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Impacts of Droughts on Economic Activities in The São Paulo Metropolitan Area

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Abstract. Droughts can lead to severe socioeconomic impacts on cities by affecting industrial production, food and energy price, and income. Given that the frequency and intensity of this climatic event are increasing because of climate change, assessing the vulnerability of economic activities to drought is essential to develop adaptation strategies. This study explores the economic effects of droughts on the São Paulo Metropolitan Area (SPMA), a region with a high concentration of people and economic activities and frequently hit by droughts. Our method comprises an integrated system of analysis that puts together climatic and economic databases. The integrated modeling system is divided into three steps: i) calculate a variable to represent drought conditions; ii) estimate the direct impact of droughts on sectoral activities through an econometric model; and iii) estimate the total impact on the economy through a Spatial Computable General Equilibrium (SCGE) model calibrated with municipal data. The econometric model results showed that energy and water-intensive industries are more sensitive to droughts in the SPMA. The results from the simulations in the SCGE model showed that the impact on these sectors could spread to the entire economy, indirectly affecting activities such as land transport, construction, and personal services and decreasing the total production and disposable income of metropolitan municipalities.

Keywords: local droughts impact, industrial activity, regional analysis, integrated modeling.

1. Introduction

The 6th Assessment Report (AR6) (IPCC, 2021) points out that there will be more droughts in the following years considering global warming of 2°C (high confidence level). Because droughts can impose several socioeconomic effects on cities, adaptation actions will be necessary for such a drier scenario.

At the local level, droughts can have a devastating impact, especially in the short term. Power cuts, reduced irrigable areas, rising food prices, and falling income are a few examples of damages (Hertel & Liu, 2016). Droughts can limit economic activities because water is a fundamental resource for several manufacturing sectors. Industries use

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it for human consumption, electricity generation, heating, and cooling fluid, among other uses. If local or regional governments are not prepared to provide enough training and infrastructure to face the negative consequences of droughts, the result will be a severe water crisis affecting the population and economic activities. This was the case faced by the São Paulo Metropolitan Area (SPMA) in Brazil.

The SPMA is located in the State of São Paulo, Southeast Brazil, and comprises 39 municipalities, including the megacity of São Paulo. According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), in 2017, the SPMA concentrated around 10% of the total Brazilian population and approximately 18% of the Brazilian Gross Domestic Product (GDP). In 2014, rainfall dropped well below the historical average in the SPMA's area, and the flow of rivers that fed the water supply reservoirs and energy dams reached the lowest mark in history (Marengo et al., 2015). The combination of this drought with the growth of water demand, the lack of adequate planning for water resource management, and the lack of collective consumer awareness of rational water use have generated the so-called water crisis (Marengo et al., 2015). Despite some news at the time calling attention to the effects of this crisis on many economic activities, we did not find any robust estimation about it. Considering that climate change can increase the intensity and the frequency of events like the 2014's, it is crucial to identify sectoral vulnerabilities for local adaptation plans in this vital region.

In the climate economics literature, while many studies assess droughts' impacts on agriculture output and aggregated variables, like GDP and exports, there is a lack of evidence about their effects on local economic activities, especially those developed in urban areas. Thus, this study intends to contribute to filling this gap by evaluating the potential effects of drought on local industrial activities in SPMA and its spillover effects. We used a combination of climatic and economic data in the analysis. First, we estimated the potential effects of droughts on the industrial activities of the SPMA using a dynamic panel data model. Then, we used the estimations together with a climate change scenario to perform simulations in a Spatial Computable General Equilibrium Model (SCGE) to assess economy-wide effects. From the results, we can identify the industrial activities more vulnerable to droughts and how this vulnerability spread to other sectors and regions of Brazil.

In the following sections, we will present some evidence about the effects of droughts on economic activities (section 2), present the methodology (section 3), show the findings of the research (section 4), and make the final remarks (section 5).

2. How do droughts affect economic activities?

Although droughts affect several economic activities, most studies focus on the impact on the agricultural sector or subsectors. This is because agriculture is highly sensitive to climate variability, and the impacts of droughts on crops and pastures are directly and immediately observed and easy to measure. Dell et al. (2014) and (Ding et al., 2011) present some examples of investigating the impacts of droughts on agriculture production.

Many studies also belong to the so-called new climate economics (Dell et al., 2014). This literature concerns a range of empirical studies that use panel data methods to explore the effects of changes in temperature, precipitation, and other climatic variables on economic variables (GDP, exports, and value-added). For example, (Dell et al., 2012) constructed a database of temperature and precipitation from 1950 to 2003 for several countries and combined it with aggregate product data to assess the historical relationship between changes in temperature and precipitation and economic performance. They found three major results: i) high temperatures affect economic growth, but only in poor countries; ii) this effect may occur because of the influence of temperature on the level and rate of growth; and iii) higher temperatures have far-reaching effects, reducing agricultural production, industrial production, and political stability. (Burke et al., 2015) made a similar analysis but got different results regarding rich and poor countries (there is no distinction between rich and poor countries, and both agricultural and non-agricultural sectors can be affected).

Jones & Olken (2010) analyzed the effects of climate shocks on exports and found that high temperatures in poor countries negatively affect the growth of their agricultural exports and exports of light manufacturers. Khan et al. (2017) estimated a panel data model with varying specifications to investigate the relationship between economic growth and hydro-climatic variables at the watershed level in national territories. Their results showed that water availability and its associated risks highly influence economic growth. Panwar & Sen (2019) and de Oliveira (2019) evidenced that drought (represented

by the number of people affected) negatively affects the growth rate of GDP and agricultural and non-agricultural (aggregate) sectors.

Drought extremes directly affect the costs and revenues of urban supply companies. Guzmán et al. (2017) and Mohor & Mendiondo (2017), for example, evaluated the situation of the Basic Sanitation Company of the State of São Paulo (Sabesp) and proposed insurance schemes to insure potential losses from extreme events. The higher the costs of the supply companies, the higher the tariffs charged to users. As the water demand is inelastic to income and price (Ruijs et al., 2008), higher tariffs affect disposable income and the population's well-being.

On the question of drought effects on industrial output, which is the focus of this work, there are four possible channels of impact. The main one is the reduction of water availability. Freire-González et al. (2017) argue that droughts represent a situation of interruption in the supply of a critical input for some production processes. In metropolitan areas, an intense drought imposes restrictions on the direct water withdrawn by industries. These restrictions can lead to interruptions or stoppages in production, especially in the more water-intensive sectors. Restriction can also occur via the urban supply system since, in water crises, there may be rationing and tariff increases for industrial users, thus increasing production costs.

Another channel is the worsening of water quality. Van Vliet & Zwolsman (2008) affirm that long-lasting droughts result in meager flow rates and cause an overall deterioration of water quality with higher temperatures. A worsening in water quality means higher costs in its treatment before use, making production more expensive.

High temperatures and dry weather are common in drought events and can significantly affect labor and capital productivity. For example, Jones & Olken (2010) estimated that high temperatures decrease the exports of several manufacturers because of their effects on labor productivity. For other studies on temperature and factor productivity, see Dell et al. (2014) and Desbureaux & Rodella (2019). Droughts also affect industrial activity through their effects on energy production and other productive inputs, as Panwar & Sen (2019) discussed.

Although we did not find evidence, it is plausible that some sectors benefit from drought events. A drought can stimulate the sale of specific products and services and/or lead to some productivity gain during production.

The drought impacts on a specific sector are not restricted to it. Because of the economic linkages, these impacts can propagate to other economic activities and even to regions that are not under drought conditions. Input-Output Models (I-O) and Computable General Equilibrium (CGE) models, linked or not to other direct estimation models, are the main methods used to assess such effects. For example, González (2011) proposed a system composed of econometric estimates and an I-O model to measure the macroeconomic impacts of restrictions on water supply near Catalonia (Spain). His simulations suggested a loss of 0.34% of GDP with modest restrictions on water supply and 2.8% with more extreme restrictions for the region studied. Pagsuyoin et al. (2019) used a dynamic and spatial I-O to examine the adverse effects of drought on sectoral interdependence. They applied the method to Massachusetts (USA), which faced historical conditions of widespread drought in 2016.

Since the 1990s, several CGE models focusing on water resources have been developed to address issues related to water availability and droughts. Some examples are Berck et al. (1991), Seung et al. (1998), Seung et al. (2000), Wittwer (2012), Freire-González et al. (2017), and Luckmann et al. (2014).

