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Fuel and biofuel sectors in Brazil - comparison with developed economies and analysis of hypothetical free fuel pricing policy

Nataliya Dimitrova Popova

Thesis presented to obtain the degree of Doctor in Science. Area: Applied Economics

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EPIGRAPH

“От финските карпи до снежната Етна,

От царствена Волга до Сена приветна,

Скитах се, дивих на хубости странски,

Но за вас мислех, о, чуки балкански.

Морета преплувах, планини превалях,

Менях кръгозори, гледки великански,

Но един лик само в душата си галях,

Една любов само – тебе, рай балкански.

Видях чудесата на дивни изкуства,

Творбите на гений и на труд титански,

Шеметни за поглед, за ум и за чувства,

Но за вас въздишах, о, рози балкански.”.

Иван Вазов

CONTENTS

RESUMO ... 7
ABSTRACT ... 8
1. INTRODUCTION ... 9
REFERENCES ... 12
2. DOMESTIC FUEL SECTORS AND INTERNATIONAL CRUDE OIL PRICE – A COMPARISON BETWEEN BRAZIL, GERMANY AND THE UNITED STATES ... 15
ABSTRACT ... 15
2.1. INTRODUCTION ... 15
2.2. CHARACTERISTICS OF THE DOMESTIC FUEL SECTORS ... 16
2.2.1. Profile of the three countries of interest ... 16
2.2.2. Profile of the domestic fuel sectors ... 17
2.2.3. Fuel pricing ... 18
2.2.4. Domestic fuel prices ... 22
2.3. METHODOLOGY AND DATA DESCRIPTION ... 24
2.3.1. Stationarity tests ... 24
2.3.2. GARCH models ... 25
2.3.3. Data description ... 26
2.4. RESULTS ... 27
2.4.1. Stationarity test ... 27
2.5. MGARCH-DCC ESTIMATION RESULTS ... 27
2.6. CONCLUSIONS ... 35
REFERENCES ... 36
3. PRICE TRANSMISSION IN THE BIOFUEL-RELATED SECTORS – A COMPARISON BETWEEN BRAZIL, GERMANY AND THE UNITED STATES ... 39
ABSTRACT ... 39
3.1. INTRODUCTION ... 39
3.2. LITERATURE REVIEW ... 41
3.2.1. Price transmission literature – an overview ... 41
3.2.2. Brazil ... 42
3.2.3. United States ... 43
3.2.4. European Union ... 44
3.2.5. International and comparative studies ... 45
3.3. METHODOLOGY ... 47

3.3.1. Stationarity tests 47
3.3.2. Cointegration and VECM 48
3.3.3. Granger causality test 49
3.3.4. Model specification 50
3.4. DATA DESCRIPTION 51
3.5. RESULTS 54
3.5.1. Stationarity test 54
3.5.2. Cointegration test and VECM estimation results 55
3.5.3. Comparison of the results 63
3.6. CONCLUSION 65
REFERENCES 65
4. HYPOTHETICAL EFFECTS OF FREE GASOLINE PRICES ON THE ETHANOL SECTOR IN THE STATE OF SÃO PAULO 71
ABSTRACT 71
4.1. INTRODUCTION 71
4.2. LITERATURE REVIEW 74
4.2.1. Fuel pricing policy and simulation of free fuel prices 74
4.2.2. Price transmission in the biofuel-related sectors and ethanol demand estimation. 76
4.3. METHODOLOGY 78
4.3.1. Stationarity tests 78
4.3.2. Structural vector autoregression (SVAR) 78
4.3.3. Cointegration and SVECM 79
4.4. THEORETICAL MODEL AND DATA DESCRIPTION 80
4.5. RESULTS 84
4.6. CONCLUSIONS 90
REFERENCES 91
5. CONCLUSION 95
APPENDIX 97

RESUMO

Combustíveis e biocombustíveis no Brasil – comparação com países desenvolvidos e análise de uma política de preços livres dos combustíveis

