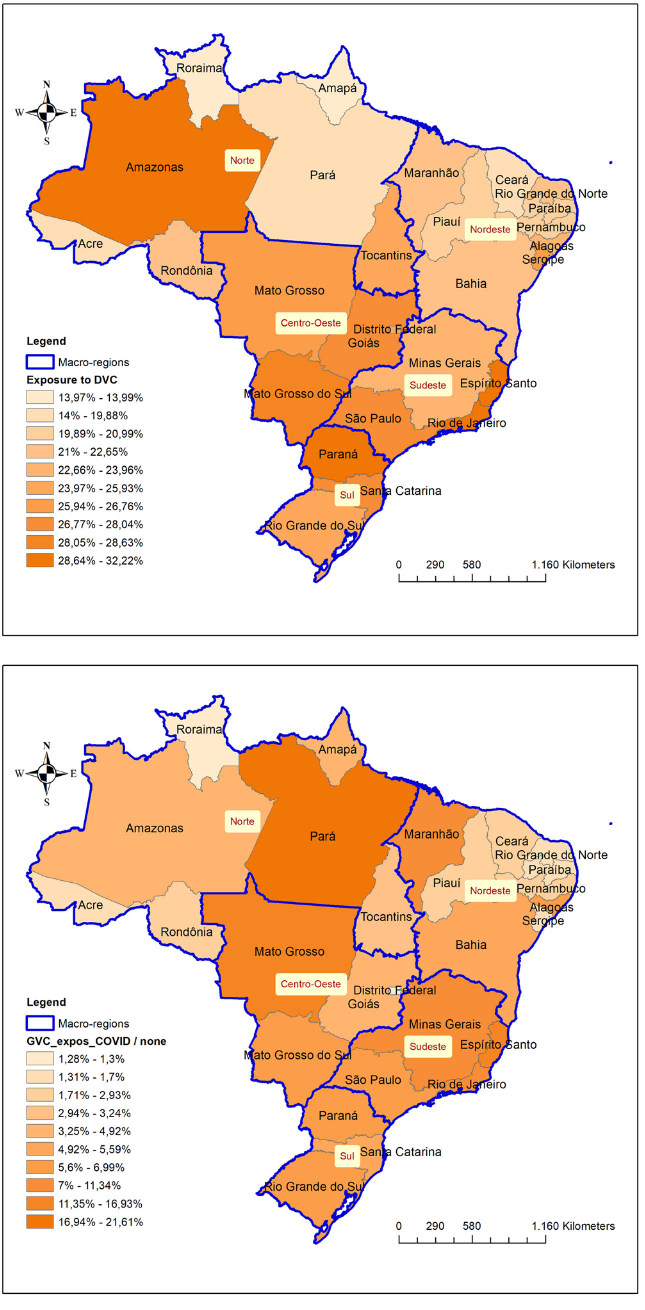
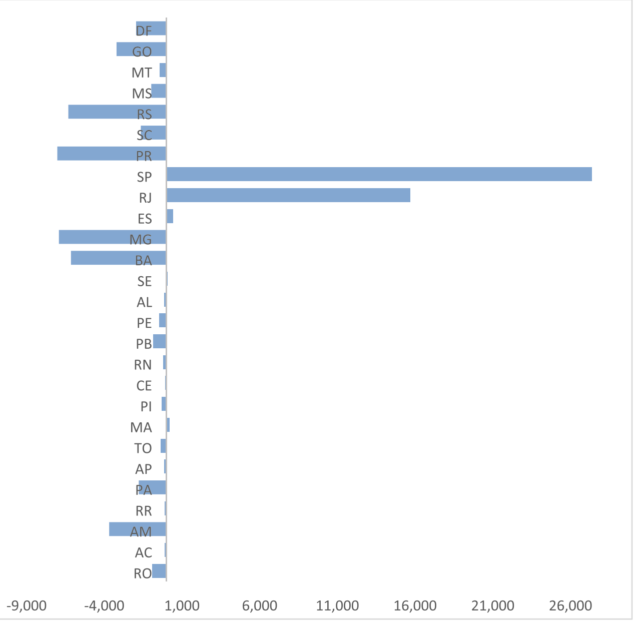


FIGURE 6 Exposure to DVC and GVC (share of TiVA by total regional GDP)
Source: elaborated by the authors, 2021

These results open up space for discussion on postpandemic recovery. Moreover, recent studies have revealed that there is a heterogeneous capacity of regions facing a recession, which provides the basis for regions to overcome the effects of crises and exogenous shocks of different natures (Cuadrado-Roura & Maroto, 2016; Ivanov, 2020; Pinto, Healy, & Cruz, 2019; Santos, Orsi, & Bond, 2009). The current debate on the different behaviors at the regional level regarding the capacity to respond to shocks becomes relevant and necessary, especially due to the uncertainty and doubts regarding the depth and duration of the global effects of the COVID-19 pandemic.