Our contribution will focus on using highly disaggregated sectoral data at the municipal level to identify the direct and spillover effects of droughts.

3. How to measure the effects of droughts on economic activities?

Figure 1 represents our strategy to estimate the total economic impacts of droughts on the SPMA. Step 1 is to process the economic and climatic data. Step 2 is to estimate the direct impacts of droughts on the production value of 21 industrial sectors using a panel data model. The estimated coefficients are combined with the projection of drought intensity in Step 3. In Step 4, we simulate scenarios in the SCGE model. In the following subsections, we present the details of each step.

Figure 1. Estimation procedures
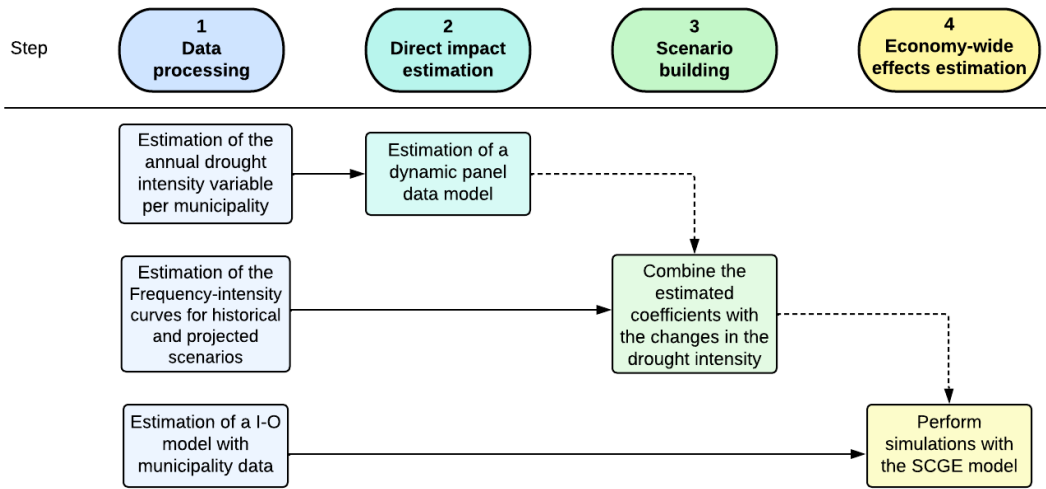
Source: the authors.

3.1 Data processing

We used two main sources of data: climate data (drought intensity) and sectoral data by the municipality, described in the following.

3.1.1 Drought intensity

Drought generally refers to a reduction in precipitation compared to normal conditions and can be grouped into four types (meteorological, agricultural, hydrological, and socioeconomic drought) (Mishra & Singh, 2010). Here we focus on the socioeconomic drought, which is associated with the impact of an inadequate supply of some economic goods resulting from the other three types of droughts.

We used the Self-Calibrated Palmer Drought Severity Index (scPDSI) proposed by Wells et al. (2004), an updated version of the traditional Palmer Drought Severity Index (Palmer, 1965), as the indicator of drought conditions. Couttenier & Soubeyran (2014) highlight that the scPDSI captures the meteorological conditions on the ground and the non-linear effects related to precipitation and temperature. In addition, Rossato et al. (2017) showed that this indicator is directly related to climatological patterns of precipitation and soil moisture at any spatial and temporal scale (including future

projections), so it can be associated with economic and social information for the creation of risk maps to support decision-makers.

The identification of drought periods is made using the classification of Palmer (1965). A scPDSI below -0.99 indicates a drought event. As our economic data are annual, we used the method presented by Kim et al. (2002) to convert monthly scPDSI into an annual drought intensity variable:

1. For each year t and municipality $i,$ we identified the months in which the scPDSI is less than -0.99. These are the dry months n.
2. The annual drought severity S_{it} is calculated by adding the scPDSI values of the dry months n in each year t.
3. The probability of occurrence of drought in each year λ_{it} is calculated by dividing the number of dry months in a year (N) by 12.
4. The drought intensity I_{it} then is calculated by multiplying the drought severity by its probability of occurrence.

In math notation:

$$S_{it} = \sum_{n=1}^{N} scPDSI_{it}$$

$$\lambda_{it} = \frac{N}{12}$$

$$I_{it} = S_{it}\lambda_{it} \tag{1}$$

This procedure allows each drought event to be randomly distributed in a given year, avoiding annual intermittence. For the econometric model, we calculated I_{it} from 2003 to 2016 to the 39 municipalities using data from the Climatic Research Unit (CRU)/The University of East Anglia (Osborn et al., 2019).

We also calculated I_{it} using projections of temperature and precipitation from a climate change scenario (RCP8.5 for the period 2011-2040) and a historical period (1976-2005).

These data are from the Center for Weather Forecasting and Climate Studies of the National Institute for Space Research (CPTEC/INPE) of the Brazilian government, and we used them to build scenarios of analysis.

From the projected I_{it}, we analyzed the frequency and intensity of droughts. This analysis associates the intensity of a drought with its return period. The return period is the expected time interval (years) for a given event to occur. It is also seen as a measure of the probability of occurrence given by one over the return period. We made this analysis based on Kim et al. (2002) and Loukas et al. (2008): i) in each period, I_{it} is classified in descending order; ii) the values are fitted to a suitable frequency distribution (Gumbel probability distribution, also called Extreme Value distribution); and iii) the return level (intensity) is identified for each return period. Figure 2 provides the theoretical drought intensity by return periods for a historical (reference scenario) and the scenario RPC 8.5 2011-2040.

Figure 2. Frequency-intensity curves for drought intensity, SPMA
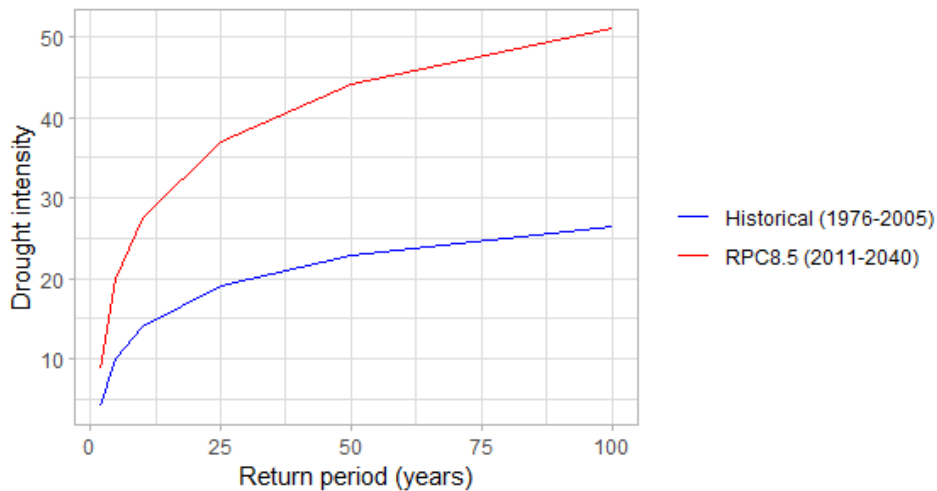
Source: the authors.

The graph shows that for the same return period, the intensity of droughts will be higher in a scenario with high-concentration emissions. This means climate change can increase the intensity of drought in the area. To perform the simulation in the SCGE model, we selected the variation of drought from the return period of 10 years because this was the approximate period between the last two severe droughts in the area

3.1.2   Sectoral and municipality data

The dependent variable of the econometric model is the Value of Industrial Transformation (VTI) per municipality provided by (Fundação Seade, 2019). The data comprises 21 divisions of the manufacturing industry by municipalities from 2003 to 2016. Data are in current values for the corresponding year; thus, we updated it to 2015 prices based on the implicit GDP deflator.

The SCGE model was calibrated with data from the Interregional Input-Output System for SPMA (IIOS-SPMA) for 2015, estimated according to the method presented in Haddad et al. (2017). The IIOS-SPMA contains production data from 56 sectors at the municipal level, as well as household consumption, investment, government consumption, and exports by municipalities. It includes the 39 municipalities of the SPMA, one region with an aggregation of data from other municipalities of the São Paulo state, and one region representing an aggregation of other Brazilian states. The list of regions and sectors of the model is in Appendix 1.

