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CHALLENGES OF THE ETHANOL SUPPLY CHAIN IN BRAZIL: an analysis of production, distribution and price policies

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A thesis presented to the Instituto Coppead de Administração, Universidade Federal do Rio de Janeiro, as part of the mandatory requirements for the degree of Doctor of Sciences in Business Administration (D.Sc.).

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To my Wife and Parents.

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This thesis is the result of a long, four-year journey, with multiple stages that were overcome one by one.

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ABSTRACT

Martins, André Luis da Cunha. **CHALLENGES OF THE ETHANOL SUPPLY CHAIN IN BRAZIL: an analysis of production, distribution and price policies.** 2018. 133f. Tese (Doutorado em Administração) **-** Instituto COPPEAD de Administração, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2018.

This thesis will address four innovative and original papers that seek to relate the main problems experienced by ethanol produced in Brazil in recent years. To do so, we will use innovative studies on ethanol production, ethanol efficiency and productivity, ethanol distribution logistics, and pricing policies. All the methodologies used are cutting edge and capable of indicating solutions that can contribute to the development and competitive capacity of biofuel. The papers also seek to analyze and understand the relationships between the various variables considered.

Keywords: Ethanol, Brazil, Ethanol Mills, MCMCglmm, Two Stage DEA, Transshipment, right-tailed ADF tests.

RESUMO

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Este trabalho abordará 4 papers inovadores e originais que buscam relacionar os problemas principais vividos pelo etanol produzido no Brasil nos últimos anos. Para tal utilizaremos estudos de caráter inovador sobre produção de etanol, eficiência e produtividade do etanol, logística de distribuição de etanol, e políticas de preço. Todos as metodologias usadas são de vanguarda e capazes de indicar soluções que podem contribuir para o desenvolvimento e a capacidade competitiva do biocombustível. Os trabalhos também visam analisar e compreender as relações entre as diversas variáveis consideradas.

Palavras Chave: Etanol, Brasil, Usinas de Etanol, MCMCglmm, DEA em dois estágios, Transshipment, right-tailed ADF tests.

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1 INTRODUCTION

1.1 ETHANOL OVERVIEW

In Brazil, fuel ethanol is considered an important vector of economic development due to its environmental, social and economic importance. Used as an alternative substitute for fossil fuel, ethanol can reduce the impact of global warming and the increasing use of the world's main energy source (Santos et al., 2017; Schirmer, 2017).

Ethanol is used in Brazil as an alternative gasoline fuel in Otto-cycle vehicles (hydrated ethanol) and as an additive in gasoline (anhydrous ethanol) at a rate of 27%. One of the purposes of mixing ethanol with ordinary gasoline is to increase the octane content. Because Brazil's Otto-cycle fleet consists almost entirely of flex-fuel vehicles, consumers have the option of using ordinary gasoline or hydrous ethanol as fuel. Distributors purchase ethanol directly from producers and then distribute it to gas stations (ANP, 2015; Schirmer, 2017).

An important aspect of the sugar and alcohol industry is that most producers produce anhydrous and hydrated ethanol along with sugar for the domestic and international markets. Also, the surplus electric power produced by the plants through cogeneration is sold to the electric power distributors. Thus, the portfolio of mill products is anhydrous ethanol, hydrous ethanol, sugar and electricity.

After more than 40 years of fuel ethanol production in Brazil, and despite a significant increase in production, the sector's persistent financial difficulties, indebtedness and low profitability have been prominent issues in recent harvests. Climatic effects (Martins and Olivette, 2015), industry revenues compromised by rising costs, and a short supply of raw materials (Nastari, 2014, Figliolino, 2012) are indicative of the hard times experienced by the sugar cane industry in Brazil.

1.2 PROBLEMS

According to the ANP (2015), characteristics such as a gross domestic product (GDP) in excess of USD 40 billion; 16% of the country's energy produced by cogeneration; 1 million new jobs; and the environmental appeal of using ethanol, have not been sufficient to overcome the difficulties. Thus, in order to account for the complexity and challenges of the sugarcane agroindustry, we must distinguish between difficulties and barriers, and crises per se.

In addition to the consequences of the debated policy of government-set gasoline prices, it is also important to discuss where the crisis is concentrated as well as its origin. Because the commodity sugar market is a solid one— despite the price oscillations, and because power generation by cogeneration is a growing alternative due to the way the industry operates, the biggest difficulties are in the ethanol market (Moraes and Bacchi, 2014, Torquato and Bini, 2009). In fact, the combination of the difficulties alluded to resulted in a crisis whereby, of the 402 companies registered with the Ministry of Agriculture, Livestock and Supply (MAPA) in 2009, some 60 had ceased operations by 2013, as reported by Siqueira (2013) and Rissardi Júnior (2015).

Thus, the crisis in the sugar and alcohol industry became a political issue in Brazil. After seven years in which the sector remained outside the government's interests and industrial policy (i.e., since the announcement of the pre-salt in 2007), nowadays, the entrepreneurs in the sugar and alcohol industry are beginning to hear a set of promises from various governmental institutions. The major crisis that this industry has been going through has been attributed by the entrepreneurs themselves to Petrobras and, indirectly, the government. The businessmen argue that the Petrobras price policy, through the freezing of gasoline prices, means the sector runs in the red in the context of significant increases in costs and inflation. With the freezing of gasoline prices, ethanol prices must remain competitive. After the pre-salt discovery, the move to clean energy—which was undertaken in the early years of President Lula's administration—was shelved, opening up space for a clear preference for fossil fuels. The situation deteriorated when the Rousseff administration began to interfere in gasoline prices, rendering ethanol prices increasingly less competitive. However, if around 70% of the Brazil's ethanol-producing groups are in difficulties, much of the problem is due to poor management and poor investment decisions. In the last fifteen years the sugar and alcohol sector has witnessed a marked increase not only in the demand for ethanol, but also in the modernization of the production process. In a short period, a segment dominated by family-owned businesses was forced to seek professionalism, improve management and invest heavily in machinery, while at the same time increasing productivity. With or without the government's bungling, few have been able to stay on track (CTBE, 2014).

According to several other authors, Brazil was expected to meet a large part of the world demand for ethanol given the prospect of a global market based on the commitment of several countries to blend gasoline with ethanol—a commitment driven by the need to reduce greenhouse gas emissions and develop a new renewable energy matrix (Ren, 2012). This context led to a significant increase in investments in production, both due to the expansion of Brazil's existing plants and the opening of new plants, based on investment from both domestic and foreign concerns. This expansion has also created opportunities for employment and economic development in rural areas of Brazil, which are generally well behind in terms of their socioeconomic indicators compared to urban or industrial areas (Gilio and Moraes, 2016). The expected demand did not occur and, according to other authors, such as Santos et al. (2015), the sector has been in a state of marked imbalance since 2008. Between 2008 and 2014, many plants ceased operations due to financial difficulties, with a direct impact on fuel ethanol production (Santos et al., 2015). On this point, the literature mentions several factors of influence of a financial, agronomic or market order, and even factors concerning governmental policies (Solowiejczyk and Costa 2013; Moraes and Zilberman, 2014, Moraes and Bacchi, 2014).

Despite their indebtedness, plant owners were able to sustain production until 2011 because they had, above all, been investing in increasing the area planted with sugar cane — albeit to the detriment of investments in productivity or improvement of strains. The mills were becoming more professionally run, but family interference was still a concern. Many producers rode the wave of euphoria to invest in land at a time of rapidly growing agribusiness, high prices notwithstanding. They also leased land at high prices, to only then incur heavy losses. (Klff, 2014)

The industry expects the government will stop interfering in gasoline prices and follow some known methodology, such as indexing to the international market. The sector would then gain predictability and then make the necessary investments to increase productivity (Unica, 2018).

Numerous high capacity plants were opened in the most distant regions of Ribeirão Preto, as well as in Goiás, the Triangulo Mineiro, and even Mato Grosso do Sul. Subsequently, in the wake of the financial crisis, the sector had to close about sixty low productivity plants that were operating in the red. The main objective of these plants would be to take advantage of economies of scale to increase efficiency. But the opposite occurred: plants in São Paulo began to close due to poor profitability.

Multiple additional factors also contributed to the stagnation of the industry. Issues such as the lack of predictability of the Brazilian economy, the freezing of gasoline prices, rising industrial costs, and the lack of investments in transportation infrastructure, did nothing to encourage new investments in ethanol production.

1.3 PAPERS

This thesis addresses four papers that seek to relate the main problems concerning ethanol produced in Brazil in recent years. With this objective, we will use studies that are innovative — all based on state-of-the-art methodologies with the potential to indicate solutions that can contribute to the development and competitive capacity of biofuel. The papers also seek to analyze and foster an understanding of the relationships between the various variables considered.

In this context, we seek to survey the main gaps that underly the problems related to the fuel ethanol sector in Brazil, aiming to contribute to (i) increased biofuel production; (ii) increased plant efficiency and productivity; (iii) analysis of the best distribution and logistics for ethanol; (vi) analysis of price policies.

The first paper studied several random and non-structural variables in an econometric model capable of simultaneously analyzing all of the variables. The MCMCglmm model was able to point to areas that could contribute to the much-needed increase in ethanol production.

The second point to be looked into would be what is needed to increase efficiency and productivity. This need derives mainly from the fact that in Brazil less efficient plants are being closed precisely in less efficient areas. Thus, in the second paper, we study the efficiency frontiers of a historical series of plants in Brazil through a two-stage DEA model. The first stage generates efficiency scores and the second stage generates Tobit, Beta and Simplex regressions to identify the contextual variables that would most contribute to increasing productive efficiency.

The third paper seeks to present the best distribution logistics for the ethanol production chain, from producers to collection centers and distribution centers, i.e., a robust transshipment problem, using linear programming. This model was developed to run one linear programming problem per year for all plants and distribution centers, presenting the best distribution logistics inserted in a multimodal context. The fourth study seeks to analyze and explain the complex behavior of the price ratio between ethanol and gasoline in Brazil in the context of certain governmental actions. The paper analyzes the occurrence of bubbles in the price ratio using right-tailed ADF tests.

The ethanol-to-gasoline price ratio is the decisive factor for biofuel competitiveness, since ethanol becomes competitive only when priced at less than 70% of the price of gasoline. The methodology used, i.e., right-tailed ADF tests, was employed in a study such as this for the first time, thus underscoring the innovative character of the work.

The objectives of this paper are to explain the complex behavior of the ethanol-gasoline price ratio in Brazil in light of certain governmental actions. Although there are several papers studying ethanol demand and production in Brazil in recent years, none uses this kind of statistical tool to explain possible bubbles in its consumer-pricing behavior, even though the method has been widely used to detect bubbles in financial and commodity markets since the method was first proposed.

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2 1ST PAPER: ETHANOL PRODUCTION IN BRAZIL: AN ASSESSMENT OF MAIN DRIVERS WITH MCMC GENERALIZED LINEAR MIXED MODELS

ETHANOL PRODUCTION IN BRAZIL: AN ASSESSMENT OF MAIN DRIVERS WITH MCMC GENERALIZED LINEAR MIXED MODELS

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.

2.1 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 hydrous ethanol, ethanol is also used in the form of anhydrous ethanol, blended with regular gasoline to increase octane (Andrade et al., 2010).

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.

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 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 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	0	0.11	1	0.31
Source: IBGE, UNICA, GoogleMaps				
Gasoline/Ethanol Price Ratio	0.45	0.63	0.87	0.09
Source: ANP, UNICA				
Sugar/ethanol Price Ratio	1.02	1.43	1.07	0.29
Source: UNICA				
Distance Factor (Km)	682	1,431.8	5,500	1,051.1
Source: IBGE, UNICA, GoogleMaps				

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. Binary Variable.
Mill Ramping Up	(+) Ramping-up mills imply newer plants, with high productivity a newer technologies and managerial practices, yielding higher ethanol production levels. Binary Variable.
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. Binary Variable.
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. Binary Variable.
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.

2.2 CONTEXTUAL SETTING

The volatility and rising prices of oil and oil by-products, along with global efforts to reduce greenhouse gases, has led many countries to seek renewable energy alternatives for their energy matrixes. In Brazil, ethanol has been used as a fuel by a significant proportion of consumer automobiles since the mid-1970s. Although at that time flexible fuel vehicles were not available, part of the national fleet ran exclusively one ethanol, and part exclusively on gasoline. This was the result of the incentives put in place by the Proálcool program. Brazil at that time had already developed a sugarcane supply chain for sugar production, which was successfully expanded and adapted to ethanol (Mendonça et al., 2008; dos Santos et al., 2018). This initiative is regarded as the world's largest commercial use of a renewable product for fuel production, thus demonstrating the feasibility of large-scale production of ethanol from sugarcane and its use as an automotive fuel (Moreira and Goldemberg, 1999; La Rovere, 2000; Ferreira and Ruas, 2000). Furthermore, according to Sant'Anna et al. (2016), sugarcane production plays a decisive role in the production of ethanol in Brazil. This is because that both ethanol and sugar are byproducts of sugarcane. In the second half of the 1980s, the international oil market began to change amid falling oil prices, which then resulted in a slower growth rate in hydrated ethanol production. The production of anhydrous ethanol, in turn, began a phase of slight decline. The combination of these facts caused a stagnation of ethanol production in Brazil, which had remained constant until 1991 when hydrous ethanol production began to decline due to changes in the gasoline-ethanol blend. Despite the end of the oil crisis, the growth of gasoline production in Brazil, controlled by Petrobras, failed to keep up with the large number of cars in circulation and being manufactured that ran on hydrous ethanol (Kohlhepp, 2010). Thus, according to Mendonça et al. (2008), the ethanol industry in Brazil began selling anhydrous ethanol blended with gasoline — in higher proportions and nationwide — to mitigate production constraints imposed by Petrobras. Besides, this measure represented a rapid escape valve for the declining market for hydrous ethanol. According to Michellon et al. (2008), throughout the 1990s the program continued to be lethargic, with the government promoting market deregulation, market pricing of goods, and free competition. In 2004, flexible fuel vehicles (using ethanol and/or gasoline) were launched in the Brazil market. The technology, which is known as flexible fuel, was introduced to stimulate domestic demand for ethanol. To this day, this option is available for almost all models of light vehicles made in Brazil (Michellon et al., 2008; Du and Carriquiry, 2013a).

After the global financial crisis broke out in 2008, the demand potential for ethanol far outstripped supplies, contrary to the expectations of the Brazilian government. Additionally, the ethanol supply was greatly affected by an endogenous crisis caused by poor government planning and populism in terms of controlling fuel prices, and resulting in an artificial demand crisis in the ethanol sector. In fact, the Brazilian government interventionism in fixing gasoline prices had clear impacts on ethanol consumption, without which consumers were able to return to their fuel of choice. Montasser et al. (2015) analyzed the ethanol gasoline price ratio in Brazil during the period of

2000–2012, showing how this affected gasoline and ethanol consumption. Consequently, the greenfield projects[1] had funding problems and corporate investments were focused on mergers and acquisitions (M&A) at the expense of expanding the sector's production capacity.

The result was a fall in agricultural productivity (Almeida and Viegas, 2011). Also in relation to the crisis faced by the sector from the 2008/2009 harvest onwards, Santos et al. (2015) noted that (i) the low profitability and reduced economic margins; (ii) interruption of operation or closure of industries; and (iii) cutbacks in investments and high indebtedness were causes of the crisis. The factors most commonly cited to explain the negative results in the balance sheet included the containment of gasoline prices, the lack of tax offsets related to impacts of fossil fuels, rising production costs, and the slow adoption of technologies to increase productivity. According to alerts predating the current crisis, inefficiencies in the management of industries and agriculture are also historical causes of difficulties. In sum, according to Santos et al. (2015), a further illustration of the crisis in the production chain indicates that of the 439 mills in the 2013/2014 harvest, 343 were operating normally; 55 were under judicial reorganization (22 operational and 33 shut down), and 10 were bankrupt.

Finally, following Santos et al. (2015), reactions of accommodation in the market (mergers and acquisitions) have been identified as alternatives in such cases. From the private sector, there has also been a call for a broad program of sanitization of the sector in order to recover the investment. Yet, even in this case, it is assumed that groups lagging in terms of technology and management would exit the market, as has already occurred. Such signs point to a matter already quite prominent, which is the need for a policy tailored to hydrous ethanol production with special attention in terms of agricultural and industrial aspects. As a matter of fact, mills still ramping up are early adopters of genetic improvement and new cultural practices technologies (Goes et al., 2011). In conjunction with the modernization of production technology, the authors indicate that ramping-up mills are at the edge of new alternatives and business opportunities represented by new products and process by products.

[1] That is, the new project involving the building of new mills and the development of sugarcane fields close to the mill.

2.3 REVIEW OF THE LITERATURE

This paper aims to contribute to this debate by identifying the main determinants of ethanol production, whether related to the (i) dynamics of sugar-ethanol-gasoline prices, (ii) dynamics of sugar-ethanol production and sugarcane milling, (iii) distances from ports and other competitive modes of transportation, (iv) or sector oversight, whether through participation in cooperative plants or through their internationalization via mergers and acquisitions.

2.3.1 Price ratios

The link between production and the prices of ethanol, sugar, oil and oil by-products has been the subject of various studies illustrating the mediating role of oil/oil by-product prices in the formation of relative prices and production trade-offs between sugar and ethanol. For example, Rezende and Richardson (2015) used a Monte Carlo simulation model to analyze the production, marketing and financial activities of mills that process sugarcane to produce sugar and ethanol. The main conclusion of the study is that the Brazilian ethanol industry should continue to undergo a high level of risk as a function of uncertainty in production, macro economy, demand, production costs and market prices. Focusing on price, Chen and Saghaian (2015) investigated the price linkage between oil, sugar, and ethanol through a Cointegration Analysis model. The main conclusions were that the price of oil and its derivatives influence ethanol and sugar prices due to their important role in the global economy, while international sugar prices significantly affect ethanol prices in Brazil. Similarly, Balcombe and Rapsomanikis (2008) examined the relationship between sugar, ethanol, and oil prices in Brazil using a Bayesian methodology. Oil prices were found to be the main driver for both ethanol and sugar prices in Brazil. In turn, Drabik et al. (2015) developed an economic model of the trade-off between sugar and ethanol production in Brazil, based on their price behavior, by examining sugarcane processing in flexible plants that can produce sugar and ethanol. Specifically regarding the relationship of ethanol to gasoline prices, Zafeiriou et al. (2014) used a time-series based model by applying Johansen cointegration techniques to investigate the volatility and behavior of oil, gasoline, and ethanol prices. One of the findings of this study indicates that increases in gasoline prices lead to increases in ethanol prices. Nazlioglu et al. (2013) examined the volatility transmission in prices of oil and selected agricultural commodities (wheat, corn, soya, and sugar) using econometric a causality-in-variance test. In addition, the study performed an analysis of impulse response functions to determine how the price volatility of agricultural commodity responds to the impact of world oil price volatility. A key finding of this study is that the risk of the global oil market is transmitted to the wheat, corn and soybean markets, but not to the sugar market.

As regards the Brazilian case, the Government interventionism in fixing gasoline prices with clear impacts on ethanol consumption is worth noting. Montasser et al. (2015) analyzed the ethanol-gasoline price ratio in Brazil during the period of 2000–2012. The authors verified that since 2008 the Brazilian Government has artificially frozen gasoline prices while allowing the retail price of ethanol to float.

Considering that annual inflation in Brazil is around 5% per year and cost increases are reflected in ethanol prices, the authors were able to explain why ethanol consumption fell while gasoline consumption increased using right-tailed ADF (Augmented Dickey-Fuller) tests to check for bubbles in this ratio. Such behavior is also explained by the fact that, in Brazil, consumers are told that ethanol is economical as fuel when the price ratio is below 0.70. The results obtained suggest the existence of two bubbles, one already collapsed, and the other underway since 2010.

Serra et al. (2011), using a new methodological approach called search engine optimization (SEO), evaluated the price volatility transmission in the Brazil's ethanol industry. The method enables a combined estimate to be made of the degree of cointegration among the respective price series and the generalized autoregressive conditional heteroskedasticity (GARCH). The results suggest a strong link between commodities and energy markets, both in terms of prices as well as volatility. Chiu et al. (2016) undertook an interesting study exploring the relationships between oil, corn and ethanol prices with a VAR (vector autoregression) model and VECM (vector error correction model) based on US data. The results indicate that the policy-oriented market results in a negative impact on crude oil prices, but has no direct impact on corn prices. From a different perspective, Archer and Szklo (2016) investigated how the evolution of petroleum production in the United States could affect the competitiveness of Brazilian ethanol and the level of investment in Brazil's sugarcane industry. The authors used an econometric analysis to estimate the rate of utilization of ethanol plants and evaluate the opening of new biofuel plants based on varying scenarios of supply and US oil prices. The main conclusion of the study was that prices below 80 USD/bbl would render the expansion of Brazilian biofuels production economically inviable.

2.3.2 Ethanol transportation modes

Another key element for understanding ethanol production is the type of insertion of the mill in the sugarcane production and ethanol distribution chains. Alonso-Pippo et al. (2013) studied the main features of the ethanol production chain, specifically the impact of transport networks (competitive modes) on the competitiveness of ethanol production in Brazil. For this purpose, the 5W2H technique was used to answer questions on it. According to the authors, the weakest point for the ethanol production growth in Brazil is the structure of the sugarcane supply chain, which may be the most important reason that explained the difficulties faced by this industry. The main reasons are listed as follows: (i) the high variety of products, such as raw sugar, VHP sugar, hydrated ethanol and anhydrous ethanol; (ii) government’s difficulties in implementing public policies for agribusiness, where state participation is practically nil; and (iii) the lack of intermodal transport linking the plants to consumer hubs.

As to the lack of appropriate transport infrastructure, for example, it is clear that road transportation prevails to the detriment of other, more efficient, transport modes. Ethanol can be transported to customers in Sao Paulo and surrounding areas, be forwarded by coastal shipping to other states of Brazil, or be exported to other countries (Alonso-Pippo et al., 2013; Leal and D’Agosto, 2011). According to the authors, more than 90% of the ethanol produced in Sao Paulo is transported to consumers in that state by road, which accounts for some 70% of national production. This scenario means the cost of ethanol logistics in Brazil is higher than that in the US, where more than 60% of produced ethanol is transported by rail, 30% by road and 10% via waterway. Although road transport per volume unit is cheaper in Brazil than in the US, the higher percentage of ethanol transported by road renders the logistics of ethanol 1.29 times more expensive in Brazil than in the US.

Using a different approach, Milanez et al. (2010) analyzed the challenges of ethanol logistics/distribution in Brazil compared to possible alternative scenarios in terms of production and consumption of ethanol in Brazil and worldwide. The authors stress that the long distances that hydrated ethanol needs to travel increase its price and, therefore, render parity with the price of gasoline unfavorable to the Brazilian consumer. One of the solutions to make ethanol more competitive in relation to gasoline, and therefore increase production levels, would be to use modes of transportation that cost less than road. Thus, the initiative of increasing investments in pipeline, rail, and waterway networks for ethanol transport is important for Brazil.