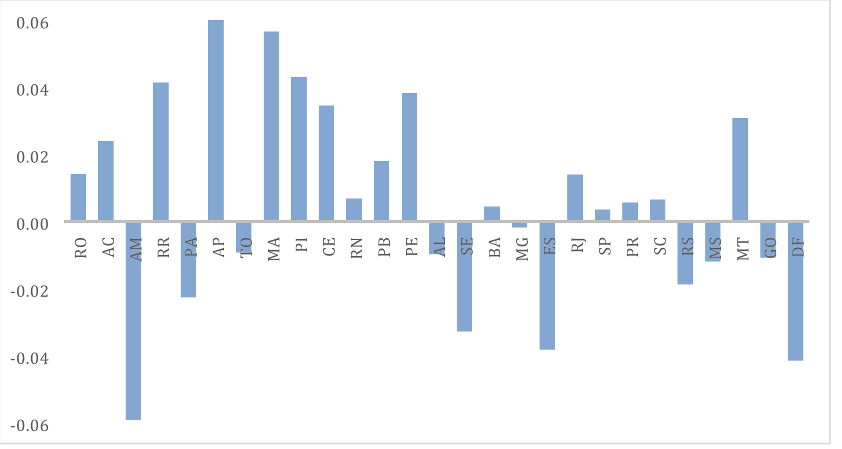
Source: Elaborated by the authors, 2021.

FIGURE 7 Net balances of TiVA (with partial constraints) (BRL millions)
Source: elaborated by the authors, 2021

Exposure to shocks is also heterogeneous because the regions are differently integrated into production networks (Cuadrado-Roura & Maroto, 2016; Martin & Sunley, 2015).

The interregional value-added flows in a scenario of partial constraints imply differentiated relative positions in the subnational geography. Figure 7 shows the net balance sheets to the buyer and seller sides (position) of $\overline{\textbf{TiVA}}$ among Brazilian states. Notably, a few states are positioned downstream in the DVC in the presence of partial restrictions on the intermediate use of inputs and final demand. Three states at the core of the economy – São Paulo and Rio de Janeiro, and, with less representativeness, Espírito Santo – are net exporters across DVCs, as well as Sergipe and Maranhão (both from the Northeastern Macroregion). The rest of the states are net importers in the DVCs, thereby revealing the potential for vulnerability in terms of bargaining power in production networks in the presence of partial lockdowns.

When we incorporate the intermediate consumption changes between the regions, the potential for backward and forward chaining is affected at the subnational level. Figure 8 shows the relative interregional losses on the outflow side of the DVC inflows (interregional VA entries). Values below 1 indicate that the losses on the outflow side exceed those on the inflow side, while values above 1 indicate the opposite relationship.[7] A core-periphery pattern of the subnational supply chain is identified because poorer states have higher inflow losses than outflow losses. In these cases, changes in the productive structure imposed by the industry-level partial constraints force the peripheral regions to amplify their role of supplying inputs to the core areas within the country (Imori, 2015; Perobelli et al., 2019). The position of Amazonas State, where the main manufacturing center Manaus Free Zone is located, is noteworthy. The state's productive dependence on interregional demand induces considerable losses on the outflow side than that of the inflow (Azzoni & Haddad, 2018; Perobelli & Haddad, 2006). The wealthiest states, which have more complex regional systems and greater interregional linkage networks, also show higher present losses on the outflow side than the inflow side, such as Amazonas, Espírito Santo, Rio Grande do Sul, and Distrito Federal. Regions specialized in the primary or agro-export sectors, such as Mato Grosso, Pará, and Maranhão, tend to lose interregional ties on the side of value-added sales incorporated into the trade.



Source: Elaborated by the authors, 2021.

FIGURE 8 Relative losses in DVCs (outflows and inflows at the state level)
Source: elaborated by the authors, 2021

The integration profile of the regions into the DVCs and GVCs has been heterogeneously affected according to their degree of exposure in the COVID-19 scenario. Parts of the regions have been proportionally more affected by changes in interregional demand compared with foreign demand. Industrialized states, such as Amazonas, São Paulo, and Rio de Janeiro, tend to alter their profile of integration into domestic markets because of partial constraints. First, southeastern economic activity acts as a stronger forward linkage pattern, requiring intermediate inputs from the peripheries. Second, the interregional net balance shows that the core acts as an essential supplier to the large Brazilian domestic market. However, peripheral regions are much more vulnerable to the risks associated with GVCs than other states, such as the core (southeast) and the south. These results reflect the dependence of foreign trade associated with their role as raw material suppliers to GVCs. At the subnational level, this occurs in the poorest peripheries and in some central states, which are highly specialized in the mining industry (such as Minas Gerais and Rio de Janeiro).

