Regional economic impacts of the Brumadinho tailing dam rupture disaster in Minas Gerais (Brazil) based on labor productivity changes

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Área Temática: 1. Economia

Abstract

This paper aims to analyze the impact of Brumadinho dam failure in Minas Gerais (Brazil) from a labor productivity perspective. The simulations primarily used Input-Output techniques to assess the economic structure and role of mining. Second, B-MARIA Computable General Equilibrium (CGE) model estimates regional effects as a function of changes in labor productivity. Input-Output Matrix database had obtained using IIOAS methodology, in which the cities directly affected are disaggregated with data referring to the year 2015. The result showed Brumadinho could have an accumulated loss of 1.17% of GDP in up to four years and the other municipalities of 1.81%.

Key words: Brumadinho; Computable General Equilibrium, B-Maria; Labor productivity; Regional Economics.

1. INTRODUCTION

The mining sector is one of the most relevant activities in the Brazilian economy, especially in Minas Gerais State. According to Regional Accounts System from the Brazilian Institute of Geography and Statistics (IBGE, 2021a), the sector represented 12% of national industry gross added value in 2018, while Minas Gerais produced almost 17% of that. It aims to obtain primary products for export, mainly iron ore, which many industries use for steel production.

This mineral is the third item on Brazilian export agenda. Data from Ministry of Economy (2021) showed the country exported, primarily to China, on average US$ 25 billion FOB (free on board) of iron ore per year between 2010 and 2020, which represented nearly 12% of Brazilian exports. Minas Gerais is the largest exporter, with 45% of the average international sales in this period. Thus, the result of Brazil's international currencies and the Balance of Payments depends on the sector outcome (NAHAS et al., 2019; SIMONATO, 2017).

Other extractive activities features are being capital-intensive, little connected with other industries, low use of labor, and concentrating its production in certain areas due to mineral deposit formation resulting from intrinsic subsoil aspects. Thus, producer regions become dependent on mining and concentrate the exports on primary products (NAHAS et al., 2019).

A range of negative environmental externalities is associated with extractive activity practice. Among them stands out contamination risk of water resources, geological impacts by erosive process, landscape degradation, and air pollution (CARVALHO et al., 2017; DIAS et al., 2018; PEREIRA et al., 2019). Tailing's dam is a structure belonging to mining process used in ore extraction, which researchers consider an environmental contamination danger in the production steps through chemical substances storage. In case of disruption, the degree of environmental, social, and economic impact could be considerably intensified (GALO, 2017).

According to Nacional Mining Agency – (ANM, 2021), tailings dams are structures designed to contain mining rejects and processing of ore commonly built with landfill or their extractive activity tailings. The ANM report showed in June 2021 that there were in Brazil registered 885 tailings dams in the Integrated Safety Management System for Mining Dams – SIGBM. Of this total, only about 50% belong to National Police of Tailings Dams Security – PNSB. The PNSB measures levels of risk and emergency added to potential damage of rupture (ANM, 2021).

Minas Gerais is included in this context, as the biggest holder of this structure. 40% of Brazilian dams are within their borders. We consider just the high-risk ones percentage increased to 81%. Thus, among the 47 tailings containments with potential for accidents, 38 are concentrated in Minas Gerais (ANM, 2021). A large part of that has been projected with the heightening method known as upstream. This structure aims to amplify its capacity through dikes construction formed by tailings decantation, displacing the axis upstream (GALO, 2017).

Mining specialists have been appointing upstream heightening methods as little safe or stable, which increases the probability of disruption risk (DUARTE, 2008; GALO, 2017; PEREIRA et al., 2019). Despite being a structure with a lower associated cost and more speed in increasing dam size and (or) water level of the reservoir (heightening), it has low safety because of liquefaction threat (GALO, 2017). It was the technical cause that has been appointed to the disasters of Mariana in 2015 and Brumadinho in 2019, both in Minas Gerais (SILVA ROTTA et al., 2020). On January 25th, 2019, the tailings of Córrego do Feijão's dam reached the Brazilian city of Brumadinho. It was the worst human and environmental disaster in Brazilian history. Over 250 people dead and spread a large amount of ore tailing with toxic waste into Paraopeba River and surrounding area (PEREIRA et al., 2019; SILVA ROTTA et al.; 2020).

Thus, studies aimed at analyzing the impacts of this occurrence are essential, owing to extractive sector importance for Brazilian and Minas Gerais economies. Particularly for formulation of public policy that intends to prevent events like Mariana and Brumadinho will not happen again and minimize their respective negative externalities (DIEPPE et al., 2021).

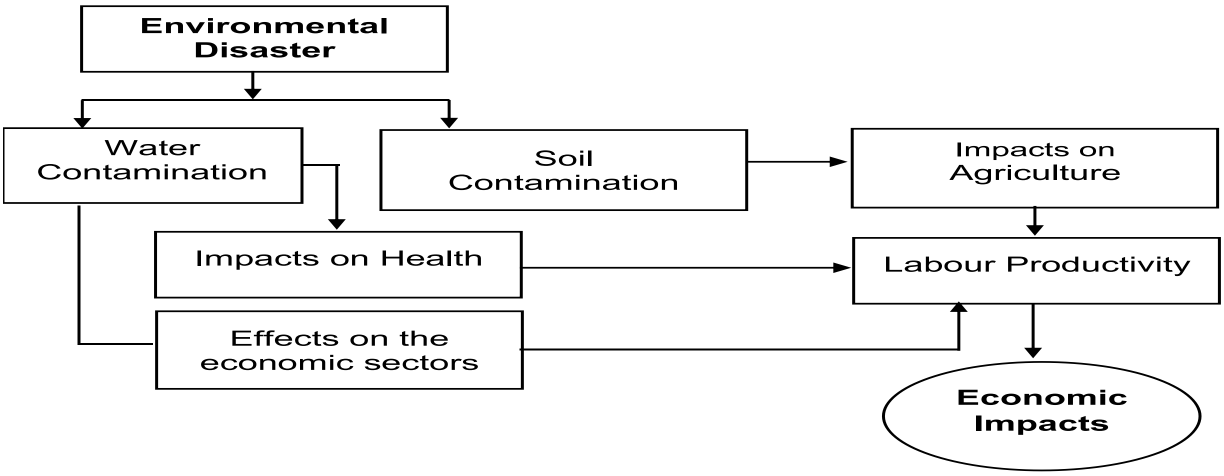
In this context, economy impacts estimation literature in cases of tailings dam rupture is scarce. Despite, Simonato (2017) estimated the regionals impact of Mariana disaster with the negatives externalities in Doce river basin. Most works remain focused on elements of the social and environmental effects (PARENTE et al., 2021; PEIXOTO AND ASMUS, 2020; SILVA, PRISCILA NEVES; HELLER, 2020).

