University of São Paulo
"Luiz de Queiroz" College of Agriculture

Economic impacts of bad output in agriculture: two essays for Brazilian sugarcane production

Pedro Soares

Thesis presented to obtain the dregree of Doctor in Science. Area: Applied Economics

Piracicaba
2022

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Economist

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versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
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À minha segunda mãe, Clarice (in memoriam).

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CONTENTS

RESUMO

Impactos econômicos de *bad outputs* na agricultura: dois ensaios para a produção brasileira de cana-de-açúcar

A presente tese, estruturada na forma de dois trabalhos principais, analisou os impactos da redução da poluição na produção de cana-de-açúcar no Brasil. O primeiro estudo investigou a contribuição de ganhos de eficiência técnica para a redução da emissão de gases de efeito estufa na produção canavieira, estimando ainda a compensação monetária que os produtores deveriam receber para reduzir a poluição. O segundo estudo analisou, em termos de bem-estar econômico, o impacto nos mercados da cadeia de produção canavieira da mudança para o sistema de colheita mecanizada, utilizando como exemplo o caso recente do estado de São Paulo. Os principais resultados dos trabalhos indicam que ganhos de eficiência podem contribuir para a redução da emissão de gases de efeito estufa, além de indicarem que na transição para um cenário de colheita mecanizada, os setores mais afetados são o mercado de trabalho manual, e a produção de cana-de-açúcar, indicando a necessidade de políticas públicas que mitiguem os impactos negativos da transição, e possam contribuir para ganhos de eficiência dos produtores.

Palavras-chave: Eficiência técnica; Bem-estar econômico; Preço sombra; Cana-de-açúcar.

ABSTRACT

Economic impacts of bad output in agriculture: two essays for Brazilian sugarcane production

This thesis, structured in the form of two main papers, analyzed the impacts of pollution reduction on sugarcane production in Brazil. Initially, it was investigated the contribution of technical efficiency gains to reduce the emission of greenhouse gases in sugarcane production, and also estimated the monetary compensation that producers should receive to reduce pollution. The second study analyzed, in terms of economic wellfare, the impact on markets of the sugarcane production chain the change to the mechanized harvesting system, using as an example the recent case of the state of São Paulo. The main results of the both studies indicate that efficiency gains can contribute to the greenhouse gas emissions reductions, in addition to indicating that in the transition to a mechanized harvesting scenario, the most affected sectors are the manual labor market, and the sugarcane production, indicating the need for public policies that mitigate the negative impacts of the transition, and that can contribute to efficiency gains for producers.

Keywords: Technical efficiency; Welfare; Shadow price; Sugarcane.

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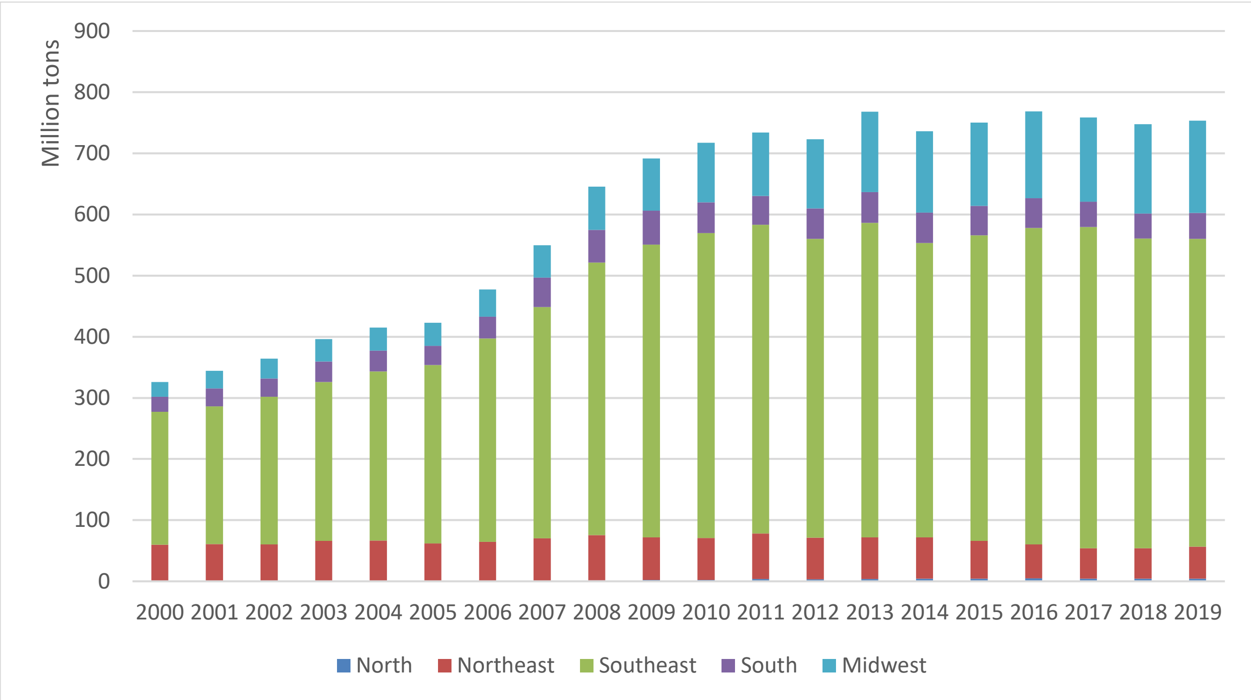
1. INTRODUCTION

Sugarcane production is one of the main crops for the Brazilian agribusiness sector, being the sixth crop that most contributed to the sector's gross production value in 2020 (Brazilian Agriculture and Livestock Confederation – CNA, 2021). Worldwide, Brazil is the wo'ld's largest producer of sugarcane (Food and Agriculture Organization - FAO, 2021) and the world largest exporter of sugar, accounting for 36% of total global exports (CNA, 2021).

Planted in Brazil since the colonial period, this crop alternated moments of great expansion and declining in production (Garofalo *et al.*, 2020) and, in the last decades, the main productive hub migrated from the Northeast to the Center-South. Valdes (2007) highlighted that since the 2000's, the advent of flex-fuel cars, driven by a greater global concern with the effects of climate change, stimulated the Brazilian ethanol production, resulting on the sugarcane production growth at high rates, and a great production expansion in the Southeast and Midwest regions (Figure 1).

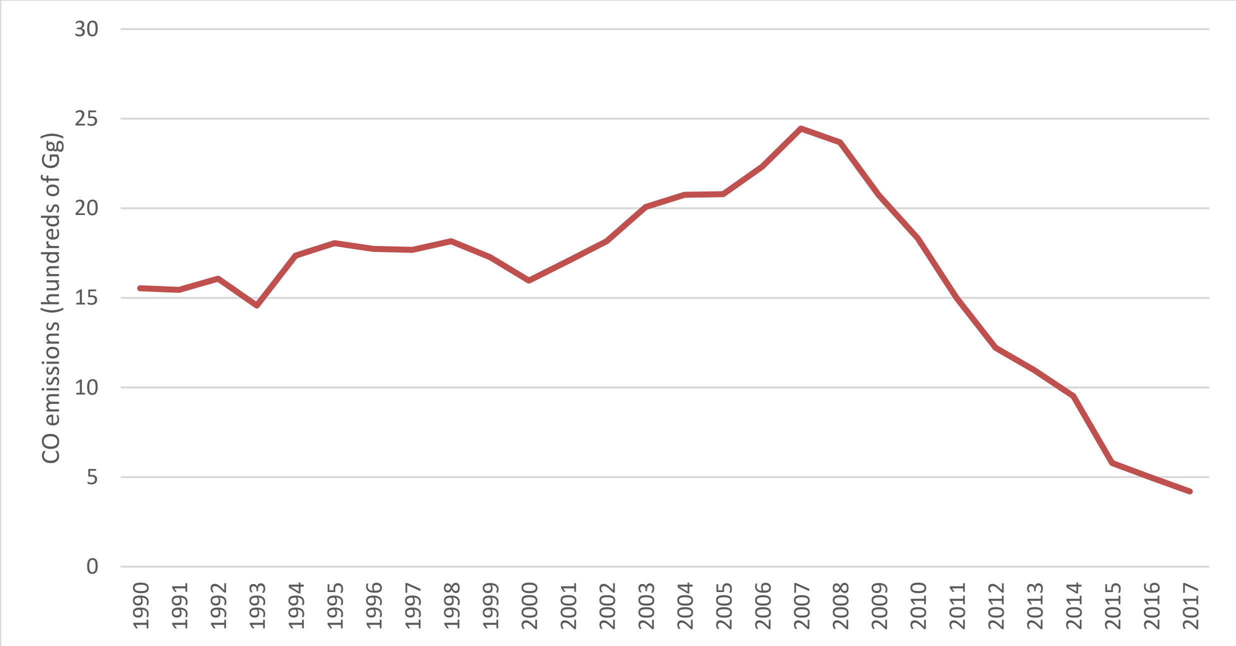
Figure 1. Sugarcane production by region – 2000-2019



Source: Brazilian Institute of Geography and Statistics - IBGE (2021).

The manual harvesting system, widely used in the country until the 2009/10 harvest, combined with the use of cane burning in the pre-harvest phase, releases at the atmosphere many greenhouse gases and represents a health hazard to people that live around the productive areas, due to the harmful gases of the burning, especially carbon monoxide. Figure 2 presents the CO emssions due to the pre-harveting burning of sugarcane from 1990 to 2017

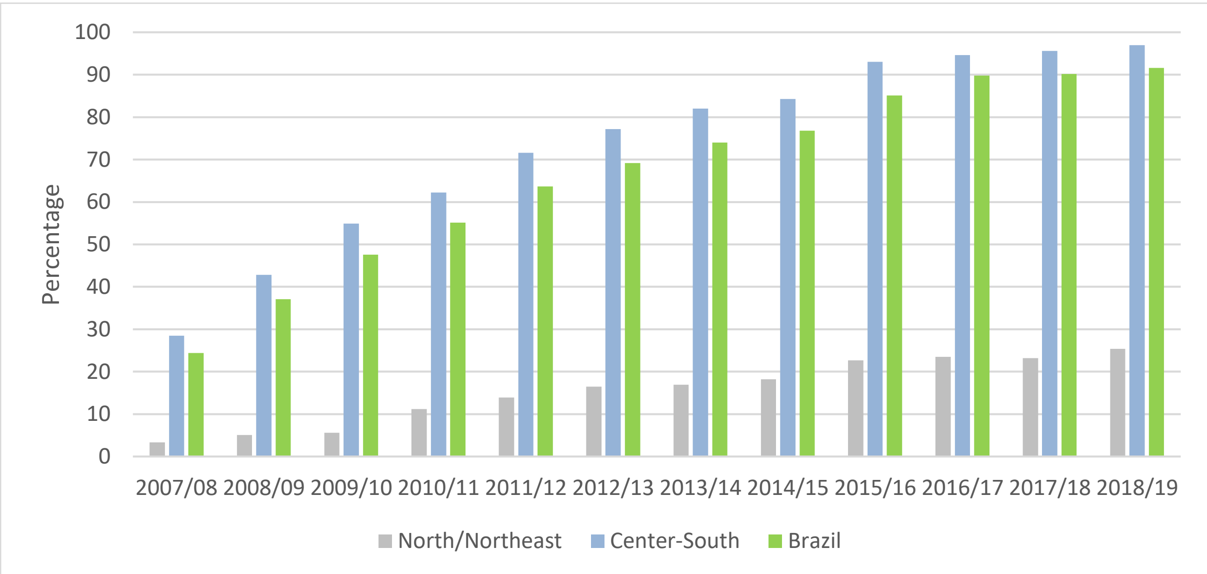
Figure 2. National CO emssions due to the pre-harveting burning of sugarcane



Source: Ministry of Science, Technology and Innovations – MCTI (2021).