Concerning territorial structures to deal with simultaneous supply and demand shocks, regional imbalances induce the spread of COVID-19 effects from the core toward subnational chains. Economic concentration implies that the Brazilian core coordinates the consolidation of domestic productive chains (Atienza, Lufin, & Soto, 2018; Iammarino & McCann, 2013). One of the main implications of this pattern is that the national economic crisis caused by the pandemic is strongly linked to how the most prosperous regions tend to be potentially affected. Thus, peripheral states have double dependence across interregional networks. On the one hand, they depend on the economic dynamics of the central areas to be able to provide goods and services, while on the other hand, they depend on international demand. Nonetheless, when the central areas are impacted more severely, the effects on production networks tend to damage local production systems in response to a break in the business cycle that spills over to regional economies (Cuadrado-Roura & Maroto, 2016). The main local capacities associated with regional assets, industrial structures, and a leading role in interregional relations are in the Brazilian core.

5 | FINAL REMARKS AND POLICY IMPLICATIONS

This article shows the relationship between partial lockdown measures and the potential effects on the degree of regional trade connectivity in value chains across both domestic and global chains. Structural path analysis based on the hypothetical partial removals from Brazil's interregional IO system is considered, and bilateral TiVA measurements from a multiscalar perspective are conducted while considering both interregional and international trade.

By imposing industry-level intermediate consumption and final demand reductions, we establish two main regional impact conclusions. First, most of the GDP losses are concentrated in rich states (mainly São Paulo and Rio de Janeiro) because of the diversified structure and the greatest presence of economic output related to the highest COVID-19 contamination risk industries, which considerably impact the aggregate value-added traded through multiscalar value chains. Second, regions specialized in natural resources – most of the northern and midwestern states – are twofold more exposed to a constraint scenario, both for restrictions on interregional demand and international demand for exports, implying considerable losses for local economic activities. These results reveal the fragility of peripheral resource-based regions to market shocks. As we have demonstrated, structural patterns impose an interplay between interregional supply and demand, concentrated in large urban centers, and the propagation of losses on TiVA. There is an economic loss in value chain flows, exposing poor regions to external demand for both DVCs and GVCs, thereby potentially reducing their capacity to generate intraregional demand.

Furthermore, we provide evidence for policymakers in a pandemic environment, and it is necessary to consider the interplay of interregional structures to build actions to support and mitigate trade and socioeconomic losses. Moreover, IO linkage network pathways are a relevant analytical tool for forecasting economic and trade impacts. This aspect is particularly important for Brazil, which faces heterogeneous industrial composition across subnational and global networks. The lack of homogeneity in economic losses can drive and intensify the propagation of spatial effects. This point is directly dependent on installed capacities at the regional level, relevant for place-based policies to support demand-based regions in an unstable market environment for both ex ante and during the crisis conditions.

Our ex ante evaluation is needed for evidence-based policies, informing policymakers about the behavior of trade imbalances. Our study addresses the aggregated regional effects of TiVA based on sectorial restrictions, showing systemic evidence. However, an important limitation of the study is the dependence of α values on the IRIO system and the limited capacity to incorporate the pandemic's behavioral dynamics into the economic system. Particularly, in Brazil, regional responses have been uneven over time, depending on the local epidemiological–economic situation. Conversely, there is a consensus that the way the sectors of economic activity are impacted by restrictive measures is relatively similar, thus justifying the use of industry-specific measures in our simulations. Despite this limitation, this study allowed emphasis of the relevance of using simulations to deal with short-term trade-offs between industry-level constraints and the economic activity of sectors in different regions of the country.

The counterfactual exercise made it possible to trace the likely paths of the effects of restrictive policies on regional and sectoral trade flows, given the context of limited capacity of healthcare systems. Analyses of this nature are particularly important in the absence of a historical record of tradeoffs between restrictions and economic activities (Haddad, Perobelli, Araújo, & Bugarin, 2020), even more so if the interdependencies of the subnational production system are explicitly incorporated. Moreover, as lockdown measures vary over time, understanding the consequences of contingency fluctuations, including the time effect and opening up space for the design of other methods, can be essential. Suggestions for future research include applying IO inoperative models capable of predicting spillover on the whole system (Dietzenbacher & Miller, 2015; Sugrue et al., 2021). Additionally, it is possible to assume the temporal behavior on the Leontief production function, being able to capture time-specific impact measurements (Haddad et al., 2020). As an extension of IO models, the application of computable general equilibrium models is increasing to impose dynamic simultaneous shocks in different markets, including labor, trade, environmental, etc. (Evans et al., 2014; Porsse et al., 2020). Furthermore, there is growing interest in using data from IO tables in econometric gravitational models, employing trade flows to build specific shocks at the industry level, thereby capturing the network effect to understand the transmission and determinants of trade imbalances (Acemoglu et al., 2016; Acemoglu & Tahbaz-Salehi, 2020).

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ENDNOTES

[1] An analysis of this nature would require information on the result of changes in production and the dynamics of demand–supply of companies and their relationship with foreign companies. Moreover, it would require assumptions about industrial and spatial standards of substitution regarding the origin of the inputs incorporated into the value chains (Chen et al., 2018).

