Gestão & Regionalidade
ISSN: 1808-5792
ISSN: 2176-5308
editoria_gr@online.uscs.edu.br
Universidade Municipal de São Caetano do Sul
Brasil

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Mining and Productive Specialization: Economic Impacts of the Collapse of the Dam of Fundão in Mariana/Brazil
Gestão & Regionalidade, vol. 38, núm. 114, 2022, pp. 183-206
Universidade Municipal de São Caetano do Sul
Sao Caetano do Sul, Brasil

Gestão & Regionalidade

DOI: https//doi.org/10.13037/gr.vol38n114.7318

Received: 27/08/2020 | Accepted: 30/11/2021

Mining and Productive Specialization: Economic Impacts of the Collapse of the Dam of Fundão in Mariana/Brazil

Mineração e Especialização Produtiva: Impactos Econômicos do Rompimento da Barragem do Fundão em Mariana / Brasil

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Abstract

This paper analyzes the economic impacts in the municipality of Mariana from the Fundão Dam rupture occurred at the end of 2015. The central hypothesis is that economic dependence on the mineral extraction sector makes this municipality more vulnerable to adverse shocks affecting this productive sector, compromising its job recovery capacity. In order to calculate the impacts of this disaster, datas on formal employment estimated through the Synthetic Control Method were used. The results showed that, although Mariana and its synthetic version show similar formal employment trajectory in the pre-shock period, Mariana recovered employability in the second year after the dam rupture, unlike the control group. However, this result is not due to the recovery of formal employment based on sustainable economic diversification strategies, but essentially by dependence of the mining activity and the post-disaster remediation actions that has been gradually implemented in order to recover affected areas.
Keywords: Productive Specialization; Collapse of the Dam of Fundão; Synthetic Control Method.

Resumo

Este artigo analisa os impactos econômicos em Mariana a partir da ruptura da barragem de Fundão ocorrida no final de 2015. A hipótese central é que a dependência econômica do setor de extração mineral torne esse município mais vulnerável a choques adversos que afetam esse setor produtivo, comprometendo sua capacidade de recuperação do emprego. Para calcular os impactos desse desastre, foram utilizados dados de emprego formal estimados pelo Método de Controle Sintético. Os resultados mostraram que, embora Mariana e sua versão sintética mostrem trajetória formal similar de emprego no período pré-choque, Mariana recuperou a empregabilidade no segundo ano após o rompimento da barragem, diferentemente do grupo de controle. No entanto, esse resultado não se deve à recuperação do emprego formal baseada em estratégias sustentáveis de diversificação econômica, mas essencialmente pela dependência da atividade de mineração e das ações de reparação pós-desastre que foram gradualmente implementadas para recuperar as áreas afetadas.
Palavras-chave: Especialização Produtiva; Rompimento da Barragem do Fundão; Método de Controle Sintético.

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1 Introduction

A relevant issue that arouses the interest of regional studies refers to the positive or negative socioeconomic impacts that exploitation of mineral products can generate in the various localities. Mining has importance in the composition of the domestic product of many Brazilian cities, but this activity always raises doubts about its role in the development of the territorial spaces in which it is present. For authors such as Lewis (1984), Bunker (1988), the mineral extraction provides possibilities of economic development because it is a productive sector that generates large volumes of financial resources. Also, mining sector can have a positive impact on other sectors, such as tourism. According to Moyle et al. (2020) for example, mining sector can induce through the development of new tourist products and economic rejuvenation, or providing the opportunity to capitalize on investment, infrastructure development and government tax revenues. On the other hand, (Solow (1956), Radetzki (1982), Davis (1995), Stijns (2006) consider that the increase in revenues from the extraction of mineral resources produces a kind of curse because it limits the expansion capacity of other productive sectors, inhibiting the productive diversification of these localities. Collier and Goderis (2008) found that commodity booms have positive short-term effects on output, but adverse long-term effects. These authors highlight that institutionally stronger countries are able to benefit more from the income earned from natural resources. Linking tourism and mining activity, Moyle et al (2020) point out that is arising within this literature the prevalent 'Dutch Disease' theory, which postulates that mining tends to crowd out tourism by inducing a rise in the real exchange rate. Therefore, there is no consensus on this debate.

According to Enriquez (2006), as the mineral deposits are spatially concentrated, the mining companies are installed close to them, making the municipalities that have mineral extraction activities acquire particularities regarding the consolidation of socioeconomic aspects in the surroundings of such activity. The author questions whether the massive presence of mineral extraction in these municipalities assumes characteristics of curse (due to economic backwardness, social impoverishment and depletion of natural resources) or a blessing (for allowing sustained and sustainable development for these places). The same study discusses the role of resources from mineral exploration, mainly the Financial Compensation for the Exploration of Mineral Resources (CFEM – Compensação Financeira pela Exploração de Recursos Minerais) important in the collection of Brazilian mining cities. The management for these resources depends on favorable institutional conditions so that they do not incur in exclusive fiscal dependence of the mining.

This article analyse the case of Mariana (Brazil), a municipality that gained worldwide notoriety in November 2015, due to the breach of the Fundão Dam, owned by Samarco Company (controlled by BHP Billiton and by Vale S.A). The same region of the state of Minas Gerais was highlighted for its geographic proximity to the city of Brumadinho [4], where another dam broke again in January 2019. Both tailings dams retain similar characteristics by using an upstream structure in a region above and near population areas. According to Machado and Figueroa (2020, p.457), the Fundão dam disaster was the biggest environmental disaster in mining in the world. This tragedy was responsible by the death of people and

[4] The disruption of Dam 1 at Vale's Córrego do Feijão Mine in the municipality of Brumadinho in Minas Gerais on January 25, 2019 is considered one of the largest industrial, humanitarian and environmental disasters in the world (VALE., 2019).With the collapse of the dam 11.7 million cubic meters were launched along the valley of Córrego do Feijão until reaching the Paraopeba River. With the tragedy, 252 people died and 18 are missing. For more information, see (VALE, 2019).

contaminating the banks of the Rio Doce, reaching the Atlantic Ocean. Consequently, thousands of people were directly or indirectly affected in various dimensions: economic, social, environmental and human (SILVA 2018)[5]. It is known the crucial role that mining plays for the State of Minas Gerais (and Brazil), so, an update of works that discuss how bless and curses related to this activity become very relevant. Especially considering that State of Minas Gerais (MG) had its fiscal situation worsened from 2015, aggravated by the Brazilian recession. The MG crisis was intensified by the decline in mining activity, as a result of the commodity market and the collapse of the dams, and all its economic consequences, such as a reduction in employment, production and tax collection.

In the line of works such as Silva (2018); the main contribution of this article is to analyze the short-term impact on employment, from the backdrop of a critique on productive specialization that makes regions less resilient to contractionary shocks. In this way, the main hypothesis of this work is that Mariana is an example of the blessing and curses provided by mineral extraction, tending to the second case.

This city failed to induce its economic trajectory to reconversion guided by greater productive diversification as well as the capacity to endogenize the income generated from economic activities and the development of new mining capacities technical learning. According to Silva, Silva e Andrade (2017), in the 2000s, Mariana became known in the national economic scenario as one of the largest municipalities producing iron ore. Consequently, the revenues generated by the tax collected from the production and commercialization of iron provided a period of economic boom from 2009, making the municipality one of the highest incomes per capita of the country. However, Mariana presents medium results when it comes to social indicators, suggesting that the income distribution in the municipality is still very concentrated and little reverted in social improvements. In this sense, another hypothesis is that faced with an adverse shock, production specialization hinders the recovery of employment in more adverse scenarios, such as a recession, volatility in commodity prices and exchange rates, etc.

