SUGAR CANE EXPANSION: DOES IT CONTRIBUTE TO AMAZON DEFORESTATION?

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Abstract

The aim of this study is to investigate the direct and indirect impacts of sugarcane expansion on deforestation in the Brazilian Amazon from 2001 to 2008. The analysis is based on the multi-output production theory where the annual agricultural acreage represents the Production Possibility Frontier. It assumes that agricultural area is limited and any agricultural expansion occurs over traditional agricultural areas displacing some crops and pushing them to the agricultural frontier, where forests will be cleared. The econometric analysis was carried out using a panel data model where the counties are the cross section unity. The output supply for São Paulo state and the agricultural frontier states (Mato Grosso, Rondônia, Maranhão and Tocantins) in the Center-West region are estimated separately, considering the acreage as proxy of the output and the crop prices of sugarcane, soybean, corn, beans, cotton and the total annual acreage as the independent variables. The impact of crop prices and the annual agricultural crop expansion over the deforestation acreage are also estimated. Our best estimates reveal that it is not possible to establish a direct connection between sugarcane area expansion and Amazon deforestation, and while the indirect effects are very small, sugarcane also expanded over pastures and perennial crops, leading to an overall increase in annual crop area.

Keywords: Brazil, sugarcane, agricultural frontier, Amazon deforestation

JEL Classification: Q110, Q160, Q230

1. Introduction

The commercial production of Brazilian flex-fuel engine vehicles, which run on any fuel combination—from 100 percent ethanol to 100 percent gasoline, started in 2003 and resulted very attractive for consumers who own these cars, as ethanol and gasoline were made perfect substitute goods. Currently more than 90 percent of all light vehicles sold in Brazil use flex-fuel technology and, as a consequence, there has been a very rapid increase in ethanol demand. However, at the center of the controversy surrounding ethanol expansion, lies the claim made by several researchers (Searchinger *et al*., 2008; Fargione *et al*., 2008; Fabiosa *et al*., 2010) that higher ethanol demand has led to land-use changes, with food crops being replaced with sugarcane production in traditional areas to support the ethanol demand. One could argue that as long as the agricultural frontier has reached the Northern region of the country, sugarcane expansion may contribute, directly or indirectly, to the Brazilian Amazon deforestation.

Besides its potential economic advantages, sugarcane ethanol is also considered an advanced biofuel that reduces greenhouse gas (GHG) emissions by 61 percent, compared with gasoline GHG emissions (EPA, 2010). However, Searchinger *et al.* (2008) argue that the benefits of biofuel use have been overestimated: sugarcane expansion would have replaced crops in agricultural areas which already contributed to lower the GHG emissions. Besides, while displacing food crops from their traditional areas, the new sugarcane acreage contributes to raising food prices and pushes the agricultural frontier towards the Amazon forest. The evidence for this argument would be the positive correlation between soybean prices and Amazon deforestation. On the other hand, Brandão *et al.* (2005) have analyzed soybean expansion in the early 2000's and found evidences that it has been occurring over low productivity livestock areas and has had low impact on Brazilian Amazon deforestation.

However, evidence exists that increased livestock activities in the Legal Amazon region[1] leads to more deforestation, with tax and credit incentives contributing to livestock expansion in this region (Margulis, 2003). Over the past decade, the beef cattle herd has increased by 25 million head in the Legal Amazon region, which account for 78 percent of the increase in the total cattle herd in Brazil, close to 33 million head. In the State of São Paulo, Brazil's leading cane-producing State, the cattle herd (including beef and dairy cattle) decreased by about 2 million head, a number corresponding to the 8 percent growth in the cattle herd in the Amazon region during 2000-2011 (IGBE, 2011). Still, some researchers (Nassar *et al.* 2008) have found that the direct contribution of sugarcane to deforestation is very low. In the Brazilian Center-South region (where 90 percent of Brazilian sugarcane is grown) sugarcane expansion has been more intensive over the past

[1] The Legal Amazon region also includes counties of the states of Mato Grosso and Maranhão, besides the states of the North region (Amazônia, Pará, Tocantins, Rondônia, Roraima, Acre and Amapá).

few years; about 70 percent of the sugarcane acreage expansion occurred over pasture areas. Data from the latest Agricultural Census indicates that in 1996-2006 pastureland in São Paulo decreased 4 percent (668 thousand hectares), while sugarcane area increased 41 percent (865 thousand hectares). Nassar *et al.* (2008) found that close to 30 percent of the expansion in sugarcane area in the São Paulo region took place over traditional crop areas.

IBGE data indicates that between 2002 and 2008 forest land was replaced only in three states: Minas Gerais (1 percent), Mato Grosso do Sul (2 percent), and Mato Grosso (8 percent), while the expansion in sugarcane area in these same states was 15 percent, 4 percent, and 3 percent, respectively. New sugarcane areas in Mato Grosso are also close to the Amazon region, but they correspond to less than 1 percent of the total new sugarcane areas in this period (Nassar *et al.,* 2008).

The indirect impact of sugarcane expansion on the Amazon forest region takes place as the prices of crops being replaced by sugarcane in São Paulo (i.e., soybeans, corn, cotton, beans) increase enough to stimulate farmers to plant in new areas, principally in the agricultural frontier. However, given São Paulo's share in total acreage for these crops (soybeans: 3 percent; corn: 8 percent; cotton: 7 percent; and beans: 5 percent), it is most likely that sugarcane would have a minimal or no impact on the prices of these crops. Moreover, Coelho *et al.* (2007) found corn to be the most substituted crop during 2000-2008, with corn acreage decreasing by 120 thousand hectares, surpassing cotton (49 thousand hectares), beans (33 thousand hectares), and soybeans (9 thousand hectares). In the case of livestock production, some other studies found that while cattle numbers increased, pastureland decreased –a reflection of increased livestock productivity (Coelho *et al*., 2007; Torquato, 2006).