The CO emissions decreasing since 2007 is directly related to the the harvest mechanization rising in the most productive region, the Center-South region, especially in the state of São Paulo. As Figure 3 demonstrates, this region has shown a great development of mechanization in recent years, reaching more than 90% of all production harvested mechanically since the 2015/16 harvest.

Figure 3. Percentage of sugarcane mechanized harvesting from 2007/08 harvest to 2018/19



Source: National Supply Company - Conab (2019).

Although the mechanization has contributed to the fall of the greenhouse gas emissions in recent years, Nyko et al. (2013) highlighted that mechanization has partially contributed to the recent drop in productivity in many regions, due to the use of machinery that was not fully adapted to the Brazilian reality, i.e, the increase in the soil compaction caused by the movement of machines and the use of varieties that were not adapted to mechanization.

Therefore, the objectives of this research were to measure how much pollution emissions could be reduced just by the production efficiency gains, the opportunity cost for producers to migrate to production mechanization and analyze the impact of mechanization in each sector of the production sugarcane chain. In addition to this introduction and the general remarks, this work is organized in the form of two papers. The first paper presents the estimates of technical efficiency of the productionand shadow price of CO_2 emissions across the country, using production and pollution emission data for 2017. The second paper analyzes the impact of mechanization in each sector of the productive chain, using as background the recent mechanization in the state of São Paulo.

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2. TECHNICAL EFFICIENCY AND SHADOW PRICES IN THE BRAZILIAN SUGARCANE PRODUCTION

ABSTRACT

Using an output distance function and its duality with the revenue function, this paper estimated the technical efficiency of sugarcane production in the Brazilian municipalities and the shadow price of reducing the CO_2 emission coming from the production of this crop. Main result is an overall technical efficiency average of 81%, which indicates if producers adopted better management practices, they could increase sugarcane production by 81,611 tons, reducing pollution by 53 tons. We also estimated a mean shadow price of R$ 9.18 per ton of CO_2, considering all municipalities. Further, highest estimated values are referent the states of Mato Grosso do Sul, Paraná, Mato Grosso, and Bahia. On the other hand, in the state of São Paulo, the national most representative producer, the estimated shadow price was R$ 6.34 per ton of CO_2.

Keywords: Sugarcane; Brazil; CO_2 shadow price; technical efficiency; greenhouse emissions; bad output.

2.1. Introduction

The sugarcane production is one of the most relevant crops for the Brazilian agribusiness, and Brazil is the largest sugarcane producer in the world [1]. Although it has been cultivated in many Brazilian states, the main production is still concentrated in the Central-South region, and the State of São Paulo is the most representative producer, accounting by 54% of the total production in the 2020/21 harvest [2].

Historically, sugarcane was manually harvested in Brazil, usually combined with the pre-harvesting straw burning, used to remove the leaves and eliminate poisonous insects that could represents additional risks for the workers. However, as argued by Paraiso and Gouveia [3] the pre-harvesting burning does not impliy only economic, political, social and environmental issues, it also affects the population health on the producer municipalities[1] once the leaves burning generates negative externalities, releasing at the atmosphere many harmful and toxic gases, smoke, and coarse particulate matter that impact the human health in different ways, and with a potential spillover effect for the border regions [5].

The development of the renewable fuels market was a result of the global rising demand for ethanol. The new environmental demands and the technological advances [6] have undergone several structural changes in the Brazilian sugarcane production since the half of 2000's. As a result, the percentual of manual harvesting in the whole country decline from 75% in 2007/08 harvest to 10% in 2016/17 [7]. However, at a regional level perspective, there are many opportunities to diminish the total emissions from pre-harvesting burning.

To the best of our knowledge, this is the first research that estimates technical efficiency of the producers and the shadow price of the pollution from the straw burning, assumed as the opportunity cost for producers to reduce

[1] For a better discussion between air quality and health, see Beatty and Shimshack [4].

one unit of pollution, for 959 Brazilian sugarcane producing municipalities in 2017. Our article adds to the literature that links technical efficiency and sugarcane production sustainability.

Bordonal et al. [8] argued that at the same time that there are advantages as a sustainable feedstock for biofuel production, the expansion of sugarcane production raise new environmental issues as changes in land use, food supply, greenhouse gases emissions from inputs and land management, water use, soil biodiversity loss and erosion. Although the public health and environmental benefits of reducing sugarcane burning are incontestable[2], the consequent mechanization implies in higher initial costs for producers in the short term with acquisition of new machineries, hiring of qualified labor and change to new sugarcane varieties adapted for the mechanization.

Bernardo et al. [10] analyzed sugarcane production mechanization in the states of Goiás and Mato Grosso do Sul. Authors verified high mechanization on those states for planting and harvesting; however, it was observed difficulty for technological adaptation, which constrains crop's performance. In this sense, there are no studies that estimated a feasible monetary compensation for producers to mitigate the initial cost with mechanization, especially through public policies, like the rural credit supplied to the sector.

To realize the analysis, it is assumed the dual relation between the output distance function and shadow price initially proposed by Färe et al. [11] and uses the production statistics from the last Agricultural Census, published by the Brazilian Institute of Geography and Statistics [12], and the greenhouse emission estimates from sugarcane production, calculated by Brazil [13].

This paper is organized as follows. The next section briefly discuss the background literature. The third section present the theoretical model and the data source descriptions. The fourth section presents the results and discussions. Finally, the fifth section contains authors' conclusion.

2.2. Background literature

We study the dual relation between the output distance function and shadow price to estimate the sugarcane production technical efficiency and CO_2 emission. Although there are several works in the recent economic literature that have analyzed the Brazilian agriculture[3] total factor productivity - TFP and the technical efficiency, there are no studies that account for the impact of bad outputs on the estimations. However, as Rezek and Perrin [17] showed for U.S. agriculture, the inclusion of the bad outputs in a TFP model can change the overall productivity estimates versus the traditional TFP measure.

In this way, worldwide many studies have adapted the stochastic frontier and data envelopment models to account for the bad outputs in the efficiency measures. Sesmero, Perrin and Fulginiti [18], for example, analyzed the environmental efficiency of the US corn ethanol industry, based on the data envelopment analysis (DEA) methodology. According to the authors' main results, on average the industrial plants considered in the study could reduce their greenhouse gas emissions by up to 6% per quarter. Furthermore, at the actual activity levels, plants can simultaneously improve their environmental efficiency and economic profitability.

The inclusion of bad outputs in production models also allows, as demonstrated by Färe et al. [11], the estimation of the shadow price of these nonmarketed outputs. Färe et al. [11] used an output distance function and exploiting the duality between this kind of technology and the revenue function derived the deflated shadow price of

[2] See for example Nicolella and Belluzo [9] for the benefits of raw sugarcane harvest in the inpatient visits for São Paulo state between 2000 and 2007.

[3] For example, Gasques et al. [14], Alves et al. [15], Contini et al. [16] and others.

all outputs, including the price of undesirable outputs, that reflects the opportunity cost of decrease one unit of the bad output, in terms of foregone revenue of desirable output.

Färe et al. [19] using a parametric directional output distance function estimated the technical efficiency of U.S. electric utilities that produce one desirable output, electricity, and one undesirable output, SO_2, and estimated the shadow price of SO_2 considering the effects of the environmental regulation in the sector. The main results from the authors indicated that electric utilities could reduce emissions by 4000–6000 tons by reducing inefficiency. Moreover, the authors found that the mean shadow price of SO_2 had increased from $1117 in 1993 to $1974 in 1997, indicating that more good output need to be foregone to reduce one unit of bad output over time.

Analyzing the shadow prices for U.S. agriculture, Färe, Grosskopf and Weber [20] used a quadratic directional output distance function and data for U.S. agriculture from 1960 to 1996 to estimate the technical inefficiency, shadow prices for undesirable outputs, and the associated pollution costs. The authors estimated that the shadow price of the runoff and leaching of pesticides are 6% of crop and animal revenues. Furthermore, the results indicated different patterns of the shadow price around the country, with a higher shadow price in the Midwest and a lower shadow price in the Western states. The results also indicated that the pollution cost could be 7% lower if states reduce their technical inefficiency.

An application of this methodology for Brazilian agricultural production could be find in Silva, Perrin and Fulginiti [21]. Using an output distance function and municipality data for deforestation, the authors looked for the relationship between forest preservation and agricultural production for the Legal Amazon region, estimating the shadow price of reducing deforestation in terms of agricultural production. The results indicated that, on the average, $797 of agricultural GDP must be foregone to preserve one hectare of forest, which implies an average shadow price of $16 per ton of CO2 sequestered in perpetuity.

2.3. Methodological Framework

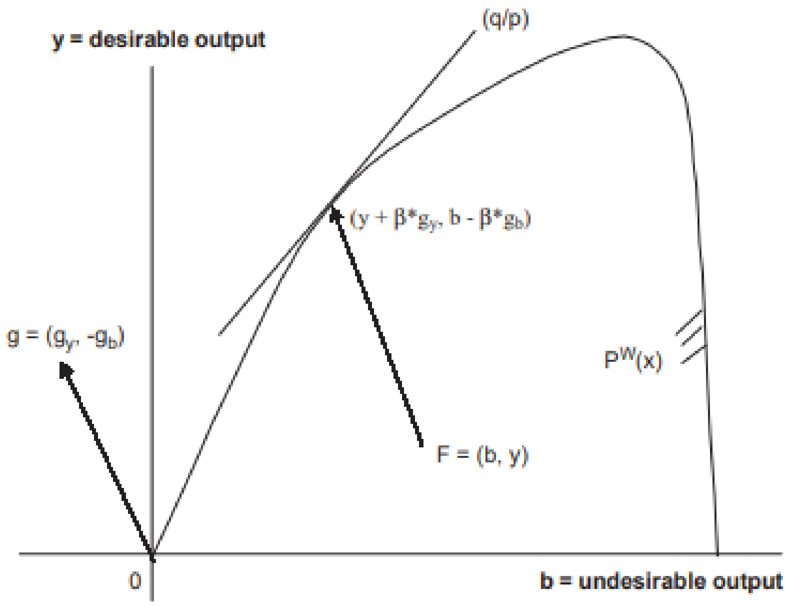
2.3.1. Empirical model

Following Färe et al. [19] this paper uses a directional distance function $(\overrightarrow{D_0})$ to characterize a technology that uses an input vector (x) to produce a desirable output (y) and an undesirable bad output (b):

$$\overrightarrow{D_0}(x, y, b; g_y, g_b) = \max_{\beta} \{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\} \quad (1)$$

where β is the distance from a point inside the production possibility frontier to its frontier, $g = (g_y, g_b)$ is the directional vector and $P(x)$ is the output possibility set.

Figure 4. Directional output distance function.



Source: Färe et al. [19].