3.1.3   Direct impact estimation

An econometric model measures the effects of drought intensity on industrial activities. The model's dependent variable is the value of industrial transformation V_{it}^{j} by industry j, municipality i, and year t. The variable of interest is the annual drought intensity of a municipality I_{it}.

We estimated a panel data model with the unit of space corresponding to the 39 municipalities of the SPMA and the unit of time being the years from 2003 to 2016. According to Dell et al. (2014), panel data techniques are widely used to analyze the effects of climatic variables on economic variables. The most used are fixed-effect panels because they control for time-variant and invariant spatial heterogeneities common to all units (national, global macroeconomic impacts, etc.)

Regarding the control variables, Hsiang (2010) states that the temporal trend T must enter directly into the model with sectoral production as a dependent variable for three reasons:

i) technological changes that occur gradually over time can be incorporated into the productive structure; ii) production in a given industry may contract or expand over time due to the performance of the economy; and iii) specific years they can be "abnormal" for reasons unrelated to the weather, such as wide swings in world commodity prices. For these reasons, we included the variables T and T^2 to capture linear and non-linear temporal trends.

We also included a time-lagged dependent variable to assess the extent to which production in year t is correlated with that of previous years, keeping hydrological conditions constant. According to Hsiang (2010), the lagged variable used as a control is essential to avoid spurious estimates for the coefficient of hydrological conditions. Equation 2 represents the model we estimated.

$$lnV_{it}^{j} = \rho lnV_{i,t-1}^{j} + \gamma_1 T + \gamma_2 T^2 + \beta I_{it} + v_{it}^{j} \qquad (2)$$

$$v_{it}^{j} = \alpha_i + \varepsilon_{it}^{j}$$

where V_{it}^{j} is the value of industrial transformation by industry j in municipality i and year t; I_{it} is the annual drought intensity in municipality i and year t; T represents the time trend; and v_{it}^{j} is a term that includes the fixed effects of municipalities α_i and the residuals ε_{it}^{j}. The coefficient β is the direct impact of the drought intensity on industrial production. We obtained the coefficients using the System GMM estimator (Arellano & Bover, 1995; Blundell & Bond, 1998). This estimator is suitable for panels where the time unit is smaller than the space unit, which is our case. We estimated the model separately for each of the 21 industries.

As a robustness check, we estimated Equation 2 using Pooled Ordinary Least Square (POLS) and Fixed Effect (FE) estimators. By POLS, $lnV_{i,t-1}^{j}$ is positively correlated with the error term, while in FE estimates, the coefficient is negatively correlated due to the negative sign in transformed v_{it}^{j}. Given the different directions of biases, consistent estimates of ρ must be within the range of estimates from POLS and FE. We also estimated a model in which the dependent variable is the growth rate of industrial production. According to Hsiang (2010), the relationship between production and the

climate variable can be spurious, as production is auto-correlated. If lnV_{it}^j is an integrated process of order one, its differentiation between periods will produce a stationary time series that should not lead to spurious correlations. Equation 3 represents the regression for the growth rate. The estimation method is the fixed effects.

$$lnV_{it}^j - lnV_{i,t-1}^j = \gamma_1 T + \gamma_2 T^2 + \beta I_{it} + e_{it}^j \tag{3}$$

$$e_{it}^j = \alpha_i + \varepsilon_{it}^j$$

3.2 Scenario building and Economy wide-effects estimation

The effects of droughts on the industrial sector can spread all over other sectors and regions. We use an SCGE model, the B-MARIA model developed by Haddad (1999), to capture these economy-wide effects. This model has been used in some applications for the SPMA, such as Haddad & Teixeira (2015), Haddad et al. (2015), and Haddad et al. (2018).

The B-MARIA model includes elements of an interregional system, allowing a better understanding of the effects of a given exogenous event in a region (Haddad & Vieira, 2015). These elements are the interregional flow of goods and services, transport costs based on origin-destination pairs, interregional migration of primary production factors, regionalization of public sector transactions, and regional labor market segmentation. The model also maps inter-industry relationships by place of production, payments to labor by place of residence, and consumption structure by place of consumption. Its results are based on a bottom-up approach; national results are obtained from aggregating regional results. The model identifies different production and investment sectors in each region, a representative household in each region, regional and federal governments, non-profit institutions (NSHI), and a single foreign area that trades with each domestic region through a network of ports (Haddad et al., 2015). Two primary local factors enter the production process, according to regional allocations (capital and labor).

In the B-MARIA model, the direct economic impacts of droughts on a sector entered the model as exogenous shocks to its production function. The value of the chocks for each

scenario is calculated by multiplying the coefficient β from Equation 2 by projections of drought intensity.

We performed simulations using two types of closure of the model. Closing an EGC model means choosing the exogenous and endogenous variables. One is the short-run closure, in which capital stock, regional population, labor supply, and real wages are fixed, investment decisions and government demand are exogenous, and the household's consumption depends on the available income. The other is the long-run closing, in which all factors can move between sectors and regions.

4. Results

This section presents the results from the direct and economy-wide effects estimations.

4.1 Direct impact estimates

Here we are presenting only the estimates of our variable of interest, the drought intensity I_{it}. Appendixes 2 and 3 show all the estimation results, its robustness check, and econometric tests. Generally speaking, in all regressions $lnV_{i,t-1}^{j}$ is positive and statistically significant, suggesting that the current production of each industry depends on its value in the previous year. The statistical significance of the time trend coefficients (T and T^2) vary according to industry.

Table 1 brings the estimates of the I_{it} coefficient. We considered a coefficient is robust if it is statistically significant in the regression estimated by System GMM (Equation 2) and First Difference (Equation 3). We interpreted the estimated coefficients as the industry's sensitivity to droughts' intensity. The higher the coefficient, the more sensitive the sector is to drought intensity variations. Of the 21 industries analyzed, in 10, the drought intensity is robust (industries in bold in Table 1).

Table 1. Annual drought intensity estimates

Industry	Coefficient (β)	SD	P>|z|
1. **Food product manufacturing**	**-0.014**	**0.006**	**0.012**
2. Beverage manufacturing	0.018	0.008	0.018
3. Textile and textile product mills	0.000	0.004	0.918
4. **Apparel manufacturing**	**0.030**	**0.012**	**0.014**
5. **Leather and leather products manufacturing**	**0.027**	**0.016**	**0.084**
6. Wood product manufacturing	0.018	0.008	0.018
7. Cellulose and Paper Products Manufacturing	0.006	0.007	0.392
8. Printing and related support activities	0.000	0.018	0.997
9. **Petroleum and coal products manufacturing**	**-0.015**	**0.006**	**0.011**
10. Chemical manufacturing	0.001	0.005	0.865
11. Pharma chemicals manufacturing	0.002	0.005	0.641
12. Plastics and rubber products manufacturing	-0.009	0.006	0.154
13. Nonmetallic mineral product manufacturing	0.009	0.006	0.125
14. **Primary metal manufacturing**	**-0.042**	**0.017**	**0.014**
15. **Metal product manufacturing**	**-0.025**	**0.005**	**0.000**
16. **Computer and electronic product manufacturing**	**-0.043**	**0.014**	**0.002**
17. **Electrical equipment and appliance manufacturing**	**-0.025**	**0.008**	**0.001**
18. **Mechanical machines manufacturing**	**-0.012**	**0.006**	**0.036**
19. Motor vehicle, body, trailer, and parts manufacturing	-0.008	0.006	0.233
20. **Other transportation equipment manufacturing**	**-0.068**	**0.020**	**0.001**
21. Furniture and related product manufacturing	-0.009	0.010	0.361

Source: the authors.

Eight industries have negative coefficients: food products; petroleum and coal products; primary metal; metal products; computer and electronic equipment; electrical equipment and appliances; mechanical machines; and other transport equipment. In terms of magnitude, the largest marginal effects are from other transport equipment (-0.068), computer and electronic equipment (-0.043), and primary metal (-0.042).

In the food industry, a drought can affect the supply of food used as intermediate inputs harming production. In addition, this is a water-intensive sector. Any restriction in the water supply can affect its production. Even if there is no restriction, the reduction in the water quality can affect this sector. Lower water availability means more inputs are needed for its treatment since there is a smaller volume of water to dilute the same number of pollutants.

