Resources, Conservation & Recycling 132 (2018) 16–27

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Ethanol production in Brazil: An assessment of main drivers with MCMC generalized linear mixed models

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ARTICLE INFO

Keywords:
Ethanol
Brazil
GLMM
MCMC

ABSTRACT

This paper analyses the production of ethanol in Brazil using an extensive, plant-based, ethanol and sugar production database, including multiple variables involved in the ethanol production chain. To this end, a generalized mixed model was used with the Markov Chain and Monte Carlo methods by applying the MCMCglmm package in the R software environment. The results obtained not only confirmed the expected signs between ethanol production and its major drivers or contextual variables, but also shed light in terms of their relative importance and their nature: whether structural, conjunctural or exogenous. The main conclusions of this paper are that the contextual variables that contribute the most to the increase in ethanol production in Brazil were, in order of importance, sugarcane milling, sugar production, and the price ratios between ethanol and sugar. Policy implications to the sector are derived.

1. Introduction

This paper aims to analyze the impact of several drivers of ethanol production in Brazil using production data of ethanol, sugar, and sugarcane milling by mill for the period 2002–2013. Because ethanol and sugar are produced from the same raw material (sugarcane), and at the same production units, the production of these products is related (Olguín et al., 1995; Prasad et al., 2007; Reijnders, 2008; Loh et al., 2013; Zhang et al., 2017). In addition to sugarcane supply-and-demand issues, ethanol and sugar are part of the same production chain in Brazil, sharing production facilities, logistics, and decisions affecting the location of ethanol and sugar production units in Brazil. The importance of this study is twofold. First, Brazil is the world's largest producer and exporter of sugar, and was—until recently passed by the United States—also the world's largest producer and exporter of ethanol (Barros et al., 2012). For export, ethanol requires a robust multimodal structure for outbound flows, which ultimately affects the location of the production plants (Nogueira et al., 2008). Secondly, it is important to note that exports are not the major destination of Brazilian ethanol. In fact, the bulk of production serves the domestic market. Thus, on a nationwide scale, a pioneering system of blending gasoline and ethanol for flex-fuel vehicles was developed in Brazil (Gorter et al., 2013; Fernandez et al., 2017). Besides being used as a fuel for passenger cars in the form of hydrated ethanol, ethanol is also used in the form of anhydrous ethanol, blended with regular gasoline to increase octane (Andrade et al., 2010).[1]

The ethanol industry in Brazil is complex. More than 400 sugarcane mills are scattered throughout the country, which are impacted by a heterogeneous set of contextual variables that affect sugar and ethanol production levels differently. Among the previous studies in Brazil investigating ethanol production and the many variables involved, Martinelli et al. (2011), for example, examined the link between the rural development and sugar and ethanol production in São Paulo. Goldemberg and Guardabassi (2010), in turn, discussed the potential for growing the ethanol industry in terms of productivity gains and geographic expansion. From a different perspective, Dias et al. (2015) described the current technology and opportunities for process improvements, and made suggestions for the future of the sugar and ethanol industry. Hira and Oliveira (2009) examined the case of Brazil as a pioneer in the use of ethanol by looking at the possible trade-offs, costs, and benefits of biofuel as an alternative to fossil fuel. Employing a qualitative approach, Liboni and Cezarino (2014) suggested the application of a systematic methodology for developing sustainability strategies for the sugarcane industry.

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[1] When ethanol flexible fuel vehicles are available in the market in the late 1990s, the term “lexible-fuel vehicle” is also used to describe ethanol flex-fuel vehicles. In Brazil, the flex-fuel vehicles are usually called “total flex” or simply “flex” cars. Flex-fuel vehicles use dual-fuel systems, which simultaneously supply two different fuels to the combustion chamber in calibrated proportions. Nowadays, unleaded gasoline and ethanol fuel are always used.

https://doi.org/10.1016/j.resconrec.2018.01.016
Received 10 October 2017; Received in revised form 12 January 2018; Accepted 14 January 2018

Another important point of this paper—and one that underscores its innovative quality—is the effect of the highly heterogeneous nature of the data used in the modeling. Data on production, geographical distance, price ratios and other contextual variables used in this study were unable to yield reliable results using non-iterative methods. For instance, as depicted in Table 1, readers can easily see that data for both dependent and predictor variables are highly dispersed around the mean, which justifies an alternative approach that relaxes the common grounds of the Normal assumption. In non-iterative methods, the values are generated independently and there is no concern with the convergence of the algorithm, provided the sample size is sufficiently large (Gamerman (1997); Robert and Casella, 1999 and Gamerman and Lopes (2006). Markov chain Monte Carlo (MCMC) methods are an alternative to non-iterative methods for complex problems. The idea is to obtain a posterior sampling distribution and calculate sampling estimates characteristic of this distribution. The difference is that in this paper, we use iterative simulation techniques based on Markov chains; therefore, the values generated are no longer independent. This methodology can be applied in various industries and countries, especially in cases where multiple, highly-complex, heterogeneous variables have proved resistant to successful analysis using conventional methods.