[2] In Brazil, disease control measures are determined at the level of the federation unit. In general, the restrictions at the economic sector level are homogeneous (which fundamentally affect intersectoral linkages between Brazilian regions), despite the uneven relationship in the performance of policies in 2020.

[3] The IO matrix used by Bonet-Morón et al. (2020) has 54 industries, while our IRIO has 68 industries.

[4] In particular, the breakdown of the PNAD and MDIC industries in IRIO industries is made by assuming the industrial distribution of the wage bill for the year 2018 based on compulsory firm-level data from the RAIS.

[5] National values result from the sum of regional measures, avoiding aggregation bias (Miller and Blair, 2009).

[6] There is evidence in the literature that IO matrices represent interregional and intersectoral dependence on the economic structure, which changes little over time.

[7] Specifically, $\left[\left(\frac{\Delta inflows_n}{\Delta \text{outflows}_n}\right) - 1\right]$.

REFERENCES

Acemoglu, D., Akcigit, U., & Kerr, W. (2016). Networks and the macroeconomy: An empirical exploration. *NBER Macroeconomics Annual*, *30*(1), 273–335.

Acemoglu, D., &Tahbaz-Salehi, A. (2020). Firms, failures, and fluctuations: The macroeconomics of supply chain disruptions. NBER working paper series. Retrieved from http://www.nber.org/papers/w27565

Aroca, P., Azzoni, C. R., & Sarrias, M. (2018). Regional concentration and national economic growth in Brazil and Chile. *Letters in Spatial and Resource Sciences*, *11*(3), 343–359. https://doi.org/10.1007/s12076-018-0217-2

Atienza, M., Arias-Loyola, M., & Phelps, N. (2020). Gateways or backdoors to development? Filtering mechanisms and territorial embeddedness in the Chilean copper GPN's urban system. *Growth and Change*, *52*, 88–110. https://doi.org/10.1111/grow.12447

Atienza, M., Lufin, M., & Soto, J. (2018). Mining linkages in the Chilean copper supply network and regional economic development. *Resources Policy*, *70*, 101154. https://doi.org/10.1016/j.resourpol.2018.02.013

Azzoni, C. R., & Haddad, E. A. (2018). The Oxford Handbook of the Brazilian Economy. In E. Amann, C. Azzoni, & W. Baer (Eds.), *Regional Disparities* (pp. 1–27). Oxford, UK: Oxford Handbooks. https://doi.org/10.1093/oxfordhb/9780190499983.013.22

Baldwin, R., & Evenett, S. (2020). *COVID-19 and Trade Policy: Why Turning Inward Won't Work* (p. 200). London, UK: Centre for Economic Policy Research (CEPR). Retrieved from https://voxeu.org/system/files/epublication/Covid-19_and_Trade_Policy.pdf

Bolwig, S., Ponte, S., Du Toit, A., Riisgaard, L., & Halberg, N. (2010). Integrating poverty and environmental concerns into value chain analysis. A conceptual framework. *Development and Policy Review*, *28*(2), 173–194. https://doi.org/10.1111/j.1467-7679.2010.00480.x

Bonet-Morón, J., Ricciulli-Marín, D., Pérez-Valbuena, G. J., Galvis-Aponte, L. A., Haddad, E. A., Araújo, I. F., & Perobelli, F. S. (2020). Impacto económico regional del Covid-19 en Colombia: Un análisis insumo-producto. Banco de La República, *288*, 34.

Chen, W., Los, B., McCann, P., Ortega-Argilés, R., Thissen, M., & van Oort, F. (2018). The continental divide? Economic exposure to Brexit in regions and countries on both sides of the channel. *Papers in Regional Science*, *97*(1), 25–54. https://doi.org/10.1111/pirs.12334

Cuadrado-Roura, J. R., & Maroto, A. (2016). Unbalanced regional resilience to the economic crisis in Spain: A tale of specialisation and productivity. *Cambridge Journal of Regions, Economy and Society*, *9*(1), 153–178. https://doi.org/10.1093/cjres/rsv034

De Backer, K., De Lombaerde, P., & Lapadre, L. (2018). Analyzing Global and Regional Value Chains. *International Economics - CEPII Research Center*, (153), 3–10. https://ideas.repec.org/a/cii/cepiie/2018-q1-153-2.html

Dietzenbacher, E., & Lahr, M. L. (2013). Expanding extractions. *Economic Systems Research*, *25*(3), 341–360. https://doi.org/10.1080/09535314.2013.774266

Dietzenbacher, E., Linden, J. van der, & Steenge, A. (1993). The regional extraction method: EC input–output comparisons. *Economic Systems Research*, *5*(2), 185–206. https://doi.org/10.1080/09535319300000017

Dietzenbacher, E., & Miller, R. E. (2015). Reflections on the inoperability input–output model. *Economic Systems Research*, *27*(4), 478–486. https://doi.org/10.1080/09535314.2015.1052375