In other industries, the reduction of water availability may explain the results, as it is used as a production input and/or production factor (cooling, testing, solution, or cleaning, for example). This should be the case in petroleum refining and coke plants and primary metal manufacturing, the sectors with the highest water withdrawal coefficients,

according to the Water Agency of Brazil (Agência Nacional de Águas, 2017). The results may also be related to higher energy consumption by industries since greater cooling and ventilation of closed production spaces will be required.

In two industries, apparel manufacturing, and leather and leather goods manufacturing, the sign of the estimated coefficient is positive, suggesting that they may benefit from drought situations. Jones & Olken (2010) showed that the export of leather products benefits from the increase in temperature, but they did not discuss possible channels behind the effects found. The positive gain may be related to the greater availability of raw materials since droughts/high temperatures harm cattle raising and boost their slaughter. Another hypothesis is that production benefits from the drier environment, as one of its stages involves drying the raw material. Regarding apparel manufacturing, no evidence was found to help explain the relationship found. As in the production of leather goods, some stages of its production process may benefit, which overlaps with the losses of the drought. Maybe their products have increased in price or demand in droughts/high temperatures, which is reflected in a higher production value.

Estimates show that the most negatively affected sectors are capital and/or technology-intensive ones. Their productivity losses in drought situations can hinder local economic development and must be considered in policies to promote industrial activity. In addition, primary metal manufacturing, metal products manufacturing, and electrical machines manufacturing figure among the sectors with the highest production multipliers in the region. A reduction in their activity levels can potentially affect other sectors' production, employment, and income levels in all the municipalities in the metropolitan area and outside it. The simulations performed with the SCGE model captured these effects.

To reduce the vulnerability to droughts in those sectors, it is necessary to encourage the development of production processes that require less water and energy, the improvement of domestic and industrial effluent treatment technologies, and water reuse.

4.2 Economy-wide impacts estimates

We performed the simulations in the SCGE model by applying an exogenous shock in the production function. The values of the shocks (Table 2) are equal to the multiplication of the robust coefficients by the drought variation. We consider all the municipalities to face the same shocks. We performed simulations using the short-run and long-run closures. Short-run and long-run refer exclusively to the closure of the model, which follows the traditional economic view: in the short-run the factors are fixed, and in the long-run they are free to move. Our aim in the simulations was to identify possible sectoral and local vulnerabilities to drought events. The question the simulations tried to answer was: what if the intensity of the drought with a return period of 10 years increased? What would be the possible local and sectoral impacts?

Table 2. Value of the exogenous shocks (direct impact), % change to the base scenario

Industry	Shock
Food product manufacturing	-1.32%
Apparel manufacturing	2.87%
Leather and leather products manufacturing	2.60%
Petroleum and coal products manufacturing	-1.40%
Primary metal manufacturing	-3.98%
Fabricated metal product manufacturing	-2.41%
Computer and electronic product manufacturing	-4.07%
Electrical equipment and appliance manufacturing	-2.43%
Mechanical machines manufacturing	-1.17%
Other transportation equipment manufacturing	-6.50%

Source: the authors.
Note: the value of the base scenario is the intensity of drought with a return period of 10 years for the period from 1976 to 2005.

The model results are the difference (%) between the base scenario of the model (2015) and the new equilibrium after the exogenous shock. In the following, we discuss some of the macroeconomic, local, and sectoral impacts of short- and long-term closures.

Table 3 presents the impact of the shock on some macroeconomic variables. Brazil's GDP can reduce in both scenarios because of different components of aggregate demand. In the short term, the major determinant is the drop in the export volume (exports lose competitiveness because of increased production costs). In the long term, there is a slowdown in domestic demand (household and investment demands), directing additional

production to the foreign market, as evidenced by the positive variation in the volume of exports.

According to the simulations, if droughts affect the industrial production in SPMA, the prices (see GDP deflator, demand side) and payments to factors of production can rise in the short term and reduce in the long term. In short-term simulations, as there is no factor mobility, the greater demand for factors increases the payment of primary factors and prices. In the long term, the slowdown in domestic demand reduces the demand for primary factors, which is reflected in aggregate payments.

These results show the relevance of the industrial production of SPMA in Brazil. Falls in the production of some industrial sectors established in the SPMA can lead to significant economic losses for the country due to economic linkages. Thus, reducing vulnerabilities to droughts in the SPMA's productive sectors is not an issue that should only be addressed at the local level.

Table 3. Macroeconomic impacts, % change to the base scenario

Variable	Short-run	Long-run
Aggregated		
GDP	-0.041	-0.343
Household consumption	0.013	-0.548
Aggregate real investment	0.000	-0.432
Real government consumption	0.026	-0.005
Actual consumption of ISFLs	0.022	-0.348
Export volume	-0.253	0.149
Volume of imports	0.175	-0.459
GDP Components		
GDP deflator, demand side	0.198	-0.369
Aggregate payment to capital	0.144	-0.578
Aggregate payment to work	0.159	-0.863

Source: simulations results.

Figure 3 shows the effects of the shock on the Gross Regional Product (GRP) of the SPMA municipalities. The main difference between the scenarios is the magnitude of the effects, which are higher in the long-run. Locally, the municipalities most affected by the shocks are Ferraz de Vasconcelos, Rio Grande da Serra, and Embu Guaçu. Industrial activities represent around 20% of the value added in these municipalities; thus, it is reasonable that they are the most negatively affected. The effects on the São Paulo city

(-0.22% and -0.57% in the short and long-run scenarios) are smaller than the effects on the other municipalities because the industrial sectors have a smaller share of GDP. However, in monetary terms, the loss in São Paulo can reach 370 mi USD in the short-run and -960 mi USD[4] in the long-run.

Another difference between the scenarios is the effect on the Rest of São Paulo and Brazil. In the short-run, these regions can benefit little from the loss caused by droughts in the SPMA as they become relatively more competitive. In the long term, the total production of these regions has a negative variation, following the results of the metropolitan municipalities.

As possible local adaptation policies, we can cite investment in technology to reduce the vulnerability of the traditional sectors to drought and investments in the so-called green sectors (those that contribute to preserving or restoring the environment, whether in traditional sectors, such as manufacturing and construction or new emerging green sectors, such as energy renewable). Investments in these sectors could also contribute to making cities more sustainable and with lower levels of GHG emissions. However, studies are still needed on the economic importance of green sectors in the SPMA.

Figure 3. Impacts on Gross Regional Product (GRP), % change to the base scenario

| (a)   Short-run | (b) Long-run |
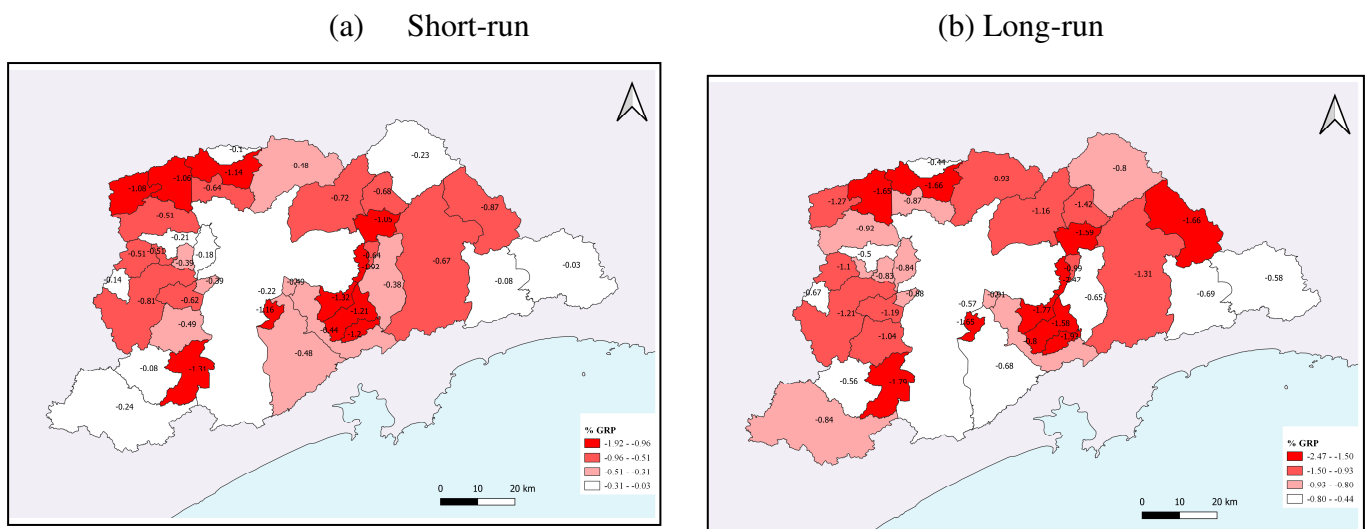
Source: simulations results.