The period of economic growth of the municipality ends from 2013, when the profitability of iron ore production is hit by the fall in the prices of the product and reduction of Chinese demand. As a result, the volume of exports and the payment of CFEM and the Tax on Operations related to the Circulation of Goods (ICMS – Imposto sobre a Circulação de Mercadorias e Serviços) were reduced. In 2015, in addition to the national economic crisis showing signs that it would aggravate Mariana's economic situation, the disruption of the Fundão Dam further accentuated the economic recession in the municipality.

In order to analyze the impacts of the shock of the Dam of Fundão in the municipality from 2016, we used the Synthetic Control Method (SCM). For this purpose, a comparison was made between Mariana and a group of municipalities with the same mining economic profile, but were not affected by the collapse of the Dam of Fundão (Synthetic Mariana), suggesting that Mariana has recovered from the labor market, unlike its synthetic version in the post-shock period. However, this result is not based on economic diversification policies, but on the reparation actions carried out by a mix de public and private investments implemented in the affected municipalities. Additionally, due to the work rotation policies introduced by Samarco to its permanently employees, who initially remained in the company with a reduced workload.

[5] For more information on the structural and technical characteristics of these dams and on both the disasters, see Machado and Figueroa (2020, p. 457-542)

Finally, the recent socioeconomic situation in Mariana will be made in order to show the condition of the productive specialization and dependence of the mineral extractive industry, which, dichotomically, has sustained the economic base of the municipality (the curse and blessing problem). On the other hand, following Silva (2018), Silva, Silva e Andrade (2017), the lack of more diversified productive activities that allow greater endogenous income in the area ends up causing an obstacle to resilience and economic recovery when the mineral extractive sector is reached. The analysis of the socioeconomic data of this city and the results of the empirical studies carried out in our study showed that all the mining municipalities of the sample continue strongly dependent on the mineral extraction activity. Specifically, in the case of Mariana, there was a substitution of jobs related to mining, to those related to the repair of damage from the dam rupture. This finding reveals that this municipality has not created its own competences in order to follow a development path beyond that dependent on the sector.

2 Socioeconomic Characterization of Mariana and the Obstacles generates by Productive Specialization

In the last decade, Mariana became one of the Brazilian municipalities that increased its tax collection revenue through the CFEM (ANM, 2019). According to Silva, Silva e Andrade (2017) the increased financial capacity of this municipality, boosted by mining would enable the local public government to increase its margin of action regarding public investments and expenditures in order to improve the socioeconomic conditions of its population. However, according to the study, the city after the disaster of the Dam of Fundão remains with problems regarding the distribution of income, land concentration and real estate speculation; others problems related to the quality of education of its population, and difficulties in establishing consistent plans for urban expansion and infrastructure.

Despite being a city with high income per capita and financial potential, the indicators and analyzes undertaken allow us to verify that Mariana still suffers from several types of structural and conjunctural fragilities. One of these is its economic vulnerability to external shocks, such as the drop-in commodity prices that began in 2013 and, more recently, the collapse of the mining tailings dam of Fundão, belonging to the mining company Samarco (SILVA, 2018).

Moving on to a synthesis of the main social indicators, according to the last Demographic Census conducted by the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística), the resident population in Mariana was 54,219 inhabitants (in 2010), with 87.87% concentrated in the urban area and 50.97% women. In 2017, the estimated population was 59,857.

Mariana Municipal Human Development Index (MHDI) is high compared to the Brazilian average (0.742 in 2010), being leveraged mainly by the Longevity dimension (0.874), followed by income (0.705) and education (0.664). According to the Atlas of Human Development in Brazil (ATLAS, 2018), based on the last Demographic Census (1991, 2000, 2010), Mariana's average per capita income grew 97.14% in the last two decades. The average annual growth rate was 3.00% between 1991 and 2000 and 4.21% between 2000 and 2010. The proportion of poor and extremely poor people measured by the Gini Index decreased, placing the municipality on a medium scale in terms of wealth concentration.

The improvement in income indicators in this municipality may be associated with positive mining activity cycles but also with advances in the Brazilian economic conditions since 2004 to 2011. According to Dedecca, Trovão e Souza (2014), since the 2000s, the minimum wage appreciation policy and income transfer added the raise of

formal employment have contributed to increase the income of the families belonging to the lower extract of the income distribution. In addition, the recovery of the Brazilian economy had increased tax collection and state spending capacity allowed governments (federal, state and municipal) to get financing for productive, infrastructure and social investments. The authors point out that the distributive question had relevance in the growth strategy, having led to the reduction of current income inequality and the reduction of monetary poverty.

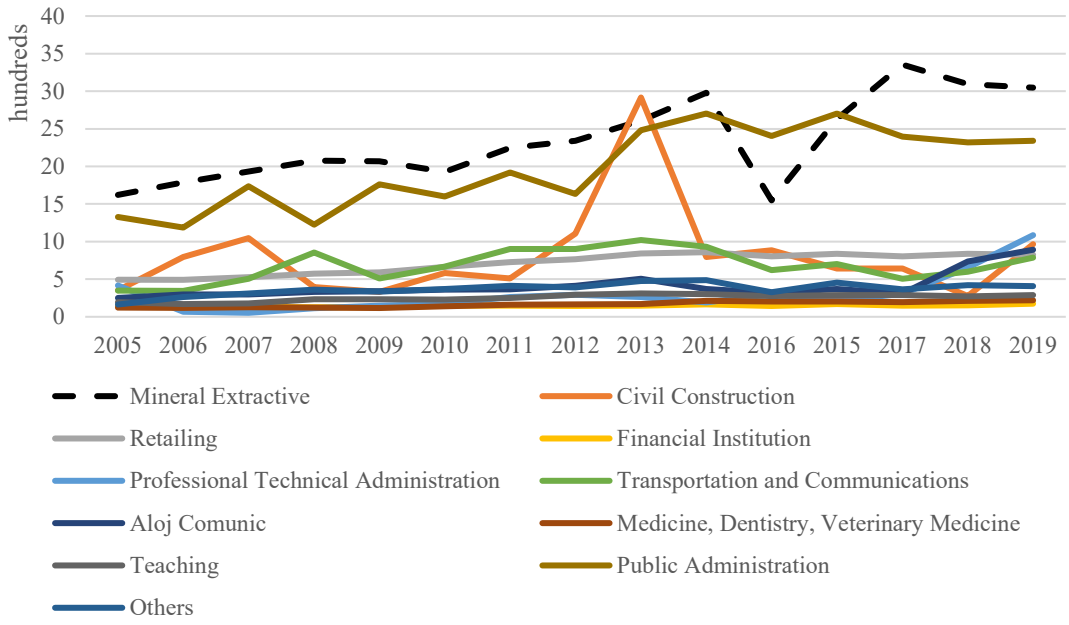
Concerning to the labor market, the working-age population is predominantly engaged in the trade and services sector. For this municipality, these sectors are characterized by the low degree of diversification and complexity, reflecting the constraints of a development model that is very much in line with the demand for mining activity, which attend to the initial stages of extraction for the most part less complex.