As demonstrated by Färe et al. [19], this directional distance function keeps the properties from the output possibility set, i.e., it is non-negative for output vectors (y, b), non-increasing and strongly disposable in desirable outputs, non-decreasing in undesirable outputs, weakly disposable in jointly desirable and undesirable outputs, concave, and also satisfies the translation property:

Equation (2) states that an expansion by βg_y in the desirable output, and a simultaneous contraction by βg_b in the undesirable output, is equal to the original distance function reduced by β.

Since this paper uses a parametric approach to estimate the distance function, and following Silva, Perrin and Fulginiti [21], we assume a quadratic functional form and a proportional directional vector, that is $g = (g_y, g_b) = (1, -1)$, that results in the parametric distance function below:

$$\overrightarrow{D_0}(x_i, y_i, b_i; 1, -1) = \alpha + \theta b_i + \psi y_i + \sum_{s=1}^{3} \gamma_k x_{si} + \frac{1}{2}\theta_1 b_i^2 + \frac{1}{2}\psi_1 y_i^2 + \frac{1}{2}\sum_{s=1}^{3}\sum_{l=1}^{3} \gamma_{kl} x_{si} x_{li} + \sum_{s=1}^{3} \delta_s x_{si} y_i + \sum_{s=1}^{3} \varphi_s x_{si} b_i + \mu y_i b_i \quad (3)$$

where x_i are the inputs, represented by harvested area, labor force and capital, y_i is the sugarcane production and b_i is the greenhouse gas emissions due to the sugarcane production. We also imposed the symmetry and translation properties in outputs:

$$\psi - \theta = 1$$
$$\psi_1 = \mu$$
$$\theta_1 = \mu$$
$$\delta_s = \varphi_s \quad (4)$$

From the translation property in (2), and assuming the parametric distance function in (3), we have:

$$\overrightarrow{D_0}(x, y + \beta, b - \beta; 1, -1) = \overrightarrow{D_0}(x, y, b; 1, -1) - \beta \quad (5)$$

As Färe et al. [19] highlighted, the directional distance function is also a measure of efficiency. Hence, $\overrightarrow{D_0}(x, y, b; 1, -1)$ should be equal to zero, given that it is on the production possibility frontier. Given that, and assuming $\beta = b_i$, we have the final distance function used to estimate the parameters:

$$b_i = \alpha + \theta b_i + \psi y_i' + \sum_{s=1}^{3} \gamma_k x_{si} + \frac{1}{2}\theta_1 {b'}_i^2 + \frac{1}{2}\psi_1 {y'}_i^2 + \frac{1}{2}\sum_{s=1}^{3}\sum_{l=1}^{3} \gamma_{kl} x_{si} x_{li} + \sum_{s=1}^{3} \delta_s x_{si} y_i' + \sum_{s=1}^{3} \varphi_s x_{si} b_i' + \mu y_i' b_i' + \sum_n \chi_n + \epsilon_i \quad (6)$$

where y' and b' are the normalized (regarding β) desirable and undesirable, ϵ_i is the composed random error term and χ_n represents the regional dummies, one for each state.

To estimate the production technical efficiency, we follow Kumbhakar, Wang, and Horncastle [22], and split the composed error term ϵ_i in two components, v_i and u_i, where u_i is the inefficiency term, following a half-normal distribution, and v_i is the random error, following a normal distribution.

The parameters of equation (6) were estimated from a stochastic frontier model, using the commands available in Kumbhakar, Wang, and Horncastle [22] and Stata statistical software. Moreover, following Färe et al. [19] and Silva, Perrin e Fulginiti [21], all variables are normalized by their means.

From these estimated parameters, and using the dual relationship between the revenue function and the output distance function derived by Färe et al. [19], we have that the bad output shadow price is obtained by:

$$q = -p\left[\frac{\partial \overrightarrow{D_0}(x,y,b,g)/\partial b}{\partial \overrightarrow{D_0}(x,y,b,g)/\partial y}\right] \rightarrow q_i = -p_i\left(\frac{\theta + \theta_1 b_i + \sum_{s=1}^{3} \varphi_s x_{si} + \mu y_i}{\psi + \psi_1 y_i + \sum_{s=1}^{3} \delta_s x_{si} + \mu b_i}\right) \quad (7)$$

where p is the price of sugarcane and q is the shadow price of bad output, that is, the price of reduce one unit of bad output, given one unit of the desirable output.

2.3.2. Data

The 2017 Agricultural Census, published by the Brazilian Institute of Geography and Statistics, and the Greenhouse Gases emissions, estimated and published by Brazil [13], were the two main databases used in the present research.

From the Agricultural Census, were used variables to characterize the production at the municipality level. In this way, we used the sugarcane production, in tons, sugarcane harvested area, in hectares, labor force (the familiar and non-familiar employees working in the sugarcane production), and the number of tractors and other machineries in the municipalities[4]. The sugarcane price, used to estimate the pollution shadow price, was calculated dividing the sugarcane production value by the quantity produced.

All the information from the Brazilian Institute of Geography and Statistics was at the municipality level, considering the whole country, and is available in the public Brazilian Institute of Geography and Statistics database.

According to 2017 Census, sugarcane was cultivated in 3,542 municipalities, in different production scales. In this paper, were considered only observations that has available information for production and emissions. This strategy reduced the database to 1,054 observations (only 30% of the total observations), representing around 76% of total production.

The Greenhouse Gases emission, published by Brazil [13], gathers information from 1990 to 2017 at the municipality and state levels for Carbon Monoxide, Methane, Nitrogen Dioxide and Nitrogen Oxides emissions from

[4] This variable counts for total temporary crops, as we do not have this variable available at the crop level.

sugarcane production. In this paper was used the two more representative gases, in terms of global warming potential, the Methane and Nitrogen Dioxide emissions in 2017, converted to CO_2 equivalent, using the global warming potential values from Stocker et al. [23], and considering a conversion factor of 28 for Methane and 265 for Nitrogen Dioxide.

Table 1 shows the production and pollution emission statistics from the corrected database. Considering the sample of 1,054 observations, the representative sugarcane producer uses 6 thousand hectares, 359 workers, 261 machineries to produce 430 thousand tons of sugarcane, i.e., a mean productivity of 71 ton per hectare, and sells its production by R$290.00 per ton.

The higher production levels were observed in the São Paulo, Goiás and Mato Groso do Sul states. In the state of São Paulo, that counts for 63% of the total production of this sample, the producers use 6 thousand of hectares on average, 581 workers, 248 machineries to produce 953 thousand tons of sugarcane and emitting 326 tons of Carbon Dioxide. The lower pollution emission in São Paulo state, although the relevancy of this state for the national production, could be associated to the impacts of the local regulation of the sector by the State Law 11,241 of 2002 [24], which stipulated deadlines for the gradual elimination of the pre-harvest burning of the cane straw in the whole state of São Paulo, and indirectly promotes the adoption of the mechanical harvest, reducing the greenhouse gases emissions.

Table 1. Average production variables

State	Area (ha)	Labor (N)	Capital (N)	Production (ton)	CO_2 equivalent (ton)	Sugarcane price (R$/ton)
AL	6,449	1,122	50	327,836	2,027	87
BA	534	229	201	32,295	210	119
ES	1,498	118	38	77,430	179	81
GO	12,813	443	505	1,011,617	279	79
MA	662	225	163	28,883	89	139
MG	2,161	166	109	162,647	5	89
MS	16,903	738	737	1,215,821	67	72
MT	5,482	169	327	431,961	258	91
PB	6,289	627	59	296,995	1,389	88
PE	4,769	955	33	218,793	1,602	99
PI	1,482	425	100	80,950	225	120
PR	4,070	174	529	241,050	241	69
RJ	1,184	209	55	66,465	308	145
RN	2,083	332	33	93,431	757	113
RS	67	56	524	2,397	4	483
SE	2,781	736	46	108,855	1,012	68
SP	13,030	581	248	953,473	326	71
BR	**6,038**	**359**	**261**	**429,533**	**284**	**76**

Source: Calculated by authors from [12] and [13].

2.4. Results

To validate the estimated stochastic frontier model, following Kumbhakar, Wang, and Horncastle [22], we first estimated the equation 6 using ordinary least squares (Appendix A) and implemented statistical tests to verify the existence of asymmetric distributions caused by the presence of non-random components. Since the tests (Appendix B and Appendix C) indicated the existence of asymmetric distributions, we proceeded with the stochastic frontier estimation.

Table 2. SFA estimation

Variable	*Coefficient (sd)*
frontier	
Area	0.993*** (0.026)
Capital	0.024** (0.011)
Labor	-0.035*** (0.011)
Sugarcane	-0.968*** (0.013)
$Area^2$	-0.089*** (0.008)
$Capital^2$	-0.005** (0.002)
$Labor^2$	0.01*** (0.002)
$Sugarcane^2$	-0.009*** (0.002)
Area x Capital	0.015 (0.011)
Area x Labor	-0.006** (0.003)
Capital x Labor	0.022*** (0.005)
Area x Sugarcane	0.045*** (0.003)
Capital x Sugarcane	-0.011 (0.007)
Labor x Sugarcane	-0.007*** (0.001)
Dummy AL	-0.186*** (0.064)
Dummy BA	0.066 (0.045)
Dummy ES	-0.006 (0.066)
Dummy GO	0.114*** (0.043)
Dummy MA	0.034 (0.075)
Dummy MG	0.093*** (0.027)
Dummy MS	0.12* (0.068)
Dummy MT	0.118* (0.063)
Dummy PB	-0.181** (0.08)
Dummy PE	-0.153*** (0.059)
Dummy PI	0.023 (0.08)
Dummy PR	-0.058 (0.038)
Dummy RJ	0.036 (0.056)
Dummy RN	-0.077 (0.096)
Dummy RS	0.041 (0.034)
Dummy SE	-0.113 (0.111)
Constant	0.124*** (0.023)
usigmas	

Constant	-2.391*** (0.129)
vsigmas	
Constant	-3.265*** (0.098)

Source: Estimated by the authors.

Notes: Standard deviations are given in parentheses. Statistically significant confidence intervals are indicated as *** (99%), ** (95%) and * (90%). Dummy for SP was omitted.

The SFA model presented a robust fit for the data and, considering the inputs coefficients, only the parameters for area x capital and capital x sugarcane are not statistically significant at the usual levels. Looking for the regional dummies, seven among seventeen were statistically significant.

Analyzing the producer's technical efficiency, the overall technical efficiency for all municipalities was 0.81, that means the sugarcane production could be expanded by 19% with a contraction by the same magnitude in the CO_2 emissions. In absolute values, it represents an average of 81,611 in the sugarcane production and an average of 53 tons of CO_2 equivalent.

As Garofalo et al. [25] argued, the expansion of sugarcane production in middle of the 2000's, toward the northwest of São Paulo, southwest of Minas Gerais (region knowns as Triangulo Mineiro) and Midwest region, was not followed by productivity gains, due to use of varieties and agronomic practices that did not consider the characteristics of these regions, diminishing the overall productivity of Brazilian production.

Although there are no studies that investigated the technical efficiency for sugarcane production in Brazil as a whole, Rodrigues et al. [26] estimated similar levels of technical efficiency for sugarcane production in the state of Sao Paulo, considering the crop year 2007/08 and a different database (Lupa Project, published by São Paulo Agricultural Economics Institute). From an agronomic perspective, Dias and Sentelhas [27] argued that the current productivity in the Central-South region could be raised by at least 20% if better agronomic managerial practices were adopted.

