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Research paper

Accelerated growth of the sugarcane, sugar, and ethanol sectors in Brazil (2000–2008): Effects on municipal gross domestic product per capita in the south-central region



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ABSTRACT

During the 2000–2008 period, there was a marked acceleration in the growth of the sugarcane, sugar, and ethanol sectors of Brazil, which are most active in the south-central region of the country. Therefore, the objective of this study was to evaluate the effects of those sectors on the municipal gross domestic product (GDP) per capita in the south-central region of Brazil during that period. To that end, we constructed a theoretical model, estimating its parameters with a generalized method of moments system estimator and using spatial dynamic panel data to estimate the direct (municipal) effects and indirect (regional) effects. The cumulative direct and indirect effects increased the real municipal GDP per capita by 1028 \$ in the host municipalities and by 324 \$ in each of their 15 closest neighboring municipalities. On the basis of our findings, we can infer that the effects of establishing a sugar mill or ethanol plant are most significant for the host municipality and persist for at least 10 years after operations begin. Our results also indicate that sugarcane production has a significant, positive impact on municipal GDP per capita, not only in the municipalities where that production takes place but also in neighboring municipalities.

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1. Introduction

The objective of this study was to quantify and evaluate the effects that the sugarcane, sugar, and ethanol sectors (hereafter collectively referred to as the sugarcane industry) have on the municipal gross domestic product (GDP) per capita in the south-central region of Brazil between 2000 and 2008, a period during which there was considerable growth of those sectors. We focused on the south-central region, which comprises the states of São Paulo, Paraná, Minas Gerais, Mato Grosso do Sul, Mato Grosso, and Goiás, as well as the Federal District of Brasília, because it surpasses all other regions of the country in terms of the production of sugarcane, sugar, and ethanol.

Because Brazil is a country of continental dimensions, the economic structure and socioeconomic conditions vary considerably among its geographic regions. Most previous studies of the effects

of the sugarcane industry have focused on the state of São Paulo [1–3]. For a more comprehensive evaluation, it is essential to expand that analysis to the other regions of the country. So, in face of this heterogeneity, the objective of this paper was to increase the current knowledge of the effects of that industry in the Brazilian states that are less industrialized and present socioeconomic conditions different than those in the state of São Paulo.

Beginning in the year 2000, there was marked acceleration in the rate of growth of the sugarcane industry in Brazil. The most rapid growth occurred in the 2000–2008 period, during which the production of sugarcane grew by 124.6% and the amount of land devoted to its cultivation grew by 68.2% [4]. That led to the construction of new mills and consequent increases in exports, as reported in an ever-increasing number of studies on the topic. Foreign trade figures indicate that, from 2000 to 2008, exports of sugar and ethanol increased by 199.4% and 2152.3%, respectively [5]. However, it should be borne in mind that the ethanol market is now considerably less vigorous.

The initial expansion of the sugarcane industry in Brazil

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occurred in the early 2000s and was mainly due to an increase in ethanol production, driven by the growing prospects for ethanol demand in domestic and foreign markets. At that time, companies invested in plants designed to produce only ethanol. Over the years, the vast majority of those plants incorporated a sugar mill, in order to increase production flexibility and to optimize profitability during periods of unfavorable ethanol pricing. In this paper, we estimate the impacts of the expansion of sugarcane production, as well as those of the expansion of the sugar and ethanol sectors considered jointly.

In a review of the sugarcane industry, Gilio [6] stated that there has also been strong post-2000 growth in the number of studies related to the industry, which the author found to correlate directly with the degree of expansion of the industry itself. The author noted that most such studies have been regionalized, underscoring the need for studies evaluating the broader effects of the growth of this industry. Given the efforts to understand the dynamics and interactions of these sectors with the Brazilian economy, together with the lack of comprehensive studies, the present study seeks to investigate the relationship between accelerated growth of the sugarcane industry and production/income—the GDP per capita—at the municipal level, for the south-central region of Brazil.

Evaluating the direct and indirect effects of sugarcane, sugar, and ethanol production is of paramount importance for quantifying the contribution of this industry to the regional and national economy, which could facilitate the selection of targets for future research and inform the decisions of policy makers. According to Barros et al. [7], studies aimed at singling out the determinants of per capita income and capturing the economic aspect also evaluate economic welfare.

In view of the aforementioned lack of comprehensive studies of the sugarcane industry of Brazil, we used econometric tools for the analysis of panel data, in order to model the relationship between municipal GDP per capita and expansion of the industry in the south-central region of the country.

The estimated models include spatial dynamic panel data, estimated with a generalized method of moments system estimator (GMM-SYS), which allows the effects to be quantified, not only for the host municipalities but also for those in the surrounding area (i.e., the regional effects) [8,9]. Dynamic panel data models that accommodate spatial dependence have recently attracted considerable attention. Therefore, there has been increasing development of new theoretical and empirical models focusing on externalities and spillover effects, with a special focus on regional effects [10].

2. Overview of the sugarcane industry in Brazil, 2000–2008

In the late 1990s, the sugarcane industry of Brazil began to undergo a profound transformation. The observed changes were not restricted to the ethanol market. There were also institutional changes related to various factors, including the cessation of government intervention, the advent of flex-fuel vehicles, mergers/acquisitions, and the rapid internationalization of assets, exemplifying the profound, comprehensive character of the changes [11]. There were external factors as well. Countries seeking to mitigate greenhouse gas emissions by introducing ethanol into their energy mix began to pay close attention to the emergence of renewable energy sources and biofuel derived from sugarcane [1]. This new structure ensured a dynamic of accelerated growth in the industry, in terms of production, processing (production units), and exports. Fig. 1 shows the evolution of sugarcane production between the harvests of 1990–91 and 2013–14.