According to Atlas of Human Development in Brazil (ATLAS, 2018) referring to the year 2010 show the total work occupation of the population of 18 years of age or more was 25,038. At the same time, the total economically active population that was unemployed was 3,674 in the same year. Analyzing recent data, it is possible to capture the first impacts of the collapse of the dam in the municipality. On the report of Mariana Employment Information Service from January to December 2016, 5,010 workers lost their jobs due to the shutdown of Samarco and the unemployment rate until April 2017 was 24%. These data suggest that employability in the municipality was related to the economic boom of the mineral extraction industry associated with the period of production expansion of Vale company and the implementation of the pellet projects of Samarco.

In the context post-rupture of Fundão dam's, after 2016, the Figure 01 shows an increase in the average remuneration for the mining extractivist sector, which may be related to the maintenance of the salaries of Samarco employees and outsourced companies, transferred to a layoff regime (temporary suspension of employment contract with maintenance of compensatory payment) and agreements Voluntary Dismissal Programs (PDV – Programas de Demissão Voluntária) signed between the company and the workers (SAMARCO, 2017). Aditionally, considering the data from the Annual Report on Social Information (RAIS – Relação Anual de Informações Sociais), the mineral extractive sector has the highest average remuneration of the municipality following by the construction, which is largely dependent on mining activity, decreasing from 2013.

Regarding the commerce and services sectors, according to Silva, Silva e Andrade (2017), it was observed that in the year after the dam collapse, there were 2,023 active companies in the municipality, in which 74 out of these were incorporated in the year in question. For 2017, 79 companies were extinguished, a result that refers to the strong relation between the inter-sectorial dependence of the mining activity on the part of the trade, the services and activities that, when they are not complementary to the mining activity, generate few chaining effects to stimulate the generation of knowledge, as well as productive and income diversification, which would improve the condition of economic resilience of the municipality.

Figure 1 - Average annual remuneration in minimum wages (2006-2019* in US$)

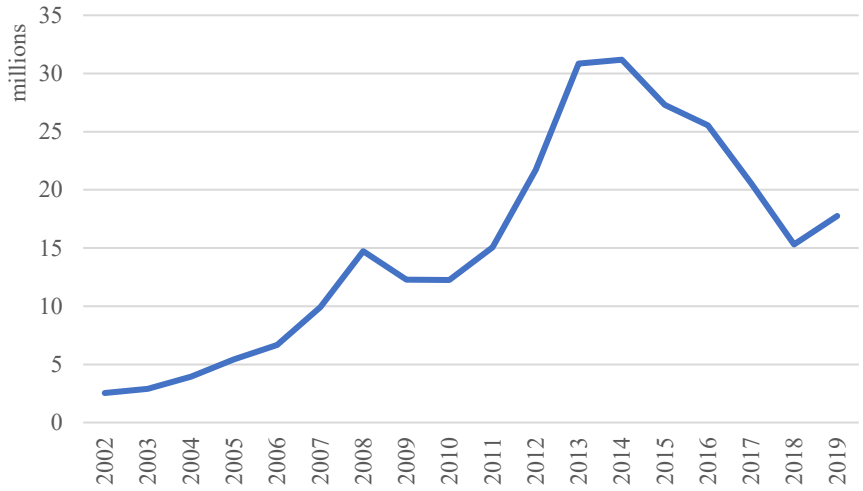


Note: When accumulated, it represents the salary mass.* Quotation date used for convertion de Real to Dollar USA was 12/29/2019 (Brazilian Central Bank, 2019). Source: Proprietary elaboration based on data from RAIS database (RAIS., 2021).

In order to finish Mariana's socioeconomic scenario, we analyze the main sources of income. One of the most important sources of municipal revenue refers to the ICMS. Accompanying the growth process of the operations of the mining companies present in the municipality, the ICMS collection also increased between 2011 and 2014 (Figure 2), starting a period of decrease in the collection of this tax from 2015, and resumes growth only in 2018, when repair work begins in the region. This performance suggests that the ICMS transferred to the municipality is mostly composed of transfers related to the 'Kandir Law', due to the loss of pass-through of amounts as compensation for the losses resulting from the ICMS exemption[6].

[6] For more information on the Kandir Law, see Federal Senate of Brazil (2020).

Figure 2 - Total ICMS transfer from the state of Minas Gerais to the municipality of Mariana (2002 – 2019 in U$)

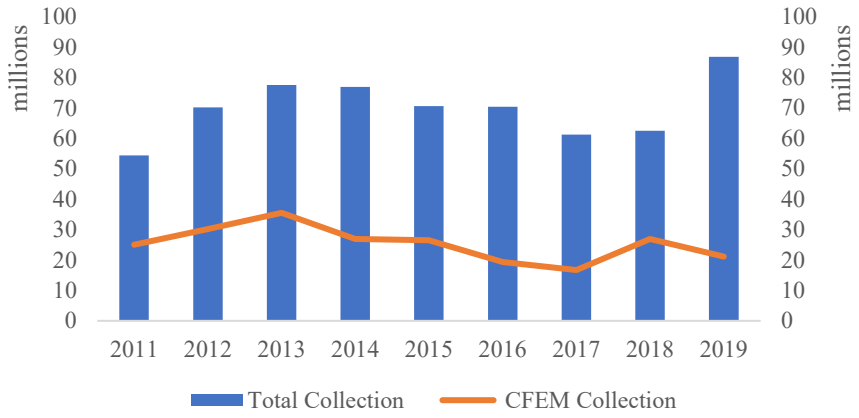


Note: Quotation date used for convertion de Real to Dollar USA was 12/29/2019 (Brazilian Central Bank, 2021).
Source: Proprietary elaboration based on data from (FJP, 2021).

The most important tax revenue for Mariana is the CFEM focuses on net sales (in the case of the sale of the raw and beneficiated ore), or the intermediate cost of production - when the mineral product is consumed or transformed into an industrial process. By the law, the CFEM must be applied in projects that revert to benefits of the local community, whether in improving infrastructure, environmental quality, health or education. Mariana, in the last decade stood out among the Brazilian municipalities with the largest CFEM resources raising, especially after the Chinese boom and exchange rate devaluation, which made iron ore a competitive product in the world market. However, due to dam disruption and the fall in iron ore prices, the fall of the compensation.

The Figure 3 shows the evolution of the total collection of the municipality based on data extracted from the Mariana Transparency Portal (2020), available from 2011, and the total CFEM collected by the municipality. The destination given to revenues originating from the exploration of non-renewable mineral resources, such as iron ore, is a controversial factor and raises the hypothesis that municipalities with high collection volumes are economically dependent on the sector with greater fiscal contribution, weakening the municipal budget. Increasing the volume of these collections can be taken as temporary, as the extraction of mineral resources is a finite activity, can hinder productive diversification and leave the local economy susceptible to the instability of the international commodity market (SIMONATO; MAGALHÃES; DOMINGUES, 2017).