In fact, the predominance of road as a transportation mode of ethanol in Brazil is attributable to its advantages on short routes/small volumes, but also because of the limited availability of more efficient high-volume modes, such as pipeline, rail, and cabotage. The ethanol plants are usually located in remote rural areas far from important transport routes. As a result, practically all produced ethanol leaves the plant by road and proceeds directly to distributors and ports. Efficient modes of transport (railway, pipeline, and sea) require storage terminals, where distribution points receive ethanol by road before offloading it to more efficient, longer haul transport modes. These efficient transport modes have unique features. The fixed cost of building a grid of railways or pipelines is high because of costly track rights, construction, and authorization to control stations and pumping equipment. Such investment limits the number of potential investors to a few private companies. Such networks also require a high capital investment in pumping systems and intake terminals. The labor and equipment for building this type of infrastructure also tends to be expensive. (Milanez et al., 2010)

Despite the cost of construction being relatively high, railway and pipeline transportation have several benefits when it comes to reducing (unit) freight costs. For instance, the technology used for pipeline transport (gravity or pumping) uses relatively little energy and results in a low unit cost of transportation. Furthermore, the number of workers required for operating a pipeline is usually lower than that for alternative modes. This also applies to the frequency and cost of maintenance which reduces overall operating costs (CNT, 2012). On the other hand, loading and unloading using rail, benefits from economies of scale. For this reason, pipeline infrastructure for ethanol is currently undergoing development (Milanez et al., 2010). One pipeline network currently under construction connects the three main producing states (Sao Paulo [SP], Minas Gerais [MG], and Goiás [GO]) to the main consumption points. Fig. 1 shows that the state of Sao Paulo has the highest concentration of sugar and ethanol mills and the largest refineries.

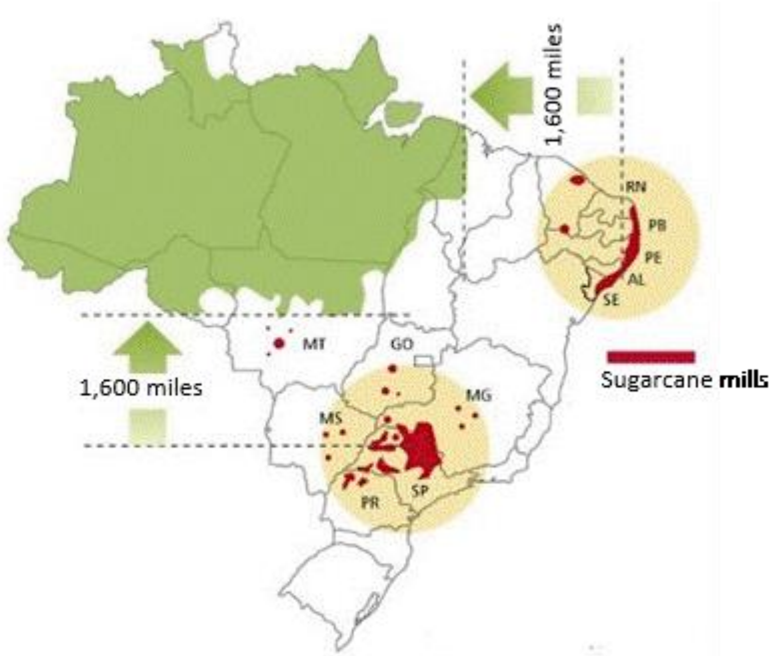

Fig. 1. Location of sugar and ethanol mills in Brazil. Source: Lógum, 2015

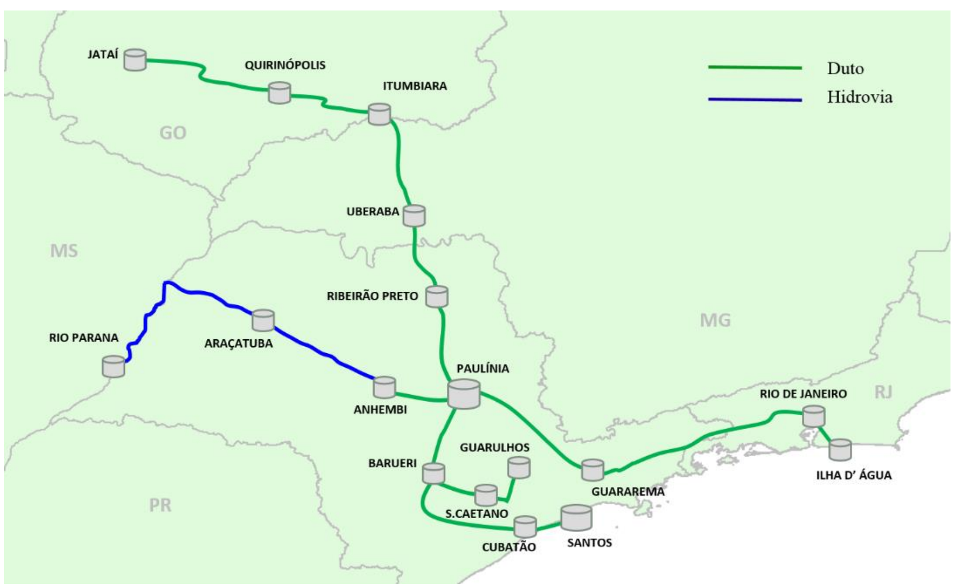

Fig. 2: Efficient modes for ethanol transport in São Paulo State: pipeline and waterway (Source: Lógum, 2015)

Outside in other states, e.g., Minas Gerais and Goiás where road conditions are generally worse, the use of trucking is higher.[2,3] This situation makes road transport even more expensive. Milanez et al. (2010) said the use of waterways and railways was studied by Transpetro, the logistics subsidiary of Petrobras.

In addition to issues relating to prices, production, and ethanol distribution logistics, a further literature—above all Brazilian, albeit incipient, and still anecdotal—that addresses the impact of different contextual variables and the characteristics of each of the sugarcane mills as relevant to understanding ethanol production levels.

Additionally, several variables, such as origin of capital, cooperative membership, and stage of project maturity have been analyzed, particularly by Brazilian researchers, in terms of their impacts on ethanol production. Indeed, the Brazilian sugar and alcohol sector is increasingly concentrated in the hands of multinationals, which are expected to control 90% of the market by the 2015/2016 harvest (Brasil Econômico, 2015). Anecdotal evidence suggests that this target may in reality be closer to 85%, due to the recent economic crisis in Brazil.

2.3.3. Cooperative mills

Sugarcane grower cooperatives in Brazil have also assumed the role of marketing their mil products, which enables them to command a higher price for ethanol and sugar due to economies of scale (Bianchini and Alves, 2003). Moreover, according to the authors, it is important to keep in mind that the cooperative mills have greater flexibility in terms of services that add value for the industrial customer and for end-users, such as remote inventory control of ethanol tanks, thus allowing automatic replenishment policies in relation to manufacturers, transportation companies, etc.

2 Please cf.:http://g1.globo.com/economia/agronegocios/globo-rural/noticia/2017/02/estradas-ruins-deixam-frete-mais-caro-para-escoar-producao-de-soja-em-go.html.

3 https://g1.globo.com/goias/transito/noticia/duas-rodovias-em-goias-estao-entre-as-5-piores-do-pais-diz-cnt.ghtml.

2.3.4. Ramping-up of mills

We should point out that sugar and ethanol mills have a cycle of increasing production until reaching maturity, usually within four years. Some examples cited by the authors indicate that new mills built in Brazil, which are mostly in Brazil's Central-West region states, have such a ramp-up pattern of production. Such mills, which have greater production capacity than those previously built, obviously also have higher overall ethanol production capacity (Viegas, 2013).[4,5]

As can be seen in this literature review, many previous papers studied aspects related to ethanol production, especially regarding prices; however, none of them addressed these aspects together, or included issues relating ethanol marketing and respective logistics. This paper innovates in terms of it being the first to use the statistical model MCMCglmm (Hadfield, 2010), thus simultaneously handling several variables with distinct characteristics.

2.4 METHODOLOGY

2.4.1 The data

A balanced panel dataset for 405 active sugarcane mills in Brazil from 2002 to 2013 was built, compiling scattered data from disparate sources, as described below. The state-by-state annual data for ethanol and sugar production were obtained from the National Agency of Petroleum (ANP) for the period 2002–2013 (www.anp.gov.br/). We also obtained important information on the sugarcane industry from União Canavieira de São Paulo – UNICA (www.unicadata.com.br/) and from Jornal da Cana (www.jornalcana.com.br/). Specifically with respect to the disaggregated data for each mill on ethanol, milling, and sugarcane production, we asked UNICA to provide data for each associated milling company. Thus, UNICA provided a database containing the location, address, and respective production levels per mill per year. This dataset can be provided to readers upon request. This database was further used as a cornerstone for compilation with additional information sources on prices and other contextual variables, as described next. With the exception of ethanol production, the only dependent variable, all other variables were used as predictors.

[4] http://www.biofuelsdigest.com/bdigest/2013/09/16/brazils-big-six-in-advancedbiofuels-chemicals-whos-doing-what-now/.

[5] http://ethanolproducer.com/articles/8083/petrobras-boosts-ethanol-investment-toincrease-capacity.

Price data for sugar and ethanol were obtained from Centro de Estudos Avançados em Economia Aplicada – ESALQ/USP (www.cepea.esalq.usp.br/) for the entire period of the series. Regarding gasoline prices, yearly averages were computed based on ANP data for the state of São Paulo. In addition, we conducted a geographical and commercial research of sugar and ethanol mills in order to discern the various economic groups and obtain information about each mill. Data were collected from different sources, including interviews with UNICAs experts. For logistics information, we used road distances from each mill to the main consumption points based on Google Maps (www.google.com.br/maps). From the table of distances between each mill and each distribution terminal, we calculated a distance factor to serve as a logistics score for each mill. This was based on the weighted average, by demand, of the distances from each mill to each point of consumption. In short, the distance factor reflects, in relative terms, the degree to which a given mill is close to a point of consumption. In turn, the contextual variables of each mill were defined based on data available from Agência Nacional do Petróleo (ANP) and União da Indústria Canavieira (UNICA). The main reason we used contextual dummy variables related to the mills is to form a relatively complete list of variables, thus increasing the amplitude of the model. As mentioned, one of the variables refers to mill membership in a cooperative, which is important because such mills have characteristics that streamline performance in business; including this dummy variable can provide a dimension of this phenomenon. Another dummy variable is whether the plant is domestic or foreign. Including this variable also provides a view of such fact. During our contacts with UNICA for data collection, we adopted the following criterion to classify whether a plant is domestic or foreign: the majority of shares (at least 50% plus one share) are held, respectively, by either domestic or multinational companies. The third dummy variable pertains to whether the plant production is ramping up or has already reached maximum capacity, given current production technology and considering all remaining factors constant. Again, contacts with UNICA and their sector experts proved helpful in defining the ramp-up period: a cut-off point of at least seven years of operation was established to classify a mill as mature (i.e., not ramping-up). The last dummy variable is whether the mill has a logistical advantage in terms of an efficient mode of transport. As regards this paper, railways, pipelines, and waterways were considered efficient transportation modes; road was excluded from this category. These efficient transportation modes, due to economies of scale, yield much lower cubic-meter transportation costs compared to traditional road transportation, which is also subject to tolls. Specifically with respect to São Paulo State, Fig. 2

depicts the networks for the existing waterway (Hidrovia Tietê-Paraná) and ethanol pipeline (operated by Lógum).

Although not shown, there is also a railway network operated by ALL – Malha Paulista. For cases where mills are located up to 60 km from a pipeline terminal, waterway, or railway, the variable is true. The importance of this variable derives from the fact that the new ethanol production mills, as well as planned projects, are more economically feasible when located near efficient modes of transportation. Similar to the variables relating to prices, the aim is to explain the relationship between the prices of ethanol, gasoline, and sugar, as well as the production of these products. Finally, including a distance factor as a variable will enable an analysis of the effect of geographic location on production.

In order to better comprehend the impact of this network of efficient transport modes on ethanol production competitiveness, it is worth mentioning that the combined lengths of railways, waterways, and pipelines totals about 1300 km across 45 municipalities. These efficient transport modes are capable of linking the main ethanol-producing regions in the states of São Paulo, Minas Gerais, Goiás, and Mato Grosso do Sul to the main ethanol consumer market in Brazil (the Greater São Paulo region) and to ports in the Southeast. The system is necessary because most ethanol production is far from major consumer markets and ports. The expectation is that the state of São Paulo, currently producing 69% of the country's ethanol, will decline to 48% of the total produced in 2021. At the same time, Goiás will increase from 10% to 18%, and Mato Grosso do Sul from 6% to 15%.

In short, the dependent variable is ethanol production; the other variables considered are (i) Ethanol Production, (ii) Sugar Production, and (iii) Sugarcane Milling. The contextual dummy variables are (i) Cooperative Mill, i.e., whether the mill belongs to a co-op (1) or not (0); (ii) mill ramping up, i.e., whether mill production is increasing (1) or not (0); (iii) National Mill, i.e., whether the mill is national (1) or not (0); and (iv) Efficient Mill Logistics, i.e., whether the plant is close to any logistically efficient terminal (1) or not (0). Moreover, as we saw earlier, we have the variables related to prices: (i) Gasoline/Ethanol Price Ratio, (ii) Sugar/Ethanol Price Ratio, and (iii) Distance Factor (as described above). The expected relationship between these variables, their underlying rationales, and their descriptive statistics are presented in Table 1 below:

2.4.2 Markov chain Monte Carlo methods for generalized linear mixed models (MCMC – GLMM)

Multiple linear regression is widely used in empirically-based policy analysis. However much of this use is inappropriate, not because of the multiple linear regression methodology, but because of the nature of the data used. Too often, analyses are carried beyond justified inferences into assertions for which there is essentially no sound defense, leading to policy recommendations of dubious provenance. Four alternative classes of policy interpretations are posited: mere description of data sets, simple prediction, causal models, and causal predictive models. GLMMs combine a generalized linear model with normal random effects on the linear predictor scale, to give a rich family of models that have been used in a wide variety of applications (Diggle et al., 2002, Verbeke and Molenberghs, 2000; Molenberghs and Verbeke, 2005; Mcculloch et al., 2008). This flexibility comes at a price, however, in terms of analytical tractability, which has a number of implications including computational complexity, and an unknown degree to which inference is dependent on modeling assumptions. For instance, although likelihood-based inference may be carried out relatively easily within many software platforms, inference is dependent on asymptotic sampling distributions of estimators, with few guidelines available as to when such theory will produce accurate inference (Fong et al., 2010).

More precisely, GLMMs extend the generalized linear model (Nelder and Wedderburn, 1972; McCullagh and Nelder, 1989), by adding normally distributed random effects on the linear predictor scale. Suppose Yij is of exponential family form: $Yij \mid qij,\varphi 1 \sim p(\cdot)$, where $p(\cdot)$ is a member of the exponential family, that is,

$p\,(yij|\theta ij,\varphi 1) = \exp\,[(yij\theta ij - b(\theta ij))/a(\varphi 1) + c(yij,\, \varphi 1)]$, (1)

for $i=1,\ldots,m$ units (clusters) and $j=1,\ldots,ni$, measurements per unit and where θij is the (scalar) canonical parameter. Let $\mu ij = E\,[Yij|\beta,bi,\, \varphi 1] = b'\,(\theta ij)$ with

$g(\mu ij)=\eta ij=xij\beta + zijbi$; (2)

where $g\,(\cdot)$ is a monotonic "link" function, xij is 1 x p vector of fixed effects, and zij is 1 x q vector of random effects; hence $\theta ij=\theta ij\,(\beta,\, bi)$.

Let us assume $b_i|Q \sim N(0, Q^{-1})$, where the precision matrix $Q=Q(\varphi_2)$ depends on parameters φ_2 and that β is assigned a normal prior distribution. Let $\gamma=(\beta, b)$ denote the G x 1 vector of parameters assigned Gaussian priors. Priors for φ_1 (if not a constant) and for φ_2 are also required. Let $\varphi=(\varphi_1, \varphi_2)$ be the variance components for which non-Gaussian priors are assigned with $V=\dim(\varphi)$.

Although a Bayesian approach is attractive, it requires the specification of prior distributions, which is not straightforward, especially as regards variance components. Recall that we assume β is normally distributed. Often there will be sufficient information in the data for β to be well estimated with a normal prior with a large variance. The use of an improper prior for will often lead to a proper posterior, though care should be taken. If we wish to use informative priors, we may specify independent normal priors with the parameters for each component being obtained via specification of 2 quantiles with associated probabilities. For logistic and log-linear models, these quantiles may be given on the exponentiated scale since these are more interpretable (as the odds ratio and rate ratio, respectively). If θ_1 and θ_2 are the quantiles on the exponentiated scale and p_1 and p_2 are the associated probabilities, then the parameters of the normal prior are given by

$$\mu=(z_2 \log(\theta_1)-z_1 \log(\theta_2))/(z_2-z_1), \quad (3)$$

$$\sigma=(\log(\theta_2)-\log(\theta_1))/(z_2-z_1), \quad (4)$$

where z_1 and z_2 are the p_1 and p_2 quantiles of a standard normal random variable. The most prominent application in the entire arena of simulation based estimation is the current generation of Bayesian econometrics based on Markov Chain Monte Carlo methods. In this area, heretofore intractable estimators of posterior means are routinely estimated with the assistance of simulation and the Gibbs sampler (Greene and Hill, 2010). These techniques offer stand-alone approaches to simulated likelihood estimation, but can also be integrated with traditional estimators (Korsgaard et al., 2003). Computation is also an issue since the usual implementation via MCMC carries a large computational overhead (Gamerman, 1997; Lange, 2010).

Previous studies have used this approach when analyzing the market dynamics of commodities. Du et al. (2011) performed a Bayesian analysis using the MCMC method to correlate crude oil price volatility with agricultural commodities markets. The authors showed that the recent shock in oil prices resulted in significant price variation in agricultural commodities markets such as corn and wheat. Du and Carriquiry (2013b) also analyzed the geographic effects of the ethanol market development in the US, as well as the heterogeneity of adoption. The authors used several explanatory variables and an MCMC method that proved capable of working effectively with all heterogenic variables. Other authors, such as Chen (2015) and Bruha and Pisa (2012), also obtained good results using MCMC methods in studies on commodities.

2.4.3 Robustness analysis

The validity of the results obtained via MCMC GLMM is addressed by running additional models to account for spatial correlation and endogeneity. Precisely, endogeneity was addressed within the ambit of spatial regressions, where data can be spatially correlated, running a regression in two phases. Although spatial regressions are often limited by normality assumptions, in this research they are used as a countervailing analytical step to the results originally derived using MCMC GLMM models. Additionally, multicollinearity between predictor variables is also explored.

2.4.3.1 Spatial data analysis and regression

As there may existing location links or spatial dependence between different sugarcane mills for the production of ethanol, we intend to further introduce the spatial regression into the basic model and check the robustness of the empirical results. However, the data generating process (DGP) that

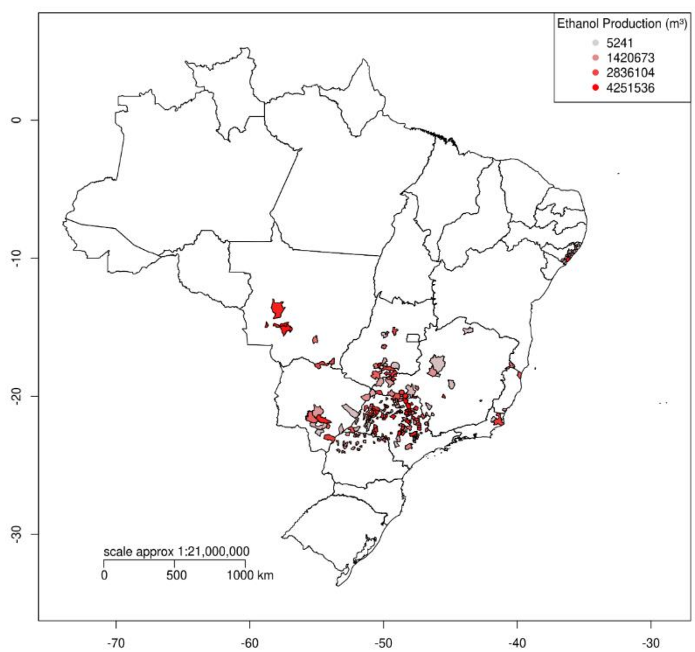

Fig. 3. a) Maap for the ethanol production per municipality. Source: the authors

produced the sample data determines the type of spatial dependence (LeSage and Pace, 2010). Because we do not know the true DGP, alternative approaches have been always applied to different modeling situations (Chen et al., 2017). Finally, we choose the spatial error model (SEM), suggesting that the spatial dependence is only in the disturbance process. Fig. 3a and b presents, respectively, the spatial maps for the total ethanol production and total number of mills by

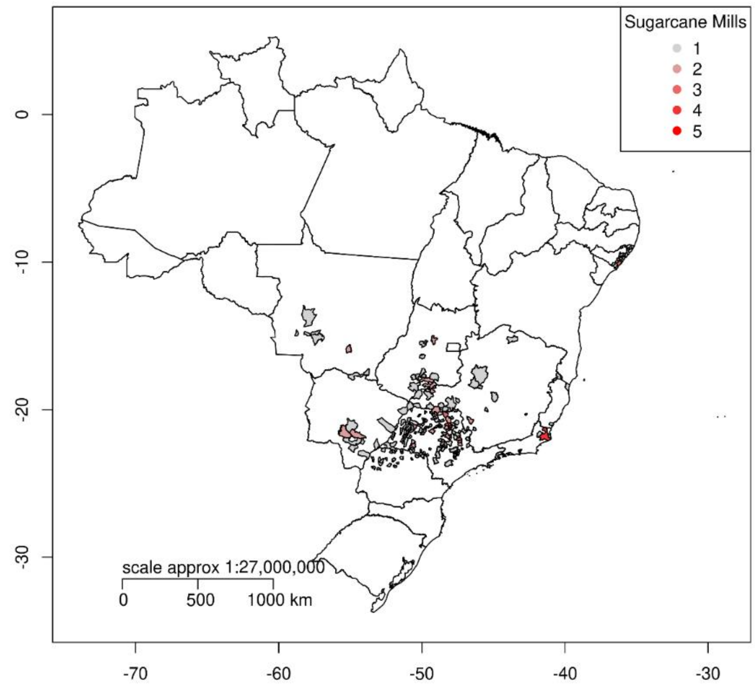

Fig. 3. b) Mbap for the number of sugarcane mills per municipality. Source: the authors

municipality. Although mill data were aggregated by municipality when geographical coordinates were not available for each mill, results for the spatial correlation indicate that higher ethanol production levels tend to be organized in clusters (I=0.319, Sig=4.81 e-5), thus suggesting evidence for a lower impact of contextual variables on ethanol production levels. The underlying reason is that spatial correlation may obfuscate the impact of some business-related variables.