Moreover, Chagas *et al.* (2008) contend that under the assumption that sugarcane production is evenly split for ethanol and sugar production, the area designated to ethanol production corresponds to just 1 percent of current agricultural area in Brazil. In addition, the authors contend, that while most of the replaced pastureland is of low productivity, and would provide needed area to support sugarcane expansion, thus reducing the pressure over food crop areas or forests. The present study aims to analyze the possible impact of sugarcane expansion in São Paulo on the expansion of the agricultural frontier and, ultimately, the impact on Brazil's Amazon deforestation. While our study is based on panel data analysis for the period from 2001 to 2008, the innovation in the study is the inclusion of all São Paulo State counties and all counties in Brazil's agricultural frontier. The analysis is carried out in three steps: first, the supply for crops produced in São Paulo State is estimated; second, the supply for crops produced in the Center-West agricultural frontier region is estimated as well, and finally, the economic impact of individual crop prices on deforestation in the agricultural frontier region of Brazil is estimated. The paper is organized as follows: the next section presents the modeling framework for the analysis, followed by the methodology; and then the results are discussed, following with concluding remarks.

2. Modeling framework

The analysis is based on the multi output production theory. According to Chambers (1986), *in the multi output framework the problem is to obtain the maximum value that a given input endowment can produce*. In this case, *a given input bundle can produce the array of outputs summarized by the producible-output set.* São Paulo State is one of the most traditional agricultural areas in Brazil and most of its producible areas are already in use. The agricultural land is considered as a fixed endowment and land use will be determined by crop prices.

The equilibrium is given when the Marginal Rate of Product Transformation equals the output prices or the ratio of prices equals the ratio of marginal costs. Assuming an input endowment x, if the price of the commodity i increases, more input is designated to this crop, that is:

$$\pi = p_i y_i + p_j y_j + \theta(c - p_x x)$$

By maximizing π with respect to the output i and j, the equilibrium is given by:

$$\frac{p_i}{p_j} = \frac{MC_i}{MC_j}$$

Where MC is the marginal cost of i and j, respectively.

The revenue function is given by:

$$R(p,x) = \max\{p \cdot y : y \in Y(x), p > 0\}$$

Where $Y(x)$ is the producible output sets.

Differentiating $R(p,x)$ with respect to p, it is possible to achieve the output supply y_i as the function of the output price and the input bundle x:

$$\frac{\partial R(p,x)}{\partial p_i} = y_i(p,x)$$

In the analysis, if there is no available area to expand agricultural activities in São Paulo State, the actual agricultural area would be the endowment input x that would be allocated to the crops according to their respective Marginal Revenue. It is assumed that the other inputs do not limit any crop production. Thus, given the marginal cost of any crop, variations on its price will change the optimum output. If the relative price p_i/p_j (assuming i as sugarcane and j as other crops) increases, more land will be designated to this crop.

The input endowment x is the total annual crop acreage. If the annual crop acreage remains constant during the period, it is clear that the only way to expand crop i is by replacing crop j. Alternatively, an increase in total acreage per year may be caused by the expansion of all crops: this is referred to as the “expansion” effect. Moreover, if this expansion occurs with no change in the relative prices, each crop would be expected to grow at the same proportion as before. However, a change in relative prices that causes crop i to achieve an increase in acreage larger than for the case of crop j is referred to as the “substitution effect.” In the agricultural frontier, in counties where new agricultural areas have been exhausted, the acreage expansion might occur over the forest, causing deforestation in order to cultivate new areas. In this situation, since the private opportunity cost of the forest is null, once the net revenue is enough to compensate the deforestation costs, it is profitable to incorporate forest areas for agricultural production[2].

3. Methodology[3]

The estimation considers the impact of the crop prices on their respective acreage. The cultivated crops are: sugarcane, soybean, corn, beans and cotton.

The model is specified as:

$$y_{it} = \beta_k \cdot X_{it} + v_{it} \quad (1)$$

Where i is the county and t is the period of time, y_{it} is the cultivated area of each crop for the cross section i in the period t; β is the parameters to be estimated; X_{it} ,the independent variables, which are the crop prices and the total annual crop acreage, which represents the limiting input bundle; v_{it} is the error term.

According to the theoretical model, the supply function is $y_i(p,x)$, where x is the input bundle. In this case, there is no limitation in the input bundle as a whole, but only in the available area. In São Paulo State, it is assumed that there are no new areas to expand the sugarcane crop and farmers have to decide to grow either traditional crops (or pasture) or sugarcane. In the Center-West region, it is necessary to occupy the *Cerrado*s or Amazon Forest biomes in order to increase grain cultivation areas. If deforestation is considered undesirable, or that it should at least be controlled, agriculture expansion in this region has some limitation for increasing grain area. Thus, besides crop prices, the econometric estimation should also include the total annual crops harvested each year, as a proxy of the limited input bundle.

The analysis in the study covers the 2001 to 2008 period. However, sugarcane expansion has been occurring more intensively since 2004, after automobiles factories

[2] Brazilian government exerts some control in the Amazon region, through satellites, to prevent expansion over forest areas. This control has decreased deforestation over the last decades. However, the huge extension of the region makes it difficult and deforestation still occurs at high rates.
[3] This section is based on Wooldridge, 2002

had started producing flex-fuel vehicles. In order to capture this effect, a dummy coefficient is also included for the total annual crop area, for the period from 2004 to 2008.