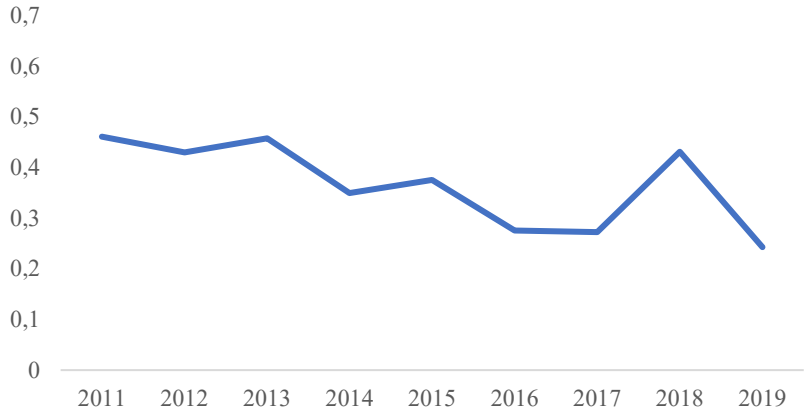
Figure 3 - Evolution of Total Tax Collection and CFEM's Collection on the Iron Ore Operation in the Municipality of Mariana (2011 – 2019 in US$)



Note: Quotation date used for convertion de Real to Dollar USA was 12/29/2019 (Brazilian Central Bank, 2021).
Source: Proprietary elaboration based on data from the ANM (2021) and Transparency Portal of the Municipality of Mariana (2021).

Figure 4 shows the relationship between CFEM collection and total tax collection in Mariana between 2011 and 2019. The curve shows the downward trend in collection led by the decrease in this contribution. It is noticeable from the data presented in this section that Mariana began to lose revenue from the moment the mineral extraction sector faced internal and external conjectural problems, which triggered reductions in the sales value of the product or even a reduction in production. These reductions directly affected ICMS and CFEM transfers to the municipality, exposing their financial fragility and dependence on extractive activity.

Figure 4 – Ratio between the Collection of CFEM and the Total Tax Collection of the Municipality of Mariana between 2011 and 2019



Source: Proprietary elaboration based on data from the ANM (2021) and Transparency Portal of the Municipality of Mariana (2021).

The socioeconomic effects generated by shocks that affect key sectors of a given economy may lead to setbacks with respect to the economic losses of resources generated at

times of regional growth, driven by productive specialization in a sector. Then, it will be analyzed by the specialization of the productive structure of Mariana, in order to understand how its economy reacted to the shock in the short term.

3 Materials and Methods

3.1 – Analysing the Mariana' Productive Structure: the Locational Quotient

In order to measure how the Mariana' economy is specialized in specific activity, we set out to identify productive agglomerations based on the Locational Quotient (*LQ*). Although reservations should be made to this technique[7], it is widely used in the regional economy literature, in order to compare sectorial-spatial structures (BRITO; DA MOTTA, 2002; CROCCO et al., 2006; SIMÕES, 2005). The *LQ* is the ratio between two economic structures, in which the numerator represents a proxy of the economy of the analyzed region and in the denominator, a proxy of the reference economy (CROCCO et al., 2006):

$$LQ = \frac{\frac{E_j^i}{E_j}}{\frac{E_{BR}^i}{E_{BR}}} \quad (1)$$

According to Crocco et al. (2006), it is possible to consider that there is specialization of activity *i* in region *j*, if its *LQ* is greater than one. A second criterion for assessing the region-activity pair is in terms of its national relevance. For this purpose, the relative participation of the region-activity pair in the national employment must be at least 1% of the national employment of that sector. Agglomerations with *LQ > 1* and relative participation greater than 1% should then be controlled by the density criterion, in which only clusters will be considered those agglomerations that present at least ten establishments in the respective sector and more than ten in associated activities.

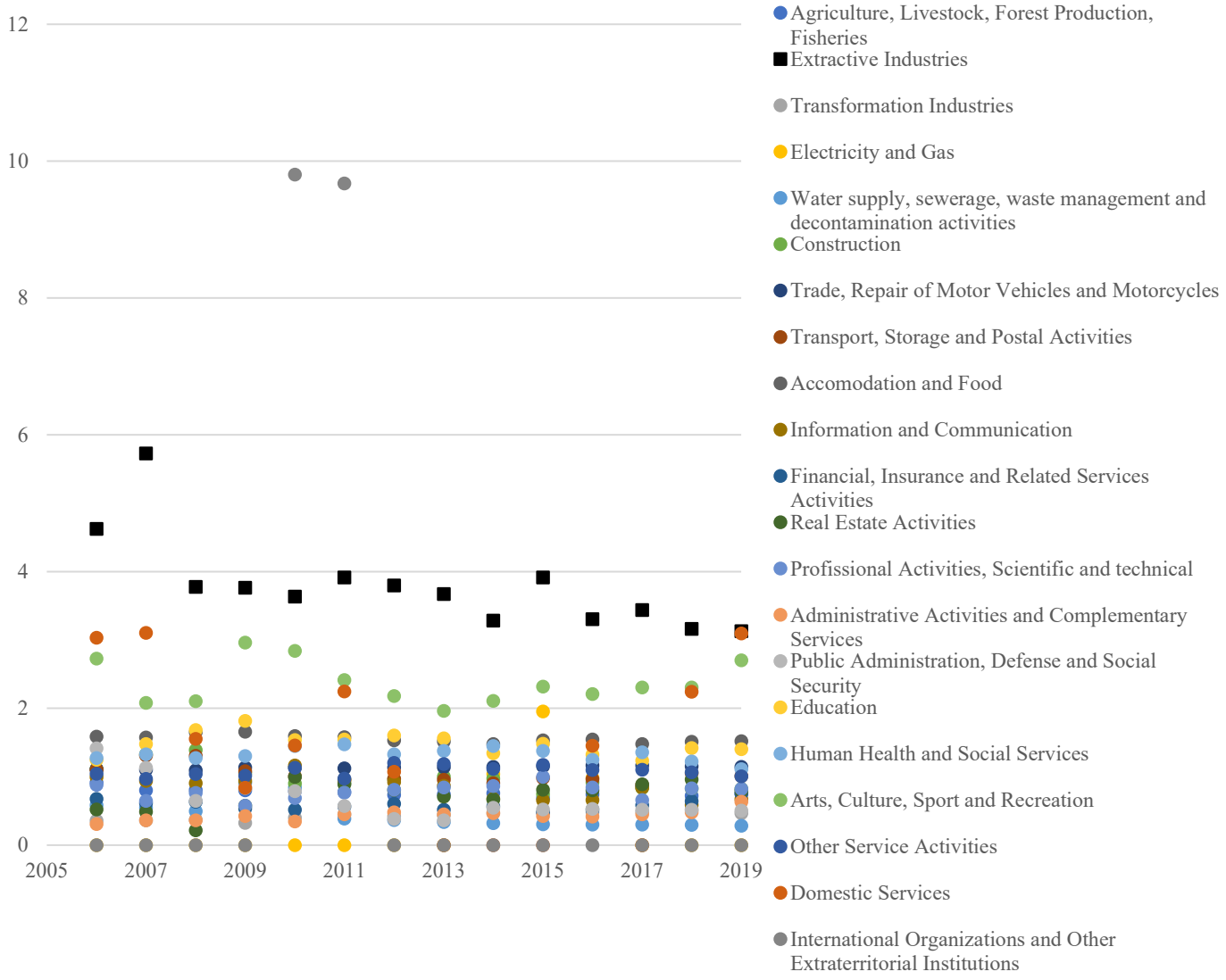
For the calculation of the sectorial *LQ* of the municipality of Mariana, data from establishments provided by the RAIS, stratified by the National Classification of Economic Activities (CNAE – Classificação Nacional de Atividades Econômicas) version 2.0, were categorized by sections of Mariana and Brazil, in the period from 2006 to 2019. The results are available in Figure 5.