As recentes tendências do preço internacional do petróleo renovaram o interesse dos pesquisadores na importância da política de formação de preços de combustíveis praticada pelo governo para a economia doméstica, especialmente em países em desenvolvimento. O Brasil constitui um caso particularmente interessante no contexto de intervenção do governo em setores domésticos de combustíveis: A empresa petrolífera estatal Petrobras atua como price-setter para todos os derivados de petróleo comercializados no país. Essa política, no entanto, trouxe graves conseqüências negativas para o setor brasileiro de combustíveis – e especialmente para a indústria nacional de etanol. Nesse contexto, o principal objetivo deste estudo foi fornecer uma base para o desenvolvimento de uma política de preços reformada, que seja mais adequada às necessidades do país e não tenha um impacto tão negativo para a economia doméstica. Para tanto, a presente pesquisa foi dividida em três capítulos distintos. O primeiro capítulo aborda uma análise comparativa da correlação dinâmica entre os preços domésticos dos combustíveis e o preço internacional do petróleo para o Brasil, a Alemanha e os Estados Unidos. Os resultados da estimativa de um modelo MGARCH-DCC realizada para os três países fornecem evidências empíricas das diferenças existentes entre o pass-through da volatilidade do mercado internacional de petróleo para a economia doméstica. O estabelecimento artificial dos preços de refinaria pelo governo brasileiro levou a uma correlação menor em comparação à Alemanha e aos EUA – dois países onde o governo não intervém nos preços dos combustíveis. Uma combinação de política de preço dos derivados do petróleo livre e uma política fiscal flexível como na Alemanhã poderia trazer competitividade para o setor doméstico de combustíveis e ao mesmo tempo garantir um preço estável ao consumidor – um exemplo que deve ser considerado pelo governo brasileiro. O segundo capítulo vai um passo além, incluindo os setores de biocombustíveis na análise, a fim de verificar se existem diferenças nos mecanismos de transmissão de preços relacionados aos biocombustíveis nos três países estudados. Os resultados obtidos nos testes de cointegração e na estimativa de um modelo VEC mostram que, enquanto no Brasil e nos EUA os setores de etanol se caracterizam por uma relação estável entre as séries de preços examinadas, na Alemanha não se observa um vínculo tão forte e permanente – um resultado que pode ser atribuído às mudanças na política de biocombustíveis no país, bem como às características específicas de seus setores de biocombustíveis. O terceiro capítulo do estudo dá continuidade à análise, focando na situação do Brasil e nos efeitos hipotéticos de uma política de preços livres dos combustíveis. Uma simulação de preço livre para a gasolina no período entre 2007 e 2016 foi construído e as respostas hipotéticas do setor de etanol foram calculadas, usando as elasticidades da demanda obtidas pela estimação de um modelo VEC estrutural. Os resultados mostram que uma política mais liberal teria levado ao aumento no preço do etanol no estado de São Paulo, tornando a produção de etanol mais lucrativa do que o açúcar para os produtores de cana, o que teria sido benéfico para o setor – especialmente depois de 2011, quando ele entrou em uma grave crise. A conclusão final deste trabalho é de que se faz necessária uma reformulação da política de formação de preços praticada no Brasil, a fim de ajudar o etanol a recuperar sua competitividade como substituto a combustíveis fósseis e a se restabelecer na matriz energética do país.

Palavras-chave: Política de formação de preços; Biocombustíveis; Comparação entre países diferentes

ABSTRACT

Fuel and biofuel sectors in Brazil – comparison with developed economies and analysis of hypothetical free fuel pricing policy

The recent trends in the international crude oil price have brought back the interest of researchers to the importance of the practiced by the government fuel pricing policy for the domestic economy, especially in the developing world. Brazil constitutes a particularly interesting case when it comes to the government participation in the domestic fuel sectors. The state-owned oil company Petrobras acts as a price-setter for all petroleum derivatives sold in the country. This policy, however, has had severe negative consequences for the Brazilian fuel sector and especially for the domestic ethanol industry. Thus, the main goal of this study is to provide a basis for the development of a reformed pricing policy, which is more suitable for the needs of the country and does not have severe negative impact on the domestic economy. For this purpose, this work is divided into three chapters that interrelate and contribute for the achieving of the objective. The first chapter focuses on a comparative analysis of the dynamic correlation between the domestic fuel prices and international crude oil in Brazil, Germany and the United States. The results of the performed MGARCH-DCC estimation for the three countries provide empirical evidence for the differences existing between the pass-through of volatility from international oil markets to the domestic economy. The artificially established by the government ex-refinery prices of petroleum derivatives in Brazil led to lower correlation in comparison to Germany and the U.S. - two countries where the government does not intervene in the formation of the prices of petroleum derivatives. The used combination of free fuel prices and flexible fiscal policy, as the case of Germany, can induce competitiveness in the domestic fuel sector and at the same time keep domestic prices stable – an example that should be considered by policy makers in Brazil. The second chapter goes one step further by including the biofuel sectors in the analysis in order to verify if there exist differences in the biofuel-related price transmission mechanisms in the three countries of interest. The obtained results of the performed cointegration tests and estimation of VECM show that while in Brazil and in the U.S. the ethanol sectors are characterized by a stable relationship between the examined price series, in Germany such a strong and permanent link is not observed – a result that can be attributed to the changes in the policy regarding biofuels in the country, as well as to the specific characteristics of its biofuel-related sectors. The third chapter of the study gives a continuation to the analysis by focusing on the situation in Brazil and the hypothetical effects of a free fuel pricing policy. A simulated free gasoline price for the period between 2007 and 2016 is constructed and the hypothetical responses of the ethanol sector are calculated, using the obtained by the estimation of a structural VEC model demand elasticities. The results show that such a change in the policy would have led to higher ethanol prices in the state of São Paulo, making it more profitable for sugarcane producers to engage in the production of biofuel instead of sugar, which would have been beneficial for the sector, especially after 2011 when it entered a severe crisis. The final conclusion of this work is that there is a need for reformulating the practiced fuel pricing policy in Brazil in order to help ethanol regain its previous competitiveness as a substitute for conventional fossil fuels and to reestablish itself in the country's energy matrix.

