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Exploring policy options to spur the expansion of ethanol production and consumption in Brazil: An agent-based modeling approach

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ABSTRACT

The Brazilian government aims to increase the share of biofuels in the energy mix to around 18% by 2030, which implies an increase of ethanol production from currently 27 bln liters to over 50 bln liters per year. Biofuel policies play an important role in ethanol production, consumption, and investment in processing capacity. Nevertheless, a clear understanding of how current policies affect the evolution of the market is lacking. We developed a spatially-explicit agent-based model to analyze the impact of different blend mandates and taxes levied on gasoline, hydrous, and anhydrous ethanol on investment in processing capacity and on production and consumption of ethanol. The model uses land use projections by the PCRaster Land Use Change model and incorporates the institutions governing the actors' strategic decision making with regard to production and consumption of ethanol, and the institutions governing the interaction among actors. From the investigated mix of policy measures, we find that an increase of the gasoline tax leads to the highest increased investments in sugarcane processing capacity. We also find that a gasoline tax above 1.23 R$/l and a tax exemption for hydrous ethanol may lead to doubling the production of ethanol by 2030 (relative to 2016).

1. Introduction

During the 2015 United Nations climate conference in Paris, Brazil indicated that bioenergy will significantly contribute towards their realization of climate objectives. The Brazilian government aims to increase the share of biofuels in the energy mix to around 18% by 2030 (Federative Republic of Brazil, 2015), which implies that ethanol demand will increase from 27 bln liters per year in 2016 to more than 50 bln liters in 2030 (IEA, 2017). If this projected demand for ethanol is to be met by domestic supply, it would be necessary to double the production of ethanol in the next years. It is expected that over 70% of the increase in ethanol supply is to be met by hydrous ethanol because of the technical blend constraints of anhydrous ethanol in the fuel market (Tolmasquim et al., 2016). Nevertheless, the feasibility of achieving this increase in ethanol supply with the current set of policies is unclear. The effect of existing Brazilian policies on the evolution of the ethanol market is not well understood (De Gorter et al., 2013).

The Brazilian experience with biofuels dates back to the early part of the last century. Nevertheless, it was not until the global crisis in 1970 that the Brazilian government initiated the large scale implementation of ethanol in Brazil with the ProAlcool program (Rosillo-Calle and Cortez, 1998). Since then, Brazil has become the world's top producer of sugar and, until 2005, the top producer of ethanol. Nowadays, Brazil has the second largest production of ethanol after the U.S. de Carvalho et al. (2016). Key success factors of the Brazilian ethanol market are the favorable environmental conditions, technological innovations, and the governmental policy (Stattman et al., 2013).

On the technical side, technological innovations such as flex plants and flex vehicles are at the core of the ethanol market structure. Flex plants can produce flexible ratios of sugar and ethanol from sugarcane (McKay et al., 2015). Based on the water content, ethanol can be classified as: hydrous ethanol (up to 4.9% v/v of water) and anhydrous ethanol (up to 0.4% v/v of water). Users of flex vehicles can switch back and forth from E100 (hydrous ethanol) to gasohol (a blend of gasoline and anhydrous ethanol, of which the max share of anhydrous ethanol is 27.5% v/v due to technical limitations) (Pacini and Silveira, 2011). Indeed, this flexibility at both the supply and the demand side of the market is one of the factors responsible for the success of ethanol in

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Brazil (Alonso-Pippo et al., 2013).

On the policy side, the governmental ethanol policy has undergone many changes (Stattman et al., 2013). The ProAlcool program had different phases (creation, consolidation, expansion, and political uncertainty) with different characteristics (Rosillo-Calle and Cortez, 1998). The period 1979–1985 was marked by strong state intervention, whereas the sugar and ethanol industry were deregulated in the 1990s. In this period subsidies and regulation were gradually removed (Hira and de Oliveira, 2009). The revitalization of the ethanol market was triggered by the introduction of the flex vehicle in 2003 (de Freitas and Kaneko, 2011).

The behavior of the Brazilian ethanol market is shaped by both governance structures and policy instruments. The interaction between farmers and mill/distillery owners is governed by the Conselho de Produtores de Cana-de-Açúcar, Açúcar e Etanol do Estado de São Paulo (CONSECANA-SP) mechanism. In this governance structure, the sugarcane price is determined by two factors: the amount of total recoverable sugar (TRS) in the sugarcane and the prices of sugar and ethanol on the domestic and foreign markets (Ferraz Dias de Moraes and Zilberman, 2014). Policy instruments such as blend mandates, and taxes levied on gasoline, hydrous, and anhydrous ethanol influence patterns of demand and production of ethanol. For instance, when the government increased the CIDE (**C**ontribution for **I**ntervention in the **E**conomic **D**omain) tax for gasoline in 2015, ethanol demand and production increased (Barros and Berk, 2015). These instruments and their interaction produce distortions in the ethanol market that might shape both the development of the ethanol industry (Demczuk and Padula, 2017; Khanna et al., 2016), and the share of biofuels in energy consumption.