As can be seen, the expansion was most pronounced between the 2000–01 and 2008–09 harvests. In addition, in the 2009–10

and 2010–11 harvests, there was a marked slowdown in the rate of growth, followed by a transitory downward trend. According to data obtained from the Brazilian Sugarcane Industry Association and the Western São Paulo Association of Ethanol Plants [5,12], the downward trend observed between the harvest of 2010–11 and that of 2012–13 constituted the so-called Brazilian sugarcane industry crisis, characterized by reduced production and the closing of many production facilities, as is also currently the case.

Another important aspect of the sugarcane industry of Brazil during the period evaluated was the regional distribution of sugarcane production, the south-central region accounting for approximately 84% of the total production of the country. By the harvests of 2012–13 and 2013–14, that proportion had increased to a mean of 91%. Conversely, there has been a relative stagnation of sugarcane production in the northern and northeastern regions.

Table 1 summarizes the data related to the production of sugarcane, sugar, and ethanol for the harvests of 2000–01, 2008–09, and 2013–14.

Foreign trade figures for the period in question confirm the importance of the sugarcane industry for generating foreign exchange gains and therefore for the Brazilian economy in general. As can be seen in Fig. 2, Brazilian sugar exports increased from approximately 6.5 Mt in 2000 to 19.4 Mt in 2008, a 199.46% increase. Likewise, exports of ethanol increased from approximately 0.22 hm³ to 5.11 hm³, an increase of 2152.30%, between 2000 and 2008.

In the 2000–2008 period, the foreign exchange gains from the export of sugar and ethanol (in free on board values) were 31 billion dollars and 7.18 billion dollars, respectively. Of all Brazilian agribusiness exports in that period, sugar and ethanol collectively accounted for 10.4% (8.5% for sugar and 1.9% for ethanol).

Despite the post-2009 crisis, exports of sugar and ethanol are still relevant for Brazilian agribusiness. According to the Brazilian Ministry of Agriculture, Animal Husbandry, and Supply [13], agribusiness exports in 2013 totaled 99.97 billion dollars, of which the sugarcane industry accounted for 13.70%, comprising sugar exports of 11.84 billion dollars (11.8%) and ethanol exports of 1.86 billion dollars (1.8%).

Within the period studied, there were also certain phases during which processing (as quantified by number of production units) was more vigorous. Fig. 3 shows the distribution of sugarcane processing facilities, distinguishing between those already operating in 2000 and those coming online between 2000 and 2008, in the 2363 municipalities within the south-central region. According to Moraes and Zilberman [11], the year of greatest expansion in the sugarcane processing capacity of Brazil was 2008, during which operations began at 30 new facilities—all located in the south-central region. Those authors also showed that there was a post-2009 slowdown, describing it as a period of crisis and of greater caution in terms of the level of investment in the sugarcane industry.

In addition to altering the agricultural landscape, the activities of the sugarcane industry have had various socioeconomic effects on sugarcane producing regions, which has raised a number of questions about this process. Efforts to understand the changes underlying the accelerated growth of this industry have intensified in recent years. Various studies, with different objectives and employing diverse methodological approaches, have addressed this topic. In a systematic review of the literature on this topic, focusing on the socioeconomic impact, Gilio [6] identified a multitude of studies.

According to Shikida and Souza [2], the presence of a sugarcane processing facility drives economic growth in municipalities in Brazil. In support of that assertion, various other authors have demonstrated that such facilities not only create jobs directly but

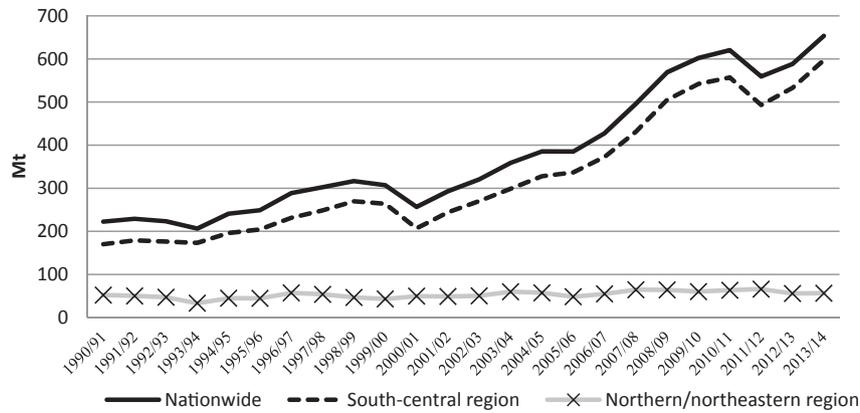


Fig. 1. Evolution of sugarcane production in Brazil between 1990 and 2014.

Source: Brazilian Sugarcane Industry Association [2].

Table 1

Sugarcane yields, sugar production, and ethanol production for the harvests of 2000–01, 2008–09, and 2013–14.

Harvest	Region	Sugarcane		Sugar		Ethanol	
		Mt	%	Mt	%	hm ³	%
2000–01	Northern/Northeastern	49.7	19.5	3.6	22.2	1.5	14.5
	South-central	205.2	80.5	12.5	77.8	9.0	85.5
	Nationwide	254.9	100.0	16.0	100.0	10.5	100.0
2008–09	Northern/Northeastern	64.1	11.2	4.3	13.6	2.4	8.7
	South-central	508.6	88.8	27.2	86.4	25.3	91.3
	Nationwide	572.7	100.0	31.5	100.0	27.7	100.0
2013–14	Northern/Northeastern	56.0	8.5	3.4	9.01	1.96	7.1
	South-central	597.0	91.3	34.2	90.7	25.7	93.4
	Nationwide	653.5	100.0	37.7	100.0	27.5	100.0

Sources: Brazilian Ministry of Agriculture, Animal Husbandry, and Supply [8]; and Brazilian Sugarcane Industry Association [2].