2.4.3.2 Endogeneity correction

The conflicting results from prior studies with respect of the impacts of prices and sugar production on ethanol production levels (Ajanovic, 2011; Chen and Saghaian, 2015) may also be explained by not properly controlling for endogeneity. One of the important issues is the direction of causal relationship between ethanol production, sugar production and prices in the empirical analysis.

This direction is not clearly ex ante, in other words, it is not clear what comes up first. A common technique to deal with the endogeneity problem is the use of instruments (Renders and Gaeremynck, 2006). Specifically, a set of instruments that are assumed to be exogenous is selected and then the robust regression is performed in two phases. Firstly, the endogenous variable is regressed on the instruments. Then the estimated value of the endogenous variable, rather than itself, is included in the second-phase equation. A good instrument has a strong correlation with the endogenous variable, but is uncorrelated with the error term of the equation, i.e., it is exogenous. However, it is extremely hard to find such a perfect instrument in practice. Therefore, most empirical research works with imperfect instruments instead (Maddala, 1997). These imperfect instruments are either exogenous but have a low correlation with the endogenous variable, so-called "weak-instruments," or are not exogenous but have a high correlation with the endogenous variables, so-called "semi-exogenous" or "quasi-instrumental" variables (Mroz, 1987). As we have panel data, ethanol production levels lagged one year were used as a "quasi-instrument," similarly to Renders and Gaeremynck (2006). This instrument should be highly correlated with the endogenous variable because it is difficult to reverse ethanol production levels scores in the short-term. Furthermore, this instrument is less endogenous than the current ethanol production levels, as prices and or sugar production levels in year t cannot have influenced ethanol production levels in year t-1. However, ethanol production levels in t-1 can be correlated with those computed in year t. The degree of exogeneity of this instrument depends on how current ethanol production is related to past ethanol production. Therefore, in this research, the spatial regression presented in the previous section is performed in two phases.

In phase 1:

$et-1 = rt + st + \varepsilon$ (5)

where: $et-1$ is the lagged ethanol production vector, rt and st are, respectively, the matrix of gasoline/ethanol and sugar/ethanol price ratios and the sugar production vector. Besides, ε is the error term. In phase 2:

$et = et-1 + it + \varepsilon$ (6)

where: et is the ethanol production vector, and it is the matrix of dummy contextual variables that characterizes each mill. Again, ε is the error term. Fig. 4 presents the aggregate correlation matrix between ethanol production and the set of endogenous contextual variables used in Eq. (5). Multicollinearity is low within the environment of the contextual variables. Furthermore, ethanol production levels appear to be moderately correlated to some of the contextual variables and to sugar production, thus complying with the prerequisites of using lagged ethanol production levels as an instrument. Results for the Arellano-Bond test confirmed the presence of a first-order correlation in the differenced residuals, albeit not implying that estimates are inconsistent.

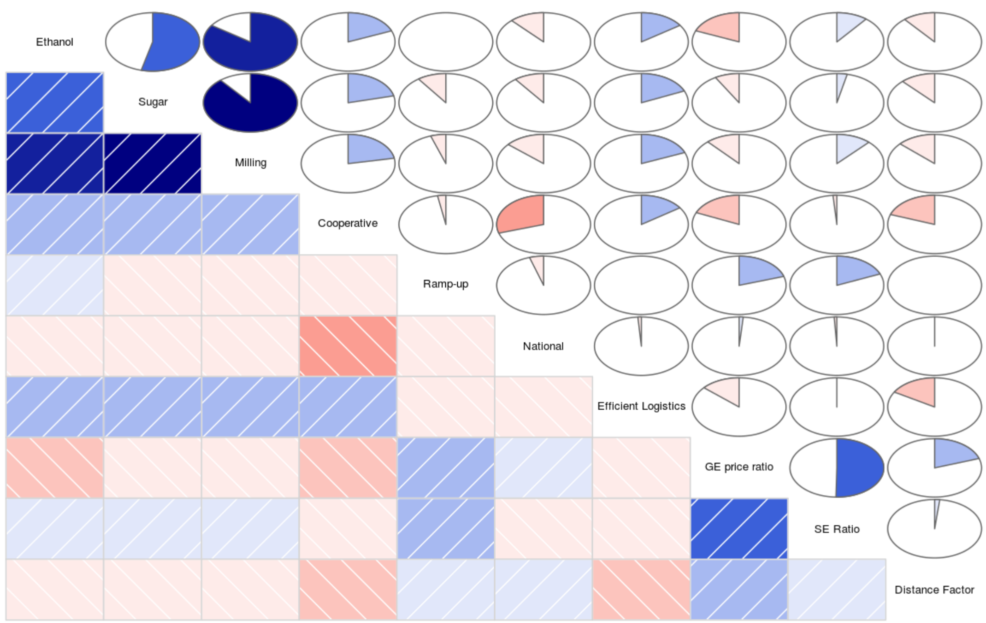

Figure 4. Correlogram for the dependent and predictor variables (cf. Table 1)

2.5 DISCUSSION OF RESULTS

As we have seen, this work includes several variables with very different characteristics, i.e., contextual variables, price indices, distances, and numerical variables for the purpose of evaluating ethanol production. A GLMM using MCMC methods was used to perform the modeling. We used the MCMCglmm R package for the following variables: Sugar Production, Sugarcane Milling, Cooperative Mill, Plant Ramping Up, National Plant, Efficient Plant Logistics, Gasoline/Ethanol Price Ratio, Sugar/Ethanol Price Ratio, and Distance Factor, while Ethanol Production was the response variable according to the results in Tables 2 and 3. Both models presented a good fit, converging after 25,000 interactions, with a thinning interval of 50 and sample size of 1000. DIC (deviance information criterion) value was −938.2826 and the prior choice followed Gelman et al. (2008), who suggested that the input variables with dummy regressors should be standardized and that the related regression parameters should be assumed independent in the prior distributions (cf. Table 3 results). Gelman et al. (2008) recommended a scaled t-distribution with a single degree of freedom (scaled Cauchy) and a scale of 10 for the intercept and 2.5 for the regression parameters.

Results presented in Table 2 confirm the expected signs for the contextual variables as regards their respective impact on ethanol production levels, as described in Table 1. Provided this is a linear model, the coefficients expressed in Table 2 can be also considered for the purposes of a marginal analysis on the impacts of each contextual variable on ethanol production levels, considering all other variables constant. As regards the production of ethanol, an additional tonne of sugar has an impact equivalent to almost ten tons of sugarcane, thus suggesting that the trade-off between ethanol and sugar production cannot be solved in the short term, as long as substantial increasing in milling is required. As regards price ratios, it is interesting to note an equivalence in the magnitude of both coefficients. In terms of ethanol production in Brazil, these results suggest that positive increases in gasoline prices can compensate, to some extent, the negative impacts of increases in sugar prices, thereby helping to maintain the balance between these two byproducts. As regards the dummy variables, technology innovations in newer mills (ramp-up) and expertise (national) are the two main drivers of ethanol production. They are almost one fifth higher than the benefits resulting from cooperative-mill status and access to efficient modes of transportation.

Table 2: Results of the MCMCglmm forecast model

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC	significance
(Intercept)	-2.14E+03	-7.32E+03	3.75E+03	1200.9	0.43	
Sugar Production	-6.24E-01	-6.33E-01	-6.15E-01	1105.3	<0.001	***
Sugarcane Milling	7.96E-02	7.88E-02	8.04E-02	1622.1	<0.001	***
Cooperative Mill	2.72E+03	1.56E+03	3.89E+03	815.5	<0.001	***
Mill Ramping Up	3.30E+03	1.77E+03	4.70E+03	922.2	<0.001	***

National mill	3.16E+03	8.91E+02	5.56E+03	870.2	0.002	**
Efficient Plant Logistics	2.73E+03	1.21E+03	4.20E+03	1000	<0.001	***
Gasoline/Ethanol price ratio	9.55E+00	7.57E+00	1.18E+01	1000	<0.001	***
Sugar/Ethanol Price Ratio	-9.72E+00	-1.14E+01	-7.97E+00	1433.2	<0.001	***
Distance Factor	-8.40E-01	-1.22E+00	-4.71E-01	1000	<0.001	***

Notes:

Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.

These results suggest that if sugarcane milling increases by 1 tonne, it is expected that ethanol.

Table 3: Results of MCMCglmm Model with standard variables

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC	significance
Intercept	-8.18E-05	0	7.78E-03	1000	1,000	
Sugar Production	-1.36E+00	-1.38E+00	-1.34E+00	1000	<0.001	***
Sugarcane Milling	1.98E+00	1.96E+00	2.00E+00	1041	<0.001	***
Cooperative Mill	2.20E-02	1.30E-02	3.12E-02	1000	<0.001	***
Mill Ramping Up	1.92E-02	9.70E-03	2.80E-02	1000	<0.001	***
National mill	1.15E-02	3.41E-03	2.07E-02	1000	0.02	*
Efficient Plant Logistics	1.49E-02	6.46E-03	2.31E-02	1000	0.002	**
Gasoline/Ethanol price ratio	3.85E-02	2.94E-02	4.64E-02	1599	<0.001	***
Sugar/Ethanol Price Ratio	-4.69E-02	-5.48E-02	-3.84E-02	1000	<0.001	***
Distance Factor	-1.88E-02	-2.82E-02	-1.04E-02	1000	<0.001	***

Note: Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.

Because the variables are in different units, it is necessary to run the model with the variables normalized, i.e., using data that has been standardized to have mean 0 and standard deviation 1. By doing so, all variables will have the same weight in the analysis because all will have the same variance. This procedure is appropriate when the variables are measured in different units or when the variance of each variable varies substantially compared to the others. Therefore, it is now possible to generalize the results, making variables measured in different scales – metric and binary – comparable in terms of their relative importance for ethanol production. This is done using the scale command of the R package. Table 3 below shows the MCMCglmm model and lists the standard variables. Because in the Bayesian analysis all effects are technically random, the coefficient to be analyzed is the mean (post. mean) in Table 3.

Again, the expected relationships between contextual variables and ethanol production levels were corroborated. Since these contextual variables were transformed to the same scale, they can be re-interpreted as structural factors and conjunctural factors in accordance with their intrinsic characteristics and relative importance to the ethanol production. Structural factors are those related directly to the ethanol production process of and are represented by the variables sugarcane milling and sugar production. As might be expected, these variables have the greatest magnitude in the forecast model, as shown in Table 3. The conjunctural factors are represented by the sugar/ethanol price ratio and gasoline/ethanol price ratio, which exert a strong impact on resource allocation decisions for each one of the two byproducts of sugarcane. The remaining contextual variables (cooperative mill, plant ramping up, national plant, efficient plant logistics, and distance factor) can be interpreted as exogenous ones, provided they impact the productive process of sugar and ethanol without being impacted directly by them in a reverse causation. Besides, their coefficients are lower when compared to the other conjunctural and structural variables. It is interesting to note that the distance factor is negative, with a mean of −1.882e-02 since the shorter the average distance, the more competitive the mill and, thus, the higher its production incentives. Cooperative Mill with a mean of +2.203e-02 (see Table 3). This confirms the main advantages of a cooperative mill: greater flexibility for customer service, increased availability of investment in products that add value for industrial customers, an information system integrating the cooperative to customers and suppliers, electronic sales, and a well-designed and shared center for product development (Bianchini and Alves, 2003). Good access to discounted bulk sugarcane supplies as well as differentiated access for working capital bank loans are also amongst the benefits of a cooperative mill. These advantages may contribute to increase ethanol production. In terms of size, the second largest dummy context variable is Mill Ramping Up with a mean of 1.924e-02 (Table 3). This variable refers to mills that are ramping up production. Mostly due to their technology, mills that are ramping up have higher sugarcane production than the old mills, which in turn results in increased ethanol production. In fact, newer plants are early adopters of the technologies that are still under development, for example, genetic improvements and new agricultural methods (Michellon et al., 2008). Additionally, the sugarcane industry has reached a high level of automatization resulting in increased yields and enabling a range of new alternatives and business opportunities in terms of new (by) products obtained from the industrial process (Michellon et al., 2008). Byproducts, such bagasse, straw, tips and vegetal residues are today considered essential raw materials. Within this approach, there are three major utility lines for the production. The first is the obtaining of second-generation ethanol, i.e., the alcohol extracted from the cellulose using sugarcane bagasse and straw as raw material. The latter two are sources of cellulose that account for two thirds of this plant's energy. The second is the use of byproducts, such as bagasse, straw, tips and sugarcane vegetable residues, which have become essential raw-materials. The third is the biomass present in the sugarcane, which can be used to generate electricity. The dummy variable Efficient Plant Logistics with a mean of 1.490e-02 highlights the mills close to distributors and linked to efficient transport modes, such as railways and pipelines. These mills have a significant commercial advantage over the others since their efficiency results in lower logistics costs. The regression model used confirms that the closer to an efficient modal, the greater the ethanol production. Somewhat surprisingly, the variable National Plant placed last among the contextual variables, with a mean of 1.151e-02. Despite the fact that sugarcane production in Brazil has been a business historically dominated by Brazilians in terms of expertise and know-how (as confirmed by the positive sign of the coefficient in Table 3), the involvement of international groups in sugar and ethanol production in Brazil is experiencing significant growth. The participation of foreign groups, which was only 3% in 2006, is expected to rise to almost 90% in the 2015/2016 harvest. An important check is that if we add the absolute values of coefficients Efficient Plant Logistics (1.49e-02) to the Distance Factor (1.88e-02), we obtain an overall magnitude of 3.37e-02. This is very close to the magnitude of the variable Gasoline/Ethanol Price Ratio (3.84e-02). This leads us to believe that the full impact of Logistics on ethanol on production is very close in importance to the price of gasoline. An improvement in terms of logistics could bring as much benefit to ethanol production as increasing the price of gasoline, which is often the target of ethanol producers' complaints. Lastly, as regards the robustness analysis, which aimed to control for endogeneity with respect to ethanol and sugar production levels, the results presented in Table 4 partially corroborate the results previously discussed. As long as the results for phase one with respect to the signs and significances of price ratios and milling and sugar production levels still hold, the results in phase two as regards dummy variables – exogenous contextual variables – are only confirmed in terms of signs. Reasons for non-significant results may be related to the fact that spatial correlation and cluster organization of mills obfuscate the impact of each individual exogenous contextual variable on ethanol production levels.

Table 4: Results for the two-phase special regression with endogeneity correction

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Phase 1 – Predictors for Ethanol t-1
                 Estimate    Std. Error   z value   Pr(>|z|)
(Intercept)     1.5507e+02  4.7336e+02   0.3276    0.7432
Sugar          -4.6435e-01  1.0426e-02  -44.5392   <2.2e-16
Milling         6.8785e-02  9.0143e-04   76.3063   <2.2e-16
GE price ratio  1.2775e+04  2.4874e+03   5.1358    2.809e-07
SE price ratio -1.9449e+03  2.2898e+02  -8.4938    <2.2e-16

Rho: 0.091342, LR test value: 46.893, p-value: 7.4981e-12
Wald statistic: 48.434, p-value: 3.4158e-12
Log likelihood: -19851.22 for lag model
AIC: 39716, (AIC for lm: 39761)

Phase 2 – Predictors for Ethanol t
                      Estimate     Std. Error  z value   Pr(>|z|)
(Intercept)          -399.36925    9.62401    -41.4972   <2e-16
Ethanol t-1           404.74784    5.16498     78.3639   <2e-16
Cooperative             0.99038    1.01562     0.9751     0.3295
Ramp-up                 2.12707    1.97684     1.0760     0.2819
National                1.85066    2.03655     0.9087     0.3635
Efficient Logistics     0.48015    1.41322     0.3398     0.7340
Distance Factor        -1.62418    2.55665    -0.6353     0.5252

Rho: 0.16461, LR test value: 108.19, p-value: < 2.22e-16
Wald statistic: 109.55, p-value: < 2.22e-16
Log likelihood: -8555.05 for lag model
AIC: 17128, (AIC for lm: 17234)
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2.6 CONCLUSION AND POLICY IMPLICATIONS

This paper has presented an analysis of the development of ethanol production in Brazil from 2002 to 2013. In view of the fact that ethanol production depends on several factors with very different characteristics, we use several variables in a model to explain the behavior of ethanol production in Brazil. The MCMCglmm model was able to work with all variables simultaneously and produced consistent results, especially after normalization of the variables. The model allows various residual and random-effect variance structures to be specified, which includes unstructured covariance matrices, heterogeneous variances and random regression, to take into account the heterogeneity among the Brazilian sugar/ethanol mills. This result confirms the robustness and reliability of the statistical techniques and the R package. Furthermore, this study is innovative inasmuch as this is the first time the MCMCglmm method has been used to analyze ethanol production in Brazil. Results were additionally cross-checked with those obtained from other modeling approaches in order to take into account spatial dependence, endogeneity, and multicollinearity, thus suggesting that spatial correlation may obfuscate the impact of exogenous contextual variables. The most important factors contributing to the necessary increase in the production of fuel ethanol in Brazil were, in order of importance, crushed sugarcane, sugar production, the sugar/ethanol and gasoline/ethanol price ratios; the contextual variables were cooperative mill, mill ramping up, distance factor, efficient mill logistics, and national plant. The relative higher importance of sugarcane production in comparison to other variables is structurally related to the very nature of the productive process: to some extent, in order to increase ethanol production, it is necessary to increase the input side, that is crushed sugarcane. However, the price ratios play a relevant role in stimulating the production of ethanol. Indeed, the ratios are a function of ethanol pricing policies, not only in concern with the price of gasoline, which is defended by the ethanol producers, but also in relation to the price of sugar. In other words, it is necessary for the government to find a reliable and consistent policy that involves the prices of the three products (gasoline, ethanol, and sugar) so that the ethanol producers can make investments to safely and profitably increase ethanol production.

What also became clear in this study was the importance of logistics infrastructure through investment in more competitive modes, such as pipelines, waterways, and railways. This is an important strategy to reduce the total cost of the ethanol production chain and consequently its competitiveness in the domestic and international markets. This paper differs from previous work on ethanol production in the following respects. First, it correlates production data with price data, logistics data, and other contextual variables in order to investigate the dynamic behavior of ethanol production. Second, our paper considers the presence of other, more efficient transportation modes via one of the contextual variables. Lastly, this work performs a Bayesian analysis using an MCMC method in order to look at all these variables which are heterogenic in nature. As regards the limitations of this research, we should highlight the impact of foreign trade and public policies as production drivers of ethanol in Brazil. Not only could exports to foreign markets have been assessed, but also the design of public policies to promote exports. Further studies may consider factors related to new technologies, such as second-generation ethanol and ways to increase productivity and therefore ethanol production. Also worthy of consideration is power produced through cogeneration: electricity is marketed by the mills and has an important relationship with second-generation ethanol since both use sugarcane bagasse as a feedstock.

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3. 2ST PAPER: EFFICIENCY IN ETHANOL PRODUCTION – A TWO STAGE DEA APPROACH

EFFICIENCY IN ETHANOL PRODUCTION – A TWO STAGE DEA APPROACH

ABSTRACT

This paper analyzes the efficiency and productivity of fuel ethanol in Brazil using a two-stage data envelopment analysis (DEA) model. The first stage is responsible for generating efficiency scores for each plant/year; the second stage uses Beta, Simplex and Tobit regressions to evaluate the productivity and efficiency of the ethanol producing plants. The main conclusions of the study are (i) the membership of a plant in a producer cooperative contributes to higher efficiency; (ii) the proximity of a plant to a pipeline, railroad or waterway terminal tends to increase efficiency and productivity; (iii) the lower the ethanol prices in relation to gasoline, the greater the efficiency of the production units; (iv) the closer the plants are to the main points of consumption, the greater the efficiency and productivity. The study confirmed the robustness of the DEA method using three different types of regression with similar results.

Keywords: Ethanol Mills, Two-Stage DEA, Brazil

3.1 INTRODUCTION

The objective of this paper is to analyze the production efficiency of fuel ethanol plants in Brazil using a two-stage data envelopment analysis (DEA) model, considering different contextual variables related to the productive efficiency of the ethanol plants in Brazil. The first stage of the model consists of calculating the efficiency scores using the DEA model; the second consists of estimating using the Beta, Tobit and Simplex regressions the parameters of the variables that can influence the indexes obtained in the first stage. In both stages, specific R packages were used.

Ethanol fuel derived from sugarcane has been important to the Brazil's economy since the mid-1970s (Pazuch et al., 2017; Fagundes et al., 2017; Antoniosi and Maintinguer, 2016). In addition, Brazilian ethanol is part of an extensive production chain that includes sugar, supplying the country's Otto cycle fleet both as anhydrous ethanol (a gasoline additive), and hydrated ethanol sold at service stations (Sant'Anna et al., 2016; De Freitas and Kaneko, 2011). However, there are still lingering questions concerning the productivity of sugarcane ethanol produced in Brazil—despite its significant evolution (Dos Santos, 2016; Santos, 2015)—resulting in the loss of market for US gasoline and corn ethanol. This issue has been the subject of intense debate among sugarcane producers, fuel distributors, government agencies and business leaders, who have sought to identify the actions required to make Brazilian ethanol more productive and competitive (Chum et al., 2014; Secretariat of Energy and Mining, 2016).

Although some studies using DEA have addressed the efficiency of ethanol-producing plants (Wang and Saito, 2016; Junior et al., 2014; Kumar and Arora, 2012), no other paper has used a two-stage DEA analysis to evaluate the efficiency scores of the plants using contextual variables related to ethanol production.

The motivations for this study are as follows: First, the need to increase the competitiveness of Brazilian ethanol vis-à-vis imported US ethanol. Second, the importance of lowering production costs, in view of the competition between fuel ethanol and gasoline. The paper is structured as follows: After the introduction, we present the contextual setting, a literature review, the methodology used to consider the data of the study, and the two stage DEA model methodology. The analysis and discussion of the results are then presented, followed by the conclusion and bibliography.

3.2 CONTEXTUAL SETTING

The sugarcane agroindustry, and ethanol production especially, are experiencing a period of raised expectations of significant gains in efficiency and productivity. Advances in research and innovation provide inputs and improve the techniques for cultivation, mechanized planting and cutting of sugarcane. In addition, we highlight the development of equipment, new industrial inputs, and revolutionary ethanol production routes. However, problems related to climate, production regions, and economic difficulties affect plant productivity generally. However, fuel ethanol production in Brazil is characterized by the technological gap among producers, which affect technical efficiency and productivity results. There is also a strong initiative by Brazilian producers to reduce industrial costs in order to make the sector more productive and efficient (Ridesa, 2010; CTC, 2012; Nyko et al., 2012; Belardo et al., 2015.