In the econometric estimation, both in São Paulo State and the Center-West Cerrados area, X_i is:

$x_1 : x_5$ are the annual prices of sugarcane, soybean, corn, beans and cotton;

$x_6 : x_7$ are the total annual crop area and its dummy coefficient (2004-08);

In the Center-West region, it is also estimated the influence of these independent variables on deforestation rates in that region. This estimation included one more independent variable: remaining forest.

The model specified in (1) is the Pooled Ordinary Least Squares estimation, which is unbiased and consistent under the assumptions:

$$— E(x_{it}'v_{it}) = 0, \; t = 1,2,...T \qquad (2)$$

$$— rank\left[\sum_{t=1}^{T}(x_{it}'x_{it})\right] = k \qquad (3)$$

$$— E(v_{it}^2 x_{it}'x_{it}) = \sigma^2 E(x_{it}'x_{it}), t = 1,2,...,T; \text{ where } \sigma^2 = E(v_{it}^2) \text{ for all } t; \qquad (4)$$

$$— E(v_{it}v_{is}x_{it}x_{is}) = 0, \text{ for } t \neq s, t, s = 1,2...T; \qquad (5)$$

The first assumption states no correlation between x_t and v_t for each time period and the second rules out perfect linear dependencies among explanatory variables. The third assumptions imply homokedasticity along the time period and no correlation between the errors over different periods of time. Besides, it implies $E(v_i'v_i) = \sigma^2 I_T$. According to Wooldridge (2002), under assumptions one and two, the pooled OLS estimator is consistent and asymptotically normal, and if the third assumptions hold, the asymptotic variance of the estimator is given by $A\,\text{var}(\hat{\beta}) = \sigma^2 \left[E(X_i'X_i)\right]^{-1} / N$, and the appropriate estimator is given by:

$$A\,\hat{\text{var}}(\hat{\beta}) = \hat{\sigma}^2 \left(\sum_{i=1}^{N}\sum_{t=1}^{T} x_{it}'x_{it}\right)^{-1} \qquad (6)$$

Where $\hat{\sigma}^2$ is the usual OLS variance estimator from the pooled regression, given by:

$$\hat{\sigma}^2 = \frac{\hat{v}_{it}'\hat{v}_{it}}{NT - k} \quad (7)$$

In the panel data estimation, while some of the independent variables for each unit can vary over time, others can be time invariant. In this case, these variables are related to the characteristic of each unit and are not usually observable. When the unobserved effects (c_i) for each cross section unit are not correlated with the independent variables specified in X_i, they can be assumed to be part of the error term, and the model specified in (1) would be correctly specified. Otherwise, $E(x_t' v_t) \neq 0$ and the pooled OLS estimator is no longer unbiased. If this is the case, the unobserved effects can be specified in two alternative ways: the Fixed Effects model and Random effects model. According to Wooldridge (2002) and Greene (2005) the difference between both approaches is whether these are, or not, correlated with the independent variables specified in X_i.

In this research, the cross section unities are the counties, for the time period from 2001 to 2008. The sugarcane production in São Paulo State, for example, is concentrated in many regions but it is not grown in every county of the State. This is also true in the case of soybeans grown in Mato Grosso, the main soybean producing Brazilian State. To avoid the inclusion of counties not producing a crop, only those counties reporting some production in all the years of the period under analysis were selected. According to Judge *et al.* (1988), the most appropriated approach in this case is the Fixed Effects analysis. According to Wooldridge (2002), FE is more robust than RE and allows the estimation of the unobserved effect for each cross section unit. The disadvantage of FE is that it is not possible to specify the time constant in X_i. Initially, the necessary assumption is:

$$- E(v_{it} | X_i, c_i) = 0; t = 1,2,...T \quad (8)$$

Which is the strict exogeneity of X_i and v_i, conditional to the unobserved effect.

To eliminate the unobserved effects from the equation to be estimated, the time averaged equation for each section:

$$\bar{y}_i = \beta_k \cdot \bar{X}_i + c_i + \bar{v}_i \quad (9)$$

is subtracted from the original equation (1) and results in the demeaned equation:

$$\left(y_i - \overline{y}_{it}\right) = \beta_k \cdot \left(X_{it} - \overline{X}_i\right) + \left(v_{it} - \overline{v}_i\right)$$

or

$$\ddot{y}_i = \beta_k \cdot \ddot{X}_{it} + \ddot{v}_{it} \tag{10}$$

The $\hat{\beta}_{FE}$ estimator is obtained from (10) applying the pooled OLS estimator. However, the interpretation of $\hat{\beta}_{FE}$ comes from the structural conditional expectation:

$$E\left(y_i \middle| X_i, c_i\right) = E\left(y_{it} \middle| x_{it}, c_i\right) = x_{it} \cdot \beta + c_i$$

To apply pooled OLS in (10), the following assumption must hold for the demeaned equation:

$$E\left(\ddot{x}_{it}\ddot{v}_{it}\right) = 0 \therefore E(x_{it} - \overline{x}_i)(v_{it} - \overline{v}) = 0 \tag{11}$$

The orthogonal condition for the demeaned equation is assured by the first assumption of the pooled OLS estimation (2) and strict exogeneity (8).