Keywords: Fuel pricing policy; Biofuels; Country comparison

1. INTRODUCTION

The understanding of the pass-through from international crude oil markets to domestic fuel sectors has been a relevant topic of research, especially after 2015, when the international crude oil price registered a significant decrease. This trend had an impact on the world economy (DEV; CHAUBEY, 2016) and highlighted the issue of petroleum product pricing in a number of developing economies (FATTOUH; OLIVEIRA; SEN, 2015), some of which have adapted their domestic fuel policies to the changing environment. Moreover, the increased production and use of biofuels as substitutes for conventional fossil fuels worldwide after 2005, has introduced another element in the transmission mechanism in the oil-related sectors, which altered the price relationship between international crude oil, domestic fuels and agricultural crops (PERI; BALDI, 2010).

Brazil is one of the major consumers of crude oil and fossil fuels in the world (EIA, 2017). The domestic fuel sector is characterized by indirect government intervention in the pricing of all petroleum derivatives. The state-controlled company Petrobras acts as a price-setter, establishing the ex-refinery price of gasoline, diesel and liquefied petroleum gas (LPG). The practiced fuel pricing in the country, however, relies on irregular adjustments without a transparent and well-defined formula and the artificially established low domestic fuel prices have brought imbalances to the domestic economy, and especially to Petrobras (SERIGATI, 2014).

In addition, Brazil is a world leader in the production and consumption of biofuels. It is one of the only countries in the world where ethanol produced from sugarcane acts as a substitute for gasoline, due to the introduction of the flex-fuel vehicle in 2003, which allowed the final consumer to choose freely between these two fuel alternatives. This specific characteristic of the biofuel industry in Brazil implies the existence of a distinct relationship between the domestic biofuel and fuel sectors. In addition, a unique link between ethanol and sugar markets is observed in the country, since the two products have the same feedstock and are considered competitors on the supply side.

In recent years, however, the Brazilian ethanol industry suffered a severe crisis, characterized by insufficient supply and a significant drop in the total production of ethanol, due to a number of factors that have their origins in the financial crisis of 2008. The global turmoil resulted in high BRL/USD exchange rate and led to a period of oversupply on the international sugar market. In the years after the crisis, the world price of sugar registered an increasing trend, which was followed by a rise in the domestic price of this commodity in Brazil, making the production of sugar much more attractive to sugarcane producers instead of ethanol. Moreover, the unfavorable climatic conditions in the country during this period, the increasing production costs for ethanol, the lack of financing, the insufficient government stimuli towards the production and use of biofuels in combination with the practiced policy of controlled domestic fossil fuel prices aggravated the crisis in the ethanol sector. The stagnation of the industry and the negative consequences of the implicit government intervention in the formation of fuel prices have raised the question of a policy reform regarding the fuel and biofuel industries in Brazil (PALACIOS, 2015).

An important initial step before considering an alternative fuel pricing policy, however, is the better understanding of the way different government policies and taxation alter the relationship between the domestic fuel and biofuel sectors, as well as the pass-through from the international crude oil market to the domestic economy. A comparative analysis of the situation in Brazil with other countries can provide important insights about the factors that drive the price transmission in the oil-related sectors, so that a reformed pricing policy that serves better the needs of the domestic economy can be developed. In particular, a comparison with countries that practice different fuel policies, but at the same time are engaged in the production and consumption of biofuels, is proposed in the present study as a crucial first step for the analysis of the possible policy alternatives for Brazil.

The United States is currently the leading producer of biofuels in the world (EIA, 2017). The country relies on the production of ethanol from corn, which is used mainly for blending with conventional gasoline in low percentages (from 5 to 15%). Pure ethanol is not widely used in the U.S., which implies that biofuels and conventional fossil fuels act as complements. In addition, the domestic fuel sector in the country is not subject to any government intervention in the price formation of petroleum derivatives, whose prices are a result of the supply and demand conditions on the market.

In Europe, the biggest producer and consumer of biofuels is Germany, which is also a global leader in the production of biodiesel (EIA, 2017). The country has a pioneering role in the promotion and adoption of government policies stimulating the biofuel sector, which have served as an example for other member countries of the European Union. Biodiesel in Germany is produced mainly form rapeseed oil and is available as a blend with conventional diesel and in a pure form as a substitute. Moreover, as is the case of the U.S., the German government does not intervene in the domestic fuel sector, which is characterized by freely fluctuating petroleum derivative prices.