Papers such as Barbosa et al. (2015); Carvalho et al. (2017); Dias et al. (2018); Pereira et al. (2019) indicated that these disasters could bring severe social and environmental effects such as contamination of physical environments and biotype, health deterioration physical and mental in the affected populations as well as socio-economic destabilization. According to a World Bank report written by Dieppe et al. (2021) tends to have significant losses in productivity, especially labor productivity. At least to our knowledge, there are no studies focused on quantifying the interregional economic impacts neither due to changes in labor productivity nor with focus on Brumadinho case. It is the gap this paper aims to fill.

As a manner of understanding the magnitude of these effects in Brumadinho case, the main objective of this study is to estimate the interregional economic impact of labor productivity reduction in municipalities affected by the disruption of Córrego do Feijão's dam. Specifically, we aim to estimate the input-output tables by disaggregation of the affected regions in Minas Gerais, analyzing their economic structures as the importance of the extractive sector, and finally, calculating the regional impacts under sectorial changes in labor productivity.

The hypothesis used in this work is that pollution due to this disaster affects the economy through negative externalities, whether driven by soil or water contamination, as it increases health problems and reduces the quality of inputs for several economic sectors. Consequently, there are changes in labor productivity, which results in negative economic impacts. Figure 01 shows the relationship between the environmental externalities of the Brumadinho disaster, labor productivity, and economics.

Figure 01. The relationship between the Brumadinho disaster, labor productivity, and economic impacts.



Source: Developed by the authors.

To that end, we have estimated the interregional input-output table with cities affected by the disaster disaggregated through Interregional Input-Output Adjustment System (IIOAS). Using the database, we have applied input-output techniques and calibrated a stylized computable general equilibrium (CGE) model for Brazil based on the comparative-static B-Maria model. The interregional system contains 21 productive sectors in each region, with data from 2015.

The remainder of this paper is organized as follows. Section 2 describes the modeling framework, including the model details and its closure besides data from which it has been calibrated. It also summarizes the scenarios considered in the simulation. Section 3 presents the results and corresponding interpretations, whereas Section 4 discusses the main conclusions.

2. MODELING FRAMEWORK

For calculating regional impacts under a labor productivity decrease, some steps had been done such as (i) estimating the interregional input-output tables for affected areas, (ii) applying backward and forward linkages indexes as well as an extraction method to analyze the economic structure of these regions, (iii) calibrating a Computable General Equilibrium (CGE) model with this database, and finally (iv) simulating a reduction on labor productivity in the model. This chapter aims to present these parts as follows:

2.1 Database

The database has been built by estimating the Interregional Input-Output for regions affected matrix based on Interregional Input-Output Adjustment System (IIOAS) method as detailed in Haddad *et al.* (2017) with values of 2015. IIOAS allows desegregating areas under little information. It is a hybrid method in which the regionalization process is flexible and permits an application to any country. That reports both Supply and Use Tables (SUTs) and regionalized sectoral information (HADDAD *et al.,* 2017).

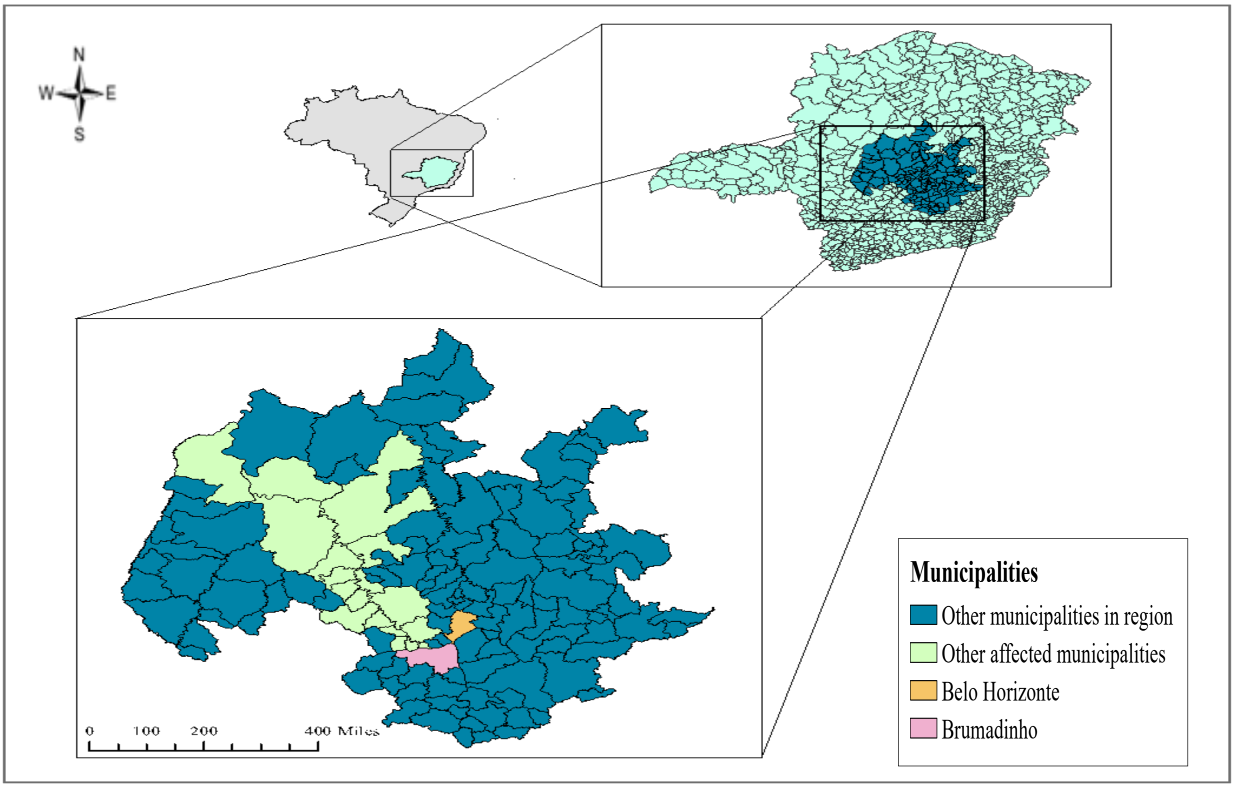
To obtain Brumadinho and other cities, we had used Brazilian Input-Output table constructed by Guilhoto[1] available at NEREUS (2021). Then, it was disaggregated into five regions as summarized in Figure 02: Belo Horizonte, capital of Minas Gerais State (R1); Brumadinho (R2); other municipalities affected by disruption of tailings dam (R3); rest of Minas Gerais State (R4) as well as rest of Brazil (R5).