The second assumption for FE estimation is:

$$-\, rank\left[E\left(\ddot{X}_i{}'\ddot{X}_i\right)\right] = k \tag{12}$$

The asymptotic inference of FE is based on the assumption:

$$-\, E\left(u_i{}'u_i \middle| X_i c_i\right) = \sigma_v^2 I_T \tag{14}$$

It allows to specify the asymptotic variance of $\hat{\beta}_{FE}$:

$$A\,\hat{\text{var}}(\hat{\beta}_{FE}) = \hat{\sigma}_v\left(\ddot{X}_i \ddot{X}_i\right)^{-1} \tag{15}$$

where the asymptotic standard errors of the FE estimates are obtained by the square roots of the main diagonal. The consistent estimator for σ_v is given by:

$$\hat{\sigma}_v = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{u}_{it}^2}{\left(N(T-1)-k\right)} \tag{16}$$

In FE, once the unobserved effects are specified in the model and are no longer part of the composite error, the covariance matrix assumes the traditional form for homoskedasticity and no serial correlation. However, these assumptions may not be true and problems with heteroskedasticity and serial correlation can arise. To avoid those problems, this research used the robust covariance matrix in the estimation:

$$A\,\hat{\text{var}}(\hat{\beta}_{FE}) = \left(\ddot{X}_i'\ddot{X}_i\right)^{-1}\left(\sum_{i=1}^{N}\ddot{X}_i'\hat{v}_i\hat{v}_i'\ddot{X}_i\right)\left(\ddot{X}_i'\ddot{X}_i\right)^{-1} \quad (17)$$

These estimates are carried out using the Matlab software.

Acreage decisions are based on the expected prices. Thus, in order to incorporate the expectation formation, this analysis also uses the Quasi Rational Expectations (QRE) model. It is based on the Rational Expectations Model which incorporates the hypothesis that the "economic agents make purposeful and efficient use of information just as they do with other scarce resources, in optimizing their decisions." The alternative approach (the Quasi Rational Expectations) has the same theoretical background and it is easier to apply than the Rational Expectations, since it neglects some of the restrictions imposed by this model (Nerlove, 2001). While RE proposed to incorporate all available information, which causes some problems in the estimation, QRE proposes two-step estimation.

To illustrate this, the following model is assumed:

$$Y_t = a + bz_{t+1} + w_t$$

Where w_t is identically, independently distributed as $WN(0,\sigma_w^{\,2})$ and z_{t+1} is the variable that incorporates the expectations. The QRE in its simple approach consists in estimating z_t from its past values using an autoregressive model and then, substituting z_{t+1} for the calculated value $\hat{z}_{t+1}$. This is what is done in this research, taking the forecast values for the crop prices, which are used in the panel data model estimation. The forecast values are estimated based on the ARIMA model, using the Eviews software system (2004).

4. Results and Discussion

The direct impacts from sugarcane expansion on deforestation would be reflected in new crop areas in the forest region. Our analysis indicates that there has been sugarcane expansion and deforestation in four states along the agricultural frontier: Rondônia, Mato Grosso, Tocantins and Maranhão. While Mato Grosso has long been an important agricultural producer in the agricultural frontier and Brazil's main soybean producer, the "new" agricultural frontier is represented by Mapito (in the State of Maranhão, Tocantins and Piauí). In addition, the lower border of the Amazon forest crosses these states, and encompass part of the Amazon biome.

Table 1 presents data for these states and selected regions for sugarcane and crop expansion and deforestation. In Maranhão, sugarcane area increased in all five regions, but more intensively in Western, Eastern and Southern Maranhão regions. Western Maranhão presented the highest growth (22.9 percent) but the sugarcane area in this region represents just 0.51 percent of the total annual crop area: total acreage increased by 1,475 hectares while forest area decreased by 1,266,910 hectares. In Southern Maranhão, sugarcane represents the largest share (5.91 percent) of total annual crop acreage; here sugarcane area increased by 14,332 hectares while the reduction in the forest area was 6,450 hectares. In Eastern Maranhão, sugarcane area increased by 12,376 hectares, an amount similar to the reduction in forest area (12,830 hectares). However, its participation in total annual crop acreage is just 2.83 percent and there is no evidence that deforestation was a result of sugarcane expansion.

In Mato Grosso State, the most significant growth in sugarcane acreage took place in the Northern region (growth rate of 9.12 percent per year), but it has a very low participation in total annual crop area (0.86 percent). In this region, forest area decreased by 3,770,440 hectares, while annual crops increased by 2,972,694 hectares. South-western Mato Grosso has 45.4 percent of its annual crop area cultivated with sugarcane and in the 2000-2008 period, area cultivated to sugarcane grew 5.39 percent per year to a total of 52,929 hectares while forest area decreased by 209,250 hectares (representing a 2.14 percent annual decline in the same period). For all other regions in this State, the increase in sugarcane area is lower than the decrease in forest area, except for South-Western Mato Grosso, where the two rates are close. Reduced forest area has been more significantly in Northern, Northeastern and Southeastern Mato-Grosso, where annual crop acreage has increased significantly.

In Rondônia, just four regions (Ariquemes, Alvorada d'Oeste, Alvorada and Cacoal) register significant growth in sugarcane acreage, but the participation of this crop in the annual crop acreage is below 1 percent, except for Cacoal, with 2.02 percent. The growth in this region did not show any significant trend, but it was the most significant in terms of acreage (2,546 hectares). It is worth highlighting that in all regions in Rondônia State, the sugarcane acreage growth and the annual crop acreage growth is significantly lower than the deforested area. In Tocantins, only three regions – Bico do Papagaio, Araguaína and Miracema do Tocantins show a small growth in sugarcane acreage, and lower than the deforested area registered.

To analyze the indirect impacts from sugarcane expansion on the Amazon deforestation, we first estimate the impact of sugarcane expansion in São Paulo State by estimating the output supply for sugarcane, soybean, corn, beans and cotton. A panel data analysis is used considering the acreage as proxy of the output production, where the counties are the cross section unities for the period 2001 to 2008. The independent variables are the crop prices, while the annual crop acreage is used as the endowment input, which represents the production possibility frontier. To incorporate the expectation formation, the expected prices are estimated using an ARIMA model, considering the annual series from 1971 to 2010 for each individual crop. Results from this estimation are presented in Table 2.