Regionally, our results indicate that the states of Paraíba, Mato Grosso and Mato Grosso do Sul have the lowest average technical efficiencies, while Bahia and Rio Grande do Sul have the highest averages. The state of São Paulo, the most representative producer, has an average of 0.8 (lower than the overall average); on the other hand, São Paulo is the Brazilian state with the higher technical efficiency amplitude among the municipalities, varying from 0.14 to 0.96.

Combining the production averages from Table 1 with the technical efficiency statistics from Table 3, we find that technical efficiency gains could expand the average output at higher rates in the states of Mato Grosso do Sul, Goiás and São Paulo (averages of 280, 202 and 191 thousands of tons, respectively), and could constraint the pollution emission more significantly in the states of Alagoas, Paraíba and Pernambuco (405, 347 and 336 tons of CO_2, respectively).

Table 3. Technical efficiency by state

State	Mean	Standard deviation	Max	Min	N
AL	0.80	0.10	0.91	0.59	29
BA	0.83	0.02	0.90	0.75	45
ES	0.82	0.05	0.85	0.69	17
GO	0.80	0.08	0.95	0.46	47
MA	0.82	0.06	0.85	0.63	13
MG	0.82	0.03	0.97	0.62	262
MS	0.77	0.11	0.96	0.55	20
MT	0.77	0.15	0.98	0.27	22
PB	0.75	0.23	0.93	0.31	12
PE	0.79	0.14	0.91	0.46	32
PI	0.82	0.08	0.85	0.57	11
PR	0.80	0.14	0.94	0.13	75
RJ	0.82	0.07	0.85	0.54	25
RN	0.82	0.05	0.87	0.74	8
RS	0.83	0.01	0.85	0.71	133
SE	0.82	0.04	0.87	0.76	6
SP	0.80	0.11	0.96	0.14	297
BR	**0.81**	**0.09**	**0.98**	**0.13**	**1054**

Source: Estimated from model.

From the coefficients estimated in Table 2, and using the translation properties from Equation 4, we calculated the shadow price of CO_2 emission for each municipality in the sample. Since 95 observations violated the monotonicity conditions for sugarcane and pollution, they were not considered for this analysis. The states with higher share of municipalities that do not follow the monotonicity properties (Appendix D) are Alagoas (45%), Pernambuco (44%), Sergipe (33%) and Rio Grande do Sul (22%).

Table 4. Shadow prices by state

State	Mean	Standard deviation	Max	Min	N
AL	1.95	1.93	8.51	0.50	16
BA	17.03	10.78	58.39	4.93	38
ES	11.84	13.16	48.93	1.46	17
GO	9.92	8.75	45.11	0.97	44
MA	19.09	14.63	44.66	2.15	12
MG	7.31	5.24	39.74	0.06	261
MS	20.02	22.51	82.95	0.52	18
MT	20.31	16.67	59.07	1.78	21
PB	3.65	2.96	10.32	1.13	11
PE	5.49	8.66	31.66	0.23	18

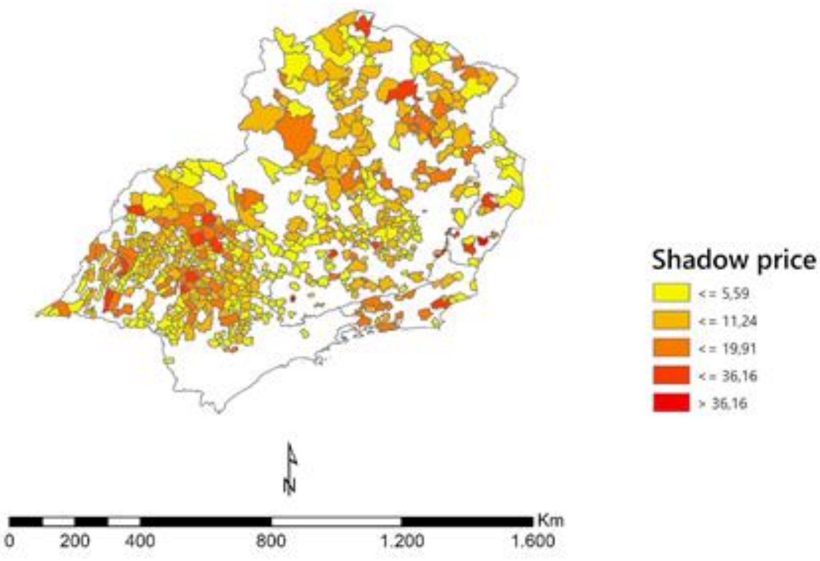
PI	11.71	13.13	48.76	0.69	11
PR	8.77	12.37	73.12	0.13	61
RJ	12.87	8.19	41.43	1.71	23
RN	3.63	3.32	9.29	0.34	7
RS	15.15	9.07	40.45	0.63	104
SE	1.84	0.54	2.53	1.34	4
SP	6.34	4.51	32.57	0.24	293
BR	**9.18**	**9.13**	**82.95**	**0.06**	**959**

Source: Estimated from model.

The Brazilian average shadow price is R$9,18 per ton of CO_2 equivalent. In the states of Mato Grosso, Mato Grosso do Sul and Maranhão producers should foregone approximately R$ 20.00 in revenue to reduce the emissions of CO_2 equivalent by one ton. The lowest shadow prices are observed in Alagoas and Sergipe, both states which higher average emissions of CO_2.

Figures 2 to 5 show the average shadow price for each municipality considered in this study among the Brazilian geographic regions producers (Southeast, Middle West, Northeast and South). The five color classes indicated the percentiles 20, 40, 60 and 80 of shadow price calculated considering all municipalities.

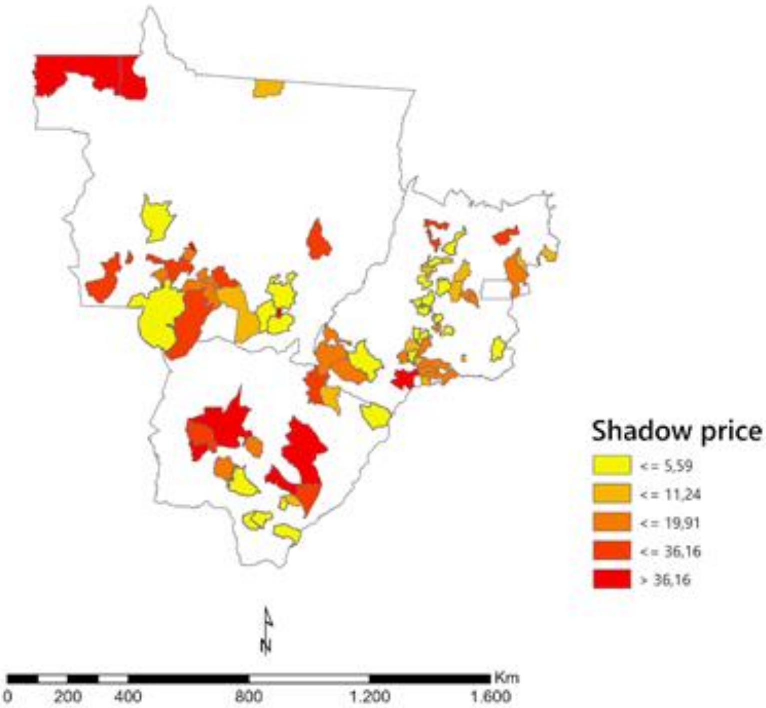
Figure 5. Spatial distribution of shadow price – Southeast region



Source: Prepared by the authors.

In the southeast region, the most traditional production region and that accounted for 66% of total production in the harvest 2017/2018 [28], most of municipalities (504 of 594) showed a shadow price lower than R$ 11.24, specially in São Paulo and Minas Gerais states. Both states created in 2007 and 2008 regulations for the sugarcane production in their municipalities, and stipulated goals to eliminate the pre-harvest burning of sugarcane in short term, that could has contributed for the lower shadow prices in these areas (lower than the national average). However, as the estimation of the shadow price depends on many variables, more studies are necessary to estimate the correlation of these sector regulations and the lower averages.

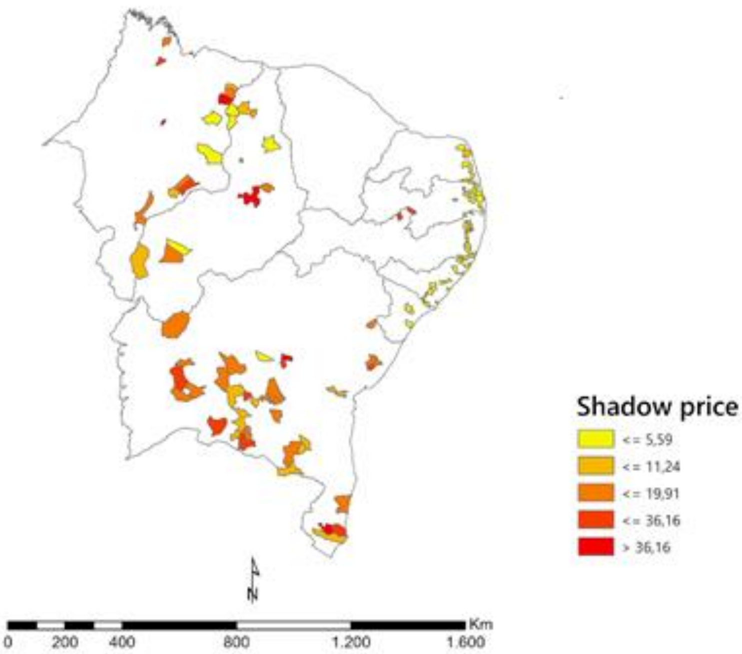
Figure 6. Spatial distribution of shadow price – Midwest region



Source: Prepared by the authors.

Midwest is the region with the highest sugarcane production growth and area expansion in the recent years, and nowadays is the second larger national producer. Although the adoption of mechanical harvest was fast in this region, due to the favorable relief conditions and the tradition of mechanization in other crops [25], this region showed the higher means and maximum shadow prices, indicating that the reduction of the emissions is more costly in this region, when compared with other Brazilian regions.

Figure 7. Spatial distribution of shadow price – Northeast region

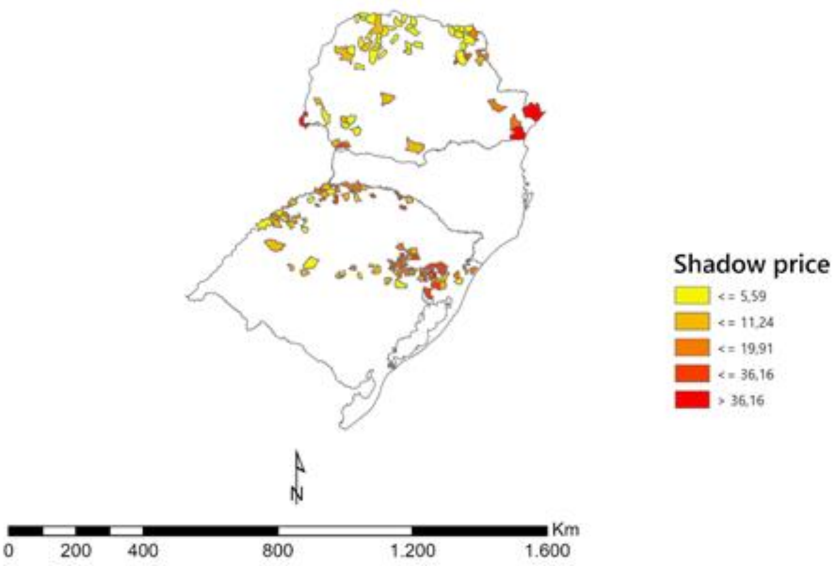


Source: Prepared by the authors.