The ethanol production chain has presented continuous gains in agricultural and industrial productivity, garnering a greater share of the foreign market and promoting ethanol as a commodity. According to the authors, these productivity gains are what supports the growth of sugar cane production in Brazil (Souza et al., 2010; Jank et al., 2009; Banco Nacional de Desenvolvimento Econômico e Social, 2008). On the other hand, challenges related to incorporating technology, low dynamism and inconsistencies in the production environment and commercialization have hindered agricultural productivity (Vian, 2003). Due to its complexity, the sugarcane production chain develops in a pattern of alternating periods of consistent progress and difficulties, while always depending on credit for production and capital goods (Carvalho, 2009, Ramos et al., 2002).

Brazil's sugarcane mills exhibit a great range of productivity. Aging sugarcane plantations and indebted plants are increasingly common amid the country's economic crisis. The sugar cane plantations, which supply the raw material for sugar and ethanol, produced an average yield of 77 tons per hectare, compared to an optimal yield of 85 (Toledo, 2017). However, disparities in crop technical indicators can be observed, even in similar production systems or between enterprises under the same production conditions (Santos, 2016).

The area harvested also decreased by 3.1%, from 9.05 million to 8.77 million hectares. This drop occurred due to the abandonment and devolution of suppliers' areas located far from the production units, especially those areas difficult to mechanize. This small reduction in areas is no cause for concern, precisely because they are places where mechanical harvesting is not possible. Compensation for abandoned/devolved areas is achieved by increasing productivity and better use of land. The Brazilian government is already planning a program to support the renovation and implementation of new sugarcane areas (Verdelio, 2017).

3.3 LITERATURE REVIEW

Few authors have used DEA models to study the production and distribution of ethanol. Using an output-oriented two-stage DEA model, Sant'Anna et al. (2017) analyzed the impact of vertical integration on the technical efficiency of ethanol and sugar mills in the Center-South region of

Brazil. The model was used to assess how the percentage of sugarcane planted per mill, in relation to the total, affects technical efficiency. According to the authors, the first stage provides the efficiency scores of each mill, while the second stage estimates a Tobit model using the efficiency scores as the dependent variable. The main conclusion obtained is that mills can increase technical efficiency by procuring sugarcane from independent producers, focusing on increasing daily milling capacity and thus ensuring ethanol and sugar production. In another study, Sesmero et al. (2010) used data envelopment analysis to decompose the overall economic efficiency of a sample of US ethanol plants into technical efficiency, allocative efficiency, and market efficiency. The authors concluded that these production units are highly efficient from a technical point of view, with the largest plants tending to be more efficient than the others. In a different study, Leal et al. (2011) conducted a study using DEA to establish a relative measure of 'ecoefficiency' for different transport modes of fuel ethanol. The proposed approach can help the Brazilian government improve the transportation infrastructure for ethanol. In an earlier study, Singh (2006) used data from 65 sugar mills in India to analyze technical and scale efficiencies. Based on the nonparametric DEA technique, the study found that 38 percent of the mills achieved the status of 'globally efficient' and 60 percent, 'locally efficient.' Subsequently, Singh et al. (2007) sought to analyze the performance of sugar mills in a region in northern India in relation to ownership, size and location. By applying the DEA method, the study concluded that a sample of mills operated at high efficiency levels, and the magnitude of inefficiency was only seven percent.

Some authors have used DEA models to analyze the efficiency of production or distribution of biodiesel and other petroleum-derived fuels. Babazadeh et al. (2015) developed a DEA-based model and mathematical programming techniques for the strategic design of the biodiesel supply chain in Iran using physic nuts and waste cooking oil as feedstock. The proposed approach was implemented for a 10-year planning horizon. The results demonstrated the efficiency and the advantages of the proposed method to support government agencies in strategic and tactical decisions regarding biodiesel supply chain planning. Costa et al. (2013) analyzed biodiesel production through different inputs using DEA. The model used allowed the construction of an efficiency index through linear programming with multiple inputs and outputs. In a different study, Eguchi et al. (2015) evaluated the performance of a biodiesel plant using DEA. The authors considered two outputs in the model (biodiesel and glycerin byproduct) and five inputs (waste cooking oil, methanol, potassium hydroxide, power consumption, and diesel fuel consumed to collect the feedstock). The study demonstrates that there are many inefficiencies in production activities and presents methods to reduce these inefficiencies. In a similar study, Kagawa et al. (2013) presented an evaluation of the productive efficiency of a biodiesel plant in Japan using DEA. The study used the traditional DEA with constant returns to scale to analyze efficiency. Monthly data for waste cooking oil, MeOH, KOH, electric power and truck diesel oil was used as inputs, and produced biodiesel was used as the output. Based on the DEA method, the authors concluded that the cost of production could be reduced significantly. It was also observed that increasing efficiency would contribute to reducing production costs. Saeidi et al. (2016) developed MDEA, a new mathematical algorithm based on data envelopment analysis (DEA) and neural networks (NN). The method was used to analyze biodiesel production based on transesterification of palm oil.

This paper is the first to address the productivity of Brazilian plants through the two-stage DEA method, which is the basis of its innovativeness. In addition, we used three regression techniques to provide robustness and reliability to the work.

3.4 METHODOLOGY

3.4.1 The Data

A balanced panel dataset for 315 active sugarcane mills in Brazil from 2009 to 2015 was built, compiling scattered data from disparate sources, as described below.

The state-by-state annual data for ethanol and sugar production were obtained from the National Agency of Petroleum (ANP) for the period 2009-2015 (www.anp.gov.br/). We also obtained important information on the sugarcane industry from União Canavieira de São Paulo - UNICA (www.unicadata.com.br/) and from Jornal da Cana (www.jornalcana.com.br/). Specifically, with respect to the disaggregated data for each mill on ethanol, milling, and sugarcane production, we asked UNICA to provide data for each associated milling company. Thus, UNICA provided a database containing the location, address, and respective production levels per mill per year. This dataset can be provided to readers upon request. This database was further used as a cornerstone for compilation with additional information sources on prices and other contextual variables, as described next.

Price data for sugar and ethanol were obtained from Centro de Estudos Avançados em Economia Aplicada - ESALQ/USP (www.cepea.esalq.usp.br/) for the entire period of the series. Regarding gasoline prices, yearly averages were computed based on ANP data for the state of São Paulo. In addition, we conducted a geographical and commercial research of sugar and ethanol mills in order to discern the various economic groups and obtain information about each mill. Data were collected from different sources, including interviews with UNICA´s experts. For logistics information, we used road distances from each mill to the main consumption points based on Google Maps (www.google.com.br/maps). From the table of distances between each mill and each distribution terminal, we calculated a distance factor to serve as a logistics score for each mill. This was based on the weighted average, by demand, of the distances from each mill to each point of consumption. In short, the distance factor reflects, in relative terms, the degree to which a given mill is close to a point of consumption.

Two additional important variables for the assessment of productivity considered in the study are the planted area (hectares) per mill, and ATR (total recoverable sugar). The ATR represents the quality of sugarcane in terms of its capacity to be converted into sugar or ethanol through the transformation coefficients of each productive unit.

In turn, the contextual variables of each mill were defined based on data available from Agência Nacional do Petróleo (ANP) and União da Indústria Canavieira (UNICA). The main reason we used contextual dummy variables related to the mills is to form a relatively complete list of variables, thus increasing the amplitude of the study. One of the variables refers to mill membership in a cooperative, which is important because such mills have characteristics that streamline performance in business; including this dummy variable can provide a dimension of this phenomenon. Another dummy variable is whether the plant is domestic or foreign. Including this variable also provides a view of such fact. During our contacts with UNICA for data collection, we adopted the following criterion to classify whether a plant is domestic or foreign: the majority of shares (at least 50% plus one share) are held, respectively, by either domestic or multinational companies. The third dummy variable pertains to whether the plant production is ramping up or has already reached maximum capacity, given current production technology and considering all remaining factors constant. Again, contacts with UNICA and their sector experts proved helpful in defining the ramp-up period: a cut-off point of at least seven years of operation was established to classify a mill as mature (i.e., not ramping-up).

The last dummy variable is whether the mill has a logistical advantage in terms of an efficient mode of transport. As regards this paper, railways, pipelines, and waterways were considered efficient transportation modes; road was excluded from this category. These efficient transportation modes, due to economies of scale, yield much lower cubic-meter transportation costs compared to traditional road transportation, which is also subject to tolls. For cases where mills are located up to 60 km from a pipeline terminal, waterway, or railway, the variable is true. The importance of this variable derives from the fact that the new ethanol production mills, as well as planned projects, are more economically feasible when located near efficient modes of transportation. Similar to the variables relating to prices, the aim is to explain the relationship between the prices of ethanol, gasoline, and sugar, as well as the production of these products. Finally, including a distance factor as a variable will enable an analysis of the effect of geographic location on production.

In order to better comprehend the impact of this network of efficient transport modes on ethanol production competitiveness, it is worth mentioning that the combined lengths of railways, waterways, and pipelines totals about 1,300 km across 45 municipalities. These efficient transport modes are capable of linking the main ethanol-producing regions in the states of São Paulo, Minas Gerais, Goiás, and Mato Grosso do Sul to the main ethanol consumer market in Brazil (the Greater São Paulo region) and to ports in the Southeast.

In short, the variable is ethanol production; the other variables considered are (i) Ethanol Production, (ii) Sugar Production, (iii) Sugarcane Milling, ATR (iv) and the Planted Area (v) . The contextual dummy variables are (i) Cooperative Mill, i.e., whether the mill belongs to a co-op (1) or not (0); (ii) mill ramping up, i.e., whether mill production is increasing (1) or not (0); (iii) National Mill, i.e., whether the mill is national (1) or not (0); and (iv) Efficient Mill Logistics, i.e., whether the plant is close to any logistically efficient terminal (1) or not (0). Moreover, as we saw earlier, we have the variables related to prices: (i) Gasoline/Ethanol Price Ratio, (ii) Sugar/Ethanol Price Ratio, and (iii) Distance Factor (as described above).

To generate the efficiency scores, we will use a DEA model where the variables Milling, ATR and Area will be considered as Inputs and the variables Ethanol Production and Sugar Production are Outputs.

3.4.2 DEA

DEA is a non-parametric method first introduced by Charnes et al. (1978). It is based on linear programming and is used to address the problem of calculating relative efficiency for a group of Decision Making Units (DMUs) by using multiple measures of inputs and outputs. Given a set of DMU inputs and outputs, DEA determines for each DMU a measure of efficiency obtained as a ratio of weighted outputs to weighted inputs. There are several variations of the technique (Cooper et al., 2007). They differ not only about the type of returns to scale and how the distance to the frontier is calculated for inefficient DMUs – but also with respect to efficiency change over time, undesirable outputs, resource congestion, disposability of outputs and inputs – to mention just some of the possible variations.

Besides, DEA imposes neither a specific functional relationship between production outputs and inputs, nor any assumptions on the specific statistical distribution of the error terms (Cullinane et al., 2006). An efficient frontier is on the boundary of a convex polytope created in the space of inputs and outputs, and in which each vertex is an efficient DMU (Dulá and Helgason, 1996). Another feature of DEA is that the relative weights (λ) of the inputs and the outputs do not need to be known a priori; that is, these weights are determined as part of the solution of the linear problem (Zhu, 2003).

Assume $s = 1..S$ production units, with inputs $x_s^T = (x_{s1},..,x_{sm})$ and outputs $y_s^T = (y_{s1},..,y_{sn})$. Column vectors x_s and y_s form the s^{th} columns of matrices *X* and *Y*. Assume further that $\lambda^T = (\lambda_1,..,\lambda_s)$ is a non-negative vector and $e^T = (1,..,1) \in R^S$ is a vector of unit values. The DEA-CCR (Charnes et al., 1978) and the DEA-BCC (Banker et al., 1984) are shown in eq. (1) to (3):

DEA-CCR		DEA-BCC		DEA-BCC	
Input Oriented		Input Oriented		Output Oriented	
Constant Returns-to-scale		Variable Returns-to-scale		Variable Returns-to-scale	
$\min_{\theta,\lambda} \theta$ s.t. $\theta x_s - X\lambda \geq 0$ $Y\lambda \geq y_s$ $\lambda \geq 0$	(1)	$\min_{\theta,\lambda} \theta$ s.t. $\theta x_s - X\lambda \geq 0$ $Y\lambda \geq y_s$ $e\lambda = 1$	(2)	$\max_{\eta,\lambda} \eta$ s.t. $\eta y_s - Y\lambda \leq 0$ $X\lambda \leq x_s$ $e\lambda = 1$	………(3)

Table 5: DEA Models

In this research, the input/output set was considered observing a variable returns-to-scale assumption. An output orientation was also observed, suggesting that outputs were maximized so that current input levels can be attained.

The methodology used is based on the attainment of efficiency scores through an output-oriented DEA-BCC model using the rDEA package of the R application. From these results we will perform three regressions (Beta Regression, Tobit Regression, Simplex Regression) using the contextual variables Year, Region, Cooperative Mill, mill ramping up, National Mill, Efficient Mill Logistics, Sugar/Ethanol Price Ratio and Distance Factor. This same methodology has been used successfully by several authors (Wanke et al., 2016; Wanke et al., 2017; Barros et al., 2017).

Table 6: Descriptive Statistics for input, output and contextual variables

Variables	**Min**	**Max**	**Mean**	**SD**	**CV**
Inputs					
Moagem	10,000	8,004,221	1,748,737	1,219,083	0.697
ATR	11	219	128	10	0.082
Area - Ha	136	100,867	22,582	15,081	0.668
Outputs					
Etanol	101	424,235	76,696	64,217	0.837
Acucar	530	879,335	154,642	110,590	0.715
Contextual Variables					
Ano	1	7	4.047	1.987	0.491
Regiao	1	2	1.069	0.253	0.237
Coop_Ind	0	1	0.439	0.496	1.130
Rampup	0	1	0.276	0.447	1.619
Nac_Est	0	1	0.945	0.227	0.241
Trsp_Efic	0	1	0.945	0.227	0.241
Razao_eg	0.53	0.87	0.679	0.058	0.086
Fator_Dist	0.682	5.5	1.253	0.969	0.773

3.5 ANALYSIS AND DISCUSSION OF RESULTS

The Table 2 presents the descriptive statistics of all the plants from 2009 to 2015. Only those mills with significant production were considered, i.e., a total of 315 mills for the seven-year period 2009 to 2015. The results of the Beta, Simplex and Tobit regressions are shown in Tables 3, 4 and 5 respectively.

Comparing the Beta, Simplex and Tobit regressions, we observe the same signs for the Estimates of the contextual variables. The differences between the Beta and Simplex regressions are very small for all contextual variables, which validates the first two regressions.

Note that the variable that contributes most to productivity is the Ethanol/Gasoline price ratio (Ratio_eg). For this variable, the coefficients were -1.346 for the Beta regression, -1.15 for the Simplex regression, and -.032 for the Tobit regression, which can be explained by virtue of the fact that all variables in the Tobit regression have smaller coefficients. We can conclude that due to its negative sign, the lower the ethanol/gasoline price ratio, the higher the efficiency of the plant.

Another contextual variable that deserves attention is Coop_ind, which shows that cooperative plants have greater efficiency and productivity. The variable Trsp_Efic also presents important results in all the regressions, confirming that plants close to pipeline/railroad/waterway terminals are more efficient. This observation makes sense, since the plants with better logistics have an advantage in terms of total cost. These mills are more profitable than a mill that needs to compensate for its poor location by lowering selling prices.

Table 7: Beta regression results

Standardized weighted residuals

Min	1Q	Median	3Q	Max
-3.8541	-0.7123	-0.0131	0.6651	2.9627

Coefficients (mean model with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	0.79864	0.17364	4.599	4.24e-06	***
Ano	0.05893	0.00703	8.382	< 2e-16	***
Regiao	0.67619	0.06105	11.075	< 2e-16	***
Coop_Ind	0.30416	0.02800	10.862	< 2e-16	***

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Rampup      -0.29199    0.02858 -10.216  < 2e-16 ***
Nac_Est     -0.22401    0.06100  -3.672 0.000241 ***
Trsp_Efic    0.21930    0.03868   5.670 1.43e-08 ***
Razao_eg    -1.34620    0.24750  -5.439 5.35e-08 ***
Fator_Dist  -0.05251    0.01460  -3.596 0.000323 ***

Phi coefficients (precision model with identity link):
      Estimate Std. Error z value Pr(>|z|)
(phi)  11.7684     0.3476   33.85   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Type of estimator: ML (maximum likelihood)
Log-likelihood:  1351 on 10 Df
Pseudo R-squared: 0.205
Number of iterations: 17 (BFGS) + 2 (Fisher scoring)
```

Table 8: Simplex Regression Results

```
Standard Pearson residuals:
    Min       1Q         Median      3Q     Max
-3.4663     -0.7197     0.0830    0.7555  2.0668
Coefficients (mean model with logit link):
            Estimate Std. Error   z value Pr(>|z|)

(Intercept)  0.72306    0.17325   4.174 3.00e-05 ***
Ano          0.05600    0.00701   7.990 1.35e-15 ***
Regiao       0.69639    0.05780  12.048  < 2e-16 ***
Coop_Ind     0.32586    0.02823  11.542  < 2e-16 ***
Rampup      -0.29934    0.02952 -10.141  < 2e-16 ***
Nac_Est     -0.27416    0.05574  -4.918 8.72e-07 ***
Trsp_Efic    0.20835    0.03698   5.634 1.76e-08 ***
Razao_eg    -1.15690    0.25301  -4.573 4.82e-06 ***
Fator_Dist  -0.05909    0.01513  -3.906 9.38e-05 ***
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Log-likelihood: -300.3, p-value: 0.4959232

Deviance: 2128

Number of Fisher Scoring iterations: 6

Table 9: Tobit Regression Results

Pearson residuals:

Min	1Q	Median	3Q	Max
-3.6065	-0.7211	0.0523	0.7377	2.322

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	0.698133	0.039947	17.476	< 2e-16	***
Ano	0.013710	0.001617	8.480	< 2e-16	***
Regiao	0.160118	0.013654	11.727	< 2e-16	***
Coop_Ind	0.076024	0.006467	11.755	< 2e-16	***
Rampup	-0.068006	0.006693	-10.161	< 2e-16	***
Nac_Est	-0.054438	0.013476	-4.040	5.35e-05	***
Trsp_Efic	0.050206	0.008701	5.770	7.92e-09	***
Razao_eg	-0.328728	0.057681	-5.699	1.20e-08	***
Fator_Dist	-0.012785	0.003427	-3.730	0.000191	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Number of linear predictors: 2

Log-likelihood: 1248.249 on 4264 degrees of freedom

Number of iterations: 6

3.6 CONCLUSIONS AND POLICY IMPLICATIONS

This paper presented an analysis of the efficiency of ethanol plants in Brazil using a two-stage DEA model. In the first stage, the DEA scores were generated; in the second stage, the Beta, Tobit and Simplex regressions were performed, thus contributing to increase the robustness and reliability of the work. The main conclusions of this study are as follows: (i) The participation of the plants in producer cooperatives contributes to higher efficiency and productivity; (ii) the proximity of a plant to a pipeline, railroad or waterway terminal tends to increase efficiency and productivity; (iii) the lower the ethanol prices in relation to gasoline, the greater the efficiency of the production units; (iv) the closer the plants are to the main points of consumption, the greater the efficiency and productivity.

The initiatives by ethanol producers in Brazil to increase productivity become imperative for the survival of the production units. This can be seen in the behavior of gasoline prices, which are set by Petrobras (Gilio et al., 2017). Another important point is that producers are investing heavily in second generation ethanol and corn ethanol as a way to increase production without increasing the planted area (Brassolatti, 2017).

The main limitations of this study are as follows: (i) The data used are from the period when government-controlled Petrobras used gasoline prices to control inflation. Currently, Petrobras has practiced prices based on the international market, which is the future trend. (ii) The study does not evaluate data on the high Brazilian tax on fuels—a recommendation for future work. (iii) The study does not include import and export data on Brazilian ethanol.

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4 3 ST PAPER: EVALUATION OF ETHANOL MULTIMODAL TRANSPORT LOGISTICS: A CASE IN BRAZIL

EVALUATION OF ETHANOL MULTIMODAL TRANSPORT LOGISTICS: A CASE IN BRAZIL

ABSTRACT

This paper evaluates a large ethanol multimodal logistics system in Brazil. This system conducts ethanol logistics activities using pipelines and waterways to supply Brazil's internal and export markets. A transshipment model is used for the treatment of logistic flows. A linear programming model was developed to determine the transshipment and replenishment flows from more than 400 ethanol plants to more than 70 terminals and distribution centers. We found that optimal results occur when pipeline and waterway systems reach full capacity by taking volume from road transportation on long distances, suggesting that these options have the potential to make the ethanol logistics in Brazil more efficient and competitive in the future.

Keywords: Ethanol, Transshipment, Pipeline, Waterways, Linear Programming

4.1 INTRODUCTION

This study evaluates the best logistics strategic options for transporting ethanol (for fuel) when considering the use of a multimodal pipeline and waterway system in the Central-South Region of Brazil between 2015 and 2030 in addition to the usual and current option of road transportation. The multimodal pipeline and waterway logistics system under consideration must transport ethanol produced in the states of São Paulo, Minas Gerais, Mato Grosso do Sul, and Goiás to the markets of the city of Campinas, cities in the greater São Paulo region, the city of Rio de Janeiro, and for the export market. The ethanol produced in Brazil supplies the entire country and some export markets. Brazil's ethanol supply network is vast, and the model developed here considers its totality when evaluating the particular multimodal pipeline and waterway logistics. The objective of this research is to evaluate and eventually demonstrate the advantages of Brazil's large-scale ethanol multimodal logistics system. A transshipment model was developed to calculate the replenishment and transshipment flows from the mills to the distribution centers and terminals.

The large-scale production and distribution of ethanol fuel in Brazil began in the mid-1970s, as a national response to the 1973 oil crisis. In the following years, some investment was directed to the expansion of railway and pipeline systems (Hira & De Oliveira 2009; Matsuoka, Ferro & Arruda, 2011). Since 2000s, the development of flex engine technologies (car engines that are able to run on ethanol and/or gasoline) and environmental reasons (laws and regulations that require lower emissions levels) have increased the demand for ethanol fuel in Brazil (Leal & D'Agosto 2011; Rodrigues, 2007).