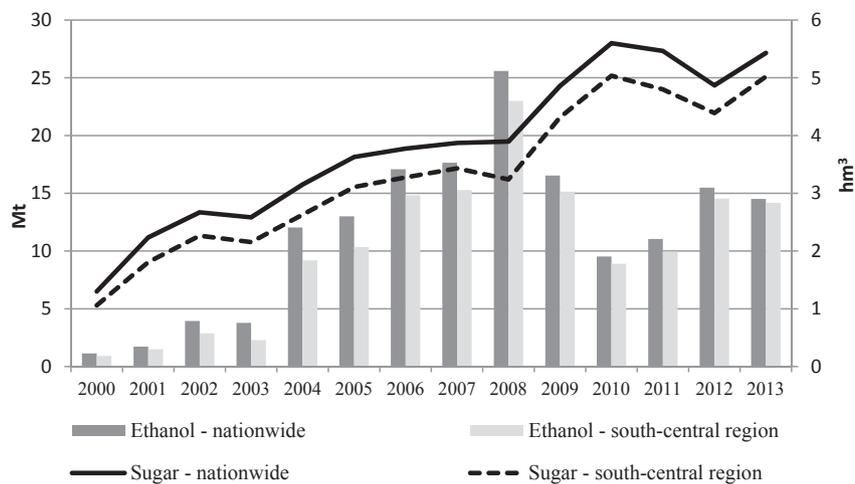


Fig. 2. Sugar and Ethanol exports from Brazil between 2000 and 2014.

Source: Brazilian Sugarcane Industry Association [2].

also have indirect effects on the local business sector and service industry, promoting urbanization, raising incomes, and expanding the population, thus increasing municipal tax revenues [2,3,14–16].

To gain a better understanding of the impacts that the expansion of the sugarcane industry has had on the Brazilian economy, it is important to consider the roles that this industry plays in its interactions with other sectors of the economy, whether as a purchaser of the inputs needed for production, as a supplier of products for indirect use (in the food, beverage, pharmaceutical, or

cosmetic sectors), or as a supplier of products for direct use (by the final consumers of sugar and ethanol). Neves et al. [17] outlined the sugarcane energy supply chain and cited various inputs used by the sugarcane industry as a whole. In the case of sugarcane cultivation, such inputs include fertilizers, herbicides, pesticides, auto parts, maintenance services, combine harvesters, tractors, farm implements, trucks, diesel fuel, and lubricating oils. The main inputs for sugar mills and ethanol plants include the following: equipment (steam generator, sugarcane press, sugar processing machinery,

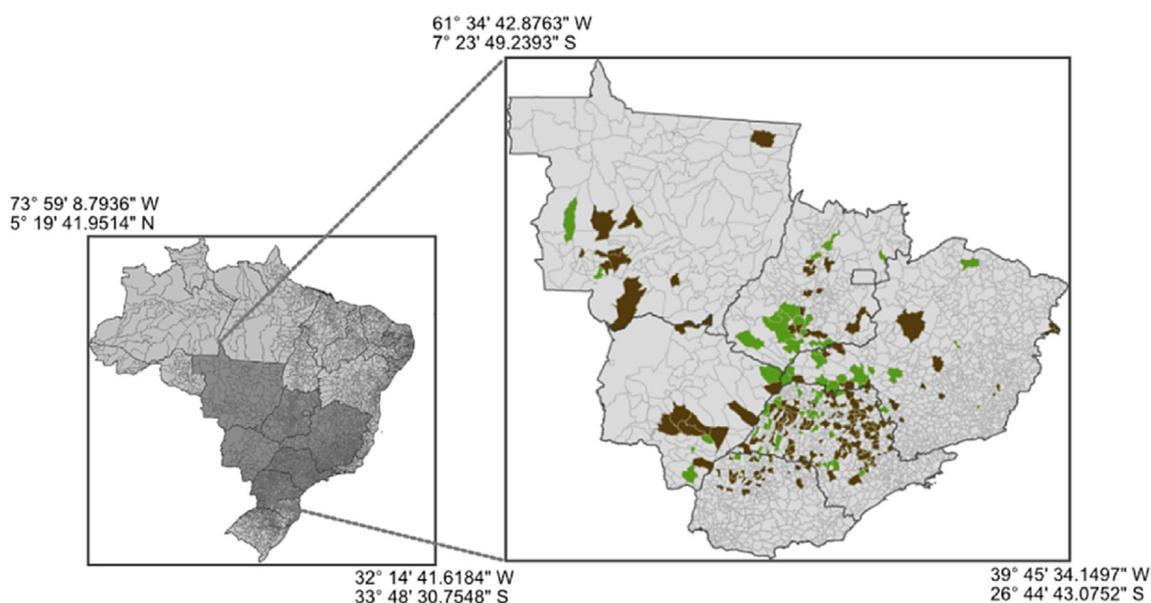


Fig. 3. Sugarcane processing facilities in the south-central region of Brazil, 2000–2008. Note: Brown shading indicates municipalities in which facilities were already operating in 2000, whereas green shading indicates municipalities in which facilities came online between 2000 and 2008. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Sources: Brazilian Sugarcane Industry Association [2]; Sugarcane Statistical Yearbook [23]; and the Brazilian Ministry of Agriculture, Animal Husbandry, and Supply [8].

power generator); automation and electric installation; construction; assembly and maintenance services; chemical products; yeasts and additives; fuel and oil lubricants; sacks; large bags; laboratory materials; and personal protective equipment. The main products, sugar and ethanol, are sold to a variety of customers, including the beverage industry, the cosmetic industry, the food industry, the animal feed industry, filling stations, and the final consumers. Thus, when there is the growth of the sugarcane industry, various other sectors of the economy benefit and the growth extends throughout the economy, because of the interactions among sectors. Computable General Equilibrium (CGE) and input-output (I-O) models are used in the literature to assess the impact that the sugarcane supply chain has on the economy as a whole.