Evans, D. K., Ferreira, F., Lofgren, H., Maliszewska, M., & Over, M. (2014). Estimating the Economic Impact of the 2014-2015 Ebola Epidemic: CGE Based Analysis. (Presented at the 18th Annual Conference on Global Economic Analysis, Melbourne, Australia; World Bank). In: *Global Trade Analysis Project (GTAP)* (pp. 1–37). West Lafayette: Purdue University. Retrieved from: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4775

Fernandes, N. (2020). Economic effects of coronavirus outbreak (COVID-19) on the world economy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3557504

Ferreira dos Santos, G., Santana Ribeiro, L. C., & Barbosa de Cerqueira, R. (2020). The informal sector and Covid-19 economic impacts: The case of Bahia, Brazil. *Regional Science Policy & Practice*, *12*(6), 1273–1285. https://doi.org/10.1111/rsp3.12366

Giammetti, R., Papi, L., Teobaldelli, D., & Ticchi, D. (2020). The Italian value chain in the pandemic: The input–output impact of Covid-19 lockdown. *Journal of Industrial and Business Economics*, *47*(3), 483–497. https://doi.org/10.1007/s40812-020-00164-9

Golan, M. S., Jernegan, L. H., & Linkov, I. (2020). Trends and applications of resilience analytics in supply chain modeling: Systematic literature review in the context of the COVID-19 pandemic. *Environment Systems and Decisions*, *40*(2), 222–243. https://doi.org/10.1007/s10669-020-09777-w

Guan, D., Wang, D., Hallegatte, S., Davis, S. J., Huo, J., Li, S., Bai, Y., Lei, T., Xue, Q., Coffman, D.'. M., Cheng, D., Chen, P., Liang, X., Xu, B., Lu, X., Wang, S., Hubacek, K., & Gong, P. (2020). Global supply-chain effects of COVID-19 control measures. *Nature Human Behaviour*, *4*(6), 577–587. https://doi.org/10.1038/s41562-020-0896-8

Guilhoto, J. J. M., Siroën, J.-M., & Yücer, A. (2015). The gravity model, global value chain and the Brazilian states. *Document de Travail UMR DIAL*, *DT/2015–02*(33), 1–20. Retrieved from http://www.dial.ird.fr/media/ird-sites-d-unites-de…travail/2015/2015-02F

Haddad, E. A., Gonçalves Júnior, C. A., & Nascimento, T. O. (2017). Matriz interestadual de insumo-produto para o Brasil: Uma aplicação do método IIOAS. *Revista Brasileira de Estudos Regionais e Urbanos*, *11*(4), 424–446. Retrieved from http://www.revistaaber.org.br

Haddad, E. A., Mengoub, F. E., & Vale, V. A. (2020). Water content in trade: A regional analysis for Morocco. *Economic Systems Research*, *5314*, 1–20. https://doi.org/10.1080/09535314.2020.1756228

Haddad, E. A., Perobelli, F. S., & Araújo, I. F. (2020). Input-output analysis of COVID-19: Methodology for assessing the impacts of lockdown measures. Td Nereus 01-2020, (April). Retrieved from https://www.researchgate.net/publication/340491646_Input-Output_Analysis_of_COVID-19_Methodology_for_Assessing_the_Impacts_of_Lockdown_Measures?channel=doi&linkId=5e8cb7164585150839c77758&showFulltext=true

Haddad, E. A., Perobelli, F. S., Araújo, I. F., & Bugarin, K. S. S. (2020). Structural propagation of pandemic shocks: An input–output analysis of the economic costs of COVID-19. *Spatial Economic Analysis*, *1*(19), 1–19. https://doi.org/10.1080/17421772.2020.1844284

Iammarino, S., & McCann, P. (2013). *Multinationals and economic geography: Location, technology and innovation*. Edward Elgar Publishing. https://doi.org/10.4337/9781781954799

Imori, D. (2015). Brazilian regions in the global value chain: Trade and the environment (Vol. *119*).

Inoue, H., & Todo, Y. (2020). The propagation of the economic impact through supply chains: The case of a Mega-City lockdown against the spread of COVID-19. *SSRN Electronic Journal*, *1*(March), 1–11. https://doi.org/10.2139/ssrn.3564898

Ivanov, D. (2020). Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transportation Research Part E: Logistics and Transportation Review*, *136*(March), 101922. https://doi.org/10.1016/j.tre.2020.101922

Javorcik, B. (2020). Global supply chains will not be the same in the post-COVID-19 world. *COVID-19 and trade policy: Why turning inward won't work* (pp. 102–111). London, UK: Centre for Economic Policy Research (CEPR). Retrieved from https://voxeu.org/system/files/epublication/Covid-19_and_Trade_Policy.pdf

Lee, D. (2019). Transmission of domestic and external shocks through input-output network: Evidence from Korean industries. *IMF Working Papers*, *19*(117), 1. https://doi.org/10.5089/9781498315821.001

Lee, K., Szapiro, M., & Mao, Z. (2018). Special issue article from global value chains (GVC) to innovation Systems for local value chains and knowledge creation. *The European Journal of Development Research*, *30*(3), 424–441. https://doi.org/10.1057/s41287-017-0111-6