Both Germany and the U.S. represent interesting cases for comparison with Brazil, since the three countries exhibit significant differences when it comes to market specifications and government policies regarding fuels and biofuels. It is interesting to observe and compare the distinct impact that specific policy and market instruments have on the biofuel-related price transmission mechanisms and the pass-through of volatility from the international crude oil market to the domestic economy. The findings of such a comparative analysis could be particularly useful for policy makers, since they could provide knowledge and better understanding of the impacts of different policy regimes and market conditions on the domestic fuel and biofuel markets. Such knowledge is crucial for many other economic agents as well, such as market operators and traders, agricultural producers, fuel and biofuel refiners, since it can affect their decisions to produce, invest and adopt mechanisms for protecting their production from different risks.

Another essential step before deciding on a reform in the practiced fuel and biofuel policies is the study of the hypothetical effects of different regimes on the domestic economy. Empirical analysis of hypothetical scenarios with different degrees of government intervention in the domestic fuel sector in Brazil could provide important insights for policy makers on the potential effects of a change in the practiced policy and could serve as a basis for the establishment of a policy reform in the country.

The main objective of this work is to examine the fuel and biofuel sectors in Brazil from a comparative point of view, in order to shed light on the effects different government fuel pricing policies and market specifications have on these sectors. In addition, the impact of a hypothetical situation, in which the government was not intervening in the price formation of gasoline in the country, is included in the performed analysis. The goal is to provide a better understanding of the situation in Brazil, which can offer a basis for a reform in the practiced fuel pricing policy by the government, considered to be essential for the further development of the domestic economy (VIEGAS, 2011; OLIVEIRA; ALMEIDA, 2015; ALMEIDA; OLIVEIRA; LOSEKANN, 2015; AZEVEDO; SERIGATI, 2015).

For achieving the main objective, the present thesis is divided into three chapters. The analysis starts with a comparison between the fuel sectors in Brazil, Germany and the U.S., focusing on the differences between the specific sector characteristics, pricing policies, and fuel price disparities in each of the three examined economies.

The empirical part of the study is devoted to the comparison between the dynamic volatilities of domestic gasoline and diesel prices and their correlation with the international crude oil price. The main idea is to examine how government policies and market characteristics of the fuel sectors alter the relationship between the domestic fuel prices and international crude oil. Using average monthly data for the period July, 2005 – November, 2016, a Dynamic Conditional Correlation Multivariate General Autoregressive Heteroscedasticity (MGARCH-DCC) model is estimated for the three countries of interest, in order to determine the dynamic volatility of the price series over time and the conditional quasi-correlations between the domestic fuel prices and international crude oil. The results of the suggested comparative analysis could provide important insights for the way different government policies and taxation affect the pass-through of volatility from the international crude oil market to the domestic economy, which for the specific case of Brazil is rather important for the consideration of fuel sector policy reforms.

The second chapter of this thesis goes one step further in the comparative analysis by introducing the effects of the biofuel sectors in the three examined economies in the empirical study. The focus of this chapter is the thorough analysis of the price transmission in the biofuel-related sectors in Brazil, Germany and the U.S. in order to identify how different market specifications alter the price linkages between fuels, biofuels and main feedstock.

A number of studies were published after 2005 analyzing the biofuel-related price transmission in Brazil and in the U.S., especially due to the existing food versus fuel debate raised by environmentalist groups in recent years as criticism to domestic biofuel stimulation policies. A thorough literature review of these studies is presented in Serra and Zilberman (2013), according to which the data used, the modelling techniques and the main findings of the literature differ significantly, which does not allow comparison across different papers and countries. Moreover, it is expected that different market characteristics and government policies result in different specifics of the domestic price relationships between the biofuel-related sectors, as pointed out by Kristoufek, Janda and Zilberman (2013). Thus, the second chapter of this thesis focuses on performing a comparative analysis, using the same methodology, data types and frequency for the three chosen economies with an emphasis on the possible causes for the discovered differences in the biofuel-related price transmission mechanisms.

In addition, the possible effects of the global financial crisis of 2008 on the price linkages in the three countries is accounted for in the analysis by splitting the sample into two sub-periods. The empirical part of the study is based on time-series techniques including stationarity and cointegration tests and the estimation of specific vector autoregression models for each country with or without error-correction terms, depending on the results of the performed a priori testing procedures. The used data consists of monthly average producer prices for the period July, 2005 – November, 2016. In particular, the price linkages between the ethanol, sugar and gasoline are examined for Brazil, between ethanol, corn and gasoline for the U.S., and between biodiesel, rapeseed oil and diesel for Germany.