This regionalization allows accounting for the municipalities affected by the Córrego do Feijão's dam rupture in the simulations (see, section 3.4). And to measure how the effects propagate to other regions, particularly Belo Horizonte and rest of Minas Gerais. Besides Brumadinho, other 17 municipalities were directly impacted by the disaster according to (IBGE, 2021b), namely: Betim, Curvelo, Esmeraldas, Felixlândia, Florestal, Fortuna de Minas, Igarapé, Juatuba, Maravilhas, Mario Campos, Papagaios, Pará de Minas, Paraopeba, Pequi, Pompeu, São João das Bicas and São José da Varginha. Finally, the sector division follows the structure proposed in Haddad *et al.* (2020) with 21 activities.

The structure of database is summarized in Table 01. The mainly regional statistics from IBGE (2021c) indicate that around 38 thousand people lived in Brumadinho in 2015, representing 0.02% of the national population. As well as the rest of municipalities affected by the rupture held 0.43% of Brazilian citizens. The relative share of Minas Gerais GDP is around 10%, which Brumadinho and other affected cities represent, respectively, from the national GDP of 0.03% and 0.54%.

Figure 02. Input-Output regions

[1] See Guilhoto and Sesso Filho (2005; 2010).



Source: Developed by the authors

Table 01. Regional statistics from data base.

Region Name	Number of Municipalities	GDP R$ (2015)*	GDP (%)	Population (2015)*	Population (%)
Belo Horizonte	1	87.310	1,46%	2.503	1,22%
Brumadinho	1	1.601	0,03%	38	0,02%
Rest of municipalities affected	17	32.554	0,54%	876	0,43%
Rest of Minas Gerais	834	397.866	6,64%	17.453	8,54%
Rest of Brazil	4.717	5.476.456	91,34%	183.581	89,79%
BRAZIL	**5.570**	**5.995.787**	**100%**	**204.450**	**100%**

*Values in thousands of Reais and people.
Source: IBGE (2021)

2.2 Input-Output Methods

Using techniques such as indexes of Rasmussen-Hirschman linkages[2] and total extraction method[3] are required to analyze the economic structure of affected cities under inter-sector perspective.

The purpose of that is primarily to identify the mainly economic activities as well as mining participation in these regions. The techniques have as a starting point the basic model of inter-regional input-output with N regions and n productive sectors per region given by:

$$X = AX + f \tag{1}$$

Where:

[2] See more details on Guilhoto (2011).
[3] See more details on Perobelli *et al.*, (2010, 2015).

X = Column vector of production vector with nN – elements;
A = Matrix (nN x nN) of input coefficients; and
f = the final demand column vector with nN – elements.
The solution of equation (1) to obtain the equilibrium is given by:

$$X = (I - A)^{-1}f \therefore X = Bf \quad (2)$$

Where $B = (I - A)^{-1}$ represents the Leontief inverse.

Based on Hirschman (1958) and Rasmussen (1956), linkage indexes can be determined from basic model of Leontief. It shows what activities would be the most connected within the economy, that is, what are the most important or keys sectors. Specifically, from information and elements of matrix B, we can constructure the forward linkages indices U_i and backward linkages U_j.

The forward linkages show the number of products demanded from other economic activities by the respective sector. Represented by:

$$U_i = \frac{\frac{b_i}{n}}{B^*} \quad (3)$$

The backward linkages indicate how much a sector would depend on inputs from other economic activities. That is:

$$U_j = \frac{\frac{b_j}{n}}{B^*} \quad (4)$$

Values greater than one for both indexes and a given sector show that it is above average and consequently plays a key role in economic growth (MILLER AND BLAIR, 2009; GUILHOTO, 2011).

However, Guilhoto (2011) said this methodology has limitation of disregarding different production levels in each sector. Thus, given extractive sector importance, total hypothetical extraction method had been applied to complement it. This approach has been widely used to measure sectoral interdependencies with relevant activities (DIETZENBACHER *et al*., 2019).

Developed by Strassert (1968) and expanded for an inter-regional analysis in Dietzenbacher *et al*. (1993). This technique allowed estimate changes in an economy's total output for each of *n* sectors, given the removal of a particular activity. In this paper, the simulation consists of removing the mining sector in all regions of matrix *A*. The output after extraction for the entire economy is calculated considering the original final demand. Algebraically, we have:

$$\bar{X} = (I - \bar{A})^{-1}\bar{f} \therefore \bar{X} = \bar{B}\bar{f} \quad (5)$$

The magnitude of the difference between the output under the extraction method $\bar{X}$ and the original output X is considered an indicator of the relative importance of the hypothetically extracted sector within an economy. That is:

$$T_j = i'X - i'\bar{X} \quad (6)$$

In which T_J represents the aggregate measure of the loss of production if mining disappeared. The hypothetical extraction implies a reduction in the economic activity so that the lower the resulting output, the larger interdependencies with the extracted sector are. It represents a measure of relative importance, representing the degree of economic interdependence (PEROBELLI *et al*.; 2010, 2015).