Lema, R., Quadros, R., & Schmitz, H. (2015). Reorganising global value chains and building innovation capabilities in Brazil and India. *Research Policy*, *44*(7), 1376–1386. https://doi.org/10.1016/j.respol.2015.03.005

Los, B., Timmer, M. P., & De Vries, G. J. (2016). Tracing value-added and double counting in gross exports: Comment. *American Economic Review*, *106*(7), 1958–1966. https://doi.org/10.1257/aer.20140883

Maria del Rio-Chanona, R., Mealy, P., Pichler, A., Lafond, F., & Doyne Farmer, J. (2020). Supply and demand shocks in the COVID-19 pandemic: An industry and occupation perspective. *Oxford Review of Economic Policy*, *36*, S94–S137. https://doi.org/10.1093/oxrep/graa033

Martin, R., & Sunley, P. (2015). On the notion of regional economic resilience: conceptualization and explanation. *Journal of Economic Geography*, *15*(1), 1–42. https://doi.org/10.1093/jeg/lbu015

Mau, K. (2016). Export diversification and income differences reconsidered: The extensive product margin in theory and application. *Review of World Economics*, *152*(2), 351–381. https://doi.org/10.1007/s10290-015-0241-x

Meng, B., Fang, Y., Guo, J., & Zhang, Y. (2017). Measuring China's domestic production networks through trade in value-added perspectives. *Economic Systems Research*, *29*(1), 48–65. https://doi.org/10.1080/09535314.2017.1282435

Meng, B., Wang, Z., & Koopman, R. (2013). How are global value chains fragmented and extended in China's domestic production networks? IDE Discussion Paper, 424(424).

Miller, R., & Blair, P. (2009). Input-output analysis: foundations and extensions. Cambridge, UK: Cambridge university press.

Miller, R., & Lahr, M. (2001). A taxonomy of extractions. *Regional Science Perspectives in Economic Analysis* (pp. 407–441). Elsevier Science. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.365.7105&rep=rep1&type=pdf

Miroudot, S., & Ye, M. (2020). Decomposing value added in gross exports. *Economic Systems Research*, *33*, 1–21. https://doi.org/10.1080/09535314.2020.1730308

Modrego, F., Canales, A., & Bahamonde, H. (2020). Employment effects of COVID-19 across Chilean regions: An application of the translog cost function. *Regional Science Policy & Practice*, *12*(6), 1151–1167. https://doi.org/10.1111/rsp3.12337

Mudambi, R., & Puck, J. (2016). A global value chain analysis of the 'regional strategy' perspective. *Journal of Management Studies*, *53*(6), 1076–1093. https://doi.org/10.1111/joms.12189

OECD (2020). The impact of the COVID-19 crisis on regional and local governments: Main findings from the joint CoR-OECD survey. *Organisation for Economic Co-operation and Development (OECD) Regional Development Papers* 5), 1–38. https://doi.org/10.1787/fb952497-en

Perobelli, F. S., De Araújo, I. F., Vale, V. d. A., & Pires, M. d. M. (2019). INSERÇÃO PRODUTIVA INTERNACIONAL E INTER-REGIONAL: UMA ANÁLISE A PARTIR DAS CADEIAS GLOBAIS DE VALOR. *Pesquisa e Planejamento Econômico*, *49*(1), 163–195. http://ppe.ipea.gov.br/index.php/ppe/article/view/1784/1284

Perobelli, F. S., & Haddad, E. A. (2006). Estrutura de interdependência inter-regional no Brasil: Uma análise espacial de insumo-produto para os anos de 1996 E 2002 *. 1–20.

Pinto, H., Healy, A., & Cruz, A. R. (2019). Varieties of capitalism and resilience clusters: An exploratory approach to European regions. *Regional Science Policy and Practice*, *11*(6), 913–933. https://doi.org/10.1111/rsp3.12183

Ponce, D. (2020, September 1). The impact of coronavirus in Brazil: Politics and the pandemic. *Nature Reviews Nephrology*, *16*, 483. https://doi.org/10.1038/s41581-020-0327-0

Porsse, A. A., Souza, K. B., Carvalho, T. S., & Vale, V. A. (2020). The economic impacts of COVID-19 in Brazil based on an interregional CGE approach. *Regional Science Policy & Practice*, *12*(6), 1105–1121. https://doi.doi.org/10.1111/rsp3.12354

Ruiz Estrada, M. A. (2020). Economic waves: The effect of the Wuhan COVID-19 on the world economy (2019-2020). Available at SSRN 3545758.