Costa et al. [18] identified the changes that occurred in the ethanol sector in the 1970–2006 period, as well as analyzing its interrelations with other sectors of the Brazilian economy. In addition to ethanol production, their analysis included sugarcane cultivation, sugar manufacturing, oil extraction, and petroleum refining. Various indices calculated by the authors demonstrated that the sugarcane industry has a significant impact on the Brazilian economy, due to multiplier effects, the employment generated, and the supply or purchase of various inputs.

Martínez et al. [19] used an I-O model to assess the socioeconomic impacts of sugarcane-derived bioethanol production, in terms of value added, imports, and employment, in the north-eastern region of Brazil. The model showed that developing and expanding the sugarcane industry in the region had significant, positive socioeconomic impacts under the conditions studied.

Santos [20] analyzed the impacts that the expansion in the production of ethanol and biodiesel, as substitutes for fossil fuels (based on the Brazilian National Energy Plan), had on the Brazilian economy between 2010 and 2030. A CGE model of the Brazilian economy was used for that purpose. The results showed that the effects generated by biofuel policies increased the macroeconomic aggregates in the economy.

Moraes et al. [21] estimated the impact that increases in the

demand for ethanol on have on the Brazilian economy. They used an inter-regional I-O matrix and calculated the multipliers that quantify the impact that a variation in final demand has on the economic variables. The results show that an increase in the consumption of hydrous ethanol has a strong potential for creating employment and income at the national level.

Taken together, the findings of the group of studies cited [17–19,21] underscore the idea that the sugarcane industry is quite important for the Brazilian economy. We can observe that the industry can affect the dynamic of the Brazilian economy due to its forward and backward linkages to other sectors. However, the I-O and CGE models do not take spatial relationships into account; nor do they evaluate impacts at the municipal level.

Satolo and Bacchi [3], using spatial dynamic panel data for the 2000–2008 period, investigated the relationship between accelerated growth of the sugarcane industry and municipal GDP per capita for the state of São Paulo. The authors found a positive relationship between the two, and their spatial analysis showed that the presence of a sugarcane processing facility in one municipality also has a positive, albeit lesser, impact on neighboring municipalities. That spillover can be explained by the migration that such facilities attract and by the growth in local income per se, which increases the demand for goods and services consumed locally, thereby multiplying the positive effects on income. Those same authors identified temporal effects that persisted for the duration of the subsequent 10-year period evaluated.

In the context of spatial effects, the main contribution of the present study, which differs from those conducted previously [1,3,6,14], is the fact that it had a broader geographic scope—encompassing the entire south-central region of Brazil, the main sugarcane-producing region of the country—as well as that it evaluated a different set of variables. This article seeks to measure and evaluate the socioeconomic impacts of the sugarcane industry, not only in the state of São Paulo, but also in all of the major sugarcane-producing and processing states in Brazil. It is of note that the area under analysis—the south-central region—presents a highly heterogeneous profile with regard to its economy,

demographics, and socioeconomic indicators. In 2013, the south-central state with the highest GDP per capita was São Paulo. In comparison with that of São Paulo, the GDP per capita of Paraná was 22% lower, whereas it was 28% lower for Mato Grosso, 31% lower for Mato Grosso do Sul, 39% lower for Minas Gerais, and 40% lower for Goiás [22]. The south-central region of Brazil is also quite heterogeneous in terms of the Human Development Index, which, in 2010, was 0.78 for São Paulo, compared with only 0.74 for Paraná, 0.73 for Goiás, 0.72 for Minas Gerais, 0.72 for Mato Grosso do Sul, and 0.72 for Mato Grosso [22]. Therefore, when assessing the effects of the sugarcane industry in the state of São Paulo [1,3,6], the analysis corresponds to an economic reality quite different from that of the states in which the expansion is more recent (Paraná, Minas Gerais, Mato Grosso do Sul, Mato Grosso and Goiás), where those effects would be expected to be different. To understand whether the effects on regions with different sociodemographic indicators and production structures are similar to those reported for the state of São Paulo, it is relevant to include the other sugarcane-producing states of the south-central region in the analysis. Also of note is the mechanization in sugarcane harvesting in the states where sugarcane production is a recent development. In such states, nearly 100% of the harvest is mechanized, unlike the state of São Paulo, which, in the studies cited above, was reported to make extensive use of manual labor.

Because the spatial correlation is such an important methodological consideration, we have not attempted to draw comparisons between our study and those whose analyses did not consider the spatial effects [2,14,21].

In the present study, we seek to understand the relationship between the activity of the sugarcane industry and municipal GDP per capita in the south-central region of Brazil, considering the various states in the aggregate, whereas previous studies of this type have examined the effects on GDP per capita only for the state of São Paulo.

3. Economic model

In this study, we aimed to build an empirical model of the determinants of municipal GDP per capita. Our methodology was based on the arguments of Bacchi and Caldarelli [1] and Satolo and Bacchi [3], who stated that, in theory, economic welfare is quantified in terms of social utility, whereas, empirically, it has most often been analyzed in terms of real per capita income. Consequently, one can use the theoretical foundation of the functions of economic welfare for the construction of the desired empirical model. Therefore, we employed GDP per capita as a proxy for real per capita income.