From this result, the mineral extraction sector presented quotients above 3 in all analyzed years, reaching the highest value (5.73) in 2007. The industry had 13 establishments in 2007, reducing to 9 on the last year. Given that the average of establishments between 2006 and 2017 is 9.83, it is considered in this paper that the

[7] Following Crocco et al. (2006), the direct use of this indicator as an identifier of productive arrangements can cause generic indications about a result. A LQ higher than unit (specialization) does not guarantee concentration, but only productive differentiation. Given the enormous Brazilian regional inequality, it is expected that the amount of localities with LQ > 1 is very high, not necessarily meaning the existence of any type of local productive arrangement, for example. Moreover, for small territorial scales - with little diversified production structure - LQ overestimates any internal differentiation. In turn, with larger territorial scales (metropolitan, for example), intense diversification underestimates the real importance of the sectors given the small value of LQ, even if they have a relevant percentage weight in the national context.

density control of this industry can be applied in this case. The data showed that the activities of construction, trade, repair of motor vehicles and motorcycles, housing and food, transportation, storage (which have a strong direct and indirect relationship with mining activity, in particular, with outsourcing companies that serve the mining companies) presented a high degree of specialization, as expected. The public administration sector, as mentioned in the first part of this work, is very representative for Mariana, being reinforced by the municipal electoral cycles and generates significant effects in other economic sectors, especially trade, service and construction.

Figure 5 - Sectorial Productive Specialization of the Municipality of Mariana (2006 to 2019)



3.2 – Measurement of short-term shock impacts by the Synthetic Control Method

This section will present the methodological part of the paper and its main contributions. The first one is, there are a few studies to analyze the short-term economic impact of shocks in the case of the extractive mining sector in Brazil. The second one, this paper updates the analysis on the effects of the dam failure shock in Mariana by considering data up to the year 2019, arising the distance from this shock. The few papers already published on this issue, using Synthetic Control Method (SCM) models cover the data until 2017 (i.e Silva, 2018).

According to Abadie, Diamond e Hainmueller (2010), the advantage of the SCM over traditional regression methods is transparency and protection against extrapolation. Synthetic Control is a weighted average of the available control units, which makes evident the relative contribution (weight) of each control unit to the counterfactual of interest. That is, the similarities between the treated unit (event, intervention or shock) and the synthetic control in terms of pre-intervention outcomes and the predictors of post-intervention results, become close given the representativeness of each unaffected unit within the control group. The weights can be restricted to be positive and must add one.

This model suppose the observation of the $J + 1$ units and only the first unit (region) is exposed to the intervention (treatment) of interest, so that the remaining that J units are potential controls (Abadie et al., 2010). Suppose also that the first unit is constantly exposed to the intervention of interest after some initial intervention period. So is be the result that would be observed for region i at time t in the absence of intervention, for the units $i = 1, ..., J + 1$, and time periods $t = 1, ..., T$. Let T_0 the number of pre intervention periods, with $1 < T_0 < T$.

Then, is the result that would be observed for unit i at time t if unit i is exposed to the intervention in periods $T_0 + 1$ to T (ABADIE; DIAMOND; HAINMUELLER, 2010).

Assuming that the intervention has no effect on the result before the implementation period, therefore, for $t \in \{1, ..., T_0\}$ and all $i \in \{1, ..., N\}$, we have $Y^I_{it} = Y^N_{it}$. For Abadie et al. Abadie, Diamond and Hainmueller (2010), interventions may have an impact before their implementation, so, T0 is the first period in which the result may react to the intervention. This means that, for the authors, the results of the untreated units are not identified by the intervention implemented in the treated unit.

The effect of the intervention for unit i at time t, we have:

$$\alpha_{it} = Y^I_{it} - Y^N_{it} \quad (2)$$

Let D_{it} a dummy that has a value of 1 if unit i is exposed to intervention at time t and 0 otherwise:

$$Y_{it} = Y^N_{it} + \alpha_{it} D_{it} \quad (3)$$

When only the first unit (unit 1) is exposed to the intervention and only after the period T_0 (with $1 \leq T_0 < T$), we have that:

$$D_{it} = \begin{cases} 1, if\ i = 1\ and\ t > T_0 \\ 0, otherwise \end{cases}$$

For $t > T_0$:

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N \quad (4)$$

As Y_{1t}^I it is observed, to estimate α_{1t}, it is only necessary to estimate Y_{1t}^N. For this purpose, suppose that Y_{1t}^N it is given by a factor model:

$$Y_{it}^N = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \quad (5)$$

where δ_t is an unknown common factor with constant factor load in units, Z_i is a vector (*r x 1*) of observed variables (not identified by the intervention), θ_t is a vector (*1 x r*) of unknown parameters, λ_t is a vector (*1 x F*) of unobserved common factors, μ_i is a vector (*F x 1*) of loads of unknown factors and the error terms ε_{it} are transient shocks not observed at the unit level with zero significance (ABADIE; DIAMOND; HAINMUELLER, 2010).

Abadie and Gardeazabal (2003) suggest a test that makes a statistical inference on the effect of intervention on the economy can be performed by observing the relationship between the curves of the dependent variables obtained in the result (synthetic unit and the treated unit) and the intensity of the intervention in the unit of interest during the sampling period. For this, they estimate a "placebo test", applying the synthetic control method in order to calculate the difference between the unit of interest and another unaffected region.

The objective is to examine whether the estimated effect of the actual intervention is greater or less than the distribution of estimated effects for units not exposed to the intervention. This is an informative inference if, under the assumption of no intervention effect, the estimated effect of the intervention is not expected to be abnormal in relation to the distribution of placebo effects. For cases where the number of comparison units available is small, the longitudinal dimension of the data may be used to calculate the placebo studies, in which the dates will be randomly defined.

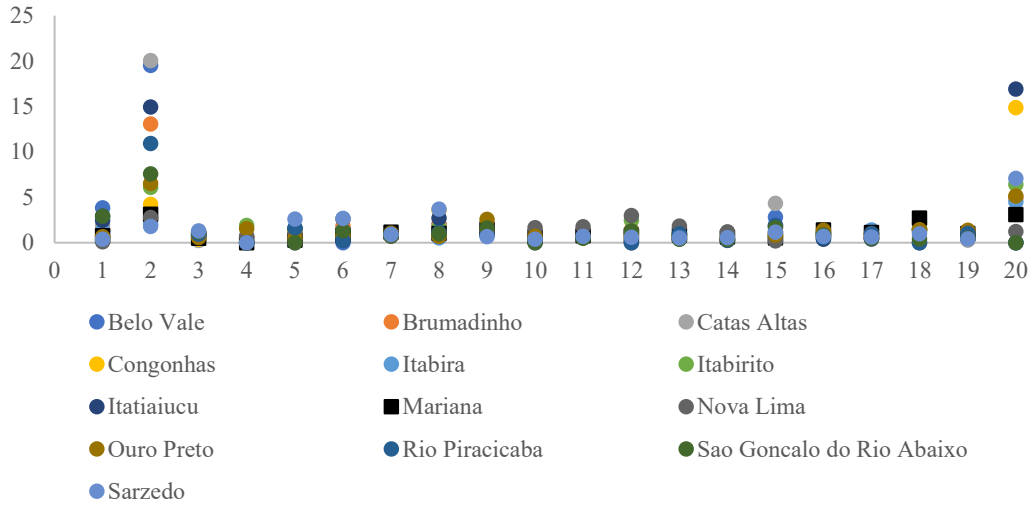
4 - Results

In the previous sections, the high degree of productive specialization of Mariana in relation to the mineral extraction activity was presented. Following the discussion, the objective of this part is to compare the evolution of employment in Mariana its synthetic version, and to observe the impact of the Fundão Dam rupture about the municipal labor market.