Santos, J. R., Orsi, M. J., & Bond, E. J. (2009). Pandemic recovery analysis using the dynamic inoperability input-output model. *Risk Analysis*, *29*(12), 1743–1758. https://doi.org/10.1111/j.1539-6924.2009.01328.x

Silveira-neto, R. M., & Azzoni, C. R. (2011). Social policy as regional policy: Market and nonmarket factors determining regional inequality. *Journal of Regional Science*, *51*(5), 1–18. https://doi.org/10.1111/j.1467-9787.2011.00747.x

Sturgeon, T. J. (2016). Brazil in global value chains. MIT Industrial Perfomance Center Working Paper Series, 16–001(June), 1–16. Retrieved from http://www.cggc.duke.edu/pdfs/2013-05-22_Sturgeon_et_al_Funcex_article_submitted.pdf

Sugrue, D., Martin, A., & Adriaens, P. (2021). Applied financial metrics to measure interdependencies in a waterway infrastructure system. *Journal of Infrastructure Systems*, *27*(1), 05020010. https://doi.org/10.1061/(asce)is.1943-555x.0000588

Surico, P., & Galeotti, A. (2020). The economics of a pandemic: The case of Covid-19. *London Business School Lecture*, *3* (March), 4.

Timmer, M., Los, B., Stehrer, R., & De Vries, G. (2016). An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release. *GGDC Research Memorandum GD-162, Groningen Growth and Development Centre, University of Groningen*, (162), 1–65. https://ideas.repec.org/p/gro/rugggd/gd-162.html

Viola, E., & Lima, J. S. (2017). Divergences between new patterns of global trade and Brazil/Mercosur. *Brazilian Political Science Review*, *11*(3), 1–31. https://doi.org/10.1590/1981-3821201700030001

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APPENDIX A

TABLE A1 Brazilian macroregions and states

Federative unit (states)		Macroregion	Acronym
1	Rondônia	North	RO
2	Acre	North	AC
3	Amazonas	North	AM
4	Roraima	North	RR
5	Pará	North	PA
6	Amapá	North	AP
7	Tocantins	North	TO
8	Maranhão	Northeast	MA
9	Piauí	Northeast	PI
10	Ceará	Northeast	CE
11	Rio Grande do Norte	Northeast	RN
12	Paraíba	Northeast	PB
13	Pernambuco	Northeast	PE
14	Alagoas	Northeast	AL
15	Sergipe	Northeast	SE
16	Bahia	Northeast	BA
17	Minas Gerais	Southeast	MG
18	Espírito Santo	Southeast	ES
19	Rio de Janeiro	Southeast	RJ
20	São Paulo	Southeast	SP
21	Paraná	South	PR
22	Santa Catarina	South	SC
23	Rio Grande do Sul	South	RS
24	Mato Grosso do Sul	Midwest	MS
25	Mato Grosso	Midwest	MT
26	Goiás	Midwest	GO
27	Distrito Federal	Midwest	DF

TABLE A2 Simulated imputed relative changes on final demand (household consumption and exports)

SCN code	SCN industry	PNADC industry compatibilization	Average of HH shock	Average of exports shock
0191	Agriculture, including support for agriculture and post-harvest	Agriculture, livestock, forest production, fisheries, and aquaculture	0.8244	0.8256
0192	Livestock, including support for livestock	Agriculture, livestock, forest production, fisheries, and aquaculture	0.8244	0.8256
0280	Forestry production fisheries and aquaculture	Agriculture, livestock, forest production, fisheries, and aquaculture	0.8141	0.8153
0580	Extraction of mineral coal and nonmetallic minerals	General industry	0.8129	0.6829
0680	Oil and gas extraction, including support activities	General industry	0.8129	0.6829
0791	Iron ore extraction, including beneficiation and agglomeration	General industry	0.8178	0.7215
0792	Extraction of nonferrous metallic minerals, including processing	General industry	0.8136	0.6884
1,091	Slaughter and meat products, including dairy and fishery products	General industry	0.7533	0.7906
1,092	Sugar manufacture and refining	General industry	0.8032	0.8350
1,093	Other food products	General industry	0.8004	0.8377
1,100	Beverage manufacturing	General industry	0.8004	0.8377
1,200	Manufacture of tobacco products	General industry	0.8004	0.8377
1,300	Manufacture of textile products	General industry	0.7706	0.8079
1,400	Manufacture of clothing artifacts and accessories	General industry	0.7706	0.8079
1,500	Manufacture of footwear and leather goods	General industry	0.7706	0.8079
1,600	Manufacture of wood products	General industry	0.7706	0.8079
1700	Manufacture of cellulose, paper, and paper products	General industry	0.7706	0.8079
1800	Printing and playback of recordings	General industry	0.7706	0.8079
1991	Oil refining and coking plants	General industry	0.8239	0.8598
1992	Manufacture of biofuels	General industry	0.8194	0.8554
2091	Manufacture of organic and inorganic chemicals, resins, and elastomers	General industry	0.8239	0.8598
2092	Manufacture of pesticides, disinfectants, paints, and various chemicals	General industry	0.8239	0.8598
2093	Manufacture of cleaning products, cosmetics/perfumery, and personal hygiene	General industry	0.8232	0.8605
2,100	Manufacture of pharmaceutical chemicals and pharmaceutical products	General industry	0.8232	0.8605