Northeastern production has historical relevance for Brazilian sugarcane production, and it was for many decades the second largest producing region. Most of the shadow prices estimated for this region are in the lower range, although the region is one of the hugest CO_2 emitters. One characteristic of this region that impact on the mechanization, and consequently in the emissions decreasing, is the soil slope. As Torquato, Fronzagila, and Martins [6] observed, Northeast region, especially in Alagoas and Pernambuco states, has lower amount of land where the mechanization is feasible, compared with the Southeast and Midwest regions.

For these regions with adverse relief conditions, one way to reduce the emissions could be productive replacement by other crops that do not require burning for harvesting, as realized in the state of São Paulo, due to the state law 11,241 from 2002, that recommended the transition for other crops in areas where soil slope is greater than 12% [24].

Figure 8. Spatial distribution of shadow price – South region



Source: Prepared by the authors.

Sugarcane production in the southern region is not very significant at the national level, representing about 5% of country's production in the 2017-2018 harvest. Additionally, almost the entire production coming from the state of Paraná [28]. As Garofalo et al. [25] highlighted, the mechanized harvesti is widely used in Paraná, which possibly contributed to the low average shadow price observed in the region.

Based on the technical efficiency and shadow price estimates, the reduction of CO_2 emissions, mainly through mechanization, represents an opportunity cost for producers, since they would have to give up part of their production to reduce the emissions. In this scenario, subsidized credit lines, as the Program to Reduce Greenhouse Gas Emissions in Agriculture (ABC Program[5]) provided by the Brazilian Development Bank, might be an important public policy instrument designated to mitigate short term losses at the same time it contributes to the emissions reduction.

Our results also indicated that other way to reduce emissions might be the producers technical efficiency improvement. As Alves et al. [15] indicated, the technical assistance, especially the public assistance, plays a relevant role on the efficiency gains in the Brazilian agriculture, disseminating knowledge and technology to small less-capitalized producers. According to Fuglie et al. [30] some policies might improve the producers assess and management of new technological opportunities like, for example, investment on rural human capital and infrastructure. Our results reinforce the role of public policies directed to encourage the use of new technologies and services to increase the efficiency of producers, especially in the less technical efficient producing regions, especially because the new technologies spillover effects in terms of environmental sustainability and public health in the Brazilian sugarcane production regions.

[5] The ABC Program is a financial resource for investments that contributes to the reduction of environmental impacts caused by agricultural activities [29].

2.5. Conclusions

Our analysis investigates how sugarcane producers may improve technical efficiency through better managerial performance that contribute to reduce the pollution. The present study investigated the technical efficiency and the shadow price of the pollution from sugarcane production at the municipality level, using data from the 2017 Agricultural Census and CO_2 equivalent emissions.

The main results show that although the sugarcane production raising in recent years, sector still has opportunities to increase the country wide production, especially in the most representative production areas, as São Paulo, Goiás and Mato Grosso do Sul. The overall technical efficiency estimated is 81%, indicating that on average producers can increase the sugarcane production by 81,611 tons while reducing the CO_2 emissions by 53 tons.

The shadow price estimates have a high variance among municipalities, varying from R$ 0.06, in Minas Gerais, to R$ 82.95 in Mato Grosso do Sul. On the average and considering all the Brazilian municipalities, producers should foregone R$9.18 of their revenue to reduce the emissions of CO_2 equivalent by one ton. Regionally, the higher prices are observed in the Midwest Region, where the sugarcane production has been developed in the last years.

Hence, our analytical approach provides results, which complement the literature of the social welfare resulted from the reduction of pollution emissions from sugarcane production. Further, our results also suggest that public policies, especially through public financing and public technical assistance, could mitigate the producers losses in the short term, since the reduction of the pollution usually implies in the mechanization, which implies on higher initial costs, or productive replacement. Furthermore, the regional pattern of the shadow price also indicated that these policies could create better outcomes if they consider the specificities of the opportunity cost around the municipalities.

Further researches might investigate the historical shadow price including data from Agricultural Censuses published in 1995/96 and 2006, and estimate the real impact of the regulations in the sector for the reduction of shadow price in the states that regulated the pre-harvested burning, as Minas Gerais and São Paulo states.

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APPENDIX

APPENDIX A. OLS estimation

Variable	*Coefficient (sd)*
Area	0.918*** (0.024)
Capital	0.03*** (0.012)
Labor	-0.03*** (0.011)
Sugarcane	-0.967*** (0.013)
Area²	-0.082*** (0.008)
Capital²	-0.006*** (0.002)
Labor²	0.009*** (0.002)
Sugarcane²	-0.009*** (0.002)
Area x Capital	0.02* (0.011)
Area x Labor	-0.009*** (0.003)
Capital x Labor	0.024*** (0.005)
Area x Sugarcane	0.045*** (0.003)
Capital x Sugarcane	-0.013* (0.007)
Labor x Sugarcane	-0.006*** (0.001)
Dummy AL	-0.24*** (0.068)
Dummy BA	0.015 (0.048)
Dummy ES	-0.056 (0.07)
Dummy GO	0.101** (0.045)
Dummy MA	-0.027 (0.08)
Dummy MG	0.045 (0.028)
Dummy MS	0.067 (0.069)
Dummy MT	0.004 (0.062)
Dummy PB	-0.347*** (0.085)
Dummy PE	-0.238*** (0.064)
Dummy PI	-0.041 (0.086)
Dummy PR	-0.134*** (0.039)
Dummy RJ	-0.024 (0.06)
Dummy RN	-0.124 (0.102)
Dummy RS	-0.018 (0.036)
Dummy SE	-0.16 (0.119)
Constant	-0.02 (0.024)

Source: Estimated by the authors based on data from the Agricultural Census (2017) and MCTI (2021). Notes: Standard deviations are given in parentheses. Statistically significant confidence intervals are indicated as *** (99%), ** (95%) and * (90%). Dummy for SP was omitted.

APPENDIX B. Skewness and kurtosis test for normality - OLS residuals

Variable	Obs	Pr(skewness)	Pr(kurtosis)	Joint test	
				χ^2	$Prob > \chi^2$
e	1,054	0	0	370.45	0

Source: Estimated by the authors based on data from the Agricultural Census (2017) and MCTI (2021).

APPENDIX C. Coelli skewness test

Variable	Obs	Value
e	1,054	-10.534

Source: Estimated by the authors based on data from the Agricultural Census (2017) and MCTI (2021).

APPENDIX D. Municipalities that do not satisfy the monotonicity conditions

State	**Total obs**	**Obs that do not satisfy monotonicity conditions**	
		N	**% of state**
AL	29	13	45%
BA	45	7	16%
ES	17	0	0%
GO	47	3	6%
MA	13	1	8%
MG	262	1	0%
MS	20	2	10%
MT	22	1	5%
PB	12	1	8%
PE	32	14	44%
PI	11	0	0%
PR	75	14	19%
RJ	25	2	8%
RN	8	1	13%
RS	133	29	22%
SE	6	2	33%
SP	297	4	1%
BR	**1,054**	**95**	**9%**

Source: Estimated by the authors.

3. THE WELFARE IMPACT OF MECHANIZATION OF SUGARCANE PRODUCTION IN SÃO PAULO - BRAZIL

ABSTRACT

Using an equilibrium displacement model this paper examines the welfare impact of the mechanical harvest on the sugarcane value chain imposed by the State Law 11,241 in the State of São Paulo, the largest Brazilian state producer of sugarcane. The main results indicate a downshift of sugarcane, sugar and ethanol supply, suggesting that the mechanization improved the output production. We also verify welfare gains in all markets, except in the land and labor markets at farm level, and capital market at mill level.

Keywords: Sugarcane; Brazil; Mechanization; Equilibrium displacement.

3.1. Introduction

Sugarcane production is one of the most important agricultural commodities of Brazilian agribusiness, and country is the world largest producer of sugarcane (FAO, 2018). In the last decades, the production of this crop in Brazil have grown at high rates, due to the growth in the domestic demand for the ethanol by flex-fuel cars and the expansion of the domestic sugar consumption (Valdes, 2007). Regionally, the Brazilian sugarcane production is concentrated in a few states, and the state of São Paulo represents more than 50 percent of the national production (IBGE, 2017).

Historically, the sugarcane is planted in Brazil in a manual harvesting system, implementing the burning in the pre-harvesting period to remove the leaves, to help the manual harvesting of the stem, and to controll pests and weeds (Matos et al., 2017; Dinardo-Miranda and Fracasso, 2013). However, the pre-harvesting burning releases in the atmosphere particulate matters and gases, like carbon monoxide and carbon dioxide, that contribute to increase public health problems (Paraiso and Gouveia, 2015).

To control the health problems resulting of the pre-harvesting burning of cane straw, the State of São Paulo promulgated the State Law 11,241, of September 19, 2002, which established the gradual elimination of cane straw burning in the State of São Paulo until 2031. In 2007, an agreement among sugar mills and farmers, called Agro-environmental Protocol, anticipated the deadline to eliminate the burning to 2017.

This policy collaborates to soften the negative externalities of the sugarcane production in the State, reducing the public diseases associated to the burning of the cane (see Nicolella and Belluzzo, 2015; Chagas, Azzoni and Almeida, 2016; Uriarte et al., 2009).

However, prohibiting the burning of cane, the State Law imposed the mechanization of the farms, and create structural changes in the labor and machinery markets, increasing the demand for specialized workers and making the production more intensified in capital (Ferraz et al., 2018). Besides this allocation issue, the mechanization of harvest could affect the level of soil compaction (Bordonal et al., 2018), compromising the productivity and the profitability of the production.

The purpose of this study is to estimate the welfare gains and losses of the mechanization harvesting of sugarcane in São Paulo due the Law 11,241, using an equilibrium displacement model, like in Perrin (1997), Fulginiti and Perrin (2005), Wamisho (2010) and Bairagi (2015), considering all the value chain of sugarcane production.

This paper is organized as follows. In the next section, there is a brief overview of the sugarcane market in Brazil and a literature background of equilibrium and welfare analysis. The third section introduces the theoretical model. The fourth section shows the procedures used to calibrate the model. The fifth section presents the results and discussions. Finally, the sixth section is the conclusions of the authors.

3.2. Background Literature

3.2.1. Brazilian sugarcane market overview

For many decades the sugarcane market in Brazil was regulated by the Alcohol and Sugar Institute - IAA, a federal autarchy that determined quotas for ethanol and sugar produced, fixing the input and output prices, and operationalizing the exports (Sachs, 2007).