According to Barros et al. [7] and Satolo and Bacchi [3], the determinants of the per capita income of a region—the expansion of real per capita income from a family to a group—taken in this study as municipal per capita income, can be expressed by the following equation:

$$y_i = \phi(w_i, u_i, r_i) \quad (1)$$

where ϕ is defined at the municipal level, y_i is the real municipal per capita income, w_i is the mean per capita yield from labor, u_i is the use of the workforce, and r_i is the proportion of adults in the population. Into this basic construction, devised by Barros et al. [7], we incorporated elements from Bacchi and Caldarelli [1], Satolo and Bacchi and Gilio [6], with the objective of making the theoretical construction consistent with the empirical aspects. Given that the model constructed is aimed at isolating the effects that the sugarcane industry has on municipal per capita income in Brazil, we incorporated the following variables: mean real income in

agriculture (w_i^A); rate of use of the workforce in agriculture (r_i^A); proportional representation of sugarcane in the area planted for temporary crops (c_i^T); proportional representation of temporary crops in the area used for agriculture (a_i^T); proportional representation of agricultural crops in the total landmass of Brazil (a_i^M); and a variable that indicates whether a sugarcane processing facility is in operation in a given municipality (Du). Those variables, collectively, serve as controls for socioeconomic and demographic aspects. Therefore, the model we propose to estimate in this study is as follows:

$$y_i = \phi(w_i, w_i^A, u_i, r_i, r_i^A, c_i^T, a_i^T, a_i^M, Du) \quad (2)$$

The rationale behind the choice of these variables is as follows:

- Mean real income in agriculture: to isolate the contribution of the mean agricultural mean income to the GDP
- Rate of use of the workforce in agriculture: to isolate the contribution of the agricultural workforce to the GDP
- Proportional representation of sugarcane in the area planted for temporary crops: to estimate the effects that the cultivation of sugarcane and other temporary crops have on the GDP
- Proportional representation of agricultural crops in the total landmass of Brazil: to determine the effect of agriculture on the GDP
- Whether a sugarcane processing facility is in operation in a given municipality: to distinguish between municipalities that have a sugar mill/ethanol plant and those that do not
- Proportional representation of temporary crops in the area used for agriculture: to evaluate the effects that crops other than temporary ones have on the total area used for agriculture in the municipality. It is important to know whether the expansion of the sugarcane sector occurred at the expense of other agricultural activities or without replacement of temporary crops, as well as whether the impacts on the GDP were different across these different scenarios. We constructed two scenarios in order to evaluate the effects that accelerated growth of the sugarcane industry had on municipal GDP per capita.

The main difficulty involved in the construction of theoretical economic models, especially of those aimed at capturing the effects of variables on economic welfare and per capita income, is the fact that not all influencing factors can be included. Because of the complexity of economic welfare, there is no consensus regarding its practical measures. Therefore, although the formulation of these models is based in theory and on the existing literature, the process also requires that the researcher selects the variables. It should be borne in mind that such difficulty is inherent to studies such as ours.

4. Methods

4.1. Spatial dynamic panel data analysis

We employed an econometric tool that involves the use of dynamic panels with spatial control. According to Greene [23], models using panel data allow economic relationships to be established while also exploring effects over time and between different units (individuals). The technique of clustering time series data and cross-sectional data (panel data) allows econometric models to be estimated more efficiently. From an estimation point of view, such models have advantages, such as a larger number of observations (which ensures the asymptotic properties of the estimators), more degrees of freedom, and reduced multicollinearity.

A dynamic panel data model, as described by Kukenova and

Monteiro [24], considers the potentially endogenous dependent variable (y_{it}), thereby mitigating the endogeneity of the dependent variable, interpreting it as a temporally lagged explanatory variable. Such a model can be represented as follows:

$$y_{it} = \tau y_{it-1} + \beta_1 x_{it1} + \beta_2 x_{it2} + \dots + Z + \varepsilon_{it} \quad (3)$$

where $i = 1, \dots, N$ represents the units, $t = 1, \dots, T$ represents the time periods, and $N \times T$ is the number of observations. It should be noted that the use of the dependent variable as a temporally lagged explanatory variable violates the assumptions of the ordinary least squares estimators. Therefore, the recommended technique for estimating dynamic panel data models is a generalized method of moments (GMM), as described by Arellano and Bond [25], an extended version of which — the generalized method of moments system (GMM-SYS), as proposed by Blundell e Bond [26] was employed in the present study. The instrumental treatment of all endogenous variables, as achieved with the GMM-SYS, can mitigate the endogeneity of the lagged dependent variable, as well as correcting other potentially endogenous explanatory variables [24]. We used the specification test devised by Arellano and Bond [25], which examines the average covariance between the residual vector of the equation with two lagged differences ($\Delta \hat{\varepsilon}_{-2}$) and the corresponding residual vector ($\Delta \hat{\varepsilon}$). These means are independent random variables and, under the null hypothesis, have a mean of zero.

In addition, when considering the geographical dimension of the effects to be analyzed, one must take into account the so-called spatial effect. The rationale for using that approach [1,3,6,10] is that one observation can be associated with another, depending on its location—it is a correlation of the variable in space.

The need to include spatial controls in the model can be preliminarily evaluated by determining Moran's I index for the overall spatial autocorrelation. The I index, developed by Moran in 1948 [27], has been widely used in studies of spatial econometrics.

The processing of spatially dependent panel data requires the introduction of spatial matrices (W), in the form of spatially lagged variables, which can capture and control such effects [27]. The spatial weight matrix (W) is a square matrix ($n \times n$) that contains a measure of the relationship of each local observation unit with another. In the present study, each element of the matrix, w_{ij} , indicates the spatial weight assigned to a municipality j and a municipality i .

Therefore, a contiguity (neighborhood) criterion, such as the 15 closest municipalities criterion applied in the present study, should be established. By definition, a spatial weights matrix W with 0-or-1 elements (known as a non-normalized neighborhood matrix) is symmetric and has zeros on the main diagonal. The model used in the present study was a normalized matrix W^* , which is constructed from the original matrix by dividing all the elements W_{ij} by the sum of the respective row in the matrix W . Therefore, the econometric model used in this study can be represented as a dynamic spatial panel:

$$\Delta y_t = \tau \Delta y_{t-1} + \delta \Delta w \cdot y_t + \beta_1 X_t^{exo} + \beta_2 W \cdot X_t^{exo} + \theta X_t^{endo} + Z + \varepsilon_t \quad (4)$$

where Δy_t is an $N \times 1$ vector composed of the first differences of the observations of the dependent variable in each spatial unit ($i = 1, 2, \dots, N$) in year t ($t = 1, 2, \dots, T - 1$); X_t^{exo} is an $N \times K$ matrix of exogenous variables; X_t^{endo} is an $N \times L$ matrix of endogenous variables; $\Delta w \cdot y_t$ and $w \cdot X_t^{exo}$ are the spatial controls; Z is the $N \times 1$ vector containing the specific spatial effects that do not vary over time; and ε_t is the error term. It is noteworthy that there were differences (Δ) between the temporal and spatial lags of the

dependent variable, suggesting that the variable has a unit root. Therefore, we opted for a treatment similar to that proposed by Enders [28] for time series models.