A proxy coefficient for the annual crop acreage is used for the period 2004 to 2008 to capture the effect of the most recent sugarcane expansion. It is estimated a single supply function for each crop, taking into consideration only the counties reporting production in the period of analysis; results are presented in Table 3. The own price elasticities are consistent with the theory, except for beans, which presented a negative response to its own price, statistically significant at the 10 percent level. A possible explanation for this result may be the fact that this crop is cultivated three times during the year with average prices and acreage for the whole year likely misestimating the prices and production relationship. Cross prices of sugarcane on other crops supply are negative and statistically significant, except for the case of beans. The impact of sugarcane prices on cotton acreage is the highest, followed by soybeans acreage. The cross price elasticity of sugarcane is higher than the own price elasticity for soybean, corn and cotton, which indicates the predominance of the former price on crop acreage. All crops included in the analysis had their acreage reduced during the 2000-2008 period.

The "Annual Crops" variable represents the area available to plant these crops, which is limited and the decision to plant one crop over another will depend on expected returns. The highest elasticity was observed for the case of sugarcane supply (1.283). A dummy variable was included to capture the most recent expansion of sugarcane resulting after the adoption of flex fuel technology in 2003. During this period, the annual crop acreage is positive and statistically significant for sugarcane supply, but corn, beans and cotton were negatively affected by the annual acreage in the 2004-2008.

Table 1 – Sugarcane and crops expansion and deforestation in selected regions of Maranhão, Mato Grosso, Rondônia and Tocantins.

		Sugarcane			Annual Crops	Forest (ha)		Annual Growth (%)	
State	Region	Annual growth (%)[1]	Acr. Var. (ha)	Share (%)	Acr. Var. (ha)	Deforested	Remaining	Deforestation	Forest
Maranhão	Northern Maranhão	4.13	99	0.12	47.748	-191.580	2.039.090	-35.91	-1.15
	Western Maranhão	22.90	1.475	0.51	36.797	-1.266.910	1.949.603	-27.19	-7.37
	Central Maranhão	6.43	429	0.46	22.226	-236.820	867.125	0.00	-3.48
	Eastern Maranhão	16.10	12.376	2.83	138.763	-12.830	1.702.173	0.00	-0.11
	Southern Maranhão	10.25	14.332	5.91	169.750	-6.450	17.448	0.00	-5.78
Mato Grosso	Northern Mato-grosso	9.12	25.666	0.86	2.972.694	-3.770.440	25.887.760	-16.42	-1.99
	Northeastern Matogrosso	2.03	496	0.75	451.610	-870.890	4.226.270	-18.83	-2.62
	Southwestern Mato-grosso	5.39	52.929	45.40	100.421	-209.250	1.185.030	-27.06	-2.14
	Cent.-Southern Mato-grosso	0.00	-1.951	6.74	45.641	-78.830	796.353	-22.47	-1.34
	Southeastern Mato-grosso	3.81	6.704	1.69	513.216	-7.600	281.288	0.00	-0.37
Rondonia	Porto Velho	0.00	-15	0.25	14.313	-854.020	4.559.365	0.00	-2.56
	Guajará-Mirim	0.00	7	0.25	4.604	-231.530	2.906.425	-14.24	-1.12
	Ariquemes	29.86	45	0.14	1.740	-299.690	1.157.488	-19.20	-3.41
	Ji-Paraná	0.00	-9	0.21	-23.952	-87.010	973.278	-27.58	-1.23
	Alvorada D'Oeste	16.51	32	0.36	-16.013	-98.710	635.083	-19.21	-2.07
	Cacoal	0.00	2.546	2.02	-23.565	-151.340	924.673	-19.75	-2.17
	Vilhena	36.29	259	0.13	67.148	-158.600	1.450.310	0.00	-1.62
	Colorado do Oeste	0.00	-71	0.07	41.175	-563.50	453.300	0.00	-1.82
Tocantins	Bico do Papagaio	21.25	50	0.34	2.612	-32.160	124.038	-17.81	-3.51
	Araguaína	78.84	1.047	1.55	20.905	-49.800	211.773	0.00	-3.21
	Miracema do Tocantins	0.00	38	0.04	40.451	-21.900	178.220	-24.70	-1.67
	Rio Formoso	-7.32	-157	0.22	23.113	-6.950	486.793	0.00	-0.24
	Gurupi	0.00	852	0.76	22.699	490	1.930	0.00	0.00
	Porto Nacional	7.60	399	0.32	63.901	-680	4.043	0.00	-2.19
	Jalapão	6.05	39	0.06	132.204	1.250	10.725	0.00	1.80
	Dianópolis	0.00	460	3.26	50.576	20	10	0.00	0.00

Sources: Author's calculations based on crop areas as reported by IBGE; forest areas as reported by INPE. Notes: 1 – Annual Growth: Exponential Growth for sugarcane crop for 2000-2008; for deforestation and forest area remaining for 2001-2008; 2 – Crop share of sugarcane and forest remaining area: 2005-2008 average.

Table 2 - Time series estimation for the analyzed crop prices.