2.3 The B-Maria Model

For modeling the short-run regional economic impacts of changes in labor productivity due to Brumadinho dam rupture, we have employed the B-Maria model developed by Haddad (2018) adapted for the case of Minas Gerais. The theory structure of Brazilian economy, regional and interregional multisectoral analysis, is based on Australian tradition of general equilibrium modeling (HADDAD AND HEWINGS, 1999; PEROBELLI *et al*., 2009).

The economy is described by an equations system that expresses behavior of representative agents. These equations determined the economic equilibrium following linearization to allow calculating the effects of a percentual change in an endogenous variable due to an exogenous variation.

As a CGE model, it can make projections of the local and surrounding impacts caused by the disaster. This ability accrues to the structural and interregional aspects of economic system. That is considered an integrated manner. For instance, the scenarios that have been simulated can capture the effects on specific prices in the affected areas and map the shift in productivity.

The theory underlying the model's equations is typical of a CGE model. It establishes supply and demand relations for private-sector agents under optimization assumptions of conventional neoclassical microeconomics, following certain market conditions. All markets reach a simultaneous equilibrium when zero profit, market-clearing, and income balance conditions are satisfied (HADDAD AND HEWINGS, 2005; PEROBELLI *et al*., 2009).

B-Maria represents production and consumption in each area considered twenty-one productive sectors. It assumes region-specific prices, industries, and consumers. The set of production functions describes how primary factors (capital and labor) and intermediate inputs are transformed into goods and services to minimize costs, given constant returns to scale and market prices technology. The fixed coefficients determine the combination between intermediate inputs and primary factors (Leontief) (PIMENTA, 2020).

The level of consumption is modeled through a representative agent that seeks to maximize a Stone-Geary utility function subject to a budget constraint. Constant elasticity of substitution (CES) accommodates interregional trading, whereby goods are treated as substitutes, being differentiated by region of origin, and having separate prices.

Regional preferences for domestic or imported products are also specified based on CES functions considering Armington's hypothesis, which each good produced in one region is an imperfect substitute for the same good produced in other regions. Moreover, B-Maria defines a wide range of regional aggregates, such as level of employment, GDP, and price index. The results are based on a Bottom-up structure. That is, the national aggregated is the sum of the regional quantity. For more details, see (HADDAD AND HEWINGS, 1999; HADDAD, 2018).

2.4. Scenarios and Model Closure

The applied simulation evaluates the inter-regional impact of the labor productivity reduction in the affected regions (R2 e R3 in the model). For this, we have used the static comparative version of B-MARIA. This paper analyzes a short-run scenario, in which real wages, and capital stock, are exogenous. Employment and capital returns are endogenous. Furthermore, labor mobility is only allowed between sectors in the same region (HADDAD AND HEWINGS, 2005).

We have used the World Bank report produced by Dieppe *et al*. (2021) as a parameter for the simulation. These authors by econometrics have appointed natural adverse events could reduce labor productivity until four years. Their results are in Table 2.

Table 2. Effects of severe natural adverse events on labor productivity (percentual values)

Period	Labor productivity
t	-2
t+1	-3.2
t+2	-5.9
t+3	-6.5

Source: Dieppe et al. (2021)

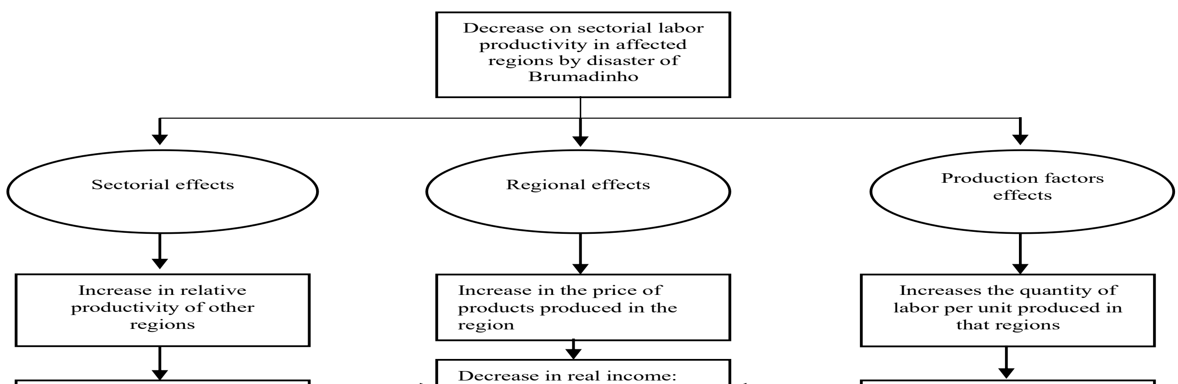
It's important to emphasize the difference between environmental and natural disasters is only human action. However, we have assumed that economic and environmental consequences are similar in cases of dams failures. (DIEPPE *et al*., 2021; SILVA ROTTA *et al*., 2020).

We have applied a reduction in the labor productivity for all sectors in affected regions (R2 and R3) based on a World Bank report. Reducing labor productivity by 1%, for example, in a determined sector, due to the Brumadinho disaster consequences means 1% more labor factor would be needed to produce the same amount of product in that sector (PIMENTA, 2020). This kind of model could capture all direct and indirect effects. An exogenous change in labor productivity within the model induces different results. Figure 03 presents a summary of these casual relationships in the simulation.

