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Expansion of the sugarcane industry and its effects on land use in São Paulo: Analysis from 2000 through 2015

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ABSTRACT

Since the turn of the century, Brazilian sugarcane production has increased and the area under sugarcane cultivation has expanded considerably, moves primarily driven by the use of ethanol as a fuel source. The crop's expansion has impacting land use patterns and employment trends in several of Brazil's regions. This study assesses the dynamics of land use competition in São Paulo, Brazil, the state responsible for the largest share of sugarcane production and fuel ethanol refining in the country. The assessment employs shift-share analysis carried out in two stages and data from 2000 through 2015. Results indicate that cultivated area dedicated to sugarcane increased dramatically over this period to the detriment not only of pasture areas, as is commonly emphasized in relevant literature, but also of land formerly dedicated to annual and perennial food crops, such as rice, beans, corn, potatoes, cassava, and fruits. The shift in agricultural land use has given rise to three main concerns: (1) land price increases; (2) food price increases; and (3) possible challenges to the use of sugarcane as an economical fuel source. The study analyzed the viability of sugarcane ethanol as a competitive alternative to other energy sources and the risks its use presents to food security. This paper also contains a summary of the "food vs. fuel" debate, adding new elements to refine the discussion.

1. Introduction

The emergence of the low-carbon economy and the search for renewable energy sources have boosted the world market for biofuels over recent decades, leading to an increase in both their production and consumption. Currently, more than 64 countries have national programs to study and stimulate the use of biofuels. Commitments made by more than 190 countries at the 2015 Climate Conference in Paris (COP-21) also reinforced the role of biofuels in the future's energy matrix considerably (Kutas et al., 2016). On the other hand, the possibility of growth in the production of biofuels has encouraged a wide academic, scientific, and political discussion on issues revolving around land use, mainly on the use of agricultural areas for energy production to the detriment of other uses.

Brazil's unique experience as a large-scale producer and user of fuel ethanol has given it considerable technological and productive advantages over other countries in the biofuel arena. Ethanol was first added to gasoline for use in Brazilian automobiles in the 1930s. In the 1970s, ethanol was effectively promoted as a complete alternative to fossil fuel through the government sponsored National Alcohol Program (Proálcool) and the introduction of E100 vehicles[1]. In 2003, flex-fuel vehicles were introduced in Brazil (Moraes and Zilberman, 2014). Currently, Brazil is the world's second-largest producer of ethanol and intends to stimulate even increased production and use of this biofuel over the coming years, as demonstrated with the emergence of new government incentive programs, such as the "RenovaBio", to expand the ethanol market (MME, 2017). In view of the continuing and increased Brazilian government interest in biofuels, our study of the effects of expanded production and use of ethanol on the Brazilian economy and agricultural land use is timely.

Between 2000 and 2015, Brazilian ethanol fuel production grew by 170%, reaching 28,488,000 m^3 (UNICA, 2017). This expansion was made possible by the incorporation of new areas for the crop's cultivation: the area dedicated to sugarcane cultivation increased from about 4,880,000 ha in 2000, to 10,870,000 ha in 2015 (123% growth), according to the Brazilian Municipal Agricultural Production Survey (IBGE, 2017).

In view of such expansion and the possibility that the use of this biofuel in the Brazilian and world energy matrix will increase, there is a need to evaluate the various social, economic and environmental

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[1] Brazil produces two types of fuel ethanol: anhydrous ethanol, which is mixed with gasoline; and hydrous ethanol, which can be used in flex-fuel automobiles and in automobiles that run exclusively on fuel ethanol (E100).

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impacts of this transformation on the rural environment. Since the availability of productive land is a factor limiting biofuel production, there is concern that continued growth of biofuel production could, in theory, threaten forest environments and the security of food supplies (GILIO, 2015).

Runge and Senauer et al. (2007) criticized the use of incentives to increase biofuel production, reporting negative effects on food security due to rising food production costs, even beyond the borders of a given producer country. Their study of the United States' ethanol program, which is based on corn, marked the beginning of a debate that has become known in scientific literature as "food vs. fuel." Empirical studies have shown a possibility of increased food prices caused by increased domestic and international production of crops grown for fuel, especially in the case of ethanol from corn (Nuñez et al., 2013). Results from similar studies of Brazil and other developing countries have arrived at conflicting results, especially with respect to the production of ethanol from sugarcane.

Coelho et al. (2006) highlight a 2005 FAO report noting that less than 3% of Brazil's arable land was devoted to sugarcane production and that only 0.6% of agricultural areas previously used by other crops were being used for the production of sugarcane. Their study found that the actual effect of sugarcane production on Brazilian food production was practically zero. Other studies of Brazilian agriculture report that the country still has a vast stock of land that can be converted to agricultural use and that only a small portion of the country's total area of agriculture and pasture production is devoted to sugarcane; these studies conclude that expansion of sugarcane production would have little effect on the demand for land in Brazil (Wilkinson and Herrera, 2010). However, Lourenzani and Caldas (2014) and Camara and Caldarelli (2016) indicated that the growth in area under sugarcane cultivation in Brazil has been mainly supported by territorial expansion, and there may have been significant impacts on food crop production in the country's main food producing regions.