The following expression represents the cumulative impact of a permanent change in the k th exogenous variable:

$$\partial \Delta y_{t+T} / \partial x_k = \sum_{s=0}^T D_s [I_N \beta_{1k} + W \beta_{2k}] \quad (5)$$

given that:

$$D_s = (-1)^s [(I_N - \delta W)^{-1} (-\tau I_N)]^s (I_N - \delta W)^{-1} \quad (6)$$

where x_k denotes the k th column of the matrix X_t^{exo} ; I_N is the dimensional identity matrix; β_{1k} and β_{2k} are the parameters defined for the variable k in Eq. (4); and W is the normalized matrix of spatial weights, δ and τ also being given by Eq. (4).

The elements of the main diagonal of the sum of the $N \times N$ matrices defined by Eq. (5) for the time horizon T , represent the effects observed from changes in the explanatory variable within the region, which have propagated and continue to affect the dependent variable in the future because of temporal and spatial dependency relationships. The sum of the elements of these matrices outside the main diagonal is a measure of spillovers (contemporaneous cross-partial derivatives) and diffusions (cross-partial derivatives in different time periods).

After estimating the proposed model, we discussed the results in view of the indicators proposed by Elhorst [9]. We also considered the trajectory of the direct and indirect effects for the 10 years to come, following the example set by Debarys et al. [8].

4.2. Data source and treatment

The database employed contained data from various sources. Data related to the labor market, employment contracts, and average incomes were obtained from the Annual Social Information Report issued by the Brazilian Ministry of Labor and Employment [29]. Municipal data related to land use (for sugarcane, temporary crops, and permanent crops) were obtained from the Municipal Agricultural Research tool and Automated Data Recovery System of the *Instituto Brasileiro de Geografia e Estatística* (IBGE, Brazilian Institute of Geography and Statistics) [4]. Data related to GDP per capita and population stratified by age were obtained from the IBGE site. The population data were used in order to construct the variables related to the proportion of adults in the population and use of the workforce. The binary variable indicating the presence/absence of a sugar mill or ethanol plant in a municipality was constructed from data obtained from the Sugarcane Statistical Yearbook [30], from the sugarcane processing facility registry of the Brazilian Ministry of Agriculture, Animal Husbandry, and Supply, and from the Brazilian Sugarcane Industry Association.

Using the consumer price index, obtained from the Brazilian Institute for Applied Economic Research [22], we transformed nominal GDP series, average total income, and average income from agriculture into real variables. Results in Brazilian reals were converted to US dollars at the mean commercial exchange rate for 2008 [22].

The annual data used for the 2000–2008 period were collected by municipalities within the states of the south-central region, resulting in balanced panel data. It is of note that we used the municipal grid for 2008, given the changes in municipalities within the states of Goiás, Mato Grosso do Sul, and Mato Grosso. The shapefiles for the municipal grids were obtained from the IBGE.

Table 2 shows the variables evaluated and the respective

Table 2
Variables and nomenclature.

Variable	Term
Real GDP per capita (in 2008 \$)	<i>y</i>
Total real mean income (in 2008 \$)	<i>sal</i>
Real mean income from agriculture (in 2008 \$)	<i>sal_agro</i>
Overall rate of use of the workforce (%)	<i>emp</i>
Rate of use of the workforce in agriculture (%)	<i>emp_agro</i>
Proportion of adults in the population (%)	<i>adul</i>
Proportional representation of sugarcane in the area planted for temporary crops (%)	<i>cane/temp</i>
Proportional representation of temporary crops in the area used for agriculture (%)	<i>temp/agro</i>
Proportional representation of agricultural crops in the total landmass of Brazil (%)	<i>agro/mun</i>
Dummy that indicates whether a sugarcane processing facility is in operation in a given municipality (0 = no; 1 = yes)	<i>Du</i>

Note: The variables shown appear throughout the article, also considering temporal lags ($t-1$ as a suffix), spatial lags (w_{-} as a prefix), and first differences (Δ as a prefix).

nomenclature.

Statistical and econometric analyses of the estimations were performed with the software STATA, version 12.0 (StataCorp, USA).

5. Results and discussion

The database aggregates information for the south-central region (six states and the Federal District of Brasília). We observed considerable variability in terms of the means, standard deviations, minimum/maximum values, for the sample as a whole, between units, and within year (Table S1 on web available supplementary material) that is yet another justification for the use of the panel data models.

A preparatory step for the model estimation was the calculation of the overall Moran's I index as a test for spatial dependence. Because it is cross-sectional, the I index was calculated for each year within the period evaluated. We thus determined that all of the variables analyzed were spatially dependent in all of the years (Table S2 on web available supplementary material).

An initial estimate of the model included the variables— and temporal and spatial controls—at their level, and the Arellano-Bond test revealed persistent autocorrelation in the error terms. The strategy used (differencing the series), follows Enders [28] for the treatment of series with a unit root. Therefore, we considered the dependent series (GDP per capita), together with the temporal and spatial lags, in the first temporal difference (Δy_{t-1} and Δw_{-y}). The results of the estimation of this model are shown in Table 3. In this type of analysis, the interpretation of the results should focus on the effects of partial derivatives associated with changes in the explanatory variables, not on the coefficients themselves. Debarsy et al. [8] derived the general expression for the cumulative T impact in periods ahead of a permanent change in the k th variable in period t .