For the construction of the “Synthetic Mariana” were selected the 13 municipalities of Minas Gerais with the

highest collection of CFEM in 2019[8], in addition to the municipality of interest, Mariana. The choice of these municipalities is mainly due to their participation in the iron ore commodity market, in which the increase in CFEM's collection is linked to the increase in operations in these locations, indicating that these municipalities also have high specialization of mining activity. For this finding, the extractive activity LQ was calculated from RAIS database, filtered by CNAE 2.0, iron ore extraction section of the selected municipalities, and the result is presented in Figure 6.

Figure 6 – Degree of productive specialization of the mining municipalities with the highest CFEM revenues in the iron ore extraction sector in Minas Gerais (2019)



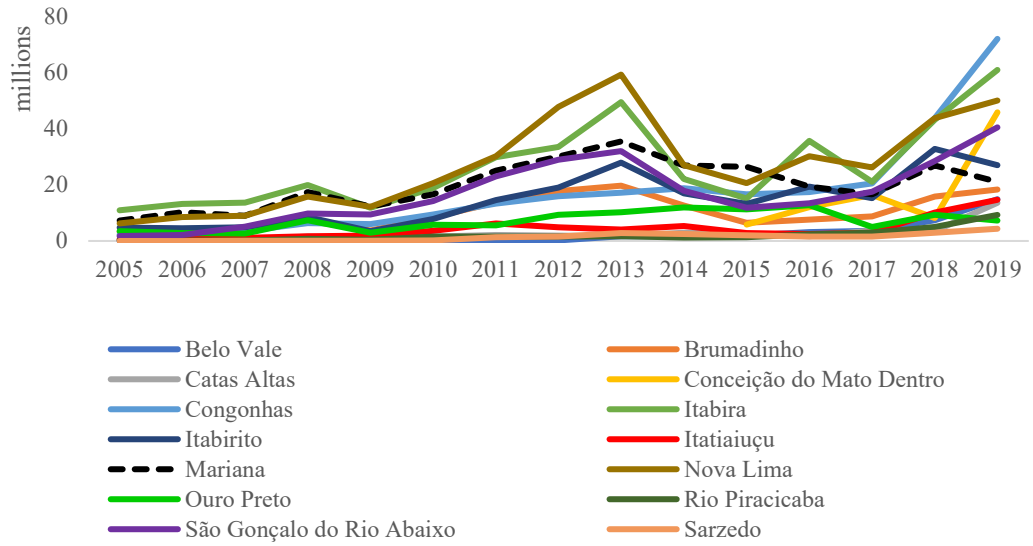
*No eixo horizontal: 1 - Agricultura, Pecuária, Produção Florestal, Pesca e Aquicultura; 2-Indústrias Extrativas; 3- Indústrias de Transformação; 4- Eletricidade e Gás; 5- Água, Esgoto, Atividades de Gestão de Resíduos e Descontaminação; 6 - Construção; 7 - Comércio, Reparação de Veículos Automotores e Motocicletas; 8 - Transporte, Armazenagem e Correio; 9 - Alojamento e Alimentação; 10 - Informação e Comunicação; 11 - Atividades Financeiras, de Seguros e Serviços Relacionados; 12-Atividades Imobiliárias; 13 - Atividades Profissionais, Científicas e Técnicas;14 - Atividades Administrativas e Serviços Complementares;15 - Administração Pública, Defesa e Seguridade Social; 16 – Educação; 17 - Saúde Humana e Serviços Sociais;18 - Artes, Cultura, Esporte e Recreação;19 - Outras Atividades de Serviços; 20 - Serviços Domésticos.
Source: Proprietary elaboration based on RAIS database.

By the Figure 7 it is possible to perceive that the trend of the collection of the CFEM for iron ore mining between the municipalities, in some cases, resembles the trend of Mariana. These municipalities also showed an increase in the participation of

[8] The municipalities Alvorada de Minas and Conceição do Mato Dentro were excluded from the sample for not having data for all the years of the selected series.

the mining sector in the local economy, raising the hypothesis that they also present an economic dependence on the mining companies, being susceptible to the expansionist and contractionary effects of the shocks that affect the sector.

Figure 7 – Tax Collection of CFEM in the selected municipalities (2005 – 2019 in US$)



Note: Quotation date used for convertion de Real to Dollar USA was 12/29/2019 (Brazilian Central Bank, 2019).

Source: Proprietary elaboration based on data from the ANM (2021).

Due to the unavailability of Municipal GDP data for Minas Gerais referring to 2019, the analysis was made based on the information of the formal employment data available in the RAIS database, from the Employment Links Totals of Mariana and of the municipalities of the synthetic version for the period from 2005 to 2019. During these years, the iron ore extraction industry underwent different shocks that directly influenced the sector and the municipalities in which this activity is present.

Another variable considered in the model is the value of the CFEM, deflated for the 2004 base year, will be used as control variable for the models that will be estimated. Also, the 13 municipalities of Minas Gerais with the largest CFEM collection in 2019 were selected [9], in

[9] Conceição do Mato Dentro was removed from the sample because the employment growth was observed in the selected period, mainly in the civil construction and mining sectors, is related to the construction works and the beginning of Anglo American operations starting in 2012. Thus, this municipality does not present CFEM data for the entire selected series.

addition to the municipality of interest, Mariana.

CFEM and average remuneration are used as predictors in the estimated model in order to capture the effects of mineral extraction revenues on the employability of Mariana. In addition, special predictors are used to capture the effect of employment in other sectors and the development of the municipality and its synthetic version. All variables used in the model are described in Table 1.

Table 1 – Variables Used in the Synthetic Control Estimation

Variable	Period	Source
Total Employment Linkages	2005-2019	RAIS
CFEM	2005-2019	ANM
Average Remuneration (minimum wage)	2005-2019	RAIS
% employed in the agricultural sector, % employed in the mining sector, % employment in the transformation industry sector, % employment in the services and utilities sector, % employment in the construction sector, % employment in the commercial sector, % employment in the service sector, % poverty, per capita income, Human Development Index–MHDI, total population	2010	Atlas of Human Development

Source: Proprietary elaboration.

Table 2 presents the adjustment and the weights of the predictors in the pre-shock period (2005 to 2014). It is possible to verify that the predictors are well adjusted since the values of the averages of the "Real Mariana" and the "Synthetic Mariana" are very approximates. This may indicate a strong relationship between its employability and the mineral extraction activity, since the occupation in the sector had greater weight among the predictors (which shows the productive specialization of the municipality in mining).

Table 2 – Predictor Fit and Weight – Synthetic Control Model (2005 - 2019)

	Mariana	Synthetic Mariana	Sample Average	Predictors weight (V)
Log. CFEM	16.8	16.2	15.2	0.5%
Average Remuneration	8098.6	8201.2	9135.8	57.5%
Employment linkages (2010-2014)	13257.4	13259.5	12291.4	10.8%
% employed in the agricultural sector	6.9	5.4	11.6	6.7%
% employed in the mining sector	14.6	13.2	10.1	1.9%

% employed in the transformation industry	4.9	9.4	7.3	0%
% employed in the construction sector	11.9	11.0	10.3	0.5%
% employed in the commerce sector	13.5	13.4	11.2	18.5%
% employed in the service sector	42.8	40.8	42.4	2.2%
% poverty	11.7	6.5	8.2	0%
per capita Income	162.7	183.3	185.9	0.5%
MHDI	0.7	0.7	0.7	0.2%
Population	54219.0	40700.7	38421.1	0.2%

Source: Proprietary elaboration.