These somewhat conflicting results indicate that the food vs. fuel discussion is far from being exhausted. As new data become available and new analyses are made, it is hoped that the answers to questions regarding the externalities associated with agricultural-based biofuels, such as land use, the transformation of agricultural production, and food security, become clearer.

Our study is intended to contribute to the food vs. fuel discussion, focusing on data from the Brazilian state of São Paulo. São Paulo is Brazil's main sugarcane-producing state and accounts for around 55% of the country's cane production (IBGE, 2017). The study used a shift-share analysis to evaluate land use dynamics related to the expansion of sugarcane production over a period from 2000 through 2015 and the effect of this expansion on other agricultural activities in the state.

The methodological approach employed is similar to that developed by Camara and Caldarelli (2016); however, there are important differences. Firstly, we augment earlier analyses of food production to include the impacts of sugarcane. Secondly, our study uses a different database period (2000 to 2015), which permits evaluation of a period of rapid sectoral expansion and an even more recent period during which productivity either stagnated or decreased.

2. The sugarcane expansion and the land use transition in the state of Sao Paulo, Brazil

Agriculture in the state of São Paulo is based on just a few crops, with sugarcane predominating, as is shown in Table 1.

Since the beginning of the 2000s, the state of São Paulo has experienced a significant increase in sugarcane production, shown in Table 1, mainly driven by an increase in the demand for ethanol and in the international price of sugar (Gilio and Castro, 2017). Between 2000 and 2015, sugarcane planted area in the state expanded 125% — an increase of about 3.1 million hectares—and production expanded 128.74%—an increase of 243.38 million tons (IBGE, 2017). This advance was also observed in the participation of sugarcane plantations in the total area planted. In 2000, approximately 44.68% of the planted area in the state was sugarcane; in the year 2015 this percentage rose to 57.15% (Table 1).

Table 1
Crops as percentages of total agricultural area in São Paulo, 2000–2015. Source: Municipal agriculture production survey (IBGE, 2017).

Product	*2000*	*2005*	*2010*	*2015*
Sugarcane	*44.68*	*44.45*	*55.3*	*57.15*
Orange	*8.46*	*18.2*	*16*	*9.23*
Soybean	*4.54*	*4.76*	*3.26*	*6.05*
Corn	*8.71*	*6.61*	*4.88*	*4.79*
Tomato	*5.15*	*2.22*	*1.88*	*3.94*
Coffee	*4.77*	*4.35*	*3.92*	*3.61*
Other crops	*23.69*	*19.41*	*14.76*	*15.23*

*Note: We have considered total planted area of São Paulo as the sum of annual and perennial crops.

Smeets et al. (2008) point out that factors such as fertile soil, favorable climate, state infrastructure, and the Proálcool program of the' 70s,' 80s and' 90s contributed to the expansion. However, it was the cessation of government intervention in 1999 and the advent of flex-fuel vehicles in 2003[2], in addition to acquisitions, mergers, and the rapid internationalization of production assets between 2007 and 2008, that propelled the crop's dramatic expansion at both state and national levels and increased pressure on traditional rural area crop cultures (Beiral, 2011; Pinto, 2012; Moraes and Zilberman, 2014).

Fig. 1 presents a spatial distribution of the sugarcane crop, demonstrating its increased representation in areas devoted to other Brazilian crops. The Figure shows that sugarcane cultivation between 2000 and 2015 expanded in several Brazilian areas, but the most notable expansion occurred in or near to areas where traditional crops were grown, mainly in the country's center-south region, where São Paulo is located,

Potential investors in the Brazilian sugarcane sector have shown greater caution and restraint since the 2009 economic crisis brought economic stagnation and a general recession to the country. Literature mentions several other factors that have hindered international investment in sector, such as gasoline price controls established by the government's energy company Petrobras in 2009, constant and unpredictable mandated changes in the percentage of anhydrous alcohol blended into Brazilian gasoline, federal taxes, government incentives preferential to other energy sources, increasing labor costs, and restrictions on land acquisition by foreigners (Moraes and Zilberman, 2014; Gilio and Castro, 2017).

Fig. 2 illustrates the spatial expansion of sugarcane production in the state of São Paulo from 2003 through 2013, evaluated using satellite imagery (CANASAT, 2017; Rudorff et al., 2010). Sugarcane cultivation expanded mainly in the state's west, northwest, and north. The Figure shows that the spatial distribution of sugarcane crop expansion is based on the presence of processing plants (mills), a fact that characterizes the ethanol-sugar production chain due to the rapid degradation of recoverable sugar after harvest (Gilio and Moraes, 2016).

Table 2 shows the relationship between planted area, production, and productivity in 2000 and 2015. These data indicate that there was continuity in the expansion of area devoted to sugarcane cultivation in São Paulo, verified for the early 1990s by Veiga Filho and Yoshii (1992) and more recently by Lourenzani and Caldas (2014) and Camara and Caldarelli (2016). This expansion came at the expense of other, previously important crops, such as orange and corn.

Fig. 3 details the evolution of the land use matrix in São Paulo. As

[2] Flex-fuel vehicles are capable of using 100% gasoline, 100% ethanol, or any arbitrary combination of these fuels. They were introduced in Brazil in 2003 and currently correspond to most of the Brazilian vehicle fleet (Santos et al., 2018).