The better understanding of the effects that government policies and market characteristics have on the price transmission in the domestic biofuel-related sectors can provide additional knowledge for the development of policy reforms for countries like Brazil. The second chapter of the thesis serves as an important continuation of the first one, deepening the understanding of the interrelations between the fuel and biofuel sectors and creating a more stable basis for the establishment of an alternative policy regarding fuels and biofuels in Brazil.

After performing a comparative analysis of the situation in Brazil with Germany and the U.S., the thesis proceeds with the study of a hypothetical situation in which the Brazilian government adopted a fuel pricing policy in 2007, similar to the one practiced in the other two examined countries, where gasoline prices are allowed to accompany the international crude oil price fluctuations. Thus, the main objective of the third chapter of the thesis is to shed light on the possible effects that such pricing policy would have had on the domestic ethanol sector. More precisely, the hypothetical impact of no government intervention in the fuel sector on biofuel prices and demanded quantities in the state of São Paulo for the period 2007-2016 is examined. For this purpose, a simulated freely fluctuation consumer price of gasoline C was constructed, using the provided by DATAGRO series of "interned" gasoline A price, which is based on the RBOB spot price and accounts for all additional costs incurred in the import of fuels to the Brazilian market.

In order to perform the hypothetical analysis, first the elasticities of fuel and biofuel demand, as well as the response of the domestic ethanol price to changes in the price of gasoline, are estimated by fitting a structural vector error-correction (SVEC) model to the data that incorporates the specific characteristics of the fuel and biofuel sectors in Brazil. The variables included in the model consist of monthly average data series for the state of São Paulo for the period January, 2007 - June, 2016. The estimated contemporaneous responses of the variables to changes in the price of gasoline are used afterwards for the calculation of the hypothetical ethanol price for a scenario with no government intervention in the domestic fuel sector and the consecutive effects on the demanded quantities of ethanol and gasoline.

Although some authors have examined the effects of simulated free fuel prices on the domestic inflation rates and on the price of ethanol in the country (SERIGATI, 2014; CORRÊA; TEIXEIRA, 2014; CUNHA, 2015; COSTA; BURNQUIST, 2016), a thorough hypothetical analysis of the absence of government intervention in the domestic fuel sector in Brazil has not been previously performed. Thus, the third chapter of the study aims at contributing to the existing literature by providing empirical evidence on the possible effects of a fuel pricing policy that relies on free prices without any government intervention.

All in all, the idea behind this thesis is to provide a basis for further investigation of the possible paths for changes in the practiced fuel pricing policy in Brazil. There is a need of a reform that would mitigate the negative consequences of the policy currently practiced in the country and would provide incentives for the production and consumption of ethanol.

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2. DOMESTIC FUEL SECTORS AND INTERNATIONAL CRUDE OIL PRICE – A COMPARISON BETWEEN BRAZIL, GERMANY AND THE UNITED STATES

ABSTRACT

The main focus of this paper is the analysis of the correlation between the domestic gasoline and diesel prices in Brazil, in the United States and in Germany, and the international crude oil price. Such a comparative study provides important insights on the way different government policies and market characteristics alter the relationship between domestic fuel prices and international crude oil. Using monthly data for the period July, 2005 – November, 2016, a Dynamic Conditional Correlation Multivariate General Autoregressive Heteroscedasticity (MGARCH-DCC) model is estimated for the three chosen economies. The obtained results provide empirical evidence that different government fuel pricing policies and taxation alter the correlation between domestic fuel prices and international crude oil. The artificially established by the government ex-refinery prices of petroleum derivatives in Brazil led to lower correlation between domestic fuel prices and oil in comparison to Germany and the United States - two countries where the government does not intervene in the formation of domestic fuel prices. In addition, the findings of the study show that the estimated correlations for Brazil and the U.S. exhibit significant time-varying behavior, while such a result was not found for the German market, where the oil-gasoline and the oil-diesel correlations remained rather stable through time. This result indicates that a combination of freely fluctuating fuel prices and flexible fiscal policy, as the one existing in Germany, introduces competitiveness to the domestic fuel sector, while, at the same time, keeps domestic fuel prices stable through time. The lack of such a consensus between the practiced fuel pricing policy and taxation in Brazil can be considered the main reason for the negative consequences of keeping fuel prices at levels different than their international equivalents.

Keywords: International crude oil price; Domestic fuel prices; Volatility; MGARCH-DCC model

2.1. Introduction

International crude oil prices are more dynamic than the prices of other commodities and affect many sectors of the economy, due to the fact that oil is used for the production and transportation of a vast majority of items that are used on a regular basis – from fuels, to fertilizers, medicine, plastics and clothing. In general, the historical oil price trend has been characterized by strong fluctuations and high volatility. Until June 2014, oil prices remained relatively high and in line with rising global demand (EIA, 2016). In the second half of 2015, however, this trend was reversed and oil prices registered a significant decrease. During the first two months of 2016, OPEC crude oil prices sat at an average of 27.63 USD/barrel - a decrease from an average annual price of 96.29 USD/barrel in 2014 (EIA, 2016).