To analyze the sectoral effects, we grouped the 56 sectors of the SCGE model into three groups, each containing the ten most affected sectors. The first group shows the ten industries directly affected; the second is the other industries (including manufacturing, mining, construction, and public utilities); and the third is the sectors linked to trade and services. The 41 regions were grouped into four to facilitate visualization: (1) the city of São Paulo, (2) the average of other municipalities from the SPMA, (3) the rest of the State of Sao Paulo (RSP), and (4) rest of Brazil (RBR).

Table 4 brings the impacts on activity levels in the short-run. In all the sectors, the effect on the level of activities in the city of São Paulo is much more significant than in the activities of other municipalities in the metropolitan area. Computer and electronic product manufacturing are the industries most affected (-8%). In sectors with a decrease (increase) in the activity level in the SPMA, there is an increase (decrease) in other regions (RSP and RBR). This is the case, for example, of primary metal, metal products, computer products, and electrical and mechanical machines. The production of these sectors becomes more competitive in regions outside the SPMA, which translates into a higher level of activity.

The effects on other industries, trade, and services are spillover effects that occur due to the productive chain of the directly affected sectors. By negatively affecting its production, an industry may demand less productive inputs, reducing its suppliers' production. It can also pass on the higher costs to its products and increase the price of its final goods.

Among the industries indirectly affected, the effect on the production of automobiles, trucks, and buses stands out. By the econometric model, no evidence was found that droughts directly affected its production. However, the simulations with the SCGE model suggest that it may be affected by its dependence on other sectors, like metal products and electrical and mechanical machinery and equipment. Beverage manufacturing and maintenance, repair, and installation of machinery and equipment are also among the most indirectly affected.

Regarding trade and services activities, all coefficients have a negative sign. In terms of magnitude, the biggest effects are in sectors such as land, air, and water transport,

accommodation, and storage. These are complementary activities to industrial production, so they are likely to be the main ones indirectly affected.

Table 4. Sectoral impacts, short-run simulation (% change)

Sector	São Paulo	Other SPMA	Rest of SP	Rest of Brazil
Industry directly affected				
Food product manufacturing	-2.138	-1.875	0.045	0.030
Apparel manufacturing	4.564	3.521	-0.281	-0.203
Leather and leather products manufacturing	3.250	2.727	-0.033	-0.027
Petroleum and coal products manufacturing	-1.510	-0.566	0.055	0.044
Primary metal manufacturing	-5.219	-3.818	0.237	0.117
Metal product manufacturing	-3.066	-2.883	0.569	0.436
Computer and electronic product manufacturing	-7.883	-5.408	0.646	0.461
Electrical equipment and appliance manufacturing	-3.223	-2.507	0.506	0.463
Mechanical machines manufacturing	-1.838	-1.624	0.133	0.123
Other transportation equipment manufacturing	-4.531	-3.200	-0.079	0.032
Industry indirectly affected				
Beverage manufacturing	-0.332	-0.055	-0.036	-0.011
Chemical manufacturing	-0.197	-0.095	-0.045	-0.030
Wood product manufacturing	-0.156	-0.086	-0.045	-0.048
Cellulose and Paper Products Manufacturing	-0.144	-0.065	-0.048	-0.046
Plastics and rubber products manufacturing	-0.131	-0.105	-0.031	-0.007
Nonmetallic mineral product manufacturing	-0.119	-0.090	-0.044	-0.019
Motor vehicle, body, trailer, and parts manufacturing	-0.286	-0.278	-0.053	0.002
Maintenance, repair, and installation of machinery and equipment	-0.288	-0.260	-0.031	-0.010
Furniture and related product manufacturing	-0.083	-0.082	-0.012	0.000
Trade and Services				
Wholesale and retail trade	-0.074	-0.066	0.009	0.010
Ground transportation	-0.142	-0.117	0.002	0.011
Water transportation	-0.127	-0.004	-0.054	-0.052
Air transport	-0.180	-0.052	-0.033	0.021
Storage. auxiliary transport and mail activities	-0.099	-0.078	-0.011	0.004
Accommodation	-0.143	-0.114	-0.078	-0.049
Food services	-0.058	-0.063	0.002	0.008
Legal accounting, consulting, and company headquarters	-0.055	-0.048	-0.008	-0.002
Architectural, engineering, technical testing/analysis	-0.081	-0.043	-0.032	-0.026
Non-real estate rentals and intellectual property asset management	-0.090	-0.055	-0.035	-0.039

Source: simulations results.

Table 5 shows the impact in the long-term scenario. We notice some differences by comparing these results with the ones from Table 4. One of them is the negative effect on the production of the food industry and oil refining in the RSP and RBR regions (in the short term, the effect was positive). The drop in the general level of activities in the SPMA, much more significant in the long term, can reduce the demand for products from these sectors from other regions, and, thus, their activity levels are reduced.

Concerning other industries and trade and services, the difference is because of the appearance of the construction sector and furniture activities among the most affected. While in the short term, the most affected are those services related to the current business level, in the long term, the most affected sectors are those linked to infrastructure. This

suggests that firms are induced to transfer production to more attractive regions, reducing the demand for facilities and infrastructure, which is reflected in the drop in the level of activity in the sectors mentioned above. We also highlighted the effects on private health, private education, and artistic activities as consequences of falling in the income generated by industries.

Table 5. Sectoral impacts, long-run simulation (% change)

Sector	São Paulo	Other SPMA	Rest of SP	Rest of Brazil
Industry directly affected				
Food product manufacturing	-2.473	-2.430	-0.217	-0.241
Apparel manufacturing	4.443	3.315	-0.693	-0.542
Leather and leather products manufacturing	3.420	2.670	-0.191	-0.138
Petroleum and coal products manufacturing	-1.938	-0.794	-0.324	-0.281
Primary metal manufacturing	-5.114	-4.025	0.341	0.270
Metal product manufacturing	-3.402	-3.266	0.493	0.324
Computer and electronic product manufacturing	-8.230	-5.737	0.419	0.252
Electrical equipment and appliance manufacturing	-3.484	-2.754	0.400	0.329
Mechanical machines manufacturing	-1.964	-1.893	0.097	0.076
Other transportation equipment manufacturing	-4.230	-3.243	0.138	0.038
Industry indirectly affected				
Tobacco products manufacturing	-0.452	-0.036	-0.478	-0.126
Printing and related support activities	-0.302	-0.370	-0.269	-0.204
Motor vehicle, body, trailer, and parts manufacturing	-0.422	-0.416	-0.240	-0.220
Furniture and related product manufacturing	-0.448	-0.571	-0.348	-0.315
Maintenance, repair, and installation of machinery and equipment	-0.444	-0.574	-0.115	-0.101
Electricity, natural gas, and other utilities	-0.575	-0.431	-0.472	-0.411
Water, sewage, and waste management	-0.326	-0.492	-0.378	-0.307
Construction	-0.532	-0.707	-0.437	-0.365
Plastics and rubber products manufacturing	-0.317	-0.321	-0.154	-0.156
Nonmetallic mineral product manufacturing	-0.268	-0.426	-0.292	-0.277
Trade and Services				
Real estate activities	-0.757	-0.861	-0.631	-0.610
Wholesale and retail trade	-0.443	-0.649	-0.317	-0.318
Ground transportation	-0.458	-0.634	-0.294	-0.291
Telecommunications	-0.422	-0.516	-0.436	-0.359
Financial intermediation, insurance, and supplementary pensions	-0.379	-0.644	-0.395	-0.271
Private health	-0.377	-0.637	-0.352	-0.307
Artistic, creative, and entertainment activities	-0.354	-0.564	-0.274	-0.284
Membership organizations and other personal services	-0.466	-0.701	-0.391	-0.357
Private education	-0.329	-0.525	-0.015	-0.029
Development of systems and other information services	-0.306	-0.524	-0.361	-0.221

Source: simulations results.