Crop	Model Specification	R^2	MAPE	TIC	BP	VP	CVP
Sugarcane	$\underset{(0.831)}{-2.737^{***}} + (1-L^1)y_t = (1-\underset{(0.036)}{0.867^{***}}L^{12})e_t$	0.502	6.595	0.032	0.006	0.015	0.978
Soybeans	$\underset{(17.425)}{-38.140^{**}} + (1-L^1)y_t = (1-\underset{(0.020)}{0.919^{***}}L^{6})e_t$	0.551	14.450	0.078	0.000	0.003	0.996
Corn	$(1-L^1)(1+\underset{(0.165)}{0.321^{*}}L^1+\underset{(0.159)}{0.319^{*}}L^2)y_t = (1-\underset{(0.084)}{0.146^{*}}L^4+\underset{(0.075)}{0.841^{***}}L^5)e_t$	0.557	11.425	0.065	0.032	0.002	0.964
Beans	$(1-L^1)(1+\underset{(0.104)}{0.410^{***}}L^1+\underset{(0.087)}{0.670^{***}}L^2)y_t = (1+\underset{(0.041)}{0.920^{***}}L^5)e_t$	0.717	18.603	0.104	0.006	0.001	0.993
Cotton	$(1-L^1)(1+\underset{(0.117)}{0{,}729^{***}}L^1+\underset{(0.105)}{0{,}304^{***}}L^2+\underset{(0.077)}{0{,}263^{***}}L^6)y_t = (1+\underset{(0{,}135)}{0.582^{***}}L^1+\underset{(0{,}171)}{0.630^{***}}L^4)e_t$	0.715	11.234	0.067	0.097	0.021	0.881

Source: Author's research data.
Standard errors are in parenthesis, below the estimated coefficients.
***: statistically significant at 1%; **: significant at 5%; *: significant at 10%; ^{ns}: statistically nonsignificant.
MAPE: Mean Absolute Percentage Error: the smaller this value, the smaller the percentage error mean of the forecast series;
TIC: Theil Inequality Coefficient: lies between zero and one, where zero indicates perfect fit. It can be decomposed in:
BP: Bias Proportion: indicates how far the mean of the forecast is from the mean of the actual series;
VP: Variance Proportion: indicates how far the variation of the forecast is from the variation of the actual series;
CVP: Covariance Proportion: measures the remaining unsystematic forecasting errors.
The bias, variance and covariance proportion add up to one (EVIEWS USER'S GUIDE, 2004).

Table 3 - Estimated coefficients and statistics for crops included in the analysis in São Paulo.

		Prices					Acreage	
		Sugarcane	Soybeans	Corn	Beans	Cotton	2001-08	2004-08
Sugarcane	Coefficient	0.190 **	-0.167 ***	0.212 *	-0.013 ns	-0.117 ns	1.283 ***	0.018 ***
	Standard error	0.092	0.034	0.122	0.017	0.095	0.073	0.002
	R^2	0.606						
	N	352						
Soybeans	Coefficient	-1.507 ***	0.374 ***	-0.647 ***	0.150 ***	-0.971 ***	0.474 ***	0.004 ns
	Standard error	0.171	0.055	0.248	0.041	0.191	0.147	0.005
	R^2	0.146						
	N	189						
Corn	Coefficient	-0.593 ***	0.055 **	-0.120 ns	0.049 **	-0.315 ***	0.480 ***	-0.028 ***
	Standard error	0.095	0.027	0.130	0.022	0.099	0.044	0.003
	R^2	0.161						
	N	565						
Beans	Coefficient	-0.328 ns	0.012 ns	-0.375 ns	-0.093 *	-0.093 ns	0.398 ***	-0.029 ***
	Standard error	0.204	0.053	0.275	0.050	0.190	0.069	0.005
	R^2	0.067						
	N	279						
Cotton	Coefficient	-2.357 ***	1.101 ***	-2.155 ***	0.173 *	0.714 *	0.654 ***	-0.031 ***
	Standard error	0.395	0.129	0.577	0.092	0.389	0.180	0.011
	R^2	0.332						
	N	85						

Source: Author's research data.
Legend: ***: statistically significant at 1%; **: significant at 5%; *: significant at 10%; "ns" : statistically nonsignificant.
N: number of cross section unities (counties) in the estimation. The time period is from 2001 to 2008, *T*=8.

Considering the 2000-2008 period, the substitution effects were not very significant, while the expansion of the annual crop acreage was a result of the expansion in the acreage for most crops. After 2004, most increases in annual crop area resulted from sugarcane expansion, with the substitution effects indicating that sugarcane replaced some traditional crops. In addition, sugarcane also expanded over pastures and perennial crops, leading to an increase in total annual crop area.

The analysis for São Paulo indicates that the sugarcane price had a negative impact on the output supply of soybeans, corn, and cotton, a result consistent with the acreage reduction of these crops in the State. The output supply for the same crops is estimated for the Center-West region to determine if the sugarcane expansion in São Paulo may cause an indirect effect on the agricultural frontier. The estimation follows the same theoretical background and has the same independent variables. Despite the difference between prices for the two regions due to transportation costs, it is assumed that the price series have the same behavior. However, instead of estimating the elasticity coefficients separately and on a State by State basis, we consider only the counties reporting production in the 2001-2008 period in the four states of the agricultural frontier: Mato Grosso, Rondônia, Maranhão and Tocantins.

The results are presented in Table 4: the results for own price elasticities are as expected, except for beans, which also presented a negative own price response. Sugarcane, soybean and cotton own price elasticity is not statistically significant. This result for soybean is not expected, since it is the most important crop in the Center-West region and higher prices have been the primary reason for the strong expansion of this crop over the last decade. However, during the period of analysis, soybean price presented a light negative trend, which may account for the results. The price of sugarcane has a positive impact only on corn, indicating that increased sugarcane prices will increase the acreage of corn in this region. Actually, this was the most replaced crop in São Paulo State and this substitution may be positively correlated to the cultivated area in the agricultural frontier. Besides, corn is the most widely cultivated crop in this region, and small changes in the price of corn lead some farmers to take advantage of it.