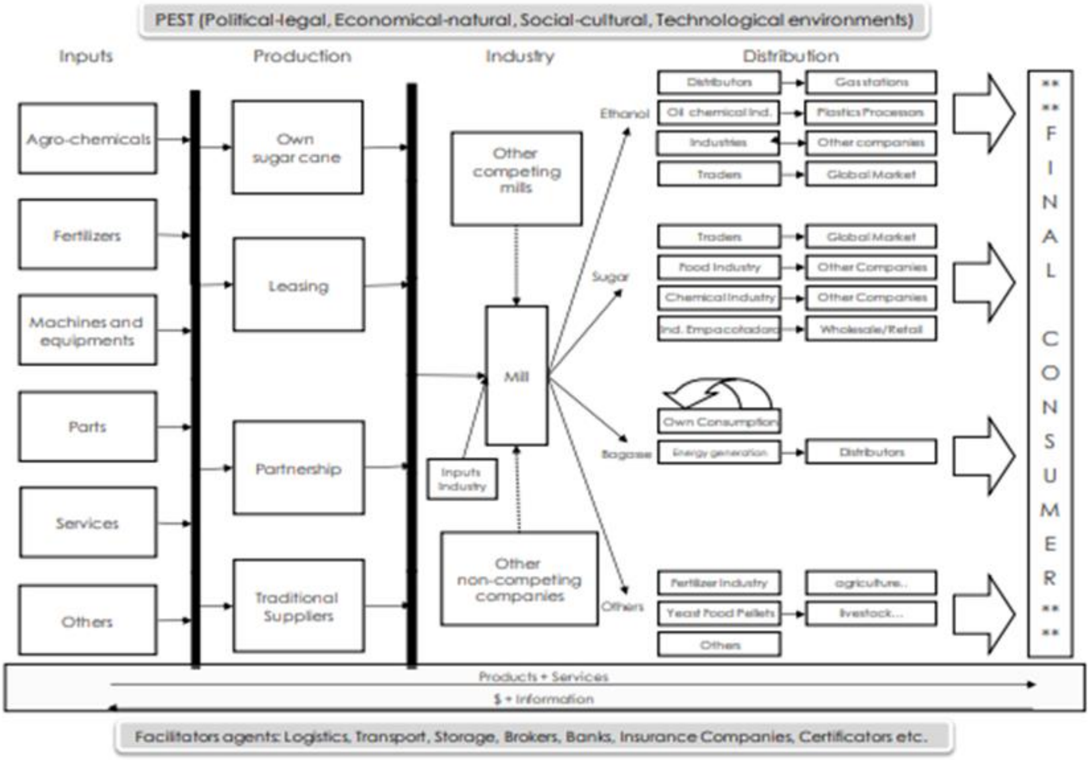
The economic crisis in Brazil in the early of 1990’s stimulated a series of public policies that deregulated many sectors, looking for competitiveness improvements (Pinheiro, Giambiagi, and Moreira, 2001). In this scenario, the Brazilian government extinguished the IAA, and in the subsequent years, the price of sugarcane, sugar, and ethanol were determined under free market conditions.

However, as Moraes (2000) discussed, the existence of a larger number of farmers and a few numbers of mills could create imperfect competition in this market, giving to the industry an oligopsony market power. In this way, new arrangements between producers and industry were created to guarantee that the industry can’t use your market power in the price determination.

The creation of Ethanol, Sugar and Sugarcane Producers’ Council of the State of São Paulo – CONSECANA in 1998 represented a tentative of equilibrating the price in the sugar and ethanol markets (Perosa, Ortega and Jesus, 2016). Gathering producers and industrial sector, this Council had as the main objective define a new methodology to be used by mills to pay the farmers for the sugarcane. By this new system, the value paid for the sugarcane is a function of its quality, that is measured as the total sugar concentration recoverable in the industrial process, expressed as kilogram by a ton of sugarcane (Sachs, 2007).

The actual value chain of sugarcane in Brazil is a complex chain that involves input suppliers, producers, industry, distributors, and final consumers (Figure 9). As Neves and Chaddad (2012) argued, the institutional arrangements at the production level can be classified as farmland leasing, partnership, supply contracts, spot markets, and vertical integration, when the mill produces the sugarcane in your own farmland. Also according to Neves and Chaddad (2012), although the historical spread use of vertical integration in the industry, the use of contracts with suppliers has increased in the last years.

Figure 9. The value chain of sugarcane in Brazil



Source: Neves and Chaddad (2012).

The institutional arrangements are also influenced by historical and social conditions of the production area. Pedroso Junior (2008), for example, analyzed the contractual arrangements between producers and sugar mills in the Center-South region, the main producer region of the country, and found different arrangements among traditional and non-traditional production areas. The author showed that in non-traditional areas, the partnership was the most common arrangement among farmers and mills, while in traditional areas the supply contracts and partnerships are those more used.

3.2.2. Equilibrium, technical change, and welfare analysis

The impact of a new technology for the market equilibrium was widely analyzed in the economic literature. Perin (1997), for example, estimated the impact of technical change on output and input markets using comparative statics analysis in a competitive industry with identical firms. The main result from the author is a new equilibrium approach that provides a framework for evaluating the changes in equilibrium prices and quantities as functions of the parameters of the technological change, which allows the ex-ante and ex-post analysis of a new technology in a specific market.

Perin and Fulginiti (2001) used an equilibrium model to derive a computable framework that account for the impact of the technical change for welfare gains, estimating how it is related with the rate and bias of technical change. The authors found that the rate of technical change usually is a biased measure of the welfare benefits from technical change, due to changes in the domestic good prices, caused by the technical change, or due to the price distotions caused by taxes.

Fulginiti and Perrin (2005) expanded this equilibrium approaches and also evaluated the impact of technical change for welfare changes, including other market failure situations caused by taxes, subsidies, quotas, imperfect competition and poorly priced goods, like environmental goods, to analyze the rate of welfare change in terms of the rate and biases of the technical change. The authors demonstrated that for a taxed economy, the difference between the welfare change and the rate of technical change may be 50% under plausible circumstances.

One application of these frameworks could be found in Wamisho (2010). The author, using an equilibrium displacement model, analyzed the impact of removing biofuel tax subsidy in the United States, considering all the biofuel industry that uses four inputs, corn, energy, labor and capital, to produce two outputs, ethanol and dried distillers grains. The author's main results indicate that the subsidy removing could generate welfare losses to ethanol producers and consumers.

Hammami and Begin (2021) implemented a multi-market displacement model to investigate the welfare and trade impacts of U.S. retaliatory tariffs on EU olive oil. The authors estimated that a 100% tariff on all EU olive oils implies in a \$924 million loss of welfare for U.S. consumers, while a 25% tariff on non-bulk Spanish olive oil mitigates the losses by \$55 million. In trade terms, in the first scenario the export revenue losses are \$360 million against around \$40 million in the second scenario.

3.3. Methodological Framework

3.3.1. Empirical model

Considering the complexity of the sugarcane production, as shown in the last section, we segmented the value chain of sugarcane production in São Paulo in two levels, farmers and sugar mills, and estimated one cost function for each sector. Besides that, as the independent suppliers are a high share of processed sugarcane in São Paulo (Bastos and Moraes, 2014), we don't account for vertical integration in the sector.

The dual cost function for the representative sugarcane producer of state of São Paulo was represented by:

$$C^F(w^F, y_{SC}) = \min_{x^F} \left\{ w^{F'} x^F \,\middle|\, (x^F, y_{SC}) \in \tau^F \right\} \tag{1}$$

where x^F is the input vector, w^F is an input price vector, y_{SC} is the output vector with associated price vector p_{SC}, and τ^F is the technology set of the farm sector. We consider that farmers use three variables inputs, land, labor and capital, and produce just one output, sugarcane.

The mechanization of the production instead of represents just an exogenous shift in the demand for machinery changes the entire sugarcane production process, representing a change in the technological set that producers are faced. In this way, and following Perrin (1997) and Bairagi (2015), we modeled the mechanization as a technical change in the input markets.

The first derivative of the cost function with respect to input prices, knowns as Shephard's lemma, give us the derived demand for inputs. The log-linearized version of this equation including the technical change can be expressed as:

$$dlnx^F - E_{xw}^F dlnw^F - E_{xy}^F dlny_{SC} = \beta_x - \iota\delta \tag{2}$$

where E_{xw}^F is the Hicksian derived demand elasticity matrix, E_{xy}^F is the matrix of elasticities of demand for inputs with respect to the sugarcane quantity, β_x is a vector that reflects the bias of technical change, δ is the dual rate of technical change and ι is a vector of ones. As we assumed constant returns to scale to the cost function, E_{xw}^{F} also exhibits symmetry property and homogeneity of degree zero in input prices and sugarcane quantity, and E_{xy}^{F} is equal to one.

Differentiating the input supply equation give us:

$$dlnx^{F} - \Sigma^{\mathrm{F}} dlnw^{F} = 0 \tag{3}$$

where Σ^{F} is the input supply elasticity matrix.

From the hypothesis of the market under perfect competition, we have that the derivative of the cost function with respect to output, i.e. the marginal cost of output, is equal to the output price, which in the log-linear version could be represented by equation 4 below.

$$dlnp_{SC} - E_{pw}^{F} dlnw^{F} - E_{py}^{F} dlny_{SC} = -\iota\delta \tag{4}$$

The E_{pw}^{F} is the matrix of the elasticities of inverse supply with respect to input prices, that is equal to the cost shares s_{x}^{F}. As the matrix of elasticities of inverse supply, E_{py}, is homogeneous of degree zero and the farms just produce one output, E_{py}^{F} is equal to zero in our model.

To integrate farms and mill sectors we assumed that all the sugarcane produced by the farms are used as input by the mills. This assumption implies that the exogenous demand for sugarcane at farm level is equal to the endogenous derived demand for sugarcane at mills levels. To avoid the inclusion of two equivalent equations, we dropped the exogenous demand for sugarcane at farm levels.

The second dual cost function used in this study models the interaction of the representative sugar mill with the farmers and final consumers and can be represented by:

$$C^{M}(w^{M}, y_{E}, y_{S}) = \min_{x^{M}} \left\{ w^{M'} x^{M} \,\middle|\, (x^{M}, y_{E}, y_{S}) \in \tau^{M} \right\} \tag{5}$$

where the inputs are labor, capital, and sugarcane, the outputs are ethanol (y_{E}) and sugar (y_{S}), with prices p_{E} and p_{S}, and τ^{M} is the technology set of the mills industry. As in the farm level, we assume that the markets are in perfect competition and that the cost function shows constant returns to scale.

The log-differentiation of the input supply for the mills is equal to:

$$dlnx^{M} - \Sigma^{\mathrm{M}} dlnw^{M} = 0 \tag{6}$$

where Σ^{M} is the input supply elasticity matrix. Like in the demand for sugarcane, we have that the sugarcane supply at mills level is equal to the sugarcane supply at the farm level, get from the marginal cost equation. Thus, to avoid the inclusion of two equals equations we didn't write the (exogenous) sugarcane supply for mills.

The input derived demand, get from Shephard's lemma, could be expressed in its log-linear version as:

$$dlnx^{M} - E_{xw}^{M} dlnw^{M} - E_{xy}^{M} \begin{pmatrix} dlny_{s} \\ dlny_{e} \end{pmatrix} = 0 \tag{7}$$

where E_{xw}^{M} and E_{xy}^{F} are, respectively, the compensated derived demand elasticity matrix and the matrix of elasticities of demand for inputs with respect to the ethanol and sugar quantity. E_{xw}^{F} shows symmetry property and homogeneity of degree zero in input prices and output quantity, and E_{xy}^{F} is homogeneous of degree zero in sugar and ethanol and its elements are equal to the ratios of output to input shares (Perrin, 2018).