To keep up with the growing demand and to respond to the need for reduced costs – and therefore to remain competitive with gasoline, the ethanol industry needed not only more logistics capacity but also a more efficient logistics system that explored the potential of pipelines, railways, and waterways in addition to roads, traditionally the main mode of transportation in Brazil. Petrobras, the large Brazilian oil manufacturer and a major distributor of oil products and ethanol, partnered with leading ethanol producers to develop a multimodal system of pipelines and waterways that would integrate an ethanol pipeline system and the Tiete-Paraná waterway in Paulinia (near Campinas in the state of São Paulo) to supply Brazil's domestic and export markets. This initiative is expected to make Brazilian ethanol more competitive (Junqueira, 2011; Milanez, Nyko, Garcia, & Xavier 2010; Pompermayer, Campos Neto, & Paula 2014; Shikida & Perosa 2012). From a different perspective, Kendon (2014) studied the environmental and economic effects of ethanol pipelines in Brazil. As ethanol production is expected to increase, optimizing the country's ethanol freight system, both for export and domestic distribution, provides opportunities for greenhouse gas mitigation, cost savings, reduced congestion along transportation corridors, and short-term job creation. The results indicate that the project would yield substantial value for the involved companies, for the global climate and for customers at the pump.

Because ethanol distribution in Brazil uses several modes of transportation, a global logistics analysis must consider the most efficient modes of transportation in this logistics network. For this evaluation, we used transshipment. Transshipment occurs when one or more hubs of the transportation network can act as both origin and destination for flows (Dubke, 2006). We describe our methodology for building a transshipment model to analyze logistics flows. We then apply the results of the application to Brazil's ethanol logistics network and draw conclusions.

Our transshipment model uses linear programming and includes pipeline, rail, waterway, road, and sea (cabotage) and major ethanol flows in Brazil. The model can predict replenishment flows for the plants and includes all the distribution points in the country plus the movement of ethanol into Brazilian ports.

The literature in transshipment problems is rich (Ghosh & Mondal 2017; McWilliams, 2014; Özdemir, Yücesan, & Herer 2013; Zhen, Wang & Wang 2016), but our review found no study that comprehensively addressed the Brazilian ethanol logistics network. Our model includes projections of costs and tariffs, as well as forecasts of supply and demand for a 15-year future horizon. Our model is innovative because it considers a transshipment problem with two links and multiple periods with transshipment operations of different modes of transport. The problem we modeled has four products, five modes of transport, more than 400 suppliers, and 70 terminals, providing a much more detailed view of Brazil's ethanol logistics network than what we found in previous studies. In order to run this model we used What'sBest!® 11.1.0.8 - Library 7.0.1.518 - 32-bit.

This article is structured as follows. Section 2 provides some context by describing the transportation and distribution of ethanol in Brazil. In section 3, we present a literature review that covers conceptual aspects and the mathematical formulation of transshipment models and studies of the distribution of ethanol and other fuels. In section 4, we describe our research methodology and mathematical formulation. Then in section 5, we analyze and discuss our results, limitations of the study, draw conclusions and, offer some recommendations and suggestions for further research.

4.2 CONTEXT

The distribution of ethanol in Brazil is carried out in compliance with the rules established by the (Brazilian) National Petroleum Agency (ANP) where the biofuel is sold either as anhydrous ethanol and hydrous ethanol. Anhydrous ethanol is used as an additive for the formation of type C gasoline with 27% anhydrous ethanol and 73% gasoline. Hydrous ethanol is sold as a competitor fuel to type C gasoline. Thus, hydrous ethanol, type C gasoline, and diesel are distributed through the same logistics channel and sold in gas stations (AEPET, 2015, Tadeu, 2010). Figure 1 shows the characteristics of the three main flows of the fuel distribution system. The primary flows of diesel and gasoline are carried out by pipelines and coastal shipping (cabotage). The import of these fuels is considered as a primary flow. Ethanol, however, leaves the plants/collection centers and goes to the primary and secondary bases by railway and road. Transfers take place to balance the inventory of the consumer markets, and their main modes are rail, pipeline, and ground because they usually cover long distances. All delivery of the final product is done by ground transportation (trucks), is usually short distance, and is done both from the primary and secondary bases (Figueiredo, 2006).

Neves (2011) argued that a combination of factors in the mid-1970s led Brazil to adopt a large-scale ethanol program. The measures adopted by the Brazilian government included subsidies and shutting down the import of ethanol. The sugarcane agricultural system is complex because the production units depend on the supply of sugarcane and capital goods. The main products: ethanol, sugar, and electricity are sold either to the food industry, to wholesalers, to retailers, exporters, and distributors of electricity.

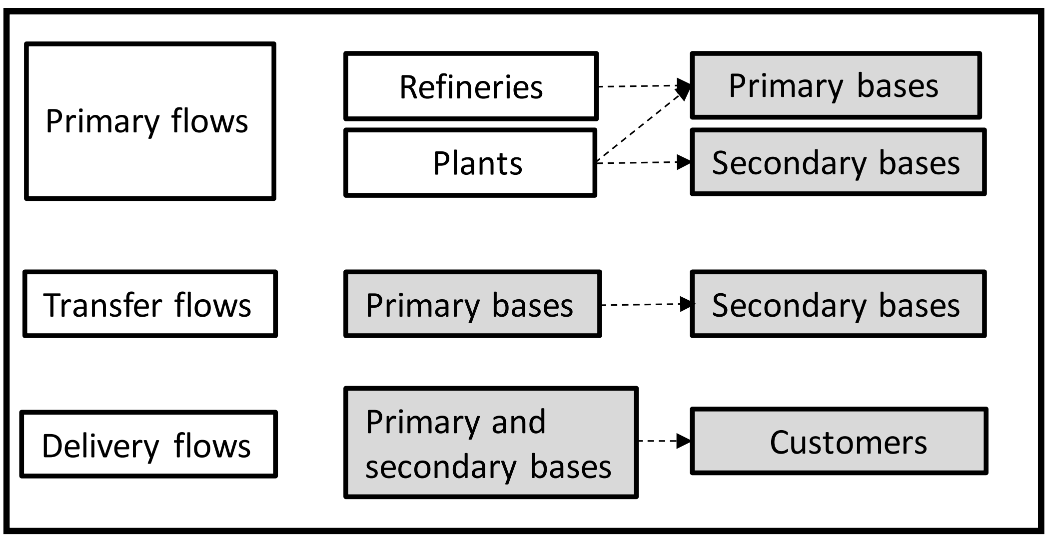

Figure 5: The three types of flows in fuel distribution in Brazil. Source: Figueiredo (2006)

According to Silva (2014), the Type A gasoline that is produced in the refineries cannot be used for consumption in Brazil, by law. Gasoline for consumption at the gas station is Type C gasoline that consists of 73% Type A gasoline and 27% anhydrous ethanol. The percentage of anhydrous ethanol in the mixture is determined by the National Agency of Petroleum, Natural Gas, and Biofuels and has ranged from 18% to 27% in previous various resolutions. Fuel in Brazil has a complex tax policy and the ICMS tax (tax on the "circulation" of goods and services) is the most significant. In most Brazilian states, the ICMS tax is calculated based on an average weighted price for the final consumer (AWPFC) that is updated every two weeks by state governments. Tax policies related to the ICMS tax differ by state, which in some cases can make the ethanol supply logistics even more complicated.

The ethanol produced from sugarcane in Brazil has gained worldwide recognition because of its high productivity and as a renewable alternative source of energy. The current scenario in the domestic market is also favorable. Currently, 54.3% of the 2014 fleet circulating in Brazil was flex (running on either ethanol or gasoline or any combination of both). According to Jonker, Junginger, Verstegen, Lin, and Rodríguez et al. (2016), Brazil is using sugarcane as a raw material to produce ethanol and it is the world leader whereas United States (US) ethanol production for fuel is made from corn. Road transport is of vital importance in the Brazilian transportation matrix. The ethanol market is no exception. Road transportation is maybe the only possible choice for fuel distribution to gas stations. For long distances, however, road transport is more expensive than the other options. In addition to the high cost, road transport in general carries high risk to public safety and to the environment because fuel is flammable and polluting (Nuñez & Otero, 2017; Pinheiro & Caixeta-Filho, 2016).

The predominance of the road as a transportation mode in ethanol in Brazil is attributable to its advantage on short routes/ low volumes, but also because of the limited availability of more efficient high-volume modes such as pipelines, railways, and cabotage. The ethanol plants are usually located in remote rural areas far from important transport routes. As a result, practically all of the ethanol production leaves the plant by road and is headed directly to distributors and ports. Efficient modes of transport such as railways, pipelines, and sea require storage terminals, where distribution points receive ethanol by road before loading it onto efficient longer haul transport modes. Around 80% of the ethanol from distributors go directly to gas stations, while the remainder passes through transfer flows. The predominance of road flows in the connection between plants, distributors, and gas stations highlights the possibility of direct delivery from the plants to gas stations. In the case of more distant regions (consumer markets), the concentration of cargo at distribution bases makes the use of these efficient modes of transportation to transfer ethanol to the distributors closest to consumer markets possible (Milanez, Nyko, Garcia, & Xavier 2010). According to ILOS (2015) in a study commissioned by the Brazilian Institute of Oil, Gas, and Biofuels (IBP), Brazil will require investments of more than US$2 billion to expand its fuel pipeline infrastructure, and as Petrobras has been forced to make cuts to its investment plan due to an unveiled massive corruption scandal in 2016, the Brazilian government will need to attract new investors to safeguard the market from problems in the transportation of oil derivatives such as gasoline and diesel in the next ten years. According to previous studies, the growth of fuel consumption in Brazil will require the construction of new transport routes in the South, Southeast, and Northeast regions, as well as duplicating the existing pipelines that will soon be at capacity.

Brazil's transport sector is the country's second-largest consumer of energy and a major emitter of greenhouse gases because the national transportation network is very dependent on road transportation, which emits about 70% more CO_2 than other less polluting modes per ton.mile. Many of these modes however, especially those that have ports as a destination, could be covered using the combination road-railway, road-waterway, or even road-waterway-railway. Thus, the combination of more than one efficient transportation mode could bring significant benefits in terms of reducing both emissions and fuel consumption. Ethanol in Brazil has a large potential for demand increase that will need a more efficient transportation network. Not expanding the distribution paths could generate not only problems and bottlenecks for the economy, but it could also cause negative environmental impacts (Miotto, 2012).

Pipeline transport has unique features. The fixed cost of building a grid of pipelines is high because of the expensive track rights, construction, authorization to control stations and pumping equipment; such investment limits the number of potential investors to a few private companies. Said transportation network also requires high capital investment with pumping systems and intake terminals. Furthermore, labor and equipment for building this type of infrastructure tends to be expensive. Despite the construction cost being relatively high, pipeline transportation has several benefits when it comes to reducing (unit) freight costs. The technology used for pipeline transport (gravity or pumping) uses relatively little energy and results in a low unit cost of transportation. Loading and unloading is simple and the need for storage is reduced. Furthermore, the number of workers required for operating a pipeline is usually lower than that for alternative modes, as is the frequency and cost of maintenance, this reduces general operational costs (CNT, 2012).

Beginning in 2010, a multimodal system of ethanol logistics was developed, extending about 1,300 km across 45 municipalities. The system linked the main ethanol-producing regions in the states of São Paulo, Minas Gerais, Goiás, and Mato Grosso do Sul to the main ethanol consumer market in Brazil (the Greater São Paulo region) and to ports in the Southeast. The system is necessary because more ethanol production is distant from major consumer markets and ports. The expectation is that the state of São Paulo, currently producing 69% of the country's ethanol, will go down to 48% of the total produced in 2021. At the same time, Goiás will go up from 10% to 18% and Mato Grosso do Sul from 6% to 15%. The states of Mato Grosso and Goiás are substantially farther from the consumer markets than is the state of São Paulo. The multimodal system foresees investments of US$ 2 billion and when completed it is expected to reach a carrying capacity of 22 billion liters per year, of which 13 billion will be transported via pipelines and nine billion by waterways. It will include collection centers and storage terminals with a capacity of 838 million liters. From Paulinia, the location of one of the Petrobras refineries, a pipeline will branch off towards the city of São Paulo and from there to the important port city of Santos. Another pipeline will run towards Rio de Janeiro. A third pipeline will go to the municipality of Anhembi along the banks of the Tietê River in the state of São Paulo. At this point, there will be a connection with the waterway network of western São Paulo and Mato Grosso do Sul, the Tietê-Paraná rivers basin. The transportation convoys will be built and operated by Transpetro, a Petrobras subsidiary (Bovolenta, 2013). According to Barros (2012), the collection of ethanol from the production units is mostly done by road to collection centers or distributors' terminals. The collection centers are used for rail loading and in some cases to transport using pipelines and waterways going to the country's major consumer centers.

Instead of being transported in tanker trucks, as is the case today, the ethanol will be stored in terminals and transported through pipelines that connect Jatai (Goiás) with Paulinia (São Paulo) or by the Tietê-Paraná waterways to Paulinia (SP) where the main storage will be located. From this point the ethanol will be distributed to terminals and ports in Rio de Janeiro and São Paulo. The integrated system will be extended from Paulinia by an extensive network of existing pipelines to the terminals in Barueri and Guarulhos in the Greater São Paulo region and Duque de Caxias in Rio de Janeiro. From these points, the ethanol will be taken directly to the gas stations by truck.

4.3 LITERATURE REVIEW

4.3.1 Transshipment

Several authors have studied transshipment problems. For Winston and Goldberg (2004), one transportation problem is that few shipments go directly from a supply point to a demand point. In many cases, unloading, maybe storage and then re-loading may be necessary between the point of supply and the point of demand. In such situations, *points of transshipment* are created through which products can be transferred between similar or different modes of transportation along the route between points of origin and points of destination.

A transshipment problem involves matching flows of products between supply points and demand points. Fortunately, transshipment problems can be approached by solving several transportation problems, a classic operations research problem (Winston & Goldberg, 2004). Moore (1978) defined the transshipment problem as a modified version of the classic transportation problem in which products can be shipped not only from origin to destination, but also through transshipment points that are both destinations and origins. As with the transportation problem, minimizing costs is typically the objective of the transshipment problem. Yang (2007) indicates that a transshipment center plays an important role in connecting suppliers to retailers; however, some of the needed transshipment operations can increase logistics costs and make loading more complicated. Zinn, Levy, and Bowersox (1989) showed that transshipment operations between facilities made it possible for companies to reduce their buffer stocks without having to close any facilities.

Winston and Goldberg (2004) describe a transportation problem as follows:

1. A set of m supply points from which a product is shipped. Supply point i can supply a maximum of s_i units.
2. A set of n demand points to which the product is shipped. Demand point j should receive at least d_j units of the product shipped.
3. For each unit produced at supply point i and shipped to demand point j, this incurs in a variable cost c_{ij}.

If, x_{ij} = number of units shipped from the supply point i to demand point j, then the overall formulation of a transportation problem is as follows:

$$\text{Min} \quad \sum_{i=1}^{i=m} \sum_{j=1}^{j=m} c_{ij} x_{ij} \qquad (1)$$

Subject to: $\sum_{j=1}^{j=n} x_{ij} \le s_i \; (i = 1, 2, \dots, m)$ (Supply Restrictions) (2)

$\sum_{i=1}^{i=m} x_{ij} \ge d_j \; (j = 1, 2, \dots, n)$ (Demand Restrictions) (3)

$x_{ij} \ge 0 \; (i = 1, 2, \dots, m; j = 1, 2, \dots, n)$ (4)

Guinet (2001) formulated a general problem of transshipment for the planning of a multi-site production where the fixed and variable costs are minimized, subject to general capacity constraints. This problem was modeled as a flow problem subject to fixed and variable costs, as shown below:

$$\text{Minimize } (Z) = \sum_{i=1}^{N} \sum_{j=1}^{T} \sum_{p=1}^{T} \sum_{w=1}^{M} x(i,j,p,w) \times C(i,j,p,w) + \sum_{i=1}^{N} \sum_{p=1}^{T} \sum_{w=1}^{M} z(i,p,w) \times S(i,w) \qquad (5)$$

Subject to:

$\sum_{p=1}^{T} \sum_{w=1}^{M} x(i,j,p,w) \ge Dem(i,j)$ ∀i=1,...,N , ∀j,p=1,...,T , ∀w=1,...,M (6)

$\sum_{i=1}^{N} \sum_{j=1}^{T} x(i,j,p,w) \le Res(p,w)$ ∀i=1,...,N , ∀j,p=1,...,T , ∀w=1,...,M (7)

$\sum_{i=1}^{N} \sum_{q=1}^{p} \sum_{j=p+1}^{T} x(i,j,q,w) \le Buf(p,w)$ ∀p=1,…, N, ∀w=1,…,M (8)

$\sum_{p=1}^{T} \sum_{w=1}^{M} y(i,j,p,w) \ge 1$ ∀i=1,...,N, ∀j=1,...T (9)

$\sum_{i=1}^{N} \sum_{j=1}^{T} y(i,j,p,w) \le N \times T$ ∀p=1,…,N, ∀w=1,…,M (10)

$x(i,j,p,w) \le y(i,j,p,w) \times Dem(i,j)$ ∀i=1,...,N, ∀j,p=1,...,T, ∀w=1,...,M (11)

$y(i,j,p,w) \times Set(i,w) \le z(i,p,w)$ ∀i=1,...,N, ∀j,p=1,...,T, ∀w=1,...,M (12)

$y(i,j,p,w) \in \{0,1\}, x(i,j,p,w) \; e \; z(i,p,w) \ge 0$ (13)

$C(i,j,p,w) = p(i,w) + H(i,w) \times (j-p) \quad C(i,j,p,w) = p(i,w) + D(i) \times (p-j)$ (14)

Where N is the number of products, T is the number of periods, M is the number of locations, Dem(i,j) is the demand of product i for the period j in units of time, Res(p,w) is the total of resources available at location w for a period p of units of time, Buf(p,w) is the space available at location w for a period p of units of time, Set(i,w) is the set-up time of product i at location w, H(i,w) is the stock holding cost of product i per unit at location w, D(i) is the delay cost of product i per unit, P(i,w) is the processing cost of product i per unit at location w, S(i,w) is the setup cost per unit of time (fixed cost) incurred at location w to meet the demand of product i, C(i,j,p,w) is the variable cost per unit of demand of product i during period j covered at location w during period p, x(i,j,p,w) is the total demand for product i during period j covered at location w during the period p, y(i,j,w,p) = 1 if location w during period p is used to meet the demand of product i for the period j and 0 otherwise, z(i,p,w) is the set-up time required to process product i at location w i during the period p.

Many researchers have used mathematical programming to model transshipment problems. In a previous study, Jasinska and Wojtych (1984) used an integer linear programming model on a transshipment problem for the location of warehouses in a sugar beet distribution system of a company in Poland. The sugar beets were delivered either directly from the farms to the mills or through warehouses. Given a possible set of locations for the warehouses, the associated costs, and unit costs of transportation, the authors sought a location plan and minimum cost of transportation, including the location and size of the warehouses to be opened and the sugar beet flows. Kirca and Erkip (1988), in a study of location of large-scale waste transfer stations, also used a transshipment model to solve a problem of location of fixed facilities for the transfer of solid waste in a large metropolis. The purpose of the proposed model, in addition to defining the location of the facilities, was to determine the number of facilities, their capacity and main characteristics, and the type and number of transfer vehicles. Kirca and Erkip (ibid.) used a linear programming model. Salam, Bandaly, and Defersha (2011) formulated the design of a supply chain network using a mixed integer linear programming model. The purpose of the study was to determine the numbers and locations of the consolidation and distribution centers.

It is also important to highlight studies on transshipment that used a mathematical modeling similar to what we are considering here, but for different purposes. For example, Zhao (2003) applied linear programming models to optimize the operations at transshipment centers. With a very different focus, Bilgen and Ozkarahan (2007) studied a transshipment problem related to blending and maritime shipping regarding wheat supplies. Kirca and Erkip (1988) analyzed cases using network models to analyze localization issues and allocation of transshipment centers. Hong-Minh, Disney, and Naim (2000) used an emergency transshipment channel by applying simulation. Hoppe and Tardus (2000) developed the first polynomial-time algorithm for a transshipment problem. The algorithm provided a very good integral flow. Moghaddam, Rabbani, and Maleki-Shoja (2012) investigated the integration of lateral transshipment to aggregate production distribution planning problems. They proposed a goal programming approach for modelling the problem. The managerial goals of the proposed model were to maximize the total profit and minimize the aggregate manufacturing lead time.

In a more recent paper, Maknoon, Soumis, and Baptiste (2017) presented a precise method of scheduling the internal transshipment process at cross-docks in less-than-truckload industries. The authors (ibid.) provide a mixed integer linear programming formulation to schedule transshipment of products at cross-docks. Noham and Tzur (2014) discussed a transshipment problem taking into account the fixed cost of transshipment. Dan He, Zheng, and Liu (2016) proposed a two-period model with two retailers and a single supplier, in which retailers can implement preventive transshipment at the beginning of the second period to rebalance their inventories. Lee and Park (2016) analyzed the inventory and transshipment policy for a supply chain with two retailers and a single supplier who has a random supply capacity. Babazadeh, Razmi and Ghodsi (2013) applied the selection of capacity levels to locations of three different stages (plants, warehouses, cross-docks) of their supply chain network. The authors (ibid.) presented a multi-stage and multi-product mixed-integer linear programming (MILP) model to the responsive and flexible supply chain network design (SCND). The proposed model could consider outsourcing, transportation modes, flexibility, cross-docking and value over time, as a criterion to reduce delivery time, to improve responsiveness of the supply chain.

4.3.2 Transshipment models applied to the distribution of ethanol and fuels in general

Most of the studies mentioned here used linear programming models as a solution for transshipment problems with a similar mathematical formulation. Some authors have studied transshipment in the ethanol industry and in the logistics of other fuels. Shen, Chu, and Chen (2011) developed a multimodal routing model of inventory with transshipment of crude oil. After formulating the problem as a mixed-integer linear programming model, a Lagrangian relaxation approach was developed to find the lowest total cost solution. Numerical experiments were used to conclude that Shen et al.'s (2011) approach outperforms existing metaheuristic algorithms, especially those in large-scale situations. Kawamura, Ronconi, and Yoshizaki (2006) developed a transshipment model for the distribution of sugar and ethanol to help plan production for the plants of an agricultural cooperative called Copersucar in the central-southern region of Brazil. The method was based on an optimization model that minimizes transportation and storage costs for both products in a classic transshipment problem with logistics and production capacity constraints and considering multiple products and periods. Based on computational results, the model produced solutions that could meet the organization's needs. Osleeb and Ratick (2010) developed a model of mixed-integer mathematical programming for the planning involved in transshipment issues for the rail transportation of biofuels in the US between ethanol plants and the refineries where the ethanol is blended with gasoline. The results projected a significant reduction of logistics costs depending on the choices of size and location of the ethanol plants and refineries.