In the present study, we employed a procedure similar to that used by Satolo and Bacchi [3] in order to calculate the effects that the variables of interest had on municipal GDP per capita. Those variables, all of which are related to the accelerated growth of the sugarcane industry, were as follows: the start of operations of a sugarcane processing facility (Du); the proportional representation of sugarcane in the area planted for temporary crops ($cane/temp$); the proportional representation of temporary crops in the area used for agriculture ($temp/agro$); and the proportional representation of agriculture in the area of the municipality ($agro/mun$). Their respective spatial controls were designated $w_{-}Du$, $w_{-}cane/temp$, $w_{-}temp/agro$, and $w_{-}agro/mun$. The inclusion of the control variables aims to isolate the effect of social and demographic variables that also influence the GDP, so we can infer that the estimated impacts on the GDP are due the sugarcane industry.

To calculate the future effects, we considered the upcoming 10

Table 3
Results of the GMM-SYS estimation of the model.

Variable	Coefficient	Prob. > z
Δy_{t-1}	-0.022*	0.008
Δw_{-y}	0.4795*	0.000
<i>sal</i>	-0.6601 ^{NS}	0.255
<i>sal_agro</i>	-0.3219 ^{NS}	0.622
<i>emp</i>	7.780 ^{NS}	0.474
<i>emp_agro</i>	-40.206**	0.022
<i>Du</i>	1763.615*	0.001
<i>w_{-}Du</i>	102.919 ^{NS}	0.949
<i>cane/temp</i>	12.208*	0.004
<i>w_{-}cane/temp</i>	-10.841 ^{NS}	0.232
<i>temp/agro</i>	-3.598 ^{NS}	0.527
<i>w_{-}temp/agro</i>	20.337 ^{NS}	0.142
<i>agro/mun</i>	12.208*	0.004
<i>w_{-}agro/mun</i>	-10.841 ^{NS}	0.232
<i>adul</i>	-153.084***	0.088
<i>w_{-}adul</i>	234.772*	0.009
<i>constant</i>	-6133.165**	0.035
Instruments for calculating differences	$\Delta y_{t-2}, Dw_{-}y_{t-2}, sal_{t-2}, sal_agro_{t-2}, emp$	
Instruments for calculating impacts of variables	$\Delta \Delta y_{t-1}, Dw_{-}y_{t-1}, sal_{t-1}, \Delta sal_agro_{t-1}$	
Wald (Prob.)	0.000	
First-order autocorrelation (Prob.)	0.002	
Second-order autocorrelation (Prob.)	0.186	
Observations, n	16,541	

Abbreviations Prob., probability; Δ ; (as prefix), first difference; y , real GDP per capita; $t-1$ (as suffix), temporal lag; *sal*, total real mean income; *sal_agro*, real mean income from agriculture; *emp*, overall rate of use of the workforce; *emp_agro* rate of use of the workforce in agriculture; w_{-} (as prefix), spatial lag; *adul*, proportion of adults in the population; Dw_{-} .

Levels of significance.

*1% of significance.

**5% of significance.

***10% of significance.

NS Not significance.

years, including only the coefficients that were significant at a 10% level of significance (Table 3). In the studies conducted by Satolo and Bacchi [3], the effects estimated by the model represent the impact of the variables at their level, whereas in the present study, the coefficients were estimated with the dependent variable in the first differences; strictly speaking, the effects would be on the cumulative change in the municipal GDP per capita, rather than on the level of the variable. However, in the model estimated here, the (estimated) effect is identical to the effect on the level of the variable. This distinction is being made only to maintain the methodological rigor, although the effect on the variation was identical to the effect on the impact of the variables. Therefore, the effects on the variation in the dependent variable can be understood as the effects on the impact of the variables [8,9].

Fig. 4 shows the direct and indirect effects that a permanent 10% point increase in the *cane/temp*, a permanent 10% point increase in the *agro/mun*, and the *Du* variable had on the change in real municipal GDP per capita.

There was a direct contemporaneous effect in the municipalities in which a sugarcane processing facility began operations, a 10% point increase in the *cane/temp* raising the real municipal GDP per capita by an average of 76 \$. That magnitude of that increase decreased slightly in subsequent years, leveling out at 71 \$ after five years. There was also a positive spillover indirect effect; the stakeholder's role agenda could be important in this scenario [31]. Contemporaneously, a 10% point increase in the *cane/temp*, under the *Du* condition, raises the real GDP per capita by an average of 31 \$ for each of the 15 closest neighboring municipalities. That magnitude of the indirect effect also decreased slightly in subsequent years, leveling out, after seven years, at approximately 22 \$.

When there was a 10% point increase in the *agro/mun*, the contemporaneous increase in the real municipal GDP per capita was, on average, 255 \$, and the corresponding indirect effect was an average reduction in the real GDP per capita of 41 \$ for each of the 15 closest neighboring municipalities. In the subsequent years, the absolute values for the direct and indirect effects decreased slightly, leveling out at 245 \$ (after five years) and approximately -34.84 \$ (after seven years), respectively.

Under the *Du* condition, the real municipal GDP per capita increased, contemporaneously, by an average of 1098 \$ in the host municipality and 457 \$ in each of the 15 closest neighboring municipalities. In the subsequent years, the magnitude of those effects diminished. However, even at 10 years after the facilities had come online, the average increase in the real municipal GDP per capita was 1028 \$ for the host municipality and 324 \$ for each of the 15 closest neighboring municipalities.

In view of our findings, we constructed two scenarios to evaluate the effects that accelerated growth of the sugarcane industry had on municipal GDP per capita:

- Expansion of sugarcane cultivation at the expense of other agricultural activities ($\Delta cane/temp \mid agro/mun = \text{constant}$)—In this scenario, because the *agro/mun* remains constant, an increase in the *cane/temp* indicates that the expansion of sugarcane cultivation has encroached upon lands previously used for other agricultural activities (Table S3 in the Supplementary Material).
- Expansion of sugarcane cultivation without replacement of temporary crops ($\Delta agro/mun \mid cane/temp = \text{constant}$)—In this scenario, the *cane/temp* remains constant and the expansion of sugarcane cultivation is therefore accompanied by a proportional increase in the land used for other temporary crops (Table S4 in the Supplementary Material).