So far, we can see differences between the short and long-term scenarios, suggesting that the assumptions about the functioning of the economy significantly affect the results. Generally, when it is assumed that factors can be reallocated between sectors and regions, the effects are more significant when looking at sectoral and regional results.

Two limitations must be taken into account when analyzing the results from the simulations. First, the SCGE model does not include the impact of companies' future investment decisions. They can cancel or postpone production expansion because of

water shortages caused by drought. Second, the approach adopted did not include the effects of drought on water utilities. In times of water scarcity, tariffs can increase, causing welfare loss and inflation. Therefore, the estimated economic losses may be even more substantial.

All the results involve some source of uncertainties. Even with robustness tests, it is impossible to eliminate the uncertainties related to the methods and data used. However, the results were obtained through the best available information and methodologies already used individually or together.

5. Final remarks

Assessing the impact of drought on aggregated output is important for estimating the magnitude of the risk it represents to a region. However, evaluations with locally and sectorally disaggregated data are more adequate to understand the vulnerability to drought better and propose adaptation policies. In our analysis, we pointed out that water and energy-intensive sectors in SPMA are the most prompt to encore in economic losses because of drought. We also showed that spillover effects could harm economic activities in many regions. This evidence should be taken into account in drought vulnerability assessments. It can be used to increase the capacity of institutions, governments, and civil society to understand how drought affects them.

The challenge is estimating locally and sectorally disaggregated data and combining them in an integrated method. Our methodology is an example of how to do it. We used all the available municipal data to estimate the econometric model and the interregional matrix and employed a method from natural (climate) science to calculate the variable representing drought conditions. Similar procedures can be used for other natural hazards and other regions of Brazil and even for other locations with data availability.

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Appendix 1. Regions and Sectors of the Interregional Input-Output Model

REGIONS	
R1	Arujá
R2	Barueri
R3	Biritiba Mirim
R4	Caieiras
R5	Cajamar
R6	Carapicuíba
R7	Cotia
R8	Diadema
R9	Embu das Artes
R10	Embu-Guaçu
R11	Ferraz de Vasconcelos
R12	Francisco Morato
R13	Franco da Rocha
R14	Guararema
R15	Guarulhos
R16	Itapecerica da Serra
R17	Itapevi
R18	Itaquaquecetuba
R19	Jandira
R20	Juquitiba
R21	Mairiporã
R22	Mauá
R23	Mogi das Cruzes
R24	Osasco
R25	Pirapora do Bom Jesus
R26	Poá
R27	Ribeirão Pires
R28	Rio Grande da Serra
R29	Salesópolis
R30	Santa Isabel
R31	Santana de Parnaíba
R32	Santo André
R33	São Bernardo do Campo
R34	São Caetano do Sul
R35	São Lourenço da Serra
R36	São Paulo
R37	Suzano
R38	Taboão da Serra
R39	Vargem Grande Paulista
R40	Rest of the São Paulo State
R41	Rest of Brazil

SECTORS	
S1	Agriculture. livestock. extractive. aquaculture and fisheries
S2	Mineral extraction
S3	Food product manufacturing
S4	Beverage manufacturing
S5	Tobacco products manufacturing
S6	Textile and textile product mills
S7	Apparel manufacturing
S8	Leather and leather products manufacturing
S9	Wood product manufacturing
S10	Cellulose and Paper Products Manufacturing
S11	Printing and related support activities
S12	Petroleum and coal products manufacturing
S13	Biofuel manufacturing
S14	Chemical manufacturing
S15	Pharma chemicals manufacturing
S16	Plastics and rubber products manufacturing
S17	Nonmetallic mineral product manufacturing
S18	Primary metal manufacturing
S19	Metal product manufacturing
S20	Computer and electronic product manufacturing
S21	Electrical equipment and appliance manufacturing
S22	Mechanical machines manufacturing
S23	Motor vehicle. body. trailer. and parts manufacturing
S24	Other transportation equipment manufacturing
S25	Furniture and related product manufacturing
S26	Maintenance. repair and installation of machinery and equipment
S27	Electricity. natural gas and other utilities
S28	Water. sewage and waste management
S29	Construction
S30	Wholesale and retail trade
S31	Ground transportation
S32	Water transportation
S33	Air Transport
S34	Storage. auxiliary transport and mail activities
S35	Accommodation
S36	Food services
S37	Print-integrated editing and editing
S38	Television. radio. film and sound and image recording/editing activities
S39	Telecommunications
S40	Development of systems and other information services
S41	Financial intermediation. insurance and supplementary pensions
S42	Real estate activities
S43	Legal. accounting. consulting and company headquarters
S44	Architectural. engineering. technical testing/analysis and R&D services
S45	Other professional. scientific and technical activities
S46	Non-real estate rentals and intellectual property asset management
S47	Other administrative activities and complementary services
S48	Surveillance. security and investigation activities
S49	Public administration. defense and social security
S50	Public education
S51	Private education
S52	Public health
S53	Private health
S54	Artistic. creative and entertainment activities
S55	Membership organizations and other personal services
S56	Domestic services

Appendix 2. Unit Root Tests

Industry	V_{it} (level)		V_{it} (ln)	
	Inverse chi-squared (P)	p-value	Inverse chi-squared (P)	p-value
1. Food product manufacturing	108,26	0,00	157,23	0,00
2. Beverage manufacturing	21,41	0,87	49,58	0,01
3. Textile and textile product mills	33,03	1,00	62,01	0,62
4. Apparel manufacturing	17,74	1,00	137,13	0,00
5. Leather and leather products manufacturing	109,43	0,00	63,30	0,03
6. Wood product manufacturing	21,41	0,87	49,58	0,01
7. Cellulose and Paper Products Manufacturing	36,09	1,00	31,49	1,00
8. Printing and related support activities	29,65	1,00	60,41	0,53
9. Petroleum and coal products manufacturing	89,83	0,00	24,11	0,84
10. Chemical manufacturing	139,13	0,00	88,61	0,03
11. Pharma chemicals manufacturing	100,70	0,00	129,33	0,00
12. Plastics and rubber products manufacturing	149,47	0,00	110,50	0,00
13. Nonmetallic mineral product manufacturing	62,23	0,67	89,55	0,04
14. Primary metal manufacturing	341,10	0,00	255,13	0,00
15. Fabricated metal product manufacturing	75,33	0,37	111,06	0,00
16. Computer and electronic product manufacturing	56,26	0,68	101,27	0,00
17. Electrical equipment and appliance manufacturing	115,93	0,00	96,26	0,01
18. Mechanical machines manufacturing	62,50	0,67	146,56	0,00
19. Motor vehicle, body, trailer, and parts manufacturing	10,77	1,00	151,27	0,00
20. Other transportation equipment manufacturing	27,37	0,78	78,37	0,00
21. Furniture and related product manufacturing	27,37	0,78	74,56	0,07

Fisher-type unit-root test based on Phillips-Perron tests. Time trend and panel means included.

Ho: All panels contain unit roots

Ha: At least one panel is stationary

Appendix 3. Estimation results

1. Food product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.956***	0.979***	0.813***	
	(0.0204)	(0.00682)	(0.0317)	
I_{it}	-0.0138**	-0.0126**	-0.0115**	-0.0145**
	(0.00552)	(0.00566)	(0.00523)	(0.00575)
T	0.0289*	0.0254	0.0342*	0.0241
	(0.0167)	(0.0203)	(0.0195)	(0.0205)
T^2	-0.00186*	-0.00177	-0.00181	-0.00175
	(0.000958)	(0.00115)	(0.00108)	(0.00118)
Constant	0.411*	0.180	1.893***	-0.0376
	(0.214)	(0.115)	(0.361)	(0.0760)
Observations	440	440	440	440
R-squared		0.985	0.716	0.019
Number of cod	34		34	34
AR(1)	0.000436			
AR(2)	0.582			
Hansen	0.223			
Number of Instruments	26			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2. Beverage manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.982***	0.990***	0.753***	
	(0.0366)	(0.00910)	(0.0842)	
I_{it}	0.0181**	0.0172	0.0174*	0.0100
	(0.00763)	(0.0123)	(0.00899)	(0.00822)
T	0.0239	0.0383	0.0781	0.0351
	(0.0442)	(0.0298)	(0.0525)	(0.0381)
T^2	-0.00216	-0.00333**	-0.00447	-0.00341
	(0.00293)	(0.00169)	(0.00292)	(0.00261)
VP_{t-1}	0.192	0.129	1.828***	0.0741
	(0.318)	(0.0849)	(0.583)	(0.112)
Observations	153	153	153	153
R-squared		0.989	0.672	0.034
AR(1)	0.133			
AR(2)	0.587			
Hansen	0.960			
Number of Instruments	28			