Regarding the other price elasticities, it is worth to comment the relationship between cotton and soybean, which, despite the fact that these crops are usually cultivated in sequence in a year, they appear to be substitutes.

The annual crop acreage presents a positive and statistically significant impact for all crops. The highest elasticity of annual crop area is for soybeans, the crop that has expanded the most in this region during the analyzed period. Sugarcane, on the other hand, had the smallest impact on the annual crop acreage. The impact of this variable on the production of beans and cotton is not statistically significant.

A comparison of the results between São Paulo State and the agricultural frontier region, reveal that it is possible to establish a connection between both regions only in the case of corn. The cross elasticity of sugarcane price on corn acreage in São Paulo State is negative, as well as the dummy variable (the annual crop acreage 2004-2008 years). In the agricultural frontier, this variable is positively correlated to corn acreage, as well as the cross elasticity of sugarcane price. That is, the reduction of corn acreage in São Paulo State could influence the acreage increase in the agricultural frontier. If so, it would be in a small magnitude, which is indicated by the elasticity coefficient of the 2004-08 variable in corn acreage, –0,028. Besides, São Paulo State's share in the total acreage of corn is less than 10 percent and the acreage variation occurred in the last years, would not be enough to cause a stronger impact on corn prices. The cross elasticity of sugarcane price in other crop acreage in São Paulo State is negative; in the agricultural frontier, it should be positive to cause some impact, as it is for corn. Besides, the 2004-08 years have no significant impact on the soybean acreage in São Paulo State. Cotton and beans have not had a significant growth in their acreage in the former region. Thus, it is not possible to state that the expansion of sugarcane in São Paulo State does impact the acreage expansion in the agricultural frontier. It also likely that the internal prices for soybean, corn and cotton are determined in the international market and other variables may affect these prices. Thus, it is necessary to obtain the international price elasticity for these commodities for achieving more precise information regarding the indirect effect.

The agricultural frontier has been moving towards the North reaching the Amazon region even before the rapid expansion in sugarcane production. Thus, there is a conflict between the agricultural expansion and forest preservation and the next model estimates the impact of commodities prices on deforestation in counties belonging to the four states of the agricultural frontier: Mato Grosso, Rondônia, Maranhão and Tocantins. An additional variable “Remaining Forest” is added to the estimation to verify the impact of the amount of forest on deforestation.

The first estimation considers the counties of the four states which had positive deforestation rate and also reported production of at least one crop among those under analysis, from 2001 to 2008 (Table 5). Results reveal that deforestation is positively correlated with the price of all crops. Besides, it is also affected by the annual crop acreage and by the recent expansion, represented by the 2004-08 acreage variable. The remaining forest has a negative impact on the deforestation rate. It is probably due to the difficulties to open new areas in the absence of roads or other infrastructure. The results from this new estimation indicate that deforestation might have been affected by the agricultural expansion in the Center-West and Northeastern regions.

Table 4 - Estimated coefficients and statistics in the agricultural frontier for the analyzed crops.

		Prices					Acreage	
		Sugarcane	Soybean	Corn	Beans	Cotton	2001-08	2004-08
Sugarcane	Coefficient	0.0878 ns	-0.0851 ns	-0.3397 *	-0.0290 ns	-0.9998 ***	0.1325 *	0.0322 ***
	Standard error	0.1172	0.0552	0.1766	0.0339	0.1739	0.0710	0.0057
	R2	0.0917						
	N[1]	221						
Soybeans	Coefficient	-0.2436 ns	0.0646 ns	-0.7135 ***	0.0763 ns	-1.4355 ***	1.2757 ***	0.0319 ***
	Standard error	0.1913	0.0793	0.2327	0.0593	0.3282	0.0786	0.0094
	R2	0.6248						
	N[1]	114						
Corn	Coefficient	0.3334 ***	-0.1350 ***	0.1645 *	-0.0722 ***	-0.6399 ***	0.6818 ***	0.0058 *
	Standard error	0.0704	0.0279	0.0935	0.0174	0.0927	0.0433	0.0034
	R2	0.3116						
	N[1]	536						
Beans	Coefficient	-0.4164 ***	-0.1907 ***	0.2011 ns	-0.0638 **	-0.1631 ns	0.5575 ***	-0.0016 ns
	Standard error	0.1050	0.0481	0.1224	0.0322	0.1405	0.0572	0.0051
	R2	0.1254						
	N[1]	382						
Cotton	Coefficient	-0.1771 ns	-0.6227 ***	1.1374 ***	-0.4131 ***	0.4257 ns	0.7798 **	-0.0137 ns
	Standard error	0.3331	0.2332	0.3486	0.0834	0.6177	0.3416	0.0172
	R2	0.1654						
	N[1]	31						

Source: Author's research data.
***: statistically significant at 1%; **: significant at 5%; *: significant at 10%; "ns": statistically nonsignificant.
N: number of cross section units (counties) in the estimation, which is the sum of the counties of the four states in this region. The time period is from 2001 to 2008, *T*=8.

[1] In Sugarcane estimation, each state has the following number of counties: Maranhão (MA): 93 counties; Mato Grosso (MT): 58; Rondônia (RO): 18; Tocantins (TO): 52; in soybean estimation: MA: 16; MT: 69; RO: 6; TO: 23; in corn estimation: MA: 212; MT: 137; RO: 52; TO: 135; in beans estimation: MA: 210; MT: 57; RO: 50; TO: 65; in cotton estimation: MA: 2; MT: 29; RO: 0; TO: 0.