First, labor productivity reduction causes an increase in the prices of goods in all sectors of the affected regions. This increase is due to production costs since there is a need for a greater quantity of work in production. In this way, the real income of families falls, causing firms in the region to become less competitive. Reduces the investments return until reaching a drop in demand, both domestic and external, for the goods in the areas analyzed. Consequently, the level of activity, exports, and imports fall. Thus, with lower demand and sectorial production, there is pressure for a fall in prices (HADDAD AND HEWINGS, 2005; PIMENTA, 2020).

On the other hand, labor demand will increase given the need for more work to produce the same goods in regions affected. That would positively pressure the factor price and result in a higher household income and a price increase. In other internal and external areas, economic sectors became relatively more productive and consequently would demand more inputs, including from affected regions, causing a tendency to increase prices. The model will account for all these relationships until it converges into a net result on the endogenous variables, which is initially unknown (HADDAD AND HEWINGS, 2005; PIMENTA, 2020).

Figure 03. Casual relationships in the simulation



Source: Developed by the authors based on HADDAD and HEWINGS (2005); PIMENTA (2020).

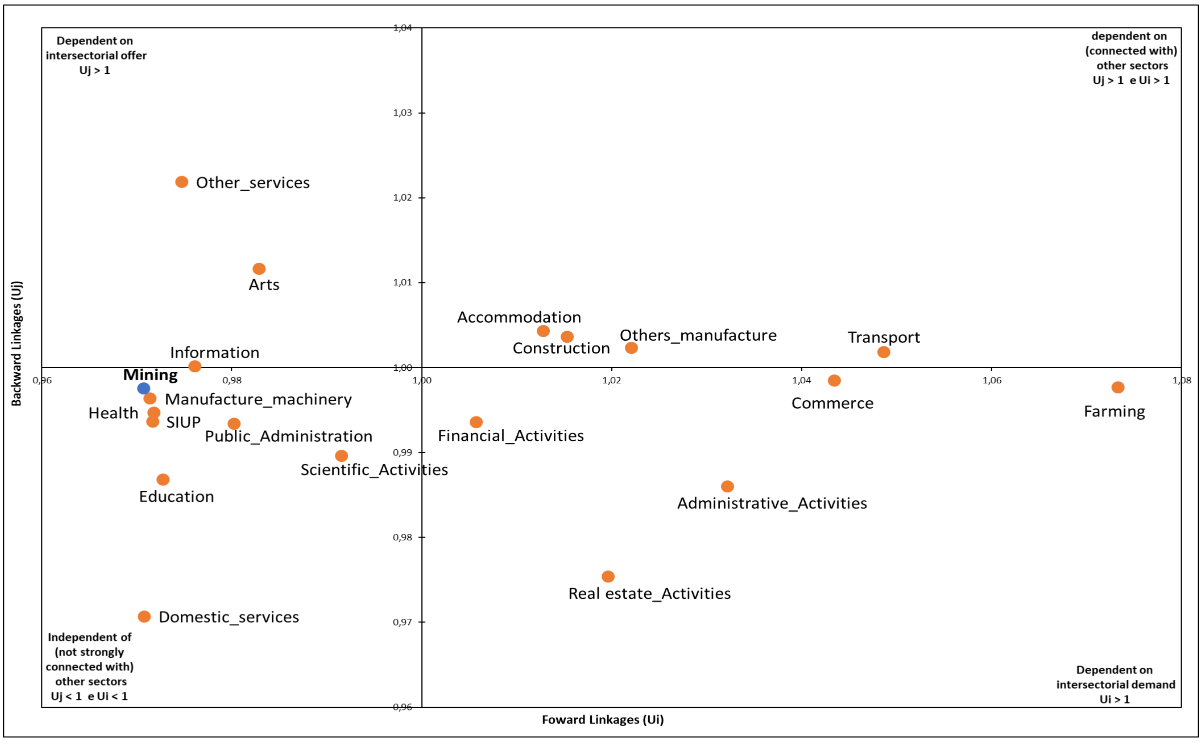
3. RESULTS

The results are divided into two parts. First, we analyze the structure economy of regions affected. Followed by effects of labor productivity reducing simulation due to Brumadinho disaster.

3.1 Economic structure of regions affected

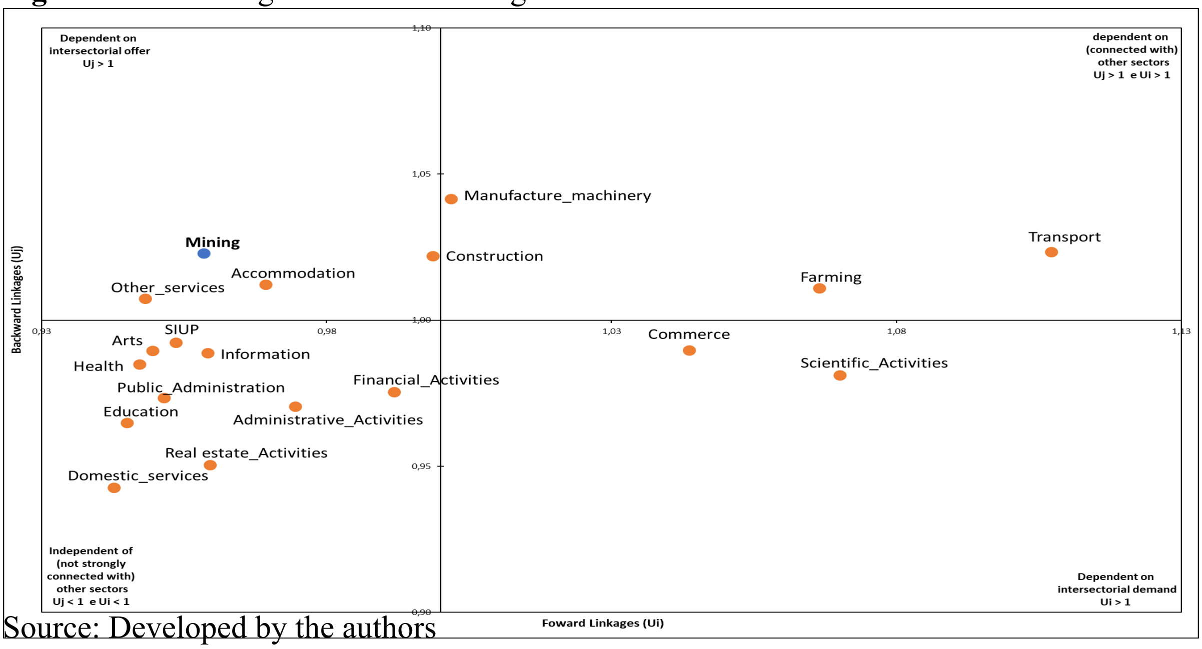
Analysis of estimated database makes it possible to verify the economic structure of regions affected by the dam failure. Figures 4 and 5 show linkages indexes for Brumadinho and other affected cities, respectively. These results identified the key economic sectors, that is, activities that are most connected with the others.