TABLE A2 (Continued)

SCN code	SCN industry	PNADC industry compatibilization	Average of HH shock	Average of exports shock
2,200	Manufacture of rubber and plastic products	General industry	0.8129	0.8502
2,300	Manufacture of nonmetallic mineral products	General industry	0.8129	0.8502
2,491	Production of pig iron/ferroalloys, steel, and seamless steel tubes	General industry	0.8129	0.8502
2,492	Nonferrous metal metallurgy and metal casting	General industry	0.8129	0.8502
2,500	Manufacture of metal products, except machinery and equipment	General industry	0.8129	0.8502
2,600	Manufacture of computer equipment, electronic, and optical products	General industry	0.8129	0.8502
2,700	Manufacture of maquis and electrical equipment	General industry	0.8136	0.8495
2,800	Machinery and mechanical equipment manufacturing	General industry	0.8136	0.8495
2,991	Manufacture of cars, trucks, and buses, except parts	General industry	0.8136	0.8495
2,992	Manufacture of parts and accessories for motor vehicles	General industry	0.8129	0.8502
3,000	Manufacture of other transport equipment, except motor vehicles	General industry	0.8136	0.8495
3,180	Manufacture of furniture and products from different industries	General industry	0.8129	0.8502
3,300	Maintenance, repair, and installation of machinery and equipment	General industry	0.8129	0.8502
3,500	Electricity, natural gas, and other utilities	General industry	0.8246	1.1208
3,680	Water, sewage, and waste management	General industry	0.8246	1.1208
4,180	Construction	Construction	0.7368	1.0138
4,500	Trade and repair of motor vehicles and motorcycles	Trade, repair of motor vehicles and motorcycles	0.6974	0.9744
4,680	Wholesale and retail trade, except motor vehicles	Trade, repair of motor vehicles and motorcycles	0.6974	0.9744
4,900	Ground transportation	Transport, storage, and mail	0.6974	0.9744
5,000	Water transportation	Transport, storage, and mail	0.6974	0.9744
5,100	Air transport	Transport, storage, and mail	0.6974	0.9744
5,280	Warehousing, auxiliary transport, and mail activities	Transport, storage, and mail	0.8048	1.0818

(Continues)

TABLE A2 (Continued)

SCN code	SCN industry	PNADC industry compatibilization	Average of HH shock	Average of exports shock
5,500	Accommodation	Accommodation and food	0.6000	0.8770
5,600	Food	Accommodation and food	0.6974	0.9744
5,800	Editing and editing integrated with printing	Information, communication and financial, real estate, professional, and administrative activities	0.7368	1.0138
5,980	Television, radio, cinema, and sound/image recording/editing activities	Information, communication and financial, real estate, professional, and administrative activities	0.6974	0.9744
6,100	Telecommunications	Information, communication and financial, real estate, professional, and administrative activities	0.8379	1.1149
6,280	Development of systems and other information services	Information, communication and financial, real estate, professional, and administrative activities	0.7548	1.0318
6,480	Financial intermediation, insurance, and private pension	Information, communication and financial, real estate, professional, and administrative activities	0.8423	1.1193
6,800	Real estate activities	Information, communication, and financial, real estate, professional and administrative activities	0.7180	0.9950
6,980	Legal, accounting, consulting, and corporate headquarters activities	Information, communication, and financial, real estate, professional and administrative activities	0.7180	0.9950
7,180	Architectural, engineering, technical testing/analysis, and R & D services	Information, communication and financial, real estate, professional, and administrative activities	0.7180	0.9950
7,380	Other professional, scientific, and technical activities	Information, communication and financial, real estate, professional, and administrative activities	0.7180	0.9950
7,700	Non-real estate rentals and management of intellectual property assets	Information, communication and financial, real estate, professional, and administrative activities	0.7180	0.9950
7,880	Other administrative activities and complementary services	Information, communication and financial, real estate, professional, and administrative activities	0.6974	0.9744
8,000	Surveillance, security, and investigation activities	Information, communication and financial, real estate, professional, and administrative activities	0.8379	1.1149
8,400	Public administration, defense and social security	Public administration, defense, social security, education, human health, and social services	0.8193	1.1149
8,591	Public education	Public administration, defense, social security, education, human health, and social services	0.8009	1.0965
8,592	Private education	Public administration, defense, social security, education, human health, and social services	0.8009	1.0965

TABLE A2 (Continued)

SCN code	SCN industry	PNADC industry compatibilization	Average of HH shock	Average of exports shock
8,691	Public health	Public administration, defense, social security, education, human health, and social services	0.8259	1.1215
8,692	Private health	Public administration, defense, social security, education, human health, and social services	0.8259	1.1215
9,080	Artistic, creative, and entertainment activities	Other service	0.6246	0.9016
9,480	Membership organizations and other personal services	Other service	0.6974	0.9744
9,700	Domestic services	Domestic service	0.6974	0.9744

Source: elaborated by the authors, 2021.