The zero-profit condition for this market, $C^{M} = p_{e}y_{e} + p_{s}y_{s}$, and the perfect competition assumption implies that the marginal cost of sugar and ethanol is equal to their prices, and the log-linear system can be written as:

$$\begin{pmatrix} dlnp_{s} \\ dlnp_{e} \end{pmatrix} - E_{pw}^{M}(dlnw^{M}) - E_{py}^{M} \begin{pmatrix} dlny_{s} \\ dlny_{e} \end{pmatrix} = 0 \tag{8}$$

where the matrix of the elasticities of inverse supply with respect to input prices, E_{pw}^{M}, is equal to the cost shares s_{x}^{M}. The inverse output supply elasticity matrix, E_{py}^{M}, shows homogeneity of degree zero and reciprocity in its terms.

Finally, the exogenous sugar and ethanol demand equation could be represented by:

$$\begin{pmatrix} dlny_s \\ dlny_e \end{pmatrix} - H \begin{pmatrix} dlnp_s \\ dlnp_e \end{pmatrix} = 0 \quad (9)$$

where H is the output demand elasticities matrix for sugar and ethanol.

From the changes in prices and quantities of the sugarcane value chain, we estimated the welfare change in every market measuring the change in the producer surplus as a fraction of the initial value of the commodity:

$$\Omega = (\mathrm{dlnw})\left[1 + \frac{1}{2}(\mathrm{dlnx})\right] \quad (10)$$

3.3.2. Model calibration

To calibrate the empirical model, we used values for elasticities and cost shares from the literature, and made some assumptions about the market structure. Appendix E summarize all the values used in this paper.

For the input markets at the farm level, the costs shares were estimated from the production costs for the Brazilian Center-South region available in Pecege (2016), and were adjusted to the shares sum equal to unity. The land supply elasticity was calculated from Barr et al. (2010) as the simple average of land elasticities for Brazilian agriculture from 2004-06 and 2006-09. To get the labor and capital supply elasticities we assumed an inelastic supply for capital and an elastic supply for labor. We also assumed an inelastic derived demand for land and labor and a substitution relationship between capital and labor.

Like in the farm level, the input cost shares for the mill level were estimated from Pecege (2016), standardized to add up to one. By hypothesis, the labor supply curve was assumed to be elastic and the capital supply curve inelastic. The derived demand for sugarcane and labor was assumed inelastic and we considered that labor and capital were substitute goods in production.

For the mills' outputs, we used the production mix of ethanol and sugar for a mill in the Center-South region from Pecege (2016). The domestic sugar demand elasticity was obtained from Babcock, Moreira, and Peng (2013) for the period 2013/2014. The ethanol demand elasticity used in this study was that estimated for the short run by Santos (2013) between 2001 and 2011[6]. The ethanol inverse output supply was assumed to be inelastic.

Finally, to estimate the rate and bias of technical change we used data of expenditures with labor and depreciation for manual and mechanical harvest system in the Lençóis Paulista region[7], in State of São Paulo, from Nachiluk and Oliveira (2013). The bias of technical change was estimated as

$$\beta = \frac{mechanical\ cost\ share_i - manual\ cost\ share_i}{manual\ cost\ share_i} \quad (11)$$

Where β is the bias of each input (labor and capital) and the cost shares are the percentage of the cost with input i regarding the total cost.

The technical change was estimated as the variation of the total cost between the both system, manual and mechanical harvesting systems.

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[6] The Brazilian ethanol demand elasticity was also estimated by Freitas and Kaneko (2011) as -1.8 in the short-run and -1.413 in the long-run considering the period 2003 to 2010.

[7] Although this region is not one of the largest producers in the state of São Paulo, it was the one that had the most detailed costs with manual and mechanized harvesting.

Our estimates for technical change indicated a technological progress biased against labor and toward capital.

3.4. Results

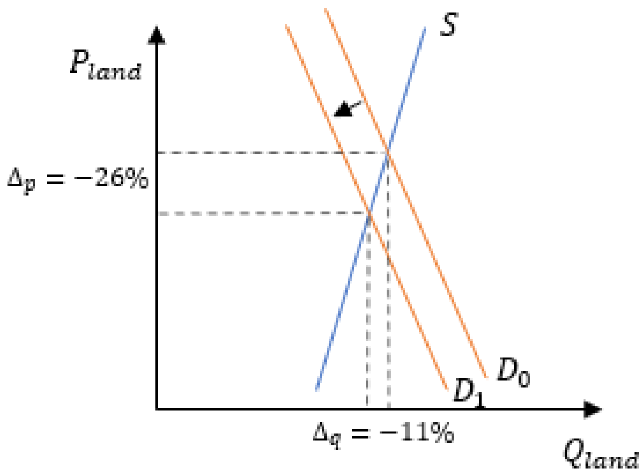
The following sections present the results of the equilibrium displacement model for all markets at each level of the sugarcane value chain, farms and sugar mills.

3.4.1. Farm level

The impact of State Law 11,241 in the land market was a decrease of 11% in the quantity demanded and a decrease of 25.5% in the price of the land (Figure 10). This decrease could be explained in our model since the land supply is almost inelastic and because land and capital are slightly substitute goods (cross-elasticity of 0.06). The analysis of the welfare change in this market showed a loss of 24% of the initial market value.

However, this fall of quantity demand and price in the land market, and the consequent welfare loss, could be mitigated or reversed in some regions of the state of São Paulo due to the expansion of demand for biofuels in the period, which pressure the demand for sugarcane, increasing the demand for new production areas, and mainly using areas previously occupied with grassland and annual crops (Vera, Wicke, and Hilst, 2020). As highlighted by Palludeto et al. (2018), the expansion of sugarcane production was also one of the main factors that collaborated to increase the land prices in the state of São Paulo between 1997 and 2013. Despite that, our model does not incorporate specific variables to capture the effects of the development of biofuels.

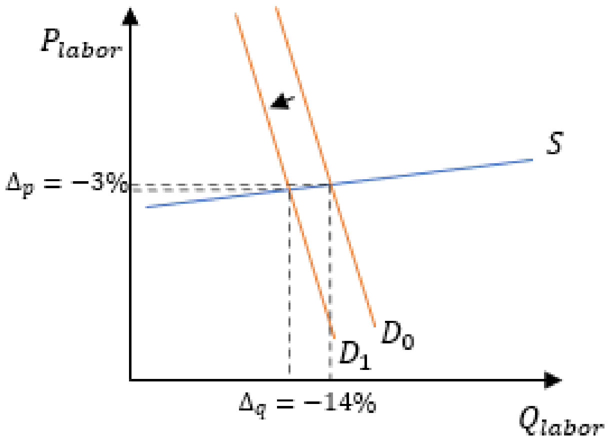
Figure 10. Changes in the land market



Source: Prepared by the authors based on the results.

Considering that our estimates for the technical change bias indicated that the mechanization was a labor-saving technology, the labor market was that most retracted after the law, decreasing the demand for labor by 14% and the wages by 2.8%. The study from Cepea (2018) analyzed the evolution of the labor in the sugar-energy sector in Brazil between 2000 and 2016, and found a similar pattern, with the labor in the farms increasing until 2008, one year after the Agro-environmental Protocol that accelerated the mechanization process and decreasing since them. The lower rate of decrease in wages could be a result of the hiring of more specialized workers to operate the new machines, as discussed by Cepea (2018) and Ferraz et al. (2018). The estimated change in the producer surplus in this market was -2.6%, a lower loss than that showed in the land market (Figure 11).

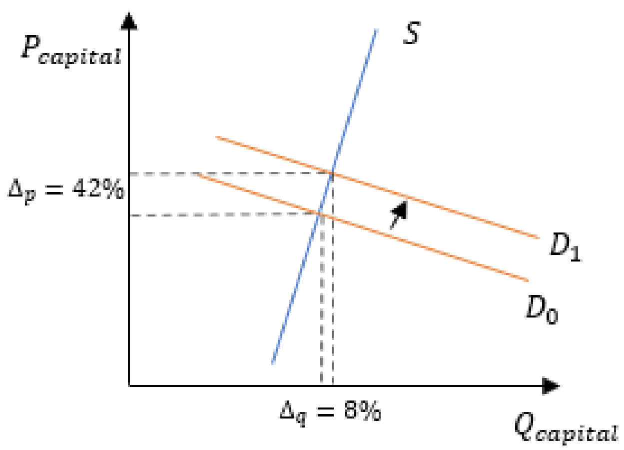
Figure 11. Changes in the labor market – farms



Source: Prepared by the authors based on the results.

The comparative static showed that the technological change shifts the demand for capital, increasing in 8.3% the equilibrium quantity, and in 42% the capital price (Figure 12). It's worth mentioning that in the last decade the Federal Government subsidized the credit for the modernization of the sugar-energy sector, especially through the Finame-Agrícola and Moderfrota credit lines from the National Bank for Economic and Social Development - BNDES for the acquisition of agricultural machines, which may have restricted the transmission of the price rising to the farmers predicted by our model. In terms of initial value, the post analysis of the welfare impact of this movement in the capital market was a gain of 43%.

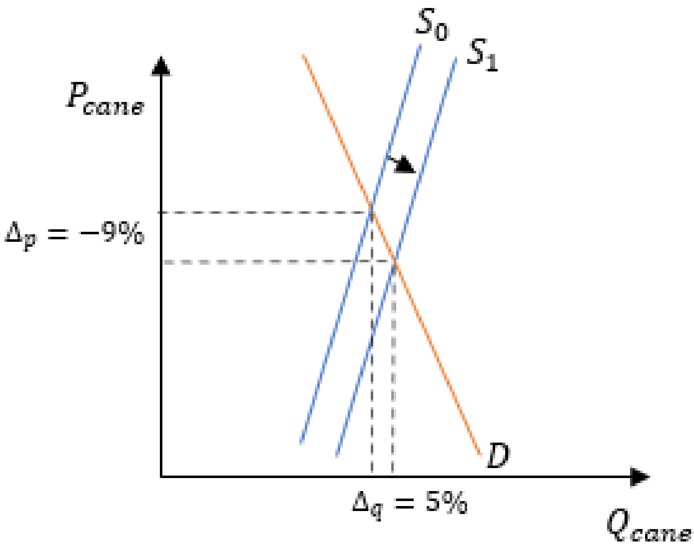
Figure 12. Changes in the capital market – farms



Source: Prepared by the authors based on the results.

In the sugarcane market, we can see a downshift of the marginal cost curve, increasing the quantity supplied by 5.4% and decreasing the price by 9.4%. (Figure 13). The welfare gain, measured as the change in the consumer surplus, was 7.3%. However, the welfare gain in this market may have been even greater, given the exogenous shock in the demand for ethanol in the 2000's, which boosted the demand for sugarcane, is not modeled in this research.