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

3. Textile and textile product mills

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.980***	0.973***	0.777***	
	(0.0196)	(0.0146)	(0.0528)	
I_{it}	0.000456	-0.00112	0.000223	1.88e-05
	(0.00445)	(0.00675)	(0.00560)	(0.00653)
T	-0.00748	-0.0131	-0.00286	-0.0142
	(0.0165)	(0.0199)	(0.0214)	(0.0228)
T^2	-0.000356	9.64e-06	-0.000872	0.000125
	(0.000978)	(0.00117)	(0.00117)	(0.00138)
Constant	0.261	0.341**	2.207***	0.0787
	(0.210)	(0.136)	(0.554)	(0.0807)
Observations	428	428	428	428
R-squared		0.979	0.620	0.018
AR(1)	0.0421			
AR(2)	0.144			
Hansen	0.357			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4. Apparel manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.886***	0.975***	0.760***	
	(0.0545)	(0.0106)	(0.0602)	
I_{it}	0.0300**	0.0309**	0.0299**	0.0320**
	(0.0122)	(0.0121)	(0.0120)	(0.0124)
T	0.0938***	0.0675*	0.107***	0.0612**
	(0.0280)	(0.0360)	(0.0354)	(0.0279)
T^2	-0.00622***	-0.00476**	-0.00645***	-0.00441**
	(0.00168)	(0.00211)	(0.00203)	(0.00169)
Constant	0.665	0.0817	1.567***	-0.0845
	(0.442)	(0.122)	(0.432)	(0.0968)
Observations	431	431	431	431
R-squared		0.974	0.604	0.031
AR(1)	0.000293			
AR(2)	0.0417			
Hansen	0.227			
Number of Instruments	33			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Leather and leather products manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.894***	0.983***	0.779***	
	(0.0403)	(0.0180)	(0.0920)	
I_{it}	0.0272*	0.0265	0.0278**	0.0328**
	(0.0158)	(0.0165)	(0.0119)	(0.0125)
T	-0.0597	-0.0585	-0.0488	-0.0562
	(0.0579)	(0.0628)	(0.0563)	(0.0538)
T^2	0.00198	0.00196	0.000696	0.00168
	(0.00297)	(0.00372)	(0.00281)	(0.00299)
Constant	1.034***	0.418*	1.831***	0.311
	(0.284)	(0.235)	(0.515)	(0.204)
Observations	279	279	279	279
R-squared		0.934	0.603	0.029
AR(1)	0.00398			
AR(2)	0.808			
Hansen	0.426			
Number of Instruments	26			

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

6. Wood product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.982***	0.990***	0.753***	
	(0.0366)	(0.00910)	(0.0842)	
I_{it}	0.0181**	0.0172	0.0174*	0.0100
	(0.00763)	(0.0123)	(0.00899)	(0.00822)
T	0.0239	0.0383	0.0781	0.0351
	(0.0442)	(0.0298)	(0.0525)	(0.0381)
T^2	-0.00216	-0.00333**	-0.00447	-0.00341
	(0.00293)	(0.00169)	(0.00292)	(0.00261)
Constant	0.192	0.129	1.828***	0.0741
	(0.318)	(0.0849)	(0.583)	(0.112)
Observations	153	153	153	153
R-squared		0.989	0.672	0.034
AR(1)	0.133			
AR(2)	0.587			
Hansen	0.960			
Number of Instruments	28			

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

7. Cellulose and Paper Products Manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.960***	0.954***	0.617***	
	(0.0688)	(0.0295)	(0.159)	
I_{it}	0.00596	0.00761	0.00225	0.00454
	(0.00697)	(0.00868)	(0.00608)	(0.00695)
T	-0.00216	0.00616	0.0289	0.00144
	(0.0264)	(0.0158)	(0.0217)	(0.0150)
T^2	0.000130	-0.000442	-0.00177	-0.000266
	(0.00180)	(0.000952)	(0.00119)	(0.000974)
Constant	0.449	0.499	4.040**	0.0292
	(0.681)	(0.305)	(1.704)	(0.0517)
Observations	390	390	390	390
R-squared		0.967	0.366	0.002
AR(1)	0.00411			
AR(2)	0.802			
Hansen	0.135			
Number of Instruments	26			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

8. Printing and related support activities

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.937***	0.968***	0.786***	
	(0.0332)	(0.00974)	(0.0410)	
I_{it}	-7.65e-05	-0.00387	0.0123	-0.00427
	(0.0177)	(0.0183)	(0.0193)	(0.0203)
T	0.00507	0.0320	-0.0388	0.0461
	(0.0332)	(0.0324)	(0.0408)	(0.0284)
T^2	0.000814	-0.000762	0.00333	-0.00158
	(0.00188)	(0.00201)	(0.00264)	(0.00169)
Constant	0.382	0.0292	1.823***	-0.284**
	(0.371)	(0.144)	(0.469)	(0.105)
Observations	392	392	392	392
R-squared		0.972	0.591	0.014
AR(1)	0.000156			
AR(2)	0.165			
Hansen	0.102			
Number of Instruments	26			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

9. Petroleum and coal products manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.914***	0.984***	0.624***	
	(0.0522)	(0.0146)	(0.156)	
I_{it}	-0.0146**	-0.0149*	-0.0145**	-0.0156**
	(0.00577)	(0.00851)	(0.00595)	(0.00658)
T	-0.0189**	-0.0273	0.0221	-0.0267**
	(0.00856)	(0.0248)	(0.0315)	(0.0103)
T^2	0.000207	0.000811	-0.00174	0.000863
	(0.000697)	(0.00146)	(0.00225)	(0.000649)
Constant	1.025*	0.324*	3.916**	0.142***
	(0.577)	(0.192)	(1.566)	(0.0445)
Observations	178	178	178	178
R-squared		0.966	0.377	0.029
AR(1)	0.0293			
AR(2)	0.217			
Hansen	0.788			
Number of Instruments	24			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

10. Chemical manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.849***	0.985***	0.455***	
	(0.0630)	(0.0108)	(0.0972)	
I_{it}	0.000773	0.00202	-0.0102**	0.00195
	(0.00455)	(0.00749)	(0.00396)	(0.00346)
T	-0.0201*	-0.00701	-0.00594	-0.00604
	(0.0111)	(0.0176)	(0.0140)	(0.0107)
T^2	0.00117*	0.000582	0.000446	0.000518
	(0.000617)	(0.000991)	(0.000961)	(0.000652)
Constant	1.758**	0.185*	6.061***	0.0141
	(0.732)	(0.104)	(1.105)	(0.0389)
Observations	426	426	426	426
R-squared		0.984	0.210	0.001
AR(1)	0.0573			
AR(2)	0.633			
Hansen	0.0609			
Number of Instruments	20			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

11. Pharma chemicals manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	1.006***	0.997***	0.771***	
	(0.00898)	(0.0122)	(0.0924)	
I_{it}	0.00214	0.00108	-0.000559	0.00178
	(0.00460)	(0.00606)	(0.00545)	(0.00562)
T	-0.0516**	-0.0501***	-0.0241	-0.0498***
	(0.0201)	(0.0176)	(0.0209)	(0.0172)
T^2	0.00253**	0.00235**	0.000739	0.00235**
	(0.00118)	(0.00101)	(0.00121)	(0.00107)
Constant	0.145	0.265*	2.856**	0.222***
	(0.117)	(0.151)	(1.080)	(0.0583)
Observations	247	247	247	247
R-squared		0.992	0.678	0.059
AR(1)	0.0783			
AR(2)	0.758			
Hansen	0.186			
Number of Instruments	20			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

12. Plastics and rubber products manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.980***	1.006***	0.837***	
	(0.0150)	(0.00824)	(0.0228)	
I_{it}	-0.00876	-0.0121**	-0.0105*	-0.0125**
	(0.00615)	(0.00574)	(0.00526)	(0.00542)
T	0.0287*	0.0330*	0.0405**	0.0332*
	(0.0165)	(0.0172)	(0.0153)	(0.0170)
T^2	-0.00230**	-0.00261**	-0.00307***	-0.00263**
	(0.00102)	(0.00102)	(0.000867)	(0.000998)
Constant	0.133	-0.158**	1.627***	-0.0959
	(0.178)	(0.0793)	(0.250)	(0.0590)
Observations	481	481	481	481
R-squared		0.990	0.674	0.032
AR(1)	0.0551			
AR(2)	0.126			
Hansen	0.0883			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