The recent oil price decrease has brought back the relevance of the analysis of the relationship between international crude oil and domestic fuel prices. In addition, this situation has posed challenges for developing countries in regards to reforms in their petroleum product pricing policies, which in general include some degree of government control of the domestic fuel sector. Brazil is an example of a developing economy in need of a policy reform regarding the domestic fuel sector, mainly due to the severe corruption scandal in which the national oil company Petrobras has been involved in recent years (PALACIOS, 2015). A comparative analysis of the situation in Brazil with other countries can provide important insights on the factors that drive the pass-through from international oil prices to the domestic fuel sector, so that a reformed pricing policy that serves better the needs of the domestic economy can be developed.

The goal of the present study is to analyze the differences between the oil-related sectors in Brazil, in the United States and in Germany – three countries with rather distinct characteristics when it comes to market specifications and government pricing policies of the fuel sectors. The main focus is the analysis of the correlation between the domestic gasoline and diesel prices in the three countries of interest and the international crude oil price, which can shed light on the way different government policies and market characteristics alter the relationship between the domestic fuel sectors and international crude oil. The empirical study is based on the estimation of a Dynamic Conditional Correlation Multivariate General Autoregressive Heteroscedasticity (MGARCH-DCC) model, using monthly data for the period July, 2005 – November, 2016.

A number of authors have discussed the price transmission between domestic fuel prices and international crude oil, especially due to the increased production and use of biofuels in recent years. For Brazil, the results of Cavalcanti, Szklo and Machado (2011) have shown no effective price relationship between gasoline and international crude oil, while Prado, Rodarte and Bonfim (2015) found a correlation between Brazilian gasoline and diesel prices and the international price of oil, but this correlation was not found to be as significant as in other countries. For Germany, Pokrivcak and Rajcaniova (2011) have demonstrated that there exists a long-term relationship between domestic gasoline prices and the price of Europe Brent oil. Studies for the U.S. market have provided evidence for a relationship between crude oil and energy prices, characterized by a significant asymmetric price transmission, where gasoline prices increase faster when crude oil prices rise and they fall more slowly when crude oil prices drop (BORENSTEIN et al., 1997; ATIL et al., 2014; BREMMER; KESSELRING, 2016).

Price volatility links between domestic fuel sectors and international crude oil prices, however, have received much less attention in the existing literature. Previous research has shown that between 2009 and 2015 fuel price volatility has increased due to the greater transmission of international oil price volatility to domestic fuel sectors (GILBERT; MUGERA, 2014). Araújo (2006) found that domestic fuel prices in Brazil do not accompany the high volatility of international crude oil prices between 2002 and 2006. Rahman (2016) found that in the United States oil price volatility affects positively the price of gasoline and contributes to the asymmetries in the transmission between these two price series.

The remainder of this work is organized as follows: Section 2.2 is dedicated to a comparative analysis of the main characteristics of the fuel sectors in the three examined countries; Section 2.3 describes the methodology and the data used in the study; Section 2.4 presents the obtained results; and Section 2.5 concludes with final remarks.

2.2. Characteristics of the domestic fuel sectors

2.2.1. Profile of the three countries of interest

In 2015, Brazil ranked among the top ten producers of crude oil worldwide, according to the U.S. Energy Information Administration. The country has the second-largest reserves of crude oil in Latin America, following Venezuela, which accounts for about 1% of the world's total reserves. The majority of these reserves (more than 94%) are located off-shore, 80% of which are found near Rio de Janeiro (EIA, 2017). Considerable amount comes from the discovered in the beginning of the 2000s pre-salt oil reserves, which accounted for about a quarter of total Brazilian oil output in 2015 (EIA, 2016).

Brazil's consumption of oil and other conventional fossil fuels continues to surpass its production. In 2014, the domestic demand for petroleum and other liquid fuels was 3.2 million b/d (EIA, 2016). The country's crude oil exports in 2014 increased 36% in comparison to the previous year. Currently, the United States is the largest importer of Brazilian crude oil, followed by China and India. When it comes to oil imports, the regions that exported the largest volumes of crude oil to Brazil in the past few years were Africa and the Middle East, accounting for 68.7% and 26.3%, respectively, of the total imported quantities.

The United States is the main producer and consumer of crude oil worldwide. According to the EIA, in 2015, the U.S. was the number one global oil producing country, followed by Saudi Arabia and Russia. Until 2008, crude oil production in the country was following a decreasing trend, which was reversed in 2009. The recent increase in U.S. oil production has been a result of the exploration of unconventional shale oil resources, which have become more accessible and economically viable.