The innovation of this study stems from the use of the multiple variables used to analyze the production of ethanol in Brazil to understand the influencing factors, their relative importance, and the signs of their impact. These variables include sugar production and sugarcane milling, gasoline-ethanol and sugar-ethanol price ratios, the distance from the plant to competitive modes of transportation (pipelines and railways), plus four other contextual variables characteristic of mills (e.g. whether mills are domestic, cooperative, etc.). In addition, this work uses Generalized Mixed Linear Models using the Markov and Monte Carlo methods for the first time to explain the complex behavior of Brazil's ethanol production in the context of such heterogeneity. Figueiredo (2017) has already witnessed the micro-level technological heterogeneity in the Brazilian sugarcane ethanol industry. Meanwhile, Tsionas (2002) and Chen et al. (2015) also prove the necessity of taking account of the heterogeneity with Bayesian estimation. Nevertheless, it is important to mention that additional robustness analysis was performed to assess the issues of spatial dependence, endogeneity between ethanol and sugar production, and multicollinearity in contextual variables.

The remainder of this paper is structured as follows: The contextual setting is presented in Section 2 and the literature review is given in Section 3. The methodology and dataset are discussed in Section 4. The analysis and discussion of the results are appear in Section 5. Final remarks and conclusions are made in Section 6.

Table 1
Descriptive statistics of the variables and their underlying rationale for ethanol production.

Dependent Variable	Min	Mean	Max	Std. Dev.
Ethanol production (m3) Source: UNICA	705	38,976	411,991	52,264
Predictor variables	Min	Mean	Max	Std. Dev.
Sugar Production (tons) Source: UNICA	530	59,843	879,335	93,607
Sugarcane Milling (tons) Source: UNICA	166,363	931,413	8,004,221	1,158,838
Cooperative Mill Source: UNICA	0	0.36	1	0.48
Mill Ramping Up Source: UNICA	0	0.29	1	0.46
National mill Source: UNICA	0	0.93	1	0.26
Efficient Mill Logistics Source: IBGE, UNICA, GoogleMaps	0	0.11	1	0.31
Gasoline/Ethanol Price Ratio Source: ANP, UNICA	0.45	0.63	0.87	0.09
Sugar/ethanol Price Ratio Source: UNICA	1.02	1.43	1.07	0.29
Distance Factor (Km) Source: IBGE, UNICA, GoogleMaps	682	1,431.8	5500	1,051.1
Expected Impact on Ethanol Production and Their Respective Rationale				
Sugar Production (tons)	(−) The higher the sugar production, the lower the ethanol production, as long as they are both by-products that compete over the sugarcane milling			
Sugarcane Milling (tons)	(+) The higher the sugarcane milling, the higher the ethanol production, as long as there is more room for left-overs, alleviating the trade-off between ethanol and sugar production			
Cooperative Mill	(+) The participation in cooperatives facilitates the access to bank credit and other technological improvements, thus helping in boosting ethanol production. Access to sugarcane supply from crops is also verified.			
Mill Ramping Up	(+) Ramping-up mills imply newer plants, with high productivity a newer technologies and managerial practices, yielding higher ethanol production levels			
National mill	(+) The share control of the mill by domestic groups positively impact on ethanol production due to the technological know-how and expertise in doing business in Brazil accumulated over centuries. The first sugarcane mills in Brazil date back from 1550.			
Efficient Mill Logistics	(+) The proximity to efficient transport modes improves the competitiveness of ethanol production, thus boosting it, since distribution costs to consumption centers are lower, leading to increased demand levels for mills with such characteristics.			
Gasoline/Ethanol Price Ratio	(+) Higher gasoline prices help in stimulating ethanol refueling by car owners in Brazil, thus stimulating ethanol production levels to meet increased demand.			
Sugar/Ethanol Price Ratio	(−) The higher the sugar prices, the higher the sugar production, thus yielding lower ethanol production levels.			
Distance Factor (Km)	(−) Farther mills tend to present lower demand for ethanol production, as long as distribution costs to consumption centers are high.			