The expansion is not the same for all states under analysis. In order to verify these differences, it was estimated a model for each state[4] (Table 5). The results for each state confirm the aggregate results for the prices of soybean, corn, beans and cotton and for the recent annual crop acreage (2004-08 acreage variable). The individual state analysis shows that sugarcane price is statistically significant only for the case of Mato Grosso and Tocantins, but the impact of the annual crop is statistically significant only for the case of Mato Grosso, meaning that annual crop area increases the deforestation rate. In the case of other states, annual crop area did not represent a significant impact.

In addition and according to the estimation results, deforestation is decreasing despite the expansion of the annual crop acreage. This result is consistent with the deforestation rate measured by the Exponential Growth Trend (EGT) presented in Table 1, which shows that deforestation is increasing at a decreasing rate, probably due to government control over the Amazon region, in an attempt to hinder the advance of illegal deforestation.

[4] The results for each state must be analyzed carefully, since the asymptotic properties in panel data are obtained with increasing N. Considering each state individually; the number of cross section units is low. However, the results seem consistent with the aggregate estimation and agree with the differences among the states previously presented.

Table 5 - Estimated coefficients and statistics in the agricultural frontier area for the deforestation acreage.

		Prices					Annual Crop Acreage		Remain. For.
		Sugarcane	Soybean	Corn	Beans	Cotton	2001-08	2004-08	
MA, MT, RO, TO	Coefficient	0.9849 ***	0.8995 ***	4.4928 ***	-0.4458 ***	2.5159 ***	0.1545 **	-0.1404 ***	-0.0003 ***
	Standard error	0.2175	0.1642	0.3416	0.0825	0.3618	0.0615	0.0121	0.0001
	R^2	0.2844							
	N[1]	233							
MA	Coefficient	0.5118 ns	-0.9114 **	7.2474 ***	-0.7037 ***	3.6540 ***	0.0041 ns	-0.1739 ***	0.0002 ***
	Standard error	0.5752	0.4650	0.8681	0.2117	0.9546	0.5173	0.0351	0.0001
	R^2	0.1682							
	N	66							
MT	Coefficient	1.0425 ***	1.3992 ***	3.3718 ***	-0.1827 *	2.5410 ***	0.1984 ***	-0.1549 ***	-0.0007 ***
	Standard error	0.2957	0.1465	0.3858	0.1074	0.4240	0.0551	0.0121	0.0002
	R^2	0.5293							
	N	88							
RO	Coefficient	0.3782 ns	1.6729 ***	1.9508 ***	-0.4975 ***	0.8095 **	0.0820 ns	-0.1101 ***	-0.0005 ***
	Standard error	0.2663	0.1212	0.3838	0.0929	0.4019	0.0977	0.0126	0.0002
	R^2	0.6269							
	N	51							
TO	Coefficient	3.5694 ***	2.2771 ***	5.9537 ***	-0.6183 ***	3.4118 ***	0.0030 ns	-0.0779 *	-0.0021 ns
	Standard error	0.5424	0.2824	0.9437	0.2387	0.9727	0.2221	0.0405	0.0049
	R^2	0.3822							
	N	28							

Source: Research data.
***: statistically significant at 1%; **: significant at 5%; *: significant at 10%; "ns": statistically nonsignificant.
N: number of counties of each state in the estimation. The time period is from 2001 to 2008, *T*=8.
[1] In this estimation, each state has the following number of counties: Maranhão: 66 counties; Mato Grosso: 88; Rondônia: 51; Tocantins: 28.

5. Conclusions

Sugarcane expansion in the Brazilian agricultural frontier cannot be associated to deforestation despite the fact that some regions in the country present a large sugarcane acreage growth. Yet, some other regions have presented a strong expansion annual crop acreage, which may have contributed to the advance of the agricultural frontier over forest areas. While sugarcane has become one of the most important crops in terms of cultivated area in São Paulo State with some regions in this State have more than half of the total annual crop area cultivated to sugarcane. The econometric results indicate a negative impact of sugarcane prices on the acreage of other crops, which may have resulted in sugarcane replacing these other crops. The annual crop acreage expansion in recent years (2004-08) appears to have been caused by sugarcane due to the increase in the ethanol demand in this period.

Comparing the estimations between São Paulo State and the agricultural frontier, it is not possible to establish a connection between the expansion of sugarcane and the expansion of all other crops considered in our analysis in the frontier region, except for corn. Although the replacement of this crop in São Paulo State may be related to the expansion of this crop in the frontier region, there are many other variables that affect corn price, including international prices.

In the Center-West region of Brazil, the agricultural frontier region expansion was strongly promoted by large increases in soybeans acreage. As the frontier reaches the Amazon region, its advance toward the northern country will necessarily be associated to deforestation. However, while deforestation may be associated to the advance in the agricultural frontier, it should be noticed that, in some regions, deforestation occurs despite a larger increase in the agricultural acreage. Livestock expansion in that region and its dynamics must be analyzed. Therefore, there are other incentives besides the agricultural expansion to cut down part of the Amazon forest. Regarding this issue, the government should increase control over that region to avoid illegal deforestation. In this sense, the positive aspect is that the deforestation rate decreased in the analyzed period, which indicates that some control measures have been effective. Thus, while we reach the conclusion that initially, at least, the increased supply of sugarcane needed to meet increased ethanol demand has no impact on forest areas. However, this issue and the advances in agricultural frontier remain of concern. And while Brazil still has large tracks of land for increasing agricultural acreage, it is necessary to continue to make efforts to maintain ethanol as a cleaner alternative energy, while preserving the Amazon forest and other Brazilian biomes.

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