Oil demand in the country has been rising steadily over the last decades. The U.S. is currently the top consumer worldwide, responsible for approximately one fifth of the total global oil consumption (EIA, 2016). Moreover, the U.S. is the world's leading oil importer. When it comes to oil reserves, the country ranked on 10th place in 2015 (EIA, 2016). The Gulf Coast accounts for about 50% of the U.S. refining capacity, and another 21% is located in the Midwest. Export destinations for U.S. refined petroleum products include Mexico, Central and South America, and Western Europe.

Petroleum and its derivatives continue to be Germany's main source of energy. In 2015, the country ranked as the fifth main consumer of crude oil worldwide and the number one energy consumer in Europe (EIA, 2016). Germany has little domestic oil and natural gas production and relies heavily on imports. Currently, it is one of the top five global crude oil importers. The country has well diversified and flexible oil supply infrastructure, which consists of pipelines and import terminals. In addition, Germany is one of the largest oil refiners in the world, and the second largest in Europe and Eurasia after Russia (EIA, 2016).

2.2.2. Profile of the domestic fuel sectors

In Brazil, the transportation sector accounts for the largest share of the demand for petroleum products. Gasoline produced by refineries in the country is pure, free of biofuel additives and is referred to as gasoline A. Pure gasoline, however, is not available to the final consumer. The gasoline that reaches retail stations in Brazil is a blend with ethanol and is referred to as gasoline C. Currently, the proportion of ethanol in this gasoline blend is 27% (NPA, 2017). This percentage, however, has been gradually increasing through time and has been used by the government as an indirect measure for controlling domestic biofuel demand.

Diesel consumption in the country is restricted primarily to the agricultural sector and road transportation, mainly heavy duty vehicles (buses and trucks) used for massive transit and load. Since January, 2008 it has been mandatory for all automotive diesel fuel marketed in Brazil to be blended with biodiesel produced from plant oils or animal fat. Currently, the proportion of biodiesel represents 8% of the diesel blend sold at the pumps and this percentage is expected to reach 10% in 2019 (NPA, 2017).

Grade A gasoline and pure diesel in Brazil can be produced by the state-owned company Petrobras, by other refineries or formulators and petrochemical plants, and they can be imported by companies authorized to do so by the National Agency of Petroleum, Natural Gas and Biofuels - NPA. Afterwards, the fuels are sold to the several distributors operating in the country, mixed with the respective biofuel and sold to consumers through thousands of service stations spread throughout the country. Currently, there are 76 companies operating in the oil industry in Brazil, with 39 national and 38 foreign companies in addition to Petrobras, which remains the largest oil producer and refiner in the country (EIA, 2016).

In the United States, gasoline is one of the major fuels consumed domestically and it is the main product refined from crude oil. There are three main grades of gasoline sold at retail refueling stations in the country: Regular, Midgrade, and Premium. These grades indicate the octane rating of the fuel, with higher ratings resulting in higher prices. In addition, a special gasoline blend called Reformulated gasoline (RFG) can be found in some regions of the U.S. with high air pollution levels, since it is cleaner than conventional gasoline and reduces smog-forming and toxic particles in the air. Currently, about 30% of total gasoline sold in the country is reformulated (EIA, 2016). Diesel fuel in the U.S. is used in most freight trucks, trains, buses, boats, and farm and construction vehicles. Blends of up to 20% biodiesel (B20) can generally be used in unmodified diesel engines. A small amount of diesel fuel is imported.

Gasoline and diesel in the U.S. are shipped from the refinery by pipelines to terminals near consuming areas, where they may be blended with other products to meet local government and market specifications. The fuels are then delivered by tanker trucks to individual retail stations. Some retail outlets are owned and operated by refiners, while others are independent businesses that purchase gasoline from refiners and marketers and are unbranded.

Germany has the highest demand for gasoline and diesel in the European Union after France. The common fuel types sold at retail stations in the country are the following: gasoline – Super E5, with up to 5% of ethanol; Super E10, with 10% ethanol; and diesel. Diesel is highly used in Germany, which is a common trend for European countries. The shift from gasoline to diesel in the EU began 20 years ago and has led to excess gasoline production capacity and a corresponding shortage of diesel production. The transportation sector in Germany accounts for the largest share of petroleum product demand (EIA, 2016). The German government, however, has a goal of reducing the country's oil dependence and putting one million electric vehicles on the road by 2020 and six million by 2030 (EIA, 2016).

The retail market for gasoline and other conventional fossil fuels in Germany is dominated by an oligopoly of five vertically integrated oil companies that have a large network of stations and direct access to refining capacities: Aral, Shell, JET, Esso and Total (FRONDEL; VANCE; KIHM, 2015). In order to increase the competition in the retail sector, German retail stations are legally obligated to post online every price change, the precise time stamp, the geographic coordinates of the station, the opening hours, and the brand. The density of fuel stations in the country varies significantly across regions, with a high density, for instance, in the Rhine-Main area and a considerably lower density in the Eastern part of the country. Fewer gasoline stations are located close to borders with countries that usually have lower fuel prices, like Poland and Luxembourg (EIA, 2016).