Figure 4. Brumadinho linkages



Source: Developed by the authors

Figure 5. Rest of regions affected linkages



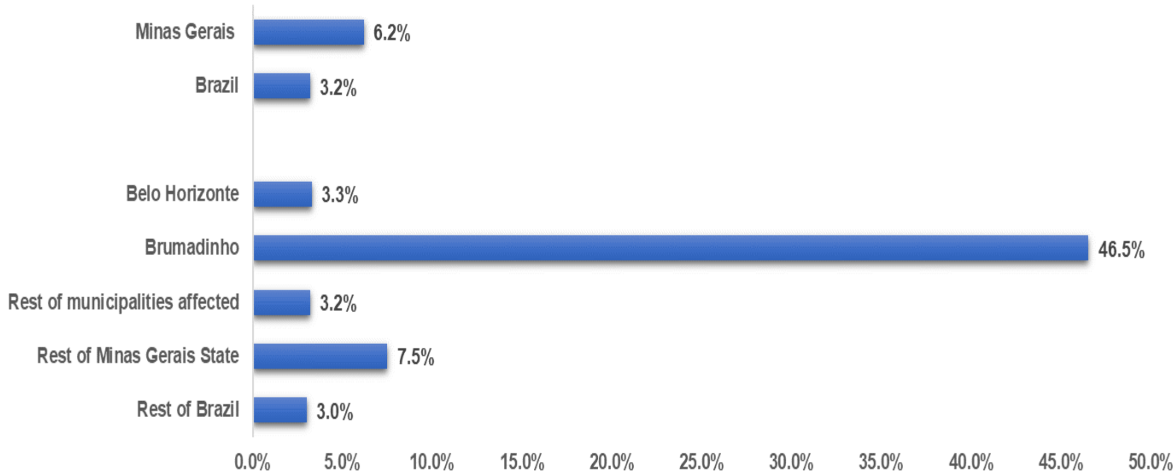
Source: Developed by the authors

In Brumadinho, the key sectors are Accommodation, Construction, Others_manufacture, and Transport. Farming, Transport, and Manufacture_machinery are the most relevant activities in other regions affected. As we have mentioned before, these sectors can be affected by the failure of dams through negative externalities such as disruption of roads and contamination of water and soil.

Mining in Minas Gerais, as well as in Brazil, is aimed at export. Thus, as it depends on external demand, it is already expected will not be a key sector. The Extractive sector in Brumadinho is independent of local demand and supply. And in other affected regions it depends on intersectoral supply, which indicates a low connection.

Thus, to capture the importance of the activity, total extraction method has been applied. The result shows that mining represents 6.2% of Minas Gerais total production, almost twice as much as for Brazilian economy. The result for Brumadinho stands out because extractive activity represents 46,5%, which demonstrates dependence on mining. The drop in output in Belo Horizonte, Rest of affected municipalities, Rest of Minas Gerais, and Rest of Brazil, if there is no Mining, are, respectively: 3.3%, 3.2%, 7.5%, and 3.0%.

Figure 6. Hypothetical extraction of mining results (total output).



Source: Developed by the authors

The information extracted from the Input-Output techniques about Mining confirms aspects pointed out in the literature by Nahas et al. (2019) of low connection with other activities and dependence on the sector. Witch indicated the base data robustness.

3.2 Labor productivity effects

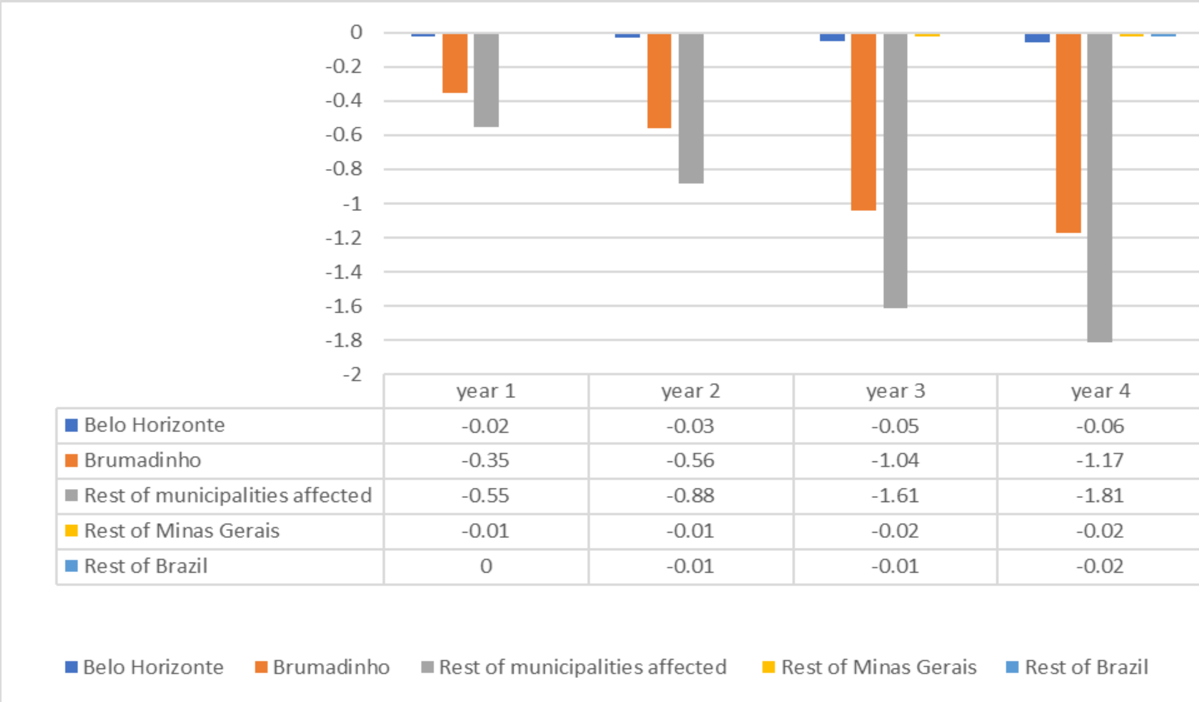
The Brumadinho dam rupture disaster in Minas Gerais (Brazil) has left economic and environmental damages to the local communities and surrounding areas. One aspect under investigation in this paper is the labor productivity changes incurred by economic sectors due to those harmful effects.