Acharya, Eksioglu and Petrolia (2008) developed a transshipment model for the supply logistics of ethanol biorefineries in the state of Mississippi in the United States. The aim of this study was to identify the number, size, and location of the collection facilities and biorefineries necessary to process the region's biomass. Acharya et al. (ibid.) developed a mixed-integer linear programming model to design the supply chain logistics of a biorefinery. The study's main recommendations were about the location of the biorefineries and of the best sources of raw materials. Tursun, Kang, Onal, Ouyang, and Scheffran (2008) developed a transshipment model of multiple periods and location of facilities with a focus on ethanol logistics in the state of Illinois, in the United States. The problem was formulated as a mixed-integer linear programming model to determine the optimal size and construction period of each ethanol plant in the region defined, the total raw material processed per production unit, and the distribution of ethanol. Along the same lines, Xie, Huang, and Eksioglu (2014) proposed a study of the supply chain of cellulosic ethanol in California. The objective of the model was to minimize the annualized total costs including the capital for infrastructure, the harvest of raw materials, production of biofuels, and the transportation across the entire supply chain for one year. The main conclusion of the study was that, as expected, trucks are convenient for short-distance deliveries while railways are better suited for long-distance transport. Taking advantage of these benefits, multimodal transport provides more cost-efficient solutions than a single-mode transport (road).

Our proposed model differs from those in the literature because it addresses Brazil's ethanol supply chain much more comprehensively in terms of projections of costs and tariffs, as well as forecasts of supply and demand for a future period of 15 years. Moreover, this research is innovative because of the way we modelled the problem. We consider a transshipment problem with two links and multiple periods with transshipment operations including different modes of transportation. The problem has four products, five modes of transport, more than 400 suppliers, and 70 terminals.

Table 10. *Summary of the Literature Review*

Acharya et al. (2008)	In-bound supply chain design for biomass-to-ethanol industry: a study of Mississippi.	Mixed-integer linear programming model.	Transshipment model for the supply logistics of ethanol biorefineries in the state of Mississippi, USA.
Babazadeh et al. (2013)	Facility location in responsive and flexible supply chain network design (SCND) considering outsourcing.	Mixed-integer linear programming model.	Multi-stage and multi-product mixed-integer linear programming (MILP) model to the responsive and flexible supply chain network design (SCND).
Bilgen & Ozkarahan (2007)	A mixed-integer linear programming model for bulk grain blending and shipping.	Mixed-Integer Linear Programming - Branch and bound algorithm.	Transshipment problem related to the blending and maritime shipping regarding the management chain of wheat supplies.
Dan et al. (2016)	Ordering and pricing model of retailers' preventive transshipment dominated by manufacturer with conditional return.	Nash Equilibrium.	Two-period ordering and pricing model about the preventive transshipment with conditional return was formulated.
Diks & de Kok (1996)	Controlling a divergent two-echelon network with transshipments using the consistent appropriate share rationing policy.	Nonlinear optimization model.	Analyze the impact of transshipments between inventory locations in order to obtain a tool to balance out inventory levels.

Guinet (2001)	Multi-site planning: A transshipment problem.	Integer Linear Programming - Branch and bound algorithm.	General problem of transshipment for the overall planning of multi-site production.
Hong-Minh et al. (2000)	The dynamics of emergency transshipment supply chains.	Simulation Exercises.	Use of an emergency transshipment channel.
Hoppe & Tardos (2000)	Quickest transshipment problem.	Problems of flow in a dynamic network.	The authors developed the first polynomial-time algorithm for a transshipment problem.
Jasinska & Wojtych (1984)	Location of warehouses in a sugar beet distribution system.	Integer Linear Programming - Branch and bound algorithm.	Location of warehouses in a sugar beet distribution system.
Kawamura et al. (2006)	Optimizing transportation and storage of final products in the sugar and ethanol industry: a case study.	Linear Programming.	Transshipment model for the distribution of sugar and ethanol aiming to help the production planning for the mills of an agricultural co-op.
Kirca (1988)	Selecting transfer station locations for large solid waste systems.	Integer Linear Programming - Branch and bound algorithm.	Transshipment model for location of fixed facilities for the transfer of solid waste in a large metropolis.
Lee (2016)	Inventory and transshipment decisions in the rationing game under capacity uncertainty.	Nash equilibrium.	Analysis of Nash equilibrium.
Maknoon et al. (2017)	An integer programming approach to scheduling the transshipment of products at cross-docks in less-than-truckload industries.	Mixed-integer linear programming model.	An integer programming formulation is presented to minimize the cost of double handling by synchronizing products' internal transferring route and the order of processing trucks.
Moghaddam et al. (2012)	Integrating lateral transshipment to aggregate production–distribution planning considering time value of money and exchange rate.	Aggregate production–distribution planning (APDP).	A goal programming approach is proposed for modelling the proposed APDP problem. Maximizing the total profit and minimizing the aggregate manufacturing lead time are considered as the managerial

			goals of the proposed APDP model.
Noham (2014)	The single and multi-item transshipment problem with fixed transshipment costs.	Heuristic model.	Supply chain systems in which lateral transshipments are allowed.
Osleeb & Ratick (2010)	An Interperiod Network Storage Location – Allocation (INSLA) model for rail distribution of ethanol biofuels.	Mixed-integer mathematical programming model.	Planning involved transshipment issues for rail transport of biofuels in the US.
Salam (2011)	Optimizing the design of a supply chain network with economies of scale using mixed integer programming.	Mixed-integer linear programming model.	Piecewise linearization technique is utilized to transform the non-linear concave-cost function of the transportation into a linear form.
Shen et al. (2011)	A Lagrangian relaxation approach for a multi-mode inventory routing problem with transshipment in crude oil transportation.	Mixed-integer linear programming model.	Crude oil transportation planning from supply centers to a set of client ports with dynamic demand, limited inventory, and shortage of capacity.
Tursun et al. (2008)	Optimal biorefinery locations and transportation network for the future biofuels industry in Illinois.	Mixed-integer linear programming model.	Transshipment model of multiple periods and location of facilities with a focus on ethanol logistics in the state of Illinois.
Winston & Goldberg (2004)	Operations research: applications and algorithms.	Transportation problem.	General mathematical formulation.
Xie (2014)	Integrating multimodal transport into cellulosic biofuel supply chain design under feedstock seasonality with a case study based on California.	Mixed-integer linear programming model.	Facilities Location model including seasonality of raw materials and integrated multimodal transportation.

4.4 METHODOLOGY

4.4.1 Model Assumptions

As our main objective is to calculate the replenishment and transshipment flows to minimize total costs, we are going to consider the total supply of ethanol to be equal to the total demand. Thus, all the ethanol produced in Brazil will be sold to the domestic and export market. This consideration reflects what happens in Brazil where the balance between supply and demand of ethanol is carried out via market pricing (Lima, 2015, Souza, 2015).

The acquisition costs of both anhydrous and hydrous ethanol, are the prices at which the ethanol produced by the plants is sold to the distributors. These rates depend on contracts and direct negotiations between buyers and sellers. The plants located closer to the consumption points tend to charge more than the plants that are farther away (NovaCana.com, 2013). However, considering that all the ethanol produced is sold to the domestic or export market with no surplus or waste, the ethanol-selling prices do not interfere in the long-term logistics. Furthermore, with the entry of new and more efficient modes of transport, the trend is for the plants closer to new transshipment centers to seek compensation for their prime locations via price increases. Therefore, we will adopt the premise of no acquisition costs for all the plants and types of ethanol with a total offer equal to the total demand so that the definition of the replenishment and transshipment flows is based on the lowest total logistics cost.

For the costs of road transport, currently the most common mode used, we will consider all possibilities, meaning that all ethanol plants can connect by road to any terminal. For the determination of road freight, we will use a simple linear regression from data obtained from the Brazilian Shipping Information System (Sifreca, 2015). For the shipping rates of rail and sea transportation, especially for cabotage operations, we will consider values obtained from Transpetro, a subsidiary of Petrobras (www.transpetro.com.br) and ANTT, the Brazilian National Ground Transportation Agency (www.antt.gov.br/). The rates for the pipeline and waterway modes were obtained from the websites of the companies Logum Logistica (www.logum.com.br) and Transpetro. The storage costs and fees, port charges, and some other services at the handling and storage terminals were also obtained from information on the websites of Logum Logistica and Transpetro. It is important to mention that the more efficient modes of transportation such as pipeline, waterway, and railway have infrastructure capacity constraints that are considered in the model. Furthermore, in the case of multimodal system of pipelines and waterway, there are contractual minimum volumes called Ship or Pay (SOP) that also impose restrictions.

To develop the models from 2015 to 2030, we used the projected tariffs and costs based on projected data from IPCA (a widely accepted inflation index in Brazil) and forecasts or the Brazilian GDP.

Taking advantage of the infrastructure of pipeline terminals, we assumed that Paulinia would remain as a hub connecting pipelines, railways, and waterways to the pipelines to supply the markets of Sao Paulo, Rio de Janeiro, and export. The entire multimodal system of ethanol was therefore planned with five pipeline terminals and two new waterway terminals going to Paulinia. In Paulinia the ethanol from these terminals would supply the local market and would connect the pipelines to supply four terminals in the Greater São Paulo region (cities of Barueri, Sao Caetano, Guarulhos, and Cubatao), one terminal in Duque de Caxias for the Rio de Janeiro market with a maritime outlet for export at the Ilha D’agua terminal (table 2). Furthermore, a new pipeline was planned to run all the way to the Port of Santos to complement the export capacity of the Brazilian ethanol. Figure 2 depicts the Multimodal System of Ethanol Transport by pipeline and waterway.

Table 11: Terminals of the multimodal system of ethanol logistics before and beyond Paulinia

Origin	Destination	Mode	Opening
Jatai	Paulinia	Pipeline	2017
Quirinopolis	Paulinia	Pipeline	2016
Itumbiara	Paulinia	Pipeline	2016
Uberaba	Paulinia	Pipeline	Existent
Rib. Preto	Paulinia	Pipeline	Existent
Parana River	Paulinia	Waterway	2016
Aracatuba	Paulinia	Waterway	2016
Anhembi	Paulinia	Pipeline	2016

Origin	Destination	Mode	Opening
Paulinia	Barueri	Pipeline	Existent
Paulinia	Guarulhos	Pipeline	2016
Paulinia	D. Caxias	Pipeline	Existent (*)
Paulinia	Ilha D’agua	Pipeline	Existent (*)
Paulinia	Santos	Pipeline	2017
Paulinia	S. Caetano	Pipeline	Existent
Paulinia	Cubatao	Pipeline	2017

(*) Will be shut down in 2018

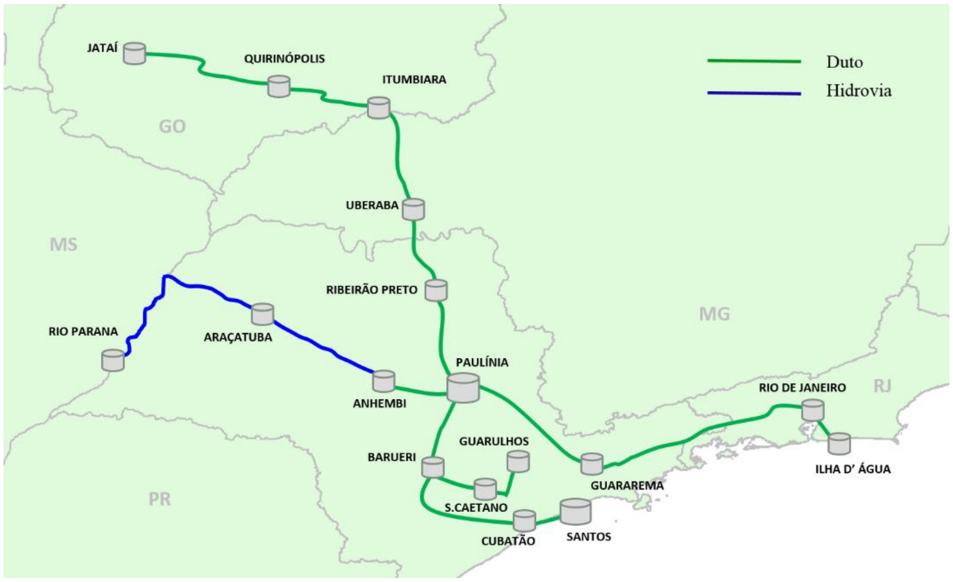

Figure 6: Multimodal system of ethanol transport by pipeline or waterway.

4.4.2 Description of the proposed model

The proposed model predicts the logistics flows of ethanol in a multimodal system of pipelines and waterways from 2015 to 2030 in Brazil; our model represents the entirety of ethanol supply logistics in Brazil: 427 plants, 76 terminals, five modes of transportation, and four products. We consider both existing and to be constructed ethanol plants, with their production capacities set as estimated by industry expert sources (Idea News, 2015, Sugarcane Yearbook, 2015) up until 2030. The products are anhydrous ethanol, hydrous ethanol, industrial ethanol, and ethanol for the export market. Of the 76 terminals, 28 are transshipment centers that can supply other centers or destination terminals and that also have a demand for ethanol. The demand by destination terminal was defined based on data from ANP (Brazilian National Petroleum Agency) and estimated for 2015 to 2030 (ANP, 2015).

In defining the problem of network flows, the replenishment flows originate in the ethanol plants. The destination flows go to destination terminals of origin or destination and transshipment flows connect origin terminals to destination terminals (fig. 3). To find the optimal solution of this problem we will use a linear programming model for each year of the period, subject to supply, demand, capacity, employment, and balance constraints. The objective function of the problem is the total cost, and the decision variables are the flow of replenishment and transshipment. As the problem has a very high number of variables, we will not consider variations in inventory levels at the ethanol plants and terminals and neither the stocks held from one year to the next. A descriptive statistic of the input data is shown in table 3.

We will consider the following parameters, data, and variables to build the model (see fig. 3):

i: Ethanol Plants; j: Origin Terminals; k: Destination Terminals; p: Products; m: Modes.

Vr_{ijp}: Volume allocated of Replenishment or collection flow (decision variable) from ethanol plant i to origin terminal j of product p.

Vr_{ikp}: Volume allocated of Replenishment or collection flow (decision variable) from ethanol plant i to destination terminal k of product p.

Vt_{jkpm}: Volume allocated of Transshipment (decision variables) from terminal j to terminal k, of product p, with mode m.

$Varm_{jpm}$: Volume allocated by Origin Terminal (input flow), to terminal j, of product p, with mode m.

Frt_{ijp}: Unit Costs of Replenishment or Freight Units of Collection from ethanol plant i to origin terminal j of product p.

Frt_{ikp}: Unit Costs of Replenishment or Freight Units of Collection from ethanol plant i to destination terminal k of product p.

Trf_{jkpm}: Unit Costs or Transshipment Tariffs from terminal j to terminal k, of product p, with mode m.

$Tarm_{jpm}$: Unit Costs or Tariffs of Storage and Handling from terminal j of product p, with mode m.

C_i is the total capacity of plant i, D_{jp} is the demand for product p at terminal j; D_{kp} is the demand of product p at terminal k; Cap_m is the capacity of mode m in the flow jk; Cap_j is the capacity of terminal j, and SOP_m is the contract minimum (Ship or Pay) for mode m in the flow jk.

Therefore, Linear Programming takes the following form:

Minimize Z= $\sum_i \sum_j \sum_p Frt_{ijp} \times Vr_{ijp}$ + $\sum_i \sum_k \sum_p Frt_{ikp} \times Vr_{ikp}$ +

$\sum_j \sum_k \sum_p \sum_m Trf_{jkpm} \times Vt_{jkpm}$+ $\sum_j \sum_p \sum_m Tarm_{jpm} \times Varm_{jpm}$
(15)

Subject to the following constraints:

$\sum_i \sum_k Vr_{ik} <= C_i$ (16)

$\sum_i Vr_{ijp}$ - $\sum_k Vt_{jkp} = D_{jp}$ (17)

$\sum_i Vr_{ikp}$ + $\sum_j Tr_{jkp} = D_{kp}$ (18)

$\sum_j \sum_k \sum_m Vt_{jkm} <= Cap_m$ (19)

$\sum_j \sum_p \sum_m Varm_{jpm} \leq Cap_j$ (20)

$\sum_j \sum_k \sum_m Vt_{jkm} \geq SOP_m$ (21)

The objective function (15) represents the total transportation, storage and handling costs. The constraint (16) ensures that the total flow from each plant does not exceed the plant capacity. The balance constraint (17) states that the difference between input and output flows in each origin terminal j is equal to the demand j for each product p. The balance constraint (18) states that the total in-flow for each destination terminal k is equal to the demand k for each product p. Equation (19) ensures that the volume allocated of transshipment does not exceed the capacity of each mode m. Equation (20) ensures that the input flow does not exceed the capacity of each origin terminal j. The model does not consider capacity constraints on destination terminals. The constraint (21) ensures that the minimum condition of contractual volume (Ship or Pay) for each mode m is respected.

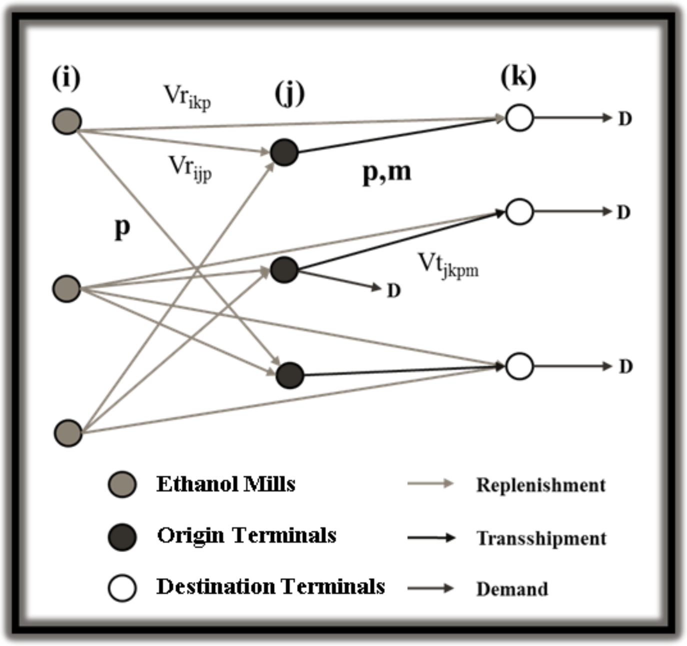

Figure 7: Representation of the flows in the network and the model's indexes.

We used the app What'sBest!® 11.1.0.8, extended version to solve the linear programming model. In the end, the model had 152,760 variables and 1,191 restrictions. For each of the 15 years between 2015 and 2030, a model was developed with supply, demand, costs, and other updated variables. The 15 models were developed in Excel using What'sBest.

4.5 ANALYSIS AND DISCUSSION OF RESULTS

Table 3 shows the descriptive statistics of the input data used in the model. Tables 4 and 5 show the results of the intake of volumes for the multimodal system of ethanol transport before the Paulinia hub until 2030. Tables 5 and 6 show the intake beyond Paulinia in the same period.

Table 12: *Descriptive Statistics of the Input Data*

(R$/m3)		Min	Max	Mean	SD
Unit Costs of Replenishment	2015	24.9	759.7	210.1	123.6
	2016	27.3	832.9	229.7	135.3
	2017	29.6	906.1	249.3	147.1
	2018	32.1	979.4	268.9	158.8
	2019	34.5	1,058.6	289.9	171.5

	2020	37.1	1,132.0	309.6	183.2
	2021	39.6	1,211.3	330.8	195.9
	2022	42.2	1,290.6	351.9	208.6
	2023	44.8	1,370.0	373.1	221.3
	2024	47.5	1,449.4	394.4	234.0
	2025	50.2	1,534.7	417.0	247.6
	2026	52.4	1,604.9	435.7	258.9
	2027	55.0	1,682.4	456.4	271.3
	2028	57.5	1,759.9	477.1	283.7
	2029	60.0	1,837.4	497.8	296.1
	2030	62.6	1,914.9	518.5	308.5
Unit Costs of Transshipment	2015	9.5	557.2	104.6	142.4
	2016	10.4	585.0	109.8	149.5
	2017	10.9	614.3	115.2	157.0
	2018	11.3	642.9	120.5	164.3
	2019	11.8	672.8	126.1	172.0
	2020	12.3	704.0	131.9	180.0
	2021	12.9	736.8	138.0	188.4
	2022	13.4	771.0	144.3	197.2
	2023	14.0	806.9	151.0	206.4
	2024	14.6	844.4	157.9	216.0
	2025	15.2	883.7	165.2	226.0
	2026	15.9	924.8	172.8	236.6
	2027	16.5	967.8	180.7	247.6
	2028	17.2	1,012.8	189.1	259.2
	2029	18.0	1,059.9	197.8	271.2
	2030	18.8	1,109.1	206.9	283.9
Unit Costs of Storage and Handling	2015	2.2	73.9	17.5	20.0
	2016	2.3	77.6	18.3	20.9
	2017	2.5	81.5	19.2	21.9

	2018	2.6	85.3	20.1	22.9
	2019	2.7	89.2	21.0	23.9
	2020	2.8	93.4	21.9	25.0
	2021	2.9	97.7	22.9	26.1
	2022	3.1	102.3	23.9	27.2
	2023	3.2	107.0	24.9	28.5
	2024	3.4	112.0	26.1	29.7
	2025	3.5	117.2	27.2	31.0
	2026	3.7	122.7	28.4	32.4
	2027	3.9	128.4	29.7	33.9
	2028	4.1	134.3	31.0	35.4
	2029	4.2	140.6	32.4	36.9
	2030	4.4	147.1	33.8	38.6

Table 13: *Volume of Ethanol Allocated to the Origin Terminals by the Linear Programming Model up until 2020. Volumes in Mm^3.*

Origin Terminals	2015	2016	2017	2018	2019	2020	Maximum Cap.
Jatai	0	0	671	681	801	1035	1300
Quirinopolis	0	743	749	796	1054	1333	2900
Itumbiara	0	968	1191	1981	2022	2382	2900
Uberaba	769	285	354	360	365	371	1900
Ribeirão Preto	2868	1907	3029	3828	4300	4300	4300
Pipeline Total	**3637**	**3903**	**5954**	**7646**	**8542**	**9421**	**13200**
Paraná River	0	204	391	676	783	905	1300
Araçatuba	0	2391	2500	2500	2500	2500	2500
Anhembi	0	16	1300	1300	1300	1300	1300
Waterway Total	**0**	**2611**	**4191**	**4476**	**4583**	**4705**	**5100**
Pre-Paulínia Total	**3637**	**6514**	**10185**	**12121**	**13126**	**14126**	**18300**
Other Modes	818	880	830	836	841	847	
Paulínia Inputs Total	**4455**	**7394**	**11015**	**12957**	**13967**	**14973**	