Figure 13. Changes in the sugarcane market

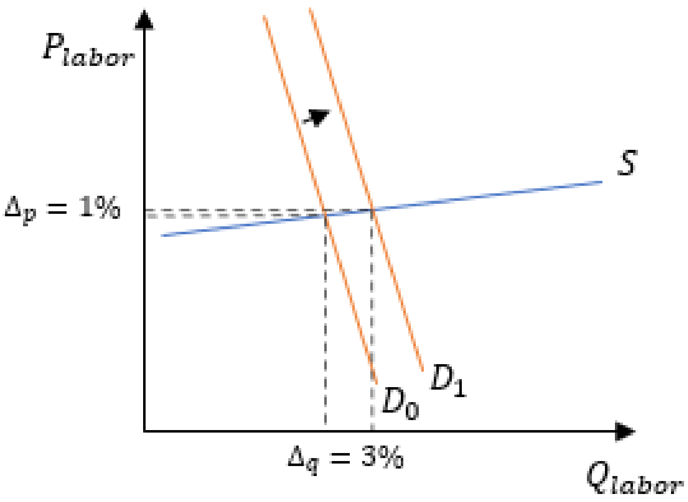


Source: Prepared by the authors based on the results.

3.4.2. Sugar mills

Analyzing the sugar mills markets inputs markets, we found an increasing of 3% in the demand for labor, with an almost flat variation in the labor price, resulting in a welfare gain of 1%. The demand for labor raise in this market r could promote a partnership between the mills and the local government, offering qualification to workers replaced by machinery in sugarcane production, absorbing part of workers and contributing to reduce the impacts of mechanization in the labor market at farm level.

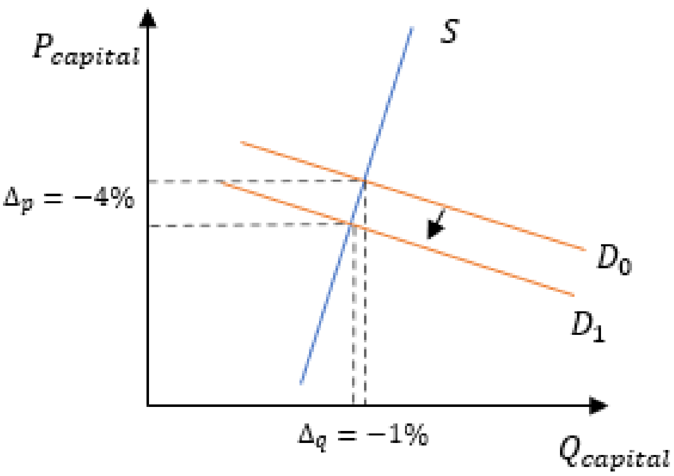
Figure 14. Changes in the labor market – mills



Source: Prepared by the authors based on the results.

Our estimates for the capital market at mills level showed a decrease in 0.8% of the capital quantity demanded, a 3.8% decrease in the capital price and a welfare loss of 3.8% (Figure 15). There are some financial incentives for this market that are not captured by our model that could modify the changes we estimated. Sant'Anna et al. (2016), for example, highlighted that the federal government provides in the 2000's subsidized loans to the sugar and ethanol industry to promote industrial technological innovations at the sugar-energy sector, like the PAISS Program. These governmental programs could contribute to a positive technical change in the capital market, reversing the welfare loss calculated by our model.

Figure 15. Changes in the capital market – mills

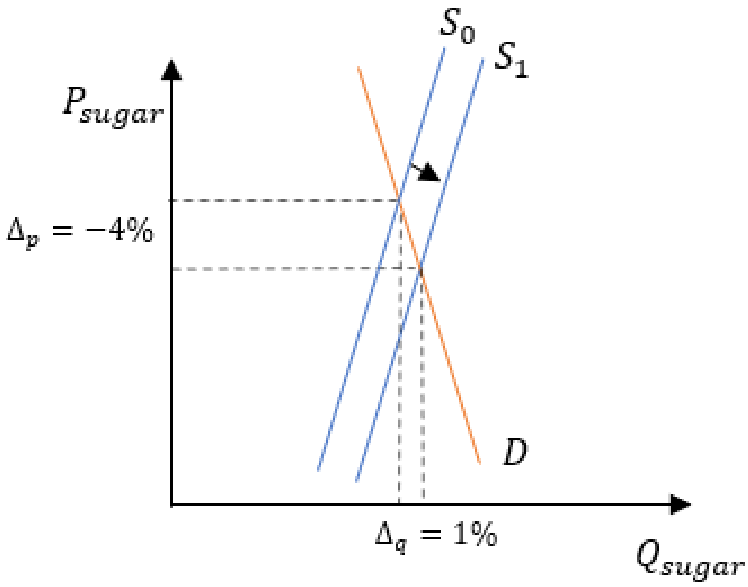


Source: Prepared by the authors based on the results.

In the output markets, we had a downshift of the supply curve for sugar, increasing the quantity supplied by 0.5% and decreasing the sugar price by 4.1%. As Morris, Angel, and Hernández (2017) pointed out the economic growth and the shortfalls in some producer countries made the world sugar price double between 2007 and 2011.

However, the increase in global sugar production led the fall in the world sugar prices in the subsequent years. Considering the changes in the quantity and price we estimated, the analysis of the welfare impact in this market showed a positive change of the producer surplus in almost 9%.

Figure 16. Changes in the sugar market

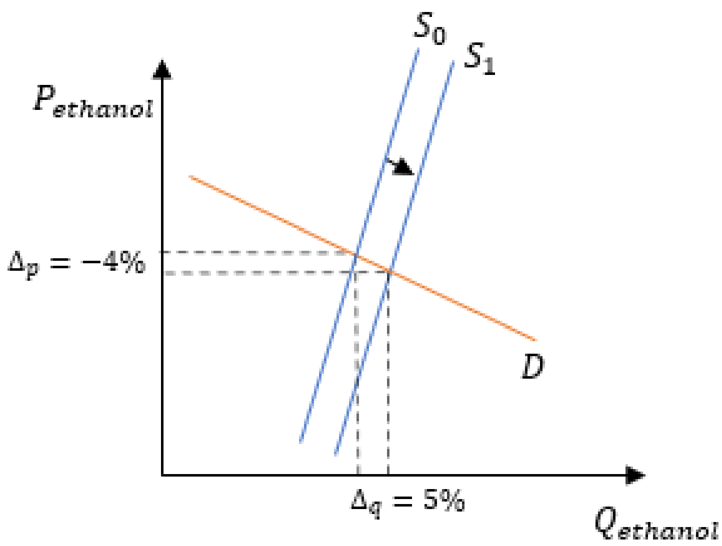


Source: Prepared by the authors based on the results.

The ethanol market increased the quantity supplied by 4.6% and decreased its price by 3.7% (Figura 17). However, our model does not account for the exogenous shock in the ethanol market due to the spread of the fuel flex cars since 2003, and the changes in mandates for ethanol in the gasoline[8], which also shift the demand curve for ethanol. The welfare gain in this market was close to 4%.

[8] As Drabik et al. (2014) showed, the share of the anhydrous ethanol mixed with gasoline is historically between 18-25%. In 2015 the Agricultural Ministerial Order change this share to 27% (BRAZIL, 2015).

Figure 17. Changes in the ethanol market



Source: Prepared by the authors based on the results.

3.5. Conclusions

This paper analyzed the welfare impact of mechanical harvest in the sugarcane value chain of the state of São Paulo, Brazil, using dual cost functions to characterize the sector and a displacement equilibrium model, like in Perrin (1997), Fulginiti and Perrin (2005) and Bairagi (2015).

Our findings suggested a positive technical change at the farm level that downshifted the supply curve of sugarcane, increasing the quantity and reducing its price. In the inputs market at the farm level, we saw a retraction in the land and labor markets, and an expansion in the capital market. This fall in the labor demanded should be higher if we consider just the unskilled labor market, like the study of Cepea (2018) suggests. The price of capital almost increases by 50%, and even with the subsidies provided by the Federal Government to the acquisition of machinery, this increase could have affected the sugarcane production profitability. The welfare analysis for this sector showed gains in the capital and sugarcane markets, and a loss in the land and labor markets.

At mills level, we found a downshift of the sugar and ethanol supplies, with an increase of the equilibrium quantity and a reduction in the price. At this level of the value chain, just the capital market showed a welfare loss, and the sugar market was that showed a higher welfare gain.

Future researches could incorporate other relevant questions that were not included in the current displacement model, which may change the results of the comparative statics, like the disaggregation of the labor market at farm level in unskilled and skilled labor, the subsidies for machines acquisition, specially from the BNDES, and the division of the ethanol market in anhydrous and hydrous, to account for external shock in the hydrous ethanol demand due the increase of the flex-fuel cars since 2003, and the change in the mandates in the anhydrous market.

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APPENDIX

APPENDIX E. Model' parameters

Variable	Value	Source
Farm level		
Cost share – land	0.4	
Cost share – labor	0.1	Estimated from Pecege (2016)
Cost share – capital	0.5	
Land supply elasticity	0.43	Estimated from Barr et al. (2010)
Labor supply elasticity	5	
Capital supply elasticity	0.2	
Land derived demand elasticity	-0.03	Assumption
Labor derived demand elasticity	-0.03	
Cross-elasticity capital labor	0.03	
Mills level		
Cost share – sugarcane	0.5	
Cost share – labor	0.1	Estimated from Pecege (2016)
Cost share – capital	0.4	
Labor supply elasticity	5	
Capital supply elasticity	0.2	
Sugarcane derived demand elasticity	-0.5	Assumption
Labor derived demand elasticity	-0.03	
Cross-elasticity capital-labor	0.03	
Ethanol demand elasticity	-1.252	Santos (2013)
Sugar demand elasticity	-0.05	Babcock, Moreira, and Peng (2013)
Ethanol output share	0.54	Pecege (2016)
Sugar output share	0.46	
Ethanol inverse supply elasticity	0.7	Assumption
Technical change		
Rate of technical change	-0.2	
Labor bias	-0.09	Estimated from Nachiluk and Oliveira (2013)
Capital bias	0.27	

4. FINAL REMARKS

This thesis analyzed the influence of the pollution in the sugarcane production in Brazil and its impact for the markets considering the elimination of pre-harvesting burning of the sugarcane straw.

In the first paper we estimated the technical efficiency of the sugarcane production in the Brazilian municipalities, assuming that the technological set produces both sugarcane and a bad output, represented by the CO_2 emissions due to the straw burning. We also estimated the shadow price of pollution, understood as the opportunity cost for producers to reduce one unit of pollution.

Second paper, using the background of the mandatory law in the São Paulo state that prohibits the pre-harvest burning, analyzed the impacts for the production markets of the transition to a non-burning scenario, investigating which markets lose and which markets win in this procution shift.

The overall results indicated that efficiency improvements could help to reduce the pollution emissions. On average, Brazilian sugarcane production could be increased by 81,611 tons while the CO_2 emissions could be reduced by 53 tons due to technical efficiency gains. Furthermore, the estimated average opportunity cost to reduce one ton of CO_2 equivalent was not expressive, R$9.18 per CO_2 equivalent, although this value varies among the regions, indicating that regional public policies should be necessary in some cases to soften the impact of reducing burning in the producers' revenue.

We also found that in a transition to a non-burning scenario, the most harmed sectors are the manual harvest labor and sugarcane production. These results indicated that future public policies that prohibit the burning should also include policies to reduce the impact in these markets, offering training and relocation for the manual workers, and providing technical assistance and funding to the farms to guarantee an efficienct production transition and productivity gains, that can soften the losses for this sector.