Those scenarios represent extreme cases, because one of the variables representing the relative variation remains constant. When both variables present variation, the result would be intermediate and would depend on the relative variation in the *cane/temp* and *agro/mun*. This is relevant because, although the direct effect of the expansion of sugarcane cultivation is positive in both scenarios, the indirect effect is negative when the expansion takes place without the replacement of other temporary crops.

The overall effect of expansion of the sugarcane industry on real GDP per capita is positive in both scenarios, regardless of the magnitude of the increased sugarcane cultivation associated with the *Du* condition. However, when sugarcane cultivation expands at the expense of other agricultural activities, that effect is directly proportional to the area of the expansion.

The descriptive statistics from the database show that the average real municipal GDP per capita in the 2000–2008 period was 6064 \$ in the south-central region. Therefore, it can be said that the installation of a new sugarcane processing facility accompanied by a 10% point increase in *agro/mun* has an effect almost equivalent to introducing, within the group of municipalities under the influence of the new facility, the entire income of an average municipality in the region. That effect would be independent of the cultivation expansion scenario considered.

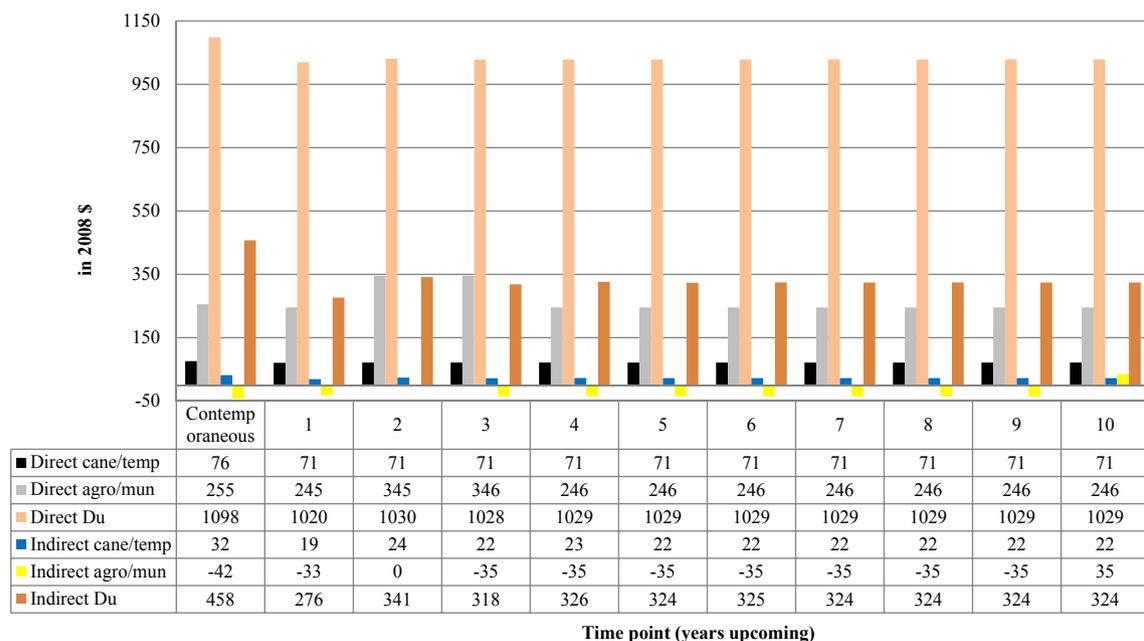


Fig. 4. Mean cumulative effects on real municipal GDP per capita (in 2008 \$). Note: The indirect effects were divided by 15 to make the results comparable in the municipal domain. Were used 10% point increase in *cane/temp* and *agro/mun* variables; *Du* is a binary variable.

Source: Research results

We observed that, although the direction of the impact was the same as that found for the state of São Paulo [1,3,6], there were differences in its magnitude. That was confirmed by comparing our results with those of Satolo and Bacchi [3]. The direct and indirect impacts reported by those authors were substantially greater than were those observed in the present study, indicating that the regional effects of the sugarcane industry are greater for the state of São Paulo than for the other states in the south-central region. That fact is partially related to the denser economic structure (greater industrialization), as well as the greater representation of sugarcane as an economic activity, in the state of São Paulo. Therefore, we emphasize the importance of analyzing the impacts of sugarcane industry growth on the less industrialized states, an analysis that can be interesting from a socioeconomic and policy perspective.

The results of this study promote reflection on recent changes in the current energy policy in Brazil, which notably aimed to combat inflation by controlling gasoline prices at the refinery level [11]. That policy had a negative impact on the sugarcane industry, stalling new investment and even leading to the closure of several plants. Therefore, it is expected that similar estimates for the more recent period would indicate a reduction in the number of jobs connected to the ethanol supply chain and a consequent decrease in the GDP per capita for municipalities that host sugarcane processing facilities.

6. Conclusions

In contrast with previous studies analyzing the socioeconomic impacts of the sugarcane industry in the state the São Paulo, our research focused on quantifying and evaluating the effects of the industry on the municipal GDP per capita in the south-central region of Brazil, which includes states that are less industrialized and present different socioeconomic conditions in comparison with the state of São Paulo. On the basis of our findings, we can conclude that the large-scale production of ethanol in Brazil has positive socioeconomic effects in the south-central region (analyzed in the aggregate), as evidenced by increases in the municipal GDP per capita. Our analysis reveals that the sugarcane industry has made a positive contribution to the development of host municipalities and the neighboring municipalities, due to spatial and temporal effects.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.biombioe.2016.05.004>.

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