Table 14 *Volume of Ethanol Allocated to the Origin Terminals by The Linear Programming Model from 2021 to 2030. Volumes in Mm³.*

Origin Terminals	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Max. Cap.**
Jatai	999	961	945	913	1046	1195	1300	1300	1300	1300	1300
Quirinopolis	1348	1470	1784	2351	2645	2900	2900	2900	2900	2900	2900
Itumbiara	2430	2438	2556	2711	2785	2800	2800	2800	2800	2800	2900
Uberaba	377	551	504	524	584	941	1523	1900	1900	1900	1900
Ribeirão Preto	4300	4300	4300	4300	4300	4300	4300	4300	4300	4300	4300
Pipeline Total	**9454**	**9720**	**10089**	**10799**	**11360**	**12136**	**12823**	**13200**	**13200**	**13200**	**13200**
Paraná River	1024	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
Araçatuba	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Anhembi	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
Waterway Total	**4824**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**	**5100**
Pre-Paulínia Total	**14279**	**14820**	**15189**	**15899**	**16460**	**17236**	**17923**	**18300**	**18300**	**18300**	**18300**
Other Modes	853	968	973	1263	1390	1262	1096	1054	1158	1262	
Paulínia Inputs Total	**15132**	**15788**	**16163**	**17161**	**17849**	**18498**	**19019**	**19354**	**19458**	**19562**	

Table 15: *Volume of Ethanol Allocated to the Destination Terminals by the Linear Programming Model up until 2020. Volumes in Mm³.*

Destination Terminals	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Barueri	679	1054	1108	1244	1365	850
Guarulhos	0	1391	1190	1192	1194	1172
São Caetano	1401	1949	2160	2425	2660	2976
Cubatão	0	0	334	373	408	454
Rio de Janeiro	1218	1345	1471	1631	0	0
Domestic Market Total	**3298**	**5739**	**6263**	**6864**	**5628**	**5453**
Ilha D’água	200	458	500	0	0	0
Santos	0	0	2796	4398	6350	7138
Export + Cabotage	200	458	3296	4398	6350	7138
After Paulínia Total	**3498**	**6198**	**9559**	**11262**	**11977**	**12591**
Paulinia Outputs (Road)	**957**	**1197**	**1456**	**1695**	**1989**	**2382**
Paulínia Outputs Total	**4455**	**7394**	**11015**	**12957**	**13967**	**14973**

Table 16: *Volume of Ethanol Allocated to the Destination Terminals by The Linear Programming Model from 2021 to 2030. Volumes in Mm³.*

Destination Terminals	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Barueri	857	863	870	877	884	891	898	906	906	906
Guarulhos	1174	1176	1179	1181	1184	1187	1190	1192	1192	1192
São Caetano	2964	3034	3089	3278	3473	3585	3703	3820	3938	4055
Cubatão	451	0	0	0	0	0	0	0	0	0
Rio de Janeiro	0	0	0	0	0	0	0	0	0	0
Domestic Market Total	**5446**	**5074**	**5138**	**5336**	**5541**	**5662**	**5790**	**5918**	**6036**	**6153**
Export + Cabotage	7301	8387	8613	9593	10000	10000	10000	10000	10000	10000
After Paulínia Total	12747	13461	13750	14928	15541	15662	15790	15918	16036	16153
Paulínia Outputs (Road)	2385	2327	2413	2233	2309	2836	3229	3436	3422	3409
Paulínia Outputs Total	**15132**	**15788**	**16163**	**17161**	**17849**	**18498**	**19019**	**19354**	**19458**	**19562**

According to tables 4 and 5, the multimodal system of ethanol transport captured a consistent volume up until 2030 for all the terminals, reaching the system's maximum capacity in 2028. By 2020, the system used 70% of the pipeline's capacity and 92% of the waterways' capacity. The reason for the high use of the pipeline and waterway is that their rates are significantly lower than road transportation rates. This difference compensates for the fact that the use of the pipeline and waterway still requires road-based collection between plants and collection terminals. The road-based collection reduces the competitiveness of the plants that are the farthest from the pipeline and waterway terminals. In some cases, capacities are not fully utilized until 2020 due to the need to meet other points of demand outside the area of influence of the pipeline and waterway. As can be seen in tables 4 and 5, as the production of Brazilian ethanol increases in the states of Goiás and Mato Grosso do Sul with the creation of greenfield plants, the terminals of Jatai, Quirinópolis, Itumbiara, and Paraná River will reach capacity. The graph in figure 3 shows that the growth of production of the state of SP slows down, giving rise to the significant increase in production in the states of Goiás and Mato Grosso do Sul.

When analyzing the results by terminal, we can see that the model assesses the possibilities and trade-offs of replenishment and transshipment in each allocation decision. When observing the pipeline terminals before Paulínia (tables 4 and 5), we realized that Uberaba in 2015 showed a 64% reduction of volume intake. The reason for this reduction is that the terminals of Itumbiara and Quirinópolis will start operation in 2016, taking on a volume of 1,711 m^3, causing a reduction in the volumes of Uberaba. This means that the plants in southern Goiás and neighboring districts that might have been using the Uberaba terminal in 2015 migrate to Itumbiara or Quirinopólis in 2016, taking advantage of the low rates of pipeline transportation. This is an example of road-based collections with a longer route being replaced with pipeline. Similarly, Ribeirão Preto had a 34% drop in its volume from 2015 to 2016. This is a response to the more competitive waterway in Araçatuba, which will start operation in 2016. The plants that are southwest of Ribeirão Preto and closer to Araçatuba migrate to this terminal to supply the consumer regions of São Paulo and Rio de Janeiro.

As for the waterway, the Araçatuba terminal is at more than 95% of capacity in its first year of operation. This is attributable to the high production of ethanol in the western part of the state of São Paulo, which has a large concentration of plants that used road transport to Paulínia to supply the domestic and export markets. The Anhembi terminal does not present movement volume until its second year, coinciding with the opening of the pipeline running to the port of Santos, dedicated to supply the foreign market. The Anhembi-Paulínia pipeline is too short to be feasible for the domestic market, losing competitiveness to road transportation. However, for the longer stretch between Anhembi and the Port of Santos, pipeline transportation is competitive. The Paraná River terminal has a low volume in the first years since the plants in the state of Mato Grosso do Sul supply the southern region of Brazil. As new greenfield plants are created with significant increase in production, the extra production becomes competitive for the main markets using the reduced rates of waterway/pipeline along the Paraná River-Paulínia stretch.

We note that by 2021, both the demand in Paulínia as well as the markets of São Paulo, Rio de Janeiro, and export are supplied by using pipelines, waterway, and railway in what had been the Paulínia section. After 2024, when the system approaches capacity, the road-based collections start, complementing the pipeline flow in the beyond Paulínia section to supply the markets of São Paulo, Rio de Janeiro, and export (tables 6 and 7). After 2023, a small increase in production will begin in São Paulo due to some predicted greenfield plants, implying an adjustment of the volumes between the terminals. It is worth mentioning that the cost of road transport is expected to increase, becoming even more expensive than the other modes (Lima, 2014, Neves, 2016). These trends will help increase the intake of ethanol by the three pipeline terminals in Goiás, which reach volume peak after 2025 when the São Paulo production stops growing and the production in the states of Goiás and Mato Grosso do Sul start to grow because of projected greenfield plants starting to operate. In the beyond-Paulínia section, when there is capacity to spare after the opening of the pipeline to Santos, there is competition between the terminals. After 2019, the more competitive rates of the pipeline sections to Santos and São Caetano will lead to a reduction in volumes on the pipeline to Barueri (see table 9). This is caused by the inability to increase the flows by pipeline and waterway along the before Paulínia section. Another important point is that the Paulínia-Santos pipeline caters to the demand for export, receiving priority among all other flows along the beyond-Paulínia section due to its greater competitiveness. A final point is that the closing of the pipeline flow to Rio de Janeiro (for contractual issues) is offset by the increase in the pipeline volumes to the Port of Santos.

Table 17: *Evolution of the Volume Share of Each Mode in the Transportation of Ethanol in Brazil.*

% Modes	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2023**	**2025**	**2027**	**2029**	**2030**
Roads &		69.4		62		62						
Roads	77.4		63.6		61.9		61.6	60.6	61	61.6	62.9	63.5
Pipeline	14.4	16.6	23.8	25.4	25.3	24.7	24.9	26	26.5	26.4	25.7	25.1
Sea	0.9	1.7	1.7	2	2.1	2.7	2.7	2.8	2.8	2.8	2.8	2.9
Waterway	0	5.1	4.7	4.5	4.3	4.1	4.2	4.3	3.9	3.7	3.5	3.5
Railway	7.3	7.3	6.3	6.1	6.4	6.5	6.6	6.3	5.9	5.5	5.1	5

Table 18: *Evolution of the Share of Road Transportation at the Destination Terminals in the Region of the Multimodal System.*

% Roads & Roads	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Barueri	28%	0%	5%	5%	5%	47%	47%	47%	48%	51%	53%	54%	55%	56%
Cubatão	100%	100%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%
Guarulhos	100%	21%	39%	46%	51%	57%	56%	57%	58%	60%	62%	64%	65%	66%
Paulinia	0%	0%	0%	0%	0%	0%	0%	7%	7%	25%	30%	22%	12%	9%
Rio de Janeiro	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Santos	100%	100%	66%	52%	26%	23%	24%	13%	12%	0%	1%	1%	5%	10%
São Caetano	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**57%**	**40%**	**29%**	**25%**	**26%**	**29%**	**29%**	**29%**	**29%**	**29%**	**31%**	**30%**	**29%**	**31%**

4.6 CONCLUSIONS

This paper presents a logistics assessment of the multimodal system of ethanol transport by pipeline and waterway, which is in its initial phase of operation in Brazil. The system was designed to supply the largest Brazilian markets and for export. The results indicate that the system will reach of 80% of its capacity in 2020 and its maximum capacity in 2028. This transport system by pipeline and waterway will replace much of the road transport, thus reducing the logistics costs especially for export and increasing the competitiveness of Brazilian ethanol on foreign markets. The pipeline and waterway terminals in the state of São Paulo will reach their peak capacity in a few years due to the state's high production of ethanol. Moreover, the pipeline to Santos beginning operation in 2017 will allow for an increase of more than 60% of the system's intake, quickly increasing competitiveness and ease of access to export markets. Another important point is that, despite the volumes before Paulínia reaches system capacity in 2028, in the beyond-Paulínia section the capacity limit is not reached (see tables 6 and 7). The pipeline to Rio de Janeiro that ceases operations in 2018 will leave this important market to be supplied by road with a significant increase in costs. Considering a future expansion of this system, a connection by pipeline or even by cabotage with the market of Rio de Janeiro and the subsequent expansion of the railway or waterway network in the before Paulínia section would allow for volume increase at lower rates thereby increasing competitiveness.

With the growing need to improve the competitiveness of ethanol in relation to gasoline in Brazil, the use of pipelines and waterways for the flow of goods produced deep inside the country is critical given the high costs of road transport. There is a tendency for the roads in Goiás, Mato Grosso do Sul, and in Minas Gerais to have new and more expensive tolls in the coming years, making modes such as pipeline and waterway more competitive for the future of ethanol logistics. A further important role of this multimodal system for ethanol is that the export infrastructure can be used for cabotage via the Port of Santos. Cabotage may be important in supplying the densely populated Brazilian Northeast, a region that is expected to have high growth in the coming years.

We can also conclude that the price policy adopted by the companies operating the ethanol multimodal system is attractive enough to capture much of the market now occupied by road transportation. The consequence is that road transport will be used for the shorter routes between the plants and collection centers. The main limitation of this study is that it did not contemplate tax policies and trade policies which can be significant and changeable in Brazil, depending on future government beliefs and decisions. Exploring the robustness of our model to changes in policies would be one of our recommendations for further analysis and research.

For further future studies, it would be interesting to include new pipeline extensions to other large Brazilian markets such as the Belo Horizonte and Salvador regions, and new destinations for cabotage via the Port of Santos. A transshipment model like the one we developed here could be applied to assess the feasibility of such alternatives.

We also believe that it would be worthwhile to further explore the use of transshipment models to assess the use of flexible pipelines, which generally are less expensive than the traditional rigid ones. They could connect the larger ethanol plants to collection centers. This alternative would replace road collection with collection using pipelines of lower capacity and investment, thereby increasing the efficiency of the ethanol multimodal system.

The transshipment model used in this study allowed the inclusion of thousands of constraints very quickly and effectively, making it possible to apply to more specific jobs or cases. The relatively low time for the model to reach the optimal solution also makes it possible to test and perform sensitivity analyses about new rates, configurations, and even new routes for the system.

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5 4 ST PAPER: ARE THERE MULTIPLE BUBBLES IN THE ETHANOL–GASOLINE PRICE RATIO OF BRAZIL?

ARE THERE MULTIPLE BUBBLES IN THE ETHANOL–GASOLINE PRICE RATIO OF BRAZIL?

ABSTRACT

This paper tests for the existence of bubbles in the ethanol-gasoline price ratio in Brazil from 2000 to 2012 using right-tailed ADF tests. Results suggest the existence of two bubbles: one which has already burst (during the re-election of President Lula); and one which has been ongoing since 2010, thus corroborating empirical and anecdotal evidence in the Brazilian sugarcane industry. Freezing gasoline prices not only depressed ethanol prices but also depressed investments in new sugarcane crops and distillation plants.

Keywords: Brazil; bubbles; ethanol-gasoline price-ratio; right-tailed ADF tests.

5.1 INTRODUCTION

This paper analyses the formation of bubbles in the ethanol-gasoline price ratio in Brazil, from 2000 to 2012. Since 2008, the Brazilian Government has artificially frozen gasoline prices to the end consumer while the price of ethanol has remained free from governmental controls. The annual inflation in Brazil of around 5-6%[1] combined with the transfer of increases in labour and distribution costs annually to ethanol prices explains why ethanol consumption tends to decay while gasoline consumption tends to increase. In Brazil, as part of a governmental policy for stimulating the consumption of bio fuels, consumers are told that ethanol is more economical for refueling cars when the price ratio is below 0.70. [2]

The difficulty in testing for the presence of bubbles lies in modelling their explosivity and labelling their occurrence (Candelise et.al, 2013). Traditional unit root (Lean and Smyth, 2013,

[1] Brazilian Central Bank - http://www.bcb.gov.br/Pec/metas/TabelaMetaseResultados.pdf

[2] Brazilian Oil Agency - http://www.anp.gov.br/?pg=57994&m=&t1=&t2=&t3=&t4=&ar=&ps=&1436268597572.

(Lean and Smyth, 2014), (Yilanci and Tunali, 2014) and co-integration tests (Zafeiriou et. Al., 2014, Shahbaz et. Al, 2015) used to identify such bubbles may not discern their existence when they are periodically collapsing (Evans, 1991). To overcome this problem, Phillips et al. (2013) developed a recursive right-tailed Generalized Sup Augmented Dickey-Fuller (GSADF) testing procedure to detect and date stamp mildly explosive pricing behavior. Such periods would then be labelled as bubbles. In General, bubbles burst when there are systematic departures from the fundamental price of an asset, which eventually collapses. From a technical point of view, the term "bubble" implies a mildly explosive departure from a unit root data generating process (DGP) (Figuerola et. al. 2015).

A number of studies on the Brazilian sugarcane industry addressing production and consumption related aspects have been carried out to date; examples include Goldemberg et al. (2004), Walter et al. (2008), Figueira et al. (2010), Bastian-Pinto et al. (2010), Barros et al. (2014) and Wang et al. (2014). Moreover, other similar studies focus on US ethanol, such as Marzhoughi and Kennedy (2013), Du and Hayes (2012) and Anderson (2010). Thus, this paper innovates because it analyses the Brazilian Government pricing policy for gasoline as an eventual driver for the formation of a bubble in the ethanol-gasoline price ratio. In addition, this paper uses for the first time right-tailed ADF tests in order to do so. Such tests have shown a pronounced ability to detect exuberance in economic and financial activities (Phillips et. al , 2012). Despite the early work of Diba and Grossman (1988), which had focused on the utility of using right-tailed ADF tests to capture explosive behaviors typifying bubbles, it is only recently that Phillips et al. (2011) and Phillips et al. (2013) have introduced this test with this aim. The objectives of this paper are to explain the complex behavior of the ethanol-gasoline price ratio in Brazil in light of certain governmental actions. Although there are several papers studying ethanol demand and production in Brazil in recent years (Mayer et. al., 2015, Mandaloufas et al., 2015) and none uses this kind of statistical tool to explain possible bubbles in its consumer-pricing behavior, even though the method has been widely used to detect bubbles in financial and commodity markets since the method was first proposed. For a detailed review in this regard, see Phillips and Yu (2011) and Caspi et al. (2014).

The paper is structured as follows. After this introduction, the background on the sugarcane industry in Brazil is presented, discussing not only ethanol production in historical and present terms, but also their future perspectives. Later the methodology will explain the data and right-tailed ADF tests, followed by a discussion of the results and the conclusion.

5.2 BACKGROUND ON THE SUGARCANE INDUSTRY IN BRAZIL

In Brazil, fuel ethanol is derived from sugarcane and is used pure or blended with gasoline in a mixture called gasohol (25% ethanol, 75% gasoline). A conjunction of factors including (i) Brazil's heavy reliance on fossil fuels; (ii) Brazilian government concerns about national sovereignty; and (iii) the low price of sugar, with the consequent possibility of bankruptcy by sugar industrialists, led Brazil to adopt subsidies and protection from alcohol imports in the mid-1970s (Oliveira et al., 2005). There has been extensive research on Brazilian ethanol with a focus on history, economics and possible energy policy and environmental implications (Goldemberg et al., 2004). According to Blottnitz and Curran (2007), the majority of these assessments focused on net energy and greenhouse gases, and despite differing assumptions and system boundaries, the following general lessons emerge: (i) make ethanol from sugar crops in tropical countries, but approach expansion of agricultural land usage with extreme caution; (ii) consider hydrolyzing and fermenting lignocelluloses residues to ethanol; and (iii) the LCA results on grasses as feedstock are insufficient to draw conclusions. Although economic competitiveness is a very frequent argument against renewable energy (Mayer et al., 2015), the economies of scale and technological advances achieved through the Brazilian experience with ethanol (Mayer et al., 2015) lead to increased competitiveness of the ethanol alternative, thus reducing the gap with conventional fossil fuels (Mandaloufas et al., 2015).

The Brazilian sugarcane industry has experienced significant growth in recent decades. Indeed, the acceleration of investments in new ethanol plants, mainly from 2003, was driven by growth in sugar demand in the international market, especially after the reform of the European policy for the product, and Brazil's increasing use of ethanol driven by the development of Flex Fuel vehicles. Moreover, Brazil saw increasing prospects of exporting the production to a growing number of countries that had chosen to add bio fuels to their energy matrixes – primarily United States and Europe – and to this end established a bio fuel policy in 2005. In response to such strong demand stimulus, the production of sugarcane has experienced a significant increase in the last decade, mainly in the period between cycles 2001/2002 and 2008/2009, year of the global economic crisis. In this interval, the sugarcane crop yield grew at a rate of 10.6% per year, reaching 573 million tons. The period from 2009/2010 until the 2012/2013 harvest saw a break with the pace previously witnessed and production declined 1% a year. After the global financial crisis of 2008, investments in the sugarcane sector ceased and the expansion of cultivated area was compromised, especially by the sharp tightening of credit, which had until then been abundant. As a result, most companies found themselves heavily indebted, a scenario that was only exacerbated by increased world supply of sugar. Nonetheless, the costs of production in Brazil rose (Mayer et al., 2015) and, even with the recovery in prices of sugar and ethanol in the 2009/2010 harvest, the unfavorable financial situation of most companies was far from being resolved. The sector began to experience a strong movement of mergers and acquisitions while part of the milling sugarcane capacity increased to multinational companies, factors that significantly changed their profile. Furthermore, some of the companies that had made acquisitions of highly indebted groups were surprised by a sequence of harvests beset with serious weather problems. Added to the unfavorable scenario, the policy gap in gasoline prices practiced by the Brazilian Government in relation to the international market led to the deactivation and failure of a large number of plants. Since the 2008 crop, the industry lost sugarcane milling capacity of 48 million tons of cane in the interim between new units coming on line and others closing. More recently, the 2013 production was about 600 million tons in the South Central Region. Yield shortfalls caused by the reduction in dealings with sugar plantations and problems with aging crops, mechanization and climate problems ameliorated only in the 2013/2014 harvest (NovaCana, 2014).

In a universe of 435 ethanol and sugar mills in Brazil, 44 closed in the last 5 seasons and 12 others may wind up operations in 2014/2015, thus wiping out 100,000 jobs. According to the Brazilian Confederation of Agriculture (CNA), the debts of such companies are equivalent to the production value of one entire crop. More than 50 mills are in judicial recovery. Indeed, the Sugarcane Agroindustry Union (UNICA) has said that, "the net average debt of ethanol companies exceeds the annual gross revenues”; in addition, almost 15% of revenue is committed to the payment of interests". This is the outlook from the sugar cane industry; and its main product, fuel ethanol, has been neglected in energy policies. According to UNICA, the biggest companies have already indicated their intention to get out of the activity. "What attracts the entrepreneur is profits, and for profits to be made again, the sector must resolve the issue of hydrated ethanol. Policies that define and maintain the proportion of hydrated ethanol in matrix national fuels would solve 90%

of the industry's problems. The anhydrous ethanol market is already regulated and inserted in the matrix of fuels in Brazil. To resolve the issue of hydrated ethanol, the first rule is transparency in gasoline pricing. In other words, without a clear rule as to how gasoline will behave over the coming decades, it is very difficult to invest in this market. Based on knowledge regarding Petrobras' pricing policies, UNICA calls for a tax that differentiates ethanol from gasoline, as was the case with CIDE (Contribution for Intervention in the Economic Domain). The tax, which lasted until 2008, added BRL 0.28 per litre to gasoline sold by the refinery. The reestablishment of CIDE taxation is the main demand of the ethanol sector (NovaCana, 2014).

The results of a research study that analyzed scenarios for Brazilian consumption of ethanol for the period 2006 to 2012, show that if the country's GDP can sustain an annual growth of 4.6%, domestic consumption of fuel ethanol could increase to 25.16 billion liters in this period. This is a volume relatively close to the forecasted gasoline consumption of 31 billion liters. At a lower GDP growth of 1.22% a year, gasoline consumption would be reduced and domestic ethanol consumption in Brazil would be no higher than 18.32 billion liters. Contrary to the current situation, forecasts indicated that hydrated ethanol consumption could become much higher than anhydrous consumption in Brazil. The former is being consumed in cars moved solely by ethanol and flex-fuel cars which were successfully introduced in Brazil in 2003. Flex-fuel cars allow Brazilian consumers to choose between gasoline and hydrated ethanol and immediately switch to whichever fuel presents the most favorable relative price (Figueira et al., 2010). On a related point, one study used a simultaneous equation system to determine the impact of ethanol fuel production on the US vehicle gasoline market, especially gasoline prices. Based on estimations, every billion-gallon increase in ethanol production would decrease gasoline prices by as much as 6 cents (Marzhoughi, 2012).