The understanding of the effect of policies on the ethanol market is still limited. Analyses have been carried out to shed light on the effects of U.S. policies on Brazilian markets (Archer and Szklo, 2016; Debnath et al., 2017), on the ethanol-sugar-oil nexus (Bentivoglio et al., 2016), on the effects of blending targets around the world on sugarcane demand in Brazil (Banse et al., 2008; Lapola et al., 2009) and on the effects of Brazilian policies on ethanol markets (De Gorter et al., 2013; Demczuk and Padula, 2017; Drabik et al., 2015; Cavalcanti et al., 2012).

Studies using a structural economic model of the Brazilian ethanol market include Drabik et al. (2015) and Demczuk and Padula (2017). The mathematical model of Dabrik et al. indicated that a low gasoline tax and a high tax exemption for anhydrous ethanol lead to a reduction in both ethanol and sugar prices. Nevertheless, this model neglected the effect of institutions at two levels. First, at the level of decision making, the profit maximizing behavior by the flex plants that determines the production of ethanol and sugar was not included. Although the authors did take into account the shift in demand curves from E100 to gasohol, this mechanism was imposed on the model. In reality, consumption patterns for both fuels emerge as a result of the strategic behavior of the flex vehicle users (Pacini and Silveira, 2011). Second, at the level of governance structures, the model neglected the CONSECANA-SP mechanism that determines the sugarcane price.

Demczuk and Padula (2017) developed a system dynamic model to analyze the effect of Brazilian policies on the development of the ethanol industry. The authors argued that the liberalization of the gasoline prices and the homogenization of sales taxes on ethanol among the Brazilian states could reduce uncertainty in the ethanol sector, and thus encourage investments in technology and production capacity. This modeling study incorporated the CONSECANA-SP mechanism, but it neglected the profit maximizing behavior by the flex plants and the arbitrage in the consumption of gasohol and hydrous ethanol by the flex vehicle users, as well as the diversity among flex plants (e.g. they do not produce the same sugar to ethanol ratio under the same market prices) and among the flex vehicle users (e.g. they do not all consume the same fuel given the same fuel prices).

In this study, we developed a spatially-explicit agent-based model of the Brazilian ethanol/sugar market to explore the effect of biofuel policies on the market behavior. The model accounts for the institutions governing the actors' strategic decision making with regard to production of ethanol by including the profit maximization behavior of the flex plants; the consumption of ethanol by including the arbitrage behavior of the users of the flex vehicles; and the investment in processing capacity of sugarcane. The model is spatially explicit to account for the influence of the location of the sugarcane fields and their availability on the decision of investment in sugarcane processing capacity. The agent-based model uses land use projections provided by the PCRaster Land Use Change (PLUC) model (Verstegen et al., 2016) to explicitly account for expansion of land for sugarcane production in specific locations. The agent-based model also accounts for the interaction among actors by incorporating the CONSECANA-SP and supply and demand mechanisms; for the diversity among actors by including differences in the preferences in the consumption of ethanol of flex vehicles users, and differences in the production ratio of sugar and ethanol of flex plants. In particular, the model is used to shed light on the following research question:

- What is the combined effect of different options for blend mandate and tax levied on gasoline, hydrous, and anhydrous ethanol on the development of the sugarcane-ethanol market in Brazil?

We focus only on sugarcane-ethanol (1st generation ethanol[1]) as it is projected that the highest share in the production of ethanol in the period 2017–2030 will come from sugarcane-ethanol. According to Tolmasquim et al. (2016), 2nd generation ethanol[2] will emerge in considerable volumes as of 2023, reaching 2.5 billion liters in 2030.

The paper is organized as follows: Section 2 provides a description of the concepts underpinning the model structure, an explanation of the developed agent-based model, and the data used. The results are presented in Section 3, followed by a discussion in Section 4. Finally, conclusions are drawn in Section 5.

2. Theory and method

This section describes the methodological improvements performed and considered crucial for modeling the ethanol market in Brazil.

2.1. System diagram and conceptual framework

Fig. 1 shows a system diagram of the Brazilian ethanol/sugar market. The system is analyzed from the perspective of the Brazilian government. It is assumed that the Brazilian government aims to increase the share of ethanol in the energy matrix as well as encourage expansion in sugarcane processing capacity of flex plants. While the government has used policy instruments to spur the production and consumption of ethanol such as investments in RD&D in universities and research centers, subsidies to metallurgic industries and farmers, fiscal policies (tax levied on gasoline, hydrous, and anhydrous ethanol), and blend mandates, we focus on fiscal policies and blend mandates. It is assumed that the behavior of the system is driven by a number of external factors as depicted in Fig. 1.

The Brazilian ethanol market is a complex adaptive system. It consists of heterogeneous actors (farmers, ethanol/sugar producers, distributors, and end-users) interacting in a dynamic environment and regulatory regime. Actors constantly adapt their behavior to changing market prices and available supply of ethanol and sugar. Producers

[1] 1st generation ethanol refers to the ethanol that has been derived from edible sources such as corn, starch, and sugarcane.

[2] 2nd generation ethanol refers to the ethanol that has been derived from non-food biomass such as lignocellulosic biomass, agricultural residues or waste, and non-food energy crops.