The weights of the municipalities that compound the Synthetic Mariana, highlighting that employment is best reproduced from the combination of the municipalities of Itabirito (which had the highest weight in the control group, 57.9%); followed by Congonhas (20.0%), São Gonçalo do Rio Abaixo (16.4%) and other municipalities (5.7%). In terms of the control group, all other municipalities added together represents weigh less than 1%.

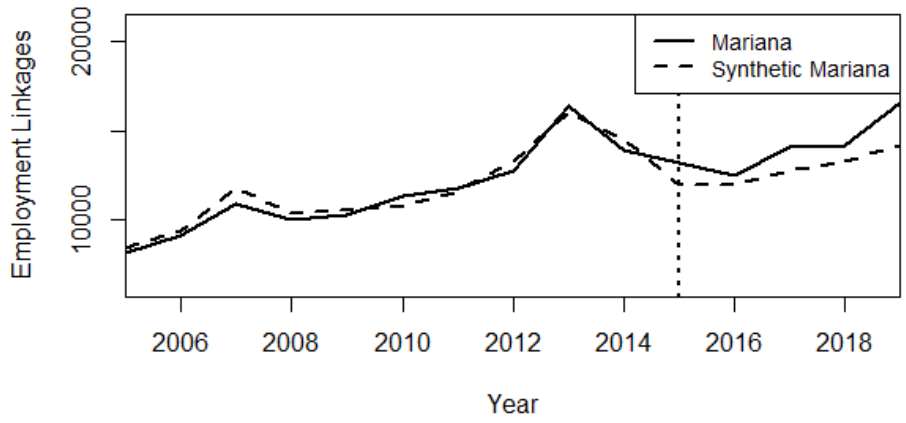
The mean squared discrepancies between the balance of employment movements in Mariana and their synthetic version in the pre-shock period (2005 to 2014) is expressed by the Mean Squared Prediction Error (MSPE). The smaller the square error of prediction, the better the adjustment between the Mariana and the Synthetic Mariana. In this estimate, the MSPE was equal to 212,019.2, a high value for standard error. This can be justified by the fact that the post-shock period is relatively short [10] . The municipality of Mariana still suffers the socioeconomic effects initiated by the fall in iron ore prices, due to the national economic crisis and intensified by the collapse of the Fundão collapse.

Still, by the Table 4 it is possible to verify that the predictors offer a good fit. The values of the averages in Mariana and Synthetic Mariana are close, except for the predictors percentage of employees in the transformation industry, poverty and total population. As expected, the mining activity variables presented a good fit, reinforcing that this characteristic is determinant for the sample choice. This suggests that the high value of the MSPE may be related to the lack of a longer observation period after the shock, and not to the inefficiency of the municipalities selected to form the synthetic unit.

Figure 8 shows the total of employment linkages in Mariana compared to Synthetic Mariana during the period 2005 to 2019. The employment trajectory of Mariana resembles the Synthetic Mariana trajectory during the period prior to the dam break, strongly diverging from 2015. The period 2012-2014 stands out for its peak employability in Mariana, the hypothesis for this would be associated to the internal shock effect of Samarco's Fourth Pelletizing

Project (P4P – Projeto de Quarta Pelotização)[11] expansion works.

Figure 8 – Trajectory of the variable 'Total employment linkages' for Mariana and the Synthetic Version (2005-2019)



Source: Proprietary elaboration calculated using R Studio software.

Moreover, the municipality had already been through the consequences of the unfavorable macroeconomic context, and this reflected on the local economy. According to the highlighted report, based on the General Register of Employed and Unemployed (CAGED – Cadastro Geral de Empregados e Desempregados), from January to December 2014, 5,377 were hired against 7,755 suspended contracts. Considering all sectors, such as services and commerce, the balance of formal jobs remained in deficit. Another important point to be noted is that since 2014 significant cuts in public investment were verified in the housing program, such as 'Minha Casa, Minha Vida'(Deddeca et al, 2014), which added to the economic crisis and the lack of resources provides by the public and private sector, also impacted the construction sector, one of the main contributors to the supply of employment in this municipality.

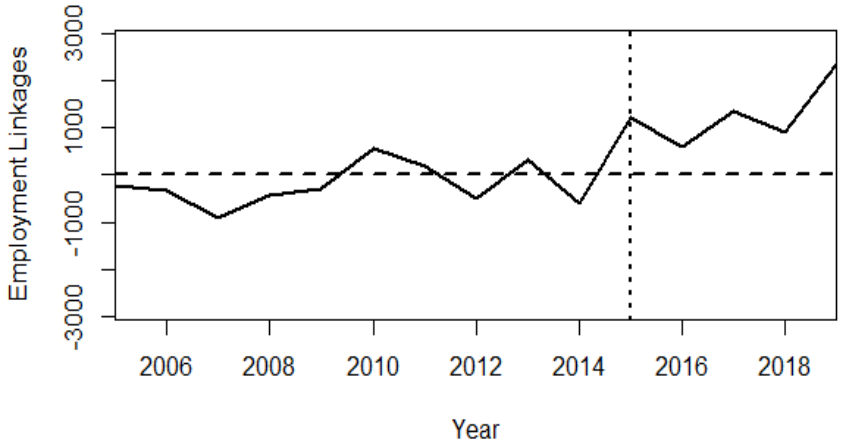
In the post-shock period, the curve of employments linkages differs from its synthetic version. In 2016, a reduction in employment in the municipality was

[11] In March 2014, Samarco's Fourth Pelletizing Project (P4P) starts its operations, one of the largest expansion projects in the Brazilian private sector. The P4P contemplated the installation of a third concentrator, at the Germano Mine (in Mariana), within the scope of this structure, the company built a pipeline for the capture of new water in Santa Bárbara (MG). The project also included a third pipeline line with capacity to transport 20 million tons per year of iron ore, as well as a fourth pelletizing plant in Ubú (ES). From Minas Gerais to Espírito Santo, the number of the workers operating at P4P at the end of 2013 was distributed among the Germano (4,626), ore (496), Ubú (3,801) and Belo Horizonte (87) units. The P4P project increased the nominal production capacity in 37%, reaching 30.5 million tons of iron ore pellets per year (SAMARCO, 2013).

verified, which may reflect the stoppage of Samarco's productive activity because of the dam disruption. From 2017, employability in Mariana presents an upward trajectory, otherwise it was not verified in the Mariana Synthetic. It is noticed that the control units started to stagnate in the labor market from 2015, after a sharp fall in 2014. This result can be related to the severe economic recession that began in the country during this period. The positive effects of remediation initiatives since 2017 were observed in all municipalities affected by the dam breach, after four consecutive years of falling employability. It can be inferred that the loss of jobs due to Samarco's production shutdown, the national economic crisis and the fall in the iron ore commodity price was offset by hiring services and labor to repair the damage.

Figure 9 plots annual estimates of gaps in the trajectories of the variable total employment linkages for the treated unit and the synthetic control group. The valleys and peaks in the curve represent changes in the labor market between Mariana and her synthetic counterpart.