Despite the attention from policy makers, relatively little is known about household preferences for biofuels or the effect that ethanol mandates will have on gasoline markets. This information is critical for designing, implementing, and evaluating policies to promote ethanol and other bio fuels (Anderson, 2011). Ethanol fuel in Brazil (E100) has approximately 34% less energy per volume unit than gasoline. However, the cost-benefit of ethanol compared to gasoline is not only based on the molecular energy content. Engines using ethanol can benefit from the higher octane rating of this fuel (i.e., higher resistance to pre-ignition), thereby allowing them to perform more efficiently (Thuijl et al., 2003). This raises the efficiency of ethanol beyond the expected 66% of that of gasoline, which would correspond to the difference in pure energy content. On average, E100 (pure ethanol) delivers 70% of the mileage of gasoline for the same volume of fuel (Goettemoeller, 2007, MME, 2009). Under the already known hypothesis that the consumer decision is based on the cost-benefit of the fuel at any given moment, the criterion for choosing ethanol as opposed to gasoline leads to a price-ratio of 0.7. A relative price larger than 0.7 indicates that using ethanol has no advantage compared to gasoline in terms of energy content. In this situation, the consumption of gasoline would provide more mileage per monetary unit than ethanol (ESALQ, 2010). Further, the dynamics of gasohol (mandatory blend of gasoline and ethanol) and ethanol prices operate in a symmetric manner over ethanol demand, thereby evidencing the increasing interchangeability between these alternative fuels (Freitas and Kaneko, 2011).

5.3 THE RIGHT-TAILED ADF TESTS

The data used in this paper was collected from the Agência Nacional do Petróleo (ANP) website (www.anp.org.br), which has information posted on average monthly prices in Brazil for gasoline and ethanol from January 2000 to December 2012. In this research, we used the ethanol-gasoline price ratio to perform right-tailed ADF tests in accordance with the earlier explanation, that is, the consumer's decision to use one type of fuel to the detriment of the other based on the price-ratio of 0.70.

At this stage, it is useful to remember that right-tailed ADF tests preserve the unit root null hypothesis, but are distinguished by explosive alternatives unlike the standard ADF tests characterized by stationary alternatives. For this reason, Diba and Grossman (1988) recommended the use of right-tailed tests to detect explosiveness in economic and financial data. However, it has been recognized in the literature that right-tailed ADF tests have low power in detecting periodically collapsing bubbles, a point which will be further explained below. For a discussion, see the simulation study in Evans (1991).

Based on these findings, Phillips et al. (2011), Phillips and Yu (2011), Phillips et al. (2012) and Phillips et al. (2013) recently developed a convincing series of testing procedures to detect the exact bubble as well as its origination and collapse dates. These authors used an ADF-type regression in a rolling window. More specifically, we consider an ADF regression for a rolling interval beginning with a fraction r_1 and ending with a r_2 fraction of the total number of observations; hence, the size of the window is $r_w = r_2 - r_1$. The econometric time series model at the root of PWY (2011) testing strategy can be written as follows:

$$y_t = m + \lambda y_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-i} + \epsilon_t,\ \epsilon_t \sim iid\ N(0, \sigma^2),\ t = 1, \dots, T, \qquad (1)$$

with y_t is the series to be tested for bubbles, the ethanol-gasoline price ratio in our paper. Δ in (1) the first difference operator, i.e. $\Delta y_t = y_t - y_{t-1}$.

Phillips et al. (2011) resorted to the mildly-integrated root as specified in Phillips and Magdalinos (2007). Thus, they opted in (1) for a right-sided ADF test to detect explosive behaviors marked by the presence of bubbles. Additionally, the usual null hypothesis $H_0: \lambda = 1$ is to be tested, although PWY consider a right sided alternative $H_1: \lambda > 1$. More specifically, PWY consider an ADF regression for a rolling interval beginning with the fraction r_1 and ending with the fraction r_2 of the total number of observations. This requires the number of observations $T_w = [r_w T]$ where [.] is the integer part and $r_w = r_2 - r_1$. Accordingly, the ADF statistic corresponding to (1) is written $ADF_{r_1}^{r_2}$. Also, the smallest fractional window size used is denoted by r_0.

Because bubbles collapse periodically, the conventional unit root tests have limited power to detect them. To overcome this shortcoming, Phillips et al. (2011) and Phillips and Yu (2011) suggest using a recursive sequence of right-tailed ADF-type statistics based on a forward-expanding sample and then proposed using the supremum (sup) of these to establish their test. While Homm and Breitung (2012) argued that the test has a fairly efficient bubble-detection method in one or two bubble alternatives, Phillips et al. (2013) showed that although the Phillips et al. (2011) procedure consistently estimates the start date of the first bubble in any sample in the case of two bubble alternatives, it may fail to identify the second bubble. This implies that in the presence of two bubbles, the second bubble may not be detected unless it is dominated by the first bubble. This motivated Phillips et al. (2013) to formulate a backward sup ADF test where the endpoint of the subsample is fixed at a fraction r_2 of the whole sample and the window size is expanded from an initial fraction r_0 to r_2. The backward sup ADF statistic is defined as follows:

$$SADF_{r_2}(r_0) = sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2}. \qquad (2)$$

The generalized sup ADF (GSADF) is then constructed by repeatedly implementing the SADF test procedure for each $r_2 \in [r_0, 1]$. The GSADF can be written as follows:

$$GSADF(r_0) = sup_{r_2 \in [r_0, 1]} SADF_{r_2}(r_0). \qquad (3)$$

5.4 RESULTS AND DISCUSSION

Table 1 summarizes the results of the application of the ADF, SADF and GSADF tests on the ethanol-gasoline price ratio. Recall that all these tests have the null hypothesis of unit root against explosive behavior. Clearly, we can conclude from this table that this ratio exhibited an explosive behavior, since the null hypothesis of unit root is overwhelmingly rejected at the one percent level of significance under all three tests. Phillips et al. (2013) noted that the GSADF diagnostic outperforms the SADF test in detecting explosive behavior if there are multiple bubbles in the studied series and seldom gives false alarms, even in relatively modest sample sizes. As we can see from the previous section, the GSADF test covers more subsamples of the data and this explains its outperformance.

Identifying explosiveness periods is ensured by comparing the calculated GSADF statistics to the corresponding critical values obtained from Monte Carlo replications on the partial sum of 1000 independent standard normal draws. The minimum size of the variable window widths are set to 36. We also used a fixed lag length of zero because Phillips et al. (2013) mentioned that considering a higher number of lags does not significantly change the results.

To rigorously date-stamp the start and end points of the bubbles, we then used the GSADF test, which recorded a bubble that began in June 2006 and collapsed in March 2007. This first bubble coincides with the period of the electoral campaign and re-election of President Lula of the left-wing labor party. The test was also able to discern another bubble which began in June 2010 but which has not, to date, collapsed.[3] The results on both bubbles seem to corroborate the empirical evidence. More precisely this second and more aggressive bubble starts after the withdrawal of CIDE in 2008, making the price-ratio more favorable to gasoline. However, since 20005 the problem has been rooted in government attempts to artificially hold down fuel prices in order to

[3] Interestingly, we obtained similar results based on the SADF recursive estimation as well. Further details on the SADF plot are available upon request from the authors. Further, using the Leybourne et al. (2007) test of changes in persistence, we observed that the series became non-stationary (*I(1)*) from stationary (*I(0)*) in November, 2005 or May, 2010, depending on whether we allowed the test to be conducted without trend or with trend. If we identify bubbles as a non-stationary process, as done in the extant literature on bubbles, the test then tends to detect only one bubble, generated earlier than detected by the GSADF test, and also suggests that the bubble has not yet collapsed. Reference: Leybourne S, Tae-Hwan K, Taylor R. Detecting multiple changes in persistence. Stud Nonlinear Dyn Econ 2007; 11(3).

"control" inflation. Freezing the pump price of gasoline (in fact the real price fell, taking into account inflation) worked up until CIDE (contribution on the importation and marketing of oil and oil products created to compensate Petrobras for price fluctuations abroad) was withdrawn.

Table 19**:** Tests for Explosive Behavior in the ethanol-gasoline price ratio

	Sample 2000 M01- 2012 M12		
	ADF	SADF	GSADF
	1.8928***	4.4806***	7.6041***
CV 1%	0.9551	1.9031	2.2795
CV 5%	0.0102	1.3164	1.8479
CV 10%	-0.3893	0.9396	1.5638

Notes: *** Indicates the significance level at 1%. Critical values are obtained from Monte Carlo simulations with 1000 replications for the ADF, SADF and GSADF tests.

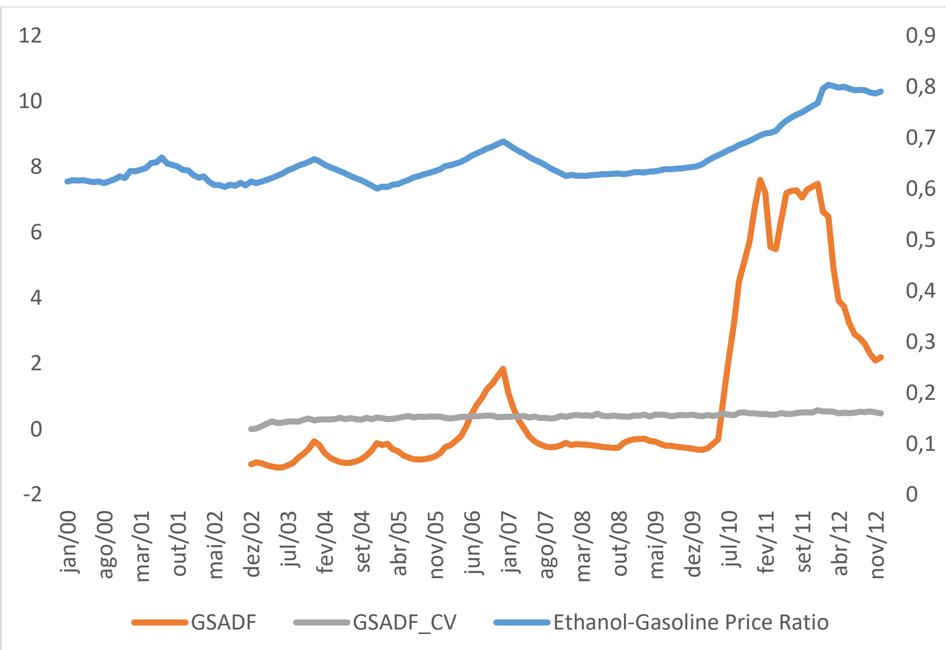

Fig. 8 GSADF statistics of the ethanol-gasoline price ratio

Notes: *This graph shows the series of the* ethanol-gasoline price ratio *(blue) and its corresponding sequence of GSADF statistics (orange). The grey line represents the 5% GSADF critical values. The initial window size is set at 36 observations. The left-axis measures the values of the GSADF test statistic, while the right-scale measures the ethanol-gasoline price ratio.*

5.5 CONCLUSIONS

This paper analyzed the formation of a bubble in the ethanol-gasoline price ratio in Brazil, from 2000 to 2012, using right-tailed ADF tests. Bubbles (or explosive behavior), essentially imply the detachment of the price of an asset from its fundamentals. To account for possible bubbles in Brazil's ethanol sector, we analyzed the ratio of the ethanol price with respect to the gasoline price, with the latter serving as the fundamental variable in our case. This makes sense, given that gasoline is a substitute of ethanol, and hence, its price is likely to play an important role in the determination of ethanol prices. We observe that there is clear evidence of explosiveness in ethanol prices relative to gasoline prices. In addition, we observe that there are multiple bubbles in the ethanol prices, with one beginning in June 2006 and collapsing in March 2007, and another originating in June 2010, which has thus far not collapsed. In general, the results corroborate the empirical and anecdotal evidence in the Brazilian sugarcane industry. The underlying problem, which impacts the entire biofuels sector and not only the ethanol sector, is the government policy of freezing prices of petroleum products, especially gasoline and diesel. Freezing gasoline prices not only weakens Petrobras' investment capacity, but also depresses investments in new sugarcane crops and distillation plants because ethanol prices are not competitive. However, allowing prices to fluctuate according to international patterns will not regain structural competitiveness for the sugarcane sector. Additionally, developments in the global crisis could also depress oil prices to lower levels than those seen today in order to justify current fuel price levels without impacting the ethanol business.

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6 CONCLUSION:

6.1 PAPERS SUMMARY

The most important factors contributing to the necessary increase in the production of fuel ethanol in Brazil were, in order of importance, sugarcane milling, sugar production, the sugar/ethanol and gasoline/ethanol price ratios; and the contextual variables—cooperative mill, mill ramping up, distance factor, efficient mill logistics and national plant. Production of sugarcane—the most important factor for increasing the production of ethanol—should be encouraged by the government and producers through the development of planting and harvesting technology and by increasing the planted area in Brazil. Moreover, the price ratios—which depend above all on the government—are fundamental to stimulate the production of ethanol. Indeed, the ratios are a function of ethanol pricing policies, not only in relation to the price of gasoline, defended by the producers, but also in relation to the price of sugar. In other words, it is necessary for the government to find a predictable policy that involves the prices of the three products (gasoline, ethanol and sugar), so that the producer can make investments to safely and profitably increase ethanol production. What also became clear in this study was the importance of Infrastructure Logistics through investment in more competitive modes, such as pipelines, waterways and railways. This is an important way to reduce the total cost of the ethanol production chain and consequently its competitiveness in the domestic and international markets.

The second paper, "Efficiency in Ethanol Production: a two-stage DEA approach," complements the first. Because the ethanol plants in Brazil have wide ranging efficiency and productivity, investing in productivity gains generally results in increased production. In other words, the second paper seeks to analyze the efficiency and productivity of fuel ethanol plants in Brazil using a two-stage data envelopment analysis (DEA) model, taking into account different contextual variables related to the productive efficiency of the ethanol plants in Brazil. The first stage of the model consists of calculating the efficiency scores using the DEA model; the second consists of estimating using Beta, Tobit and Simplex regressions the parameters of the variables that can influence the indexes obtained in the first stage.

The variables used in this work are the same as those of the first paper, with the exception of the additional data for planted area and total recoverable sugar (ATR) per plant. The ATR represents the quality of sugarcane in terms of its capacity to be converted into sugar or ethanol through the transformation coefficients of each productive unit. The period studied is 2009 to 2015.

The methodology used in the second paper is based on the attainment of efficiency scores through an output-oriented DEA-BCC model using the rDEA package of the R application. After obtaining these scores, we performed three regressions (Beta regression, Tobit regression and Simplex regression) using the following contextual variables: year; region; plant organized as a cooperative; increasing production; national ownership; efficient transportation; ethanol/gasoline ratio; distance factor. Importantly, this paper is the first to address the productivity of Brazilian plants through the two-stage DEA method, which is the basis of its innovativeness. In addition, we used three regression techniques to provide robustness and reliability to the work.

The main conclusions of the second paper are as follows: (i) The ethanol/gasoline price ratio contributes to increasing efficiency and productivity. The ratio shows a negative sign in all regressions; thus, the lower the parity, the higher the productivity. (ii) Another contextual variable that deserves attention is whether the plant is organized as a cooperative; the variable indicates that cooperative plants have greater efficiency and productivity. (iii) The variable Efficient Transport also presents important results in all the regressions, confirming that plants close to pipeline/railroad/waterway terminals are more efficient. These mills are more profitable than a mill that needs to compensate for its poor location by lowering selling prices.

The third paper, "Evaluation of Ethanol Multimodal Transport Logistics: a Case in Brazil," addresses issues related to the ethanol distribution logistics between mills and various distribution hubs scattered throughout Brazil. The problem in question can be categorized as a classic transshipment model, with more than 400 mills and more than 70 distributions hubs. Transshipment occurs when one or more hubs of the transportation network can act as both origin and destination for flows. In other words, we describe our methodology for building a transshipment model to analyze logistics flows. We then apply the results of the application to Brazil's ethanol logistics network and draw conclusions.

The problem is colossal, with thousands of variables. The methodology used to solve transshipment problems is linear programming, which produces the best logistics solution for the minimum total cost. Thus, an operational research model was developed, relating all possible flows and returning the replenishment and transshipment flows of an optimal solution. In this way, a model was constructed with a view to represent the logistics of ethanol distribution in Brazil, including a multimodal ethanol transport system that links the main points of production to the main points of consumption (São Paulo, Rio de Janeiro, and Port of Santos) to service the foreign market.

The transshipment model used was capable of showing that large-scale transport modes (such as pipelines, waterways and railways) can capture a significant volume of ethanol at reduced costs, thereby reducing reliance on the more expensive road mode, and rendering biofuel a competitive alternative to gasoline. As our main objective is to calculate the replenishment and transshipment flows to minimize total costs, we are going to consider the total supply of ethanol to be equal to the total demand. The model will work ethanol demand from 2015 to 2030 based on data from ANP (Brazilian National Petroleum Agency). For the costs of road transport, currently the most common mode used, we will consider all possibilities, meaning that all ethanol plants can connect by road to any terminal. For the determination of road freight, we will use a simple linear regression from data obtained from the Brazilian Shipping Information System. For the shipping rates of rail and sea transportation, especially for cabotage operations, we will consider values obtained from Transpetro, a subsidiary of Petrobras and ANTT, the Brazilian National Ground Transportation Agency. The rates for the pipeline and waterway modes were obtained from the websites of the companies Logum Logistica and Transpetro. The storage costs and fees, port charges, and some other services at the handling and storage terminals were also obtained from information on the websites of Logum Logistica and Transpetro. It is important to mention that the more efficient modes of transportation such as pipeline, waterway, and railway have infrastructure capacity constraints that are considered in the model. Furthermore, in the case of multimodal system of pipelines and waterway, there are contractual minimum volumes called Ship or Pay (SOP) that also impose restrictions.

To develop the models from 2015 to 2030, we used the projected tariffs and costs based on projected data from IPCA (a widely accepted inflation index in Brazil) and forecasts or the Brazilian GDP. Taking advantage of the infrastructure of pipeline terminals, we assumed that Paulinia would remain as a hub connecting pipelines, railways, and waterways to the pipelines to supply the markets of Sao Paulo, Rio de Janeiro, and export. The entire multimodal system of ethanol was therefore planned with five pipeline terminals and two new waterway terminals going to Paulinia. In Paulinia the ethanol from these terminals would supply the local market and would connect the pipelines to supply four terminals in the Greater São Paulo region (cities of Barueri, Sao Caetano, Guarulhos, and Cubatao), one terminal in Duque de Caxias for the Rio de Janeiro market with a maritime outlet for export at the Ilha D'agua terminal. Furthermore, a new pipeline was planned to run all the way to the Port of Santos to complement the export capacity of the Brazilian ethanol.

This paper presents a logistics assessment of the multimodal system of ethanol transport by pipeline and waterway, which is in its initial phase of operation in Brazil. The system was designed to supply the largest Brazilian markets and for export. The results indicate that the system will reach of 80% of its capacity in 2020 and its maximum capacity in 2028. This transport system by pipeline and waterway will replace much of the road transport, thus reducing the logistics costs especially for export and increasing the competitiveness of Brazilian ethanol on foreign markets. The pipeline and waterway terminals in the state of São Paulo will reach their peak capacity in a few years due to the state's high production of ethanol.

On last paper, Are there multiple bubbles in the ethanol–gasoline price ratio of Brazil?, the use of right tailed tests to detect explosiveness in economic and financial data was recommended. It has been recognized in the literature that right tailed ADF tests have low power in detecting periodically collapsing bubbles. As we have seen, a convincing series of testing were recently developed to detect the exact bubble as well as its origination and collapse dates.

This paper analyzed the formation of a bubble in the ethanol-gasoline price ratio in Brazil, using right tailed ADF tests. Bubbles essentially imply the detachment of the price of an asset from its fundamentals. To account for possible bubbles in Brazil's ethanol sector, we analyzed the ratio of the ethanol price with respect to the gasoline price, with the latter serving as the fundamental variable in our case. This makes sense, given that gasoline is a substitute of ethanol, and hence, its price is likely to play an important role in the determination of ethanol prices. We observe that there is clear evidence of explosiveness in ethanol prices relative to gasoline prices. In addition, we observe that there are multiple bubbles in the ethanol prices, which has thus far not collapsed. In general, the results corroborate the empirical and anecdotal evidence in the Brazilian sugarcane industry.

We can conclude that the first two papers—despite their completely different approaches and methodologies—confirm the fact that cooperative plants have better results, and that lower ethanol/gas price ratios are key for significant gains in scale and therefore greater efficiency and profitability. We also observe that the first paper on ethanol production highlighted the use of efficient modes, such as pipelines, waterways and railroads, and that plants with this advantage can obtain better margins. This fact is reinforced in the third paper, which uses a transshipment model to show that capacities for new projects in logistics will be attained in the coming years. It is worth mentioning that the road mode of transportation of ethanol is more expensive, thus removing biofuel's competitiveness over gasoline.

The fourth paper on ethanol and gasoline prices shows that the industry cannot be leveraged only with investment and business initiatives: government action is also needed to prevent bubbles in the ethanol/gasoline price ratio from driving power plants into a deficit scenario. In other words, the industry must have predictability regarding the price of gasoline so it can plan investments.

6.2 FUTURE CHALLENGES AND SUGGESTIONS

The four papers presented address current issues related to fuel ethanol in Brazil. All of them are innovative, both with respect to theme and the methodologies used.

An important challenge for the ethanol market is the fact that (as of 2018) the National Petroleum Agency sets the prices of gasoline and diesel by refinery (Gazeta Digital, 2018). Therefore, the mills will have a planning horizon, despite the known difficulties of an excessive tax burden and tight margins. Additionally, in the context of such data, it will be possible to track the external ethanol market. Other challenges concern expectations related to productivity gains with second generation ethanol and corn ethanol, which will allow for a significant marginal production of biofuel in Brazil. Moreover, direct ethanol delivery between producer and retailer should be analysed in future studies.

Due to expected advances in the production and conversion stages of biomass and lower costs of enzymes and equipment, second-generation ethanol has the potential to be more competitive in the long term than conventional ethanol and gasoline. With this level of competitiveness, second-generation ethanol is a viable solution to reduce the amount of gasoline imported by Brazil, moreover it is alternative for increasing ethanol exports, given that the consumption of advanced fuels is valued by public policies in the USA and in Europe (ANP, 2015).

6.3 REFERENCES:

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