According to simulations, changes in labor productivity impact interregional gross domestic product – GDP. A negative GDP in all regions is because of shock applied in all impacted regions sectors. That is because lower productivity increases production cost, which results in higher goods prices. It makes the economy relatively less competitive, including decreasing household consumption and exports.

Higher prices of inputs and lower household consumption in a determined area cause an increase in cost production additionally a drop in demand in other regions. It occurs given by interregional and intersectoral relations expressed in base data. Thus, GDP from Belo Horizonte, the Rest of Minas Gerais, and the Rest of Brazil are negatively affected. Figure 07 shows these results.

This Figure presents the accumulated values, in other words, minimum until maximum impacts over the period. The rest of Municipalities Affected was the most affected area given by a reduction in the GDP starting from -0.55% could reach a total of -1.81%, followed by Brumadinho with values of -0.35% and -1.17%. Belo Horizonte, Rest of Minas Gerais, and Rest of Brazil could have a reduction, respectively, by up to 0.06%, 0,02%, and 0,02%.

Figure 07. Interregional GDP effects (percentual values).



Source: Developed by the authors

Table 2 presents other macroeconomy percentual changes variables. As the price and cost of production have increased, we have two effects. First, the regional economy is less competitive, and importation becomes cheaper, increasing your demand. Second, disposable income reduces due to household consumption decrease. Because of that, importation would increase or decrease depending on which effect predominates. In our simulation, household consumption, as well as disposable income, reduce in all regions. Imports have dropped, except for Belo Horizonte.

All areas have a fall in exports. It is a result of the loss of competitiveness. Employment is positive in Brumadinho and affected areas because of the need for more workers to produce the same quantity, which is has expected by shock aspects. However, these do not occur in other regions because of intersectoral interdependence with affected areas. It is relevant to highlight that not have labor mobility in the simulation.

Table 2. Macroeconomy results (maximum percentual changes over the period)

	Household Consuption	Household disponible income	Employment	Export	Import
Belo Horizonte	-0.14	-0.07	-0.01	-0.04	0.14
Brumadinho	-2.54	-2.43	2.06	-1.04	-0.97
Rest of municipalities affected	-3.29	-3.15	2.84	-2.64	-1.95
Rest of Minas Gerais	-0.03	0.00	-0.03	-0.04	-0.01
Rest of Brazil	-0.02	0.00	-0.03	-0.04	-0.13

Source: Developed by the authors

Table 3 presents sectorial activity. Manufacture_machinery sector was the most impacted in all regions by simulation. In Brumadinho could fall to 3.76% and the Rest of the cities affected decrease up to 2.59%. Other sectors worth mentioning were Transport, Commerce, Others_manufacture, Accommodation, Construction Information, Financial_activities, Scientific_activities, Administrative_activities, Education, and Health. Remember that Transport, Others_manufacture, Accommodation, and Construction are Key sectors from

Brumadinho, besides Manufacture_machinery and Transport are from the Rest of the municipalities affected (see figures 4 and 5). These results are interesting because it shows a fall in labor productivity due to the Brumadinho disaster affecting relevant sectors of the local economy.

As we had mentioned, Mining is Capital intensive, which implies a not expressive result in this simulation. Farming is another sector directly affected by the disaster that had not to be relatively large. These could happen out of tailings dam rupture impacted by other economic factors, especially Land and Capital. The Land is fixed in the short run and aggregated in Capital on Base Data.

Table 3. Activity Level by sector (maximum percentual changes over the period)

Sector	Belo Horizonte	Brumadinho	Rest of municipalities affected	Rest of Minas Gerais	Rest of Brazil
Farming	-0.039	-0.979	-0.834	-0.003	0.000
Mining	-0.076	-1.043	-1.135	-0.005	0.005
Manufacture_food	-0.112	-1.583	-1.667	-0.027	-0.021
Manufacture_machinery	-0.559	-3.754	-2.591	-0.528	-0.479
Others_manufacture	-0.075	-1.721	-1.711	0.002	0.014
SIUP	-0.061	-1.990	-2.125	-0.015	0.005
Construction	-0.032	-1.568	-1.712	-0.004	-0.002
Commerce	-0.032	-2.336	-2.363	-0.002	-0.001
Transport	-0.061	-2.505	-2.527	-0.011	-0.010
Accommodation	-0.068	-2.133	-2.226	-0.005	0.000
Information	-0.058	-2.200	-2.261	-0.002	0.002
Financial_Activities	-0.028	-1.839	-1.840	-0.001	0.001
Real estate_Activities	-0.001	-0.058	-0.059	0.000	0.000
Scientific_Activities	-0.050	-1.935	-2.068	-0.001	0.006
Administrative_Activities	-0.111	-3.693	-3.241	-0.008	0.001
Public_Administration	-0.020	-0.527	-0.468	-0.024	-0.028
Education	-0.095	-2.730	-2.647	-0.043	-0.040
Health	-0.063	-2.072	-2.328	-0.012	-0.007
Arts	0.060	-0.971	-4.124	0.128	-0.013
Other_services	-0.153	-1.766	-1.921	-0.014	-0.001
Domestic services	-0.217	-0.884	-2.101	0.141	0.275

Source: Developed by the authors

Table 4 presents the maximum percentage variations of sectorial exports in the period. Manufacturing industries such as Food, Machinery, and others lost most of their sales abroad. Brumadinho exports only Mining and Other_manufacturing products, which could have decreased to 1.04% and 2.03%, respectively.