Figure 9 - Total Employment Linkages difference between Mariana and Synthetic Mariana (2005-2019)



Source: Proprietary elaboration calculated using R Studio software.

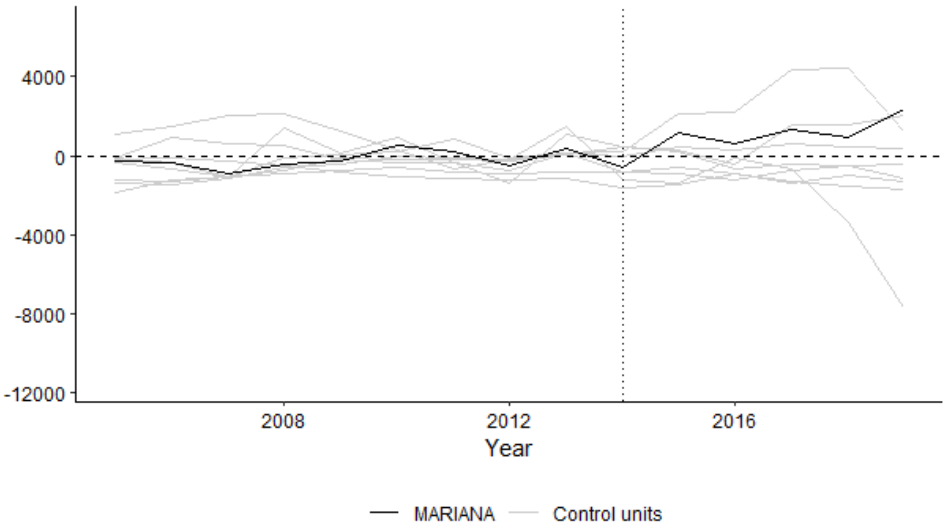
The hypothesis for the resumption of employment growth in Mariana would be to increase the hiring of workers for the recovery of the affected areas, as well as the repairing of the dam structures still existing in Samarco's production area. According to the Renova Foundation(2019a), the resettlement works of the community of Bento Rodrigues, in Mariana, are already in the earthmoving phase, elaboration of housing projects, and public works (Health Center and Municipal School). In another area hit in the municipality, Paracatu de Baixo, the infrastructure works are in the planning phase. As a result, the civil construction sector has been showing an increase in the hiring of workers for the resettlement of the almost 400 affected families of these communities.

In order to analyses the significance of the estimation, Placebos Tests were performed Abadie, Diamond and Hainmueller (2010). Thus, interactions were performed for each of the 12 municipalities in the control group. In each interaction, data for dam disruption were simulated for

all municipalities, that is, a synthetic unit was created for each of the analyzed municipalities, as these were also hypothetically affected by dam disruptions. Then, the estimated effect associated with each placebo was calculated. This interactive procedure provides a distribution of estimated gaps for municipalities where no intervention has taken place.

Figure 10 displays the results for the placebo test. The gray lines represent the difference associated with each of the 10 tests. That is, it shows the difference in the total number of employment linkages between each municipality in the control group and its respective synthetic version. The overlapping black line indicates the estimated range for Mariana without the effect of shock.

Figure 10 – Placebo Test



Source: Proprietary elaboration calculated using R Studio software.

The estimated difference for Mariana during the period from 2014 to 2016 increased in relation to the distribution of the different lines to the municipalities in the control group. This observation shows that the synthetic control method provides a good fit for the total employment relationships in Mariana before the dam rupture. When considering the Mariana without interference (2015 shock) and the placebos of the other mining municipalities under the effect of the shock, become evident the discrepancies between the curves (gray and black), suggesting that the Fundão dam rupture shock had significant effects on the employment performance.

From this results we can infer that the disruption of the dam had affected the employment in Mariana and a larger process of job losses was only avoided, due to the fulfillment of wage contracts already used and the demand for labor for actions to recover the affected areas, mainly in the civil construction sector. According to

Renova Foundation (2019b), the increase in employability in Mariana had continued in 2018 by the actions to repair and promote economic development throughout the impacted territory encouraged the hiring of labor, products and local services, taking into account the vocations and potentialities of each city. According to this foundation, from January to July 2018, the 180 contracts were signed in Mariana registered a total of 2556 contract workers, of which 1853 are local workers. In addition, a portion destined to local suppliers, distributed in 88 contracts.

These results also show the absence of long term strategies by the public sector, especially in terms of the management of CFEM's resources, which seems to be typical of mining municipalities (Enríquez, 2006; Silva, 2018; Simonato et al., 2017). Institutional and political aspects, especially in terms of governance (Collier and Godeins, 2008; Stijns, 2006); a low inter-sector linkage of extractive activity with other sectors such as tourism (Moyle et al, 2020); the volatility of prices and demand involving this market are elements that help to understand how specialization in the mining activity can contribute to a curse feature in these regions (Collier and Codeins, 2008; Radetzki (1982); Davis (1995).

Finally, the results were obtained using variables that represent Mariana's formal employment, which reveals additional concern with other important dimensions that are not captured in this paper, such as job insecurity, informality and underemployment, in which these characteristics did not be captured by the estimation made in this work.

5 - Conclusions

This article aimed to investigate the hypothesis that Mariana is an example of the blessing and curses provided by mineral extraction, whose evidenced lack of long-term sustainable growth strategy can enhance the condition of curse to the detriment of blessings. Faced with an adverse shock, production specialization hinders the recovery of employment in more adverse scenarios, such as a recession, volatility in commodity prices and exchange rates, dam disruption, etc. Data on the evolution of employment from 2002 to 2019 were used in order to reveal the economic implications of this shock and the problems that became evident due the high productive specialization of this municipality.

After discussing the main socioeconomic and structural characteristics, evidenced by the sectoral location quotient, an empirical analysis based on the synthetic control method was performed. The objective was to make comparisons between the unit of interest and its synthetic reproduction, understanding as synthetic a set of units with economic profile similar to the first, capable of reproducing the economic trajectory of the real unit without the intervention of a particular event in a specific period. To this end, the Synthetic Mariana was created, composed of 10 cities of the state of Minas Gerais where iron ore exploration is present, which were not affected by the rupture of the Fundão Dam.

The results showed that despite the Mariana and the Synthetic Mariana behaving similarly to all employment linkages, the synthetic version tended to stagnate, while Mariana has been able to recover its employability. The discrepancy between the two trajectories suggests that there was a negative effect of the dam disruption on employment in Mariana, but some compensatory actions made by Samarco required as judicial recovery may be compensating for the loss of jobs (such

as some actions to repair private institutions and emergency transfers from the public sector, in order to mitigate the impacts of the dam rupture, provided a slight recovery of the total employment relationships in the municipality), unlike Synthetic version.

Therefore, it is important to highlight that the recovery of employment in Mariana has been done, basically, through short-term operations of recovery, which does not guarantee adaptability and long-term productive reconversion strategies. As a policy recommendation, this study emphasized the definition of productive diversification strategies by the public sector; enterprises; stakeholders and population in general that allow new growth trajectory with less dependence on mining.

Acknowledgments: The authors would like to thank the anonymous referees and the participants at Seminar of Minas Gerais Economy at Diamantina in 2019 (Minas Gerais, Brazil) for their comments and constructive criticisms to earlier drafts of this paper, relieving them of any responsibility; also the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/ Brazil).

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