13. Nonmetallic mineral product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) lnVP14	(3) lnVP14	(4) D.lnVP14
VP_{t-1}	0.986***	0.988***	0.793***	
	(0.0284)	(0.00651)	(0.0322)	
I_{it}	0.00877	0.00438	0.00758	0.00526
	(0.00573)	(0.00579)	(0.00488)	(0.00529)
T	0.0713***	0.0759***	0.0957***	0.0747***
	(0.0259)	(0.0175)	(0.0194)	(0.0209)
T^2	-0.00516***	-0.00544***	-0.00604***	-0.00543***
	(0.00148)	(0.00102)	(0.00105)	(0.00122)
Constant	0.00206	-0.0380	1.826***	-0.152**
	(0.290)	(0.0982)	(0.343)	(0.0745)
Observations	438	438	438	438
R-squared		0.989	0.731	0.095
Number of cod	34		34	34
AR(1)	0.0222			
AR(2)	0.502			
Hansen	0.0978			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

14. Primary metal manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.976***	0.998***	0.567***	
	(0.0407)	(0.0133)	(0.0611)	
I_{it}	-0.0415**	-0.0441**	-0.0259***	-0.0461***
	(0.0168)	(0.0190)	(0.00938)	(0.0165)
T	-0.0967***	-0.0942***	-0.0348	-0.0936***
	(0.0373)	(0.0289)	(0.0365)	(0.0228)
T^2	0.00387*	0.00377**	-0.00101	0.00375**
	(0.00231)	(0.00172)	(0.00264)	(0.00151)
Constant	0.610*	0.384**	4.534***	0.360***
	(0.329)	(0.153)	(0.561)	(0.0764)
Observations	398	398	398	398
R-squared		0.968	0.410	0.068
AR(1)	0.0291			
AR(2)	0.0898			
Hansen	0.0900			
Number of Instruments	26			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

15. Fabricated metal product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.978***	0.987***	0.648***	
	(0.0167)	(0.0123)	(0.0558)	
I_{it}	-0.0252***	-0.0242***	-0.0170***	-0.0258***
	(0.00543)	(0.00631)	(0.00575)	(0.00552)
T	-0.0121	-0.0147	0.0400**	-0.0174
	(0.0121)	(0.0182)	(0.0180)	(0.0113)
T^2	-0.000732	-0.000567	-0.00371***	-0.000434
	(0.000730)	(0.00108)	(0.00114)	(0.000658)
Constant	0.359*	0.275**	3.744***	0.142***
	(0.189)	(0.134)	(0.579)	(0.0436)
Observations	462	462	462	462
R-squared		0.985	0.497	0.102
AR(1)	0.0210			
AR(2)	0.889			
Hansen	0.389			
Number of Instruments	39			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

16. Computer and electronic product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.955***	0.962***	0.761***	
	(0.0297)	(0.0176)	(0.0625)	
I_{it}	-0.0425***	-0.0340**	-0.0341**	-0.0416***
	(0.0141)	(0.0146)	(0.0126)	(0.0133)
T	0.0146	0.0272	0.00172	0.0262
	(0.0312)	(0.0370)	(0.0321)	(0.0308)
T^2	-0.00151	-0.00228	-0.000506	-0.00246
	(0.00197)	(0.00232)	(0.00208)	(0.00199)
Constant	0.347	0.248	2.177***	-0.0933
	(0.273)	(0.189)	(0.605)	(0.100)
Observations	351	351	351	351
R-squared		0.947	0.585	0.035
AR(1)	0.0198			
AR(2)	0.00414			
Hansen	0.191			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

17. Electrical equipment and appliance manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.943***	0.966***	0.629***	
	(0.0204)	(0.0168)	(0.0781)	
I_{it}	-0.0253***	-0.0211***	-0.0212**	-0.0248***
	(0.00776)	(0.00749)	(0.00792)	(0.00817)
T	-0.0287	-0.0283	0.00835	-0.0322
	(0.0214)	(0.0247)	(0.0231)	(0.0220)
T^2	0.000455	0.000567	-0.00198	0.000800
	(0.00130)	(0.00148)	(0.00132)	(0.00133)
Constant	0.764***	0.514***	3.991***	0.160**
	(0.219)	(0.182)	(0.791)	(0.0758)
Observations	402	402	402	402
R-squared		0.973	0.458	0.046
AR(1)	0.00517			
AR(2)	0.0239			
Hansen	0.126			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

18. Mechanical machines manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.970***	0.975***	0.588***	
	(0.0237)	(0.00817)	(0.0711)	
I_{it}	-0.0106**	-0.0129**	-0.00715	-0.0131***
	(0.00471)	(0.00539)	(0.00471)	(0.00471)
T	-0.00179	0.000459	0.0654***	-0.00592
	(0.0166)	(0.0196)	(0.0147)	(0.0178)
T^2	-0.00129	-0.00141	-0.00464***	-0.00101
	(0.000949)	(0.00117)	(0.000862)	(0.00102)
Constant	0.447	0.388***	4.465***	0.124*
	(0.285)	(0.141)	(0.793)	(0.0682)
Observations	432	432	432	432
R-squared		0.980	0.488	0.088
AR(1)	0.000197			
AR(2)	0.531			
Hansen	0.270			
Number of Instruments	33			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

19. Motor vehicle, body, trailer, and parts manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.963***	0.977***	0.704***	
	(0.0274)	(0.00936)	(0.0836)	
I_{it}	-0.00771	-0.00459	-0.00887	-0.00877
	(0.00647)	(0.00655)	(0.00592)	(0.00668)
T	0.0233	0.0183	0.0995***	0.0127
	(0.0232)	(0.0251)	(0.0343)	(0.0242)
T^2	-0.00338**	-0.00304**	-0.00805***	-0.00289*
	(0.00133)	(0.00143)	(0.00206)	(0.00145)
Constant	0.477	0.336***	3.119***	0.108
	(0.314)	(0.111)	(0.862)	(0.0821)
Observations	408	408	408	408
R-squared		0.981	0.659	0.120
AR(1)	0.00242			
AR(2)	0.646			
Hansen	0.121			
Number of Instruments	28			

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

20. Other transportation equipment manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.971***	0.999***	0.768***	
	(0.0796)	(0.0138)	(0.0789)	
I_{it}	-0.0679***	-0.0601***	-0.0494**	-0.0594***
	(0.0202)	(0.0172)	(0.0202)	(0.0195)
T	-0.159**	-0.155***	-0.137***	-0.152***
	(0.0682)	(0.0487)	(0.0364)	(0.0499)
T^2	0.00810**	0.00809***	0.00591**	0.00774***
	(0.00370)	(0.00269)	(0.00214)	(0.00262)
Constant	0.745	0.514**	2.386***	0.508**
	(0.614)	(0.223)	(0.710)	(0.200)
Observations	203	203	203	203
R-squared		0.963	0.642	0.113
AR(1)	0.0118			
AR(2)	0.183			
Hansen	0.738			
Number of Instruments	24			

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

21. Furniture and related product manufacturing

VARIABLES	(1) SYSTEM GMM	(2) POLS	(3) FE	(4) FIRST DIFFERENCE
VP_{t-1}	0.947***	0.966***	0.810***	
	(0.0275)	(0.0155)	(0.0530)	
I_{it}	-0.00900	-0.0112	-0.0109	-0.0135
	(0.00986)	(0.0120)	(0.0119)	(0.0119)
T	0.0807**	0.0837**	0.0894**	0.0758**
	(0.0365)	(0.0425)	(0.0411)	(0.0368)
T^2	-0.00528**	-0.00546**	-0.00521**	-0.00505**
	(0.00217)	(0.00249)	(0.00237)	(0.00217)
Constant	0.257	0.0730	1.403***	-0.204
	(0.229)	(0.134)	(0.492)	(0.138)
Observations	348	348	348	348
R-squared		0.948	0.662	0.011
AR(1)	0.0389			
AR(2)	0.910			
Hansen	0.216			
Number of Instruments	28			

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1