2.2.3. Fuel pricing

Fuel pricing policies and taxation are the main tools used by governments in order to influence domestic fuel prices. According to Pires and Schechtman (2010), fuel pricing policies can be divided into three main categories: ad hoc decisions, automatic adjustments through formulas, and market prices. The first type occurs when fuel prices are adjusted as a result of macroeconomic factors or political considerations by the government or by a company, which is directly or indirectly controlled by the State. Usually the adjustments happen in irregular time intervals and the used criteria are non-transparent. Countries following this mechanism include Brazil, China, India, and Indonesia. The second type of policy, which is practiced in South Africa, Bolivia, Chile, Pakistan and Peru, for instance, relies on previously determined formulas by the government or by the national oil company. The adjustments occur automatically in certain periods of time, which makes this mechanism more transparent than the first one. The third policy is practiced in most OECD countries, where prices of oil derivatives are driven by the market conditions and the role of the government is reduced to taxation. Germany and the United States fall into this category.

Regarding fuel taxation, two main types of taxes are usually applied, according to Pires and Schechtman (2010) – specific tributes, which have a fixed value, such as excise taxes or duties and transportation taxes, and value-added taxes (VATs), which are fixed as a percentage of the final fuel price. Differences in the fuel pricing policy and taxation result in divergence of domestic fuel prices from the international crude oil price and in addition generate significant price dissimilarities among countries.

In Brazil, Petrobras is the dominant participant in the domestic oil-related sectors, holding important positions in upstream, midstream, and downstream activities. The company held a monopoly until 1997, when the government opened the sector to competition. The liberalization process was effectively completed in 2002, and currently, there is no official government control over the industry. Nevertheless, fuel prices in Brazil are not entirely free to follow international crude oil price fluctuations. The ex-refinery prices of all petroleum derivatives are set and adjusted by Petrobras. The price adjustments use as a reference the variations in the Brent crude oil price and the USD exchange rate published by the Central Bank of Brazil. The established pricing system aims at diminishing the negative effects that volatile fuel prices accompanying the fluctuations in the international crude oil price, would have on the inflation rate (FATTOUH; OLIVEIRA; SEN, 2015). Moreover, the Brazilian government frequently adjusts taxation in order to maintain the domestic fuel price stable in times of high international crude oil prices. The federal flat-rate fuel tax CIDE has been altered four times since 2010 and remained zero between June, 2012 and February, 2015 as a result of the government policy, which had as an objective during this period keeping domestic gasoline prices lower than their international equivalents.

The practiced fuel pricing policy has been an important decision for the Brazilian government, since the country has a history of periods with extremely high inflation. The fact that in Brazil the distribution system of goods relies mainly on road transportation implies that higher fuel prices will be passed on to the final price of consumer goods, since the majority is transported by trucks. The inadequate infrastructure for using cheaper types of goods transportation, such as rail, for instance, makes almost all sectors of the economy vulnerable to fuel price fluctuations.

Currently, the final consumer price of petroleum derivatives in Brazil consists of four components: producer or importer realization price, costs of biofuel for blending, federal and state taxes, distributor and retailer transportation costs and margins (see figure 1). The ex-refinery price of gasoline set by Petrobras constitutes 29% of the final consumer price, while for diesel this component accounts for 48% of the final price. As it can be seen on figure 1, the tax burden in Brazil for diesel is lower than for gasoline, accounting for 25% and 40% of the final consumer fuel price, respectively.

The fuel taxes practiced in Brazil include the following federal and state taxes:

- Value-Added Tax on Services and Circulation of Goods (ICMS) – a state tax, calculated using a weighted average price for the final consumer, which is updated fortnightly. Currently, the value of this tax is 25% for gasoline for the state of São Paulo, while the average for the entire country is 25.7% (NPA, 2017).
- Contribution for Intervention in the Economic Domain (CIDE) - a federal tax, which resembles a contribution on the import and marketing of oil and oil products, as well as ethanol. The CIDE adjustments are effectively used by the Brazilian government as a tool for offsetting adjustments in the ex-refinery price of fuels in the country. In 2012, this tax rate reached zero for both gasoline and diesel as an attempt to maintain domestic fuel prices at lower levels than their international equivalents. Currently, it is set at 100 R$/cubic meter for gasoline (NPA, 2017).
- Social Integration Program/Public Service Employee Savings Program (PIS/PASEP) – federal taxes, whose rates are charges levied on the gross revenue of companies. Since September, 2016 the value of this tax has been set to 67.94 R$/cubic meter for gasoline (NPA, 2017).
- Contribution to Social Security Funding (Cofins) - a federal tax, levied on the gross revenue of companies. Since September, 2016 it is established at 313.67 R$/cubic meter for gasoline (NPA, 2017).