Mining and agriculture are the main items on the Brazilian export agenda. Mining could have fallen by 0.720% in Rest of regions affected, 0.03% in Rest of Minas Gerais, and 0.07% in Rest of Brazil. Farming could drop in exports up to 0.64% in Rest of Municipalities affected, 0.03% in Rest of Minas Gerais, and 0.05% in Rest of Brazil. Belo Horizonte presents a different result. Minas Gerais capital can increase by 0.21% in Farming products sales and 0.24% in Mining. In these sectors specifically, the predominant effect was gain in competitiveness.

Table 4. Sectorial Exports (maximum percentual changes over the period)

Sector	Belo Horizonte	Brumadinho	Rest of municipalities affected	Rest of Minas Gerais	Rest of Brazil
Farming	0.210	0.000	-0.641	-0.030	-0.050
Mining	0.247	-1.045	-0.717	-0.026	-0.069
Manufacture_food	-0.062	0.000	-1.948	-0.042	-0.040
Manufacture_machinery	-0.074	0.000	-2.759	0.062	0.062
Others_manufacture	-0.072	-2.030	-2.112	-0.058	-0.064
SIUP	0.234	0.000	0.000	0.026	-0.068
Construction	-0.022	0.000	0.000	-0.041	-0.044
Commerce	-0.003	0.000	0.000	-0.043	-0.046
Transport	-0.045	0.000	0.000	-0.039	-0.037
Accommodation	0.041	0.000	0.000	-0.041	-0.051
Information	0.057	0.000	0.000	-0.042	-0.052
Financial_Activities	0.043	0.000	0.000	-0.042	-0.050
Real estate_Activities	0.000	0.000	0.000	0.000	-0.051
Scientific_Activities	0.093	0.000	0.000	-0.045	-0.066
Administrative_Activities	0.056	0.000	0.000	-0.038	-0.049
Public_Administration	-0.050	0.000	0.000	-0.036	-0.034
Education	-0.040	0.000	0.000	-0.039	-0.039
Health	-0.019	0.000	0.000	-0.039	-0.042
Arts	-0.170	0.000	-1.417	-0.252	-0.028
Other_services	0.134	0.000	0.000	-0.027	-0.046
Domestic services	0.000	0.000	0.000	0.000	0.000

Source: Developed by the authors

To analyze sensitivity of results, we have used the elasticity of production parameter. It applied variations between 10% and 100% in the degree of substitution between capital and labor and analyzed their impacts on employment. The choice of these variables is due to the shock to labor productivity. Table 5 presents the results obtained.

Table 5. Sensitivity Text

Elasticity	**SIGMA1FAC**					
Variation	-	10%	20%	30%	50%	100%
Value	0.5	0.55	0.60	0.65	0.75	1
Region\Variable	**EMPLOY (%)**					
Belo Horizonte	-0.099	-0.11	-0.12	-0.131	-0.165	-0.161
Brumadinho	2.580	1.909	1.775	1.660	1.629	0.775
Rest of municipalities affected	2.839	2.672	2.508	2.339	1.804	1.846
Rest of Minas Gerais	-0.027	-0.032	-0.038	-0.046	-0.091	-0.022
Rest of Brazil	-0.026	-0.032	-0.039	-0.05	-0.134	0.009

Source: Developed by the authors

It is relevant to emphasize that although capital is fixed in the short run, there is possibility of exchange with labor. The idea of the analysis is to assess the direction of the signals as the relationship of factors becomes more elastic. Thus, finding a range for the simulations. If the result does not change, the estimates are less dependent on the applied elasticities and consequently more robust.

The table indicates that the estimations found in this paper are solid since when changing the benchmark elasticity of the model, the values follow the same direction as the original simulations. Furthermore, as the variation increases, the difference in results becomes smaller and smaller. There is only one exchange in the sense of the employment result when the initial elasticity for the rest of Brazil has doubled.

4. CONCLUSIONS

The dam rupture of Brumadinho in Minas Gerais affected 18 municipalities in the state. It generated severe socioeconomic and environmental effects. The study objective is to estimate how pollution from environmental disasters affects the economy, whether driven by soil or water contamination. It increases health problems and reduces the quality of inputs for several economic sectors. Consequently, there are changes in labor productivity, which translate into economic impacts.

With this study, we fill a gap in the literature by providing preliminary evidence of how these impacts from changes in labor productivity propagate to other regions through economic modeling. Simulations used B-Maria model calibrated with a MIP of disaggregate areas affected by the disaster. The main results showed Brumadinho could have an accumulated loss in four years of up to 1.17% in its GDP and other affected municipalities of up to 1.81%. In general, regions had a loss of competitiveness expressed through a fall in exports and level of sectoral activity.

Results also showed economic dependence on extractive sector, especially Brumadinho. Thus, a sector stoppage due to the disaster can aggravate economic and social impacts. In this way, public policies aimed at increasing the safety of mining activities are essential so that new tragedies do not occur again. In the background, it is necessary to discuss ways of diversifying production to reduce dependence on extractive sector.

The work has static and short-term modeling as limitations. There is no accumulation of capital over time, and level of investment does not change. Furthermore, a World Bank report on natural disasters based the shock due to the lack of data and specific work on this subject.

In this sense, future research can perform a dynamic analysis of Brumadinho impact disaster on labor and capital since agriculture and mining are capital-intensive. Finally, it also intended to estimate, through econometric models, the effect of the dam failure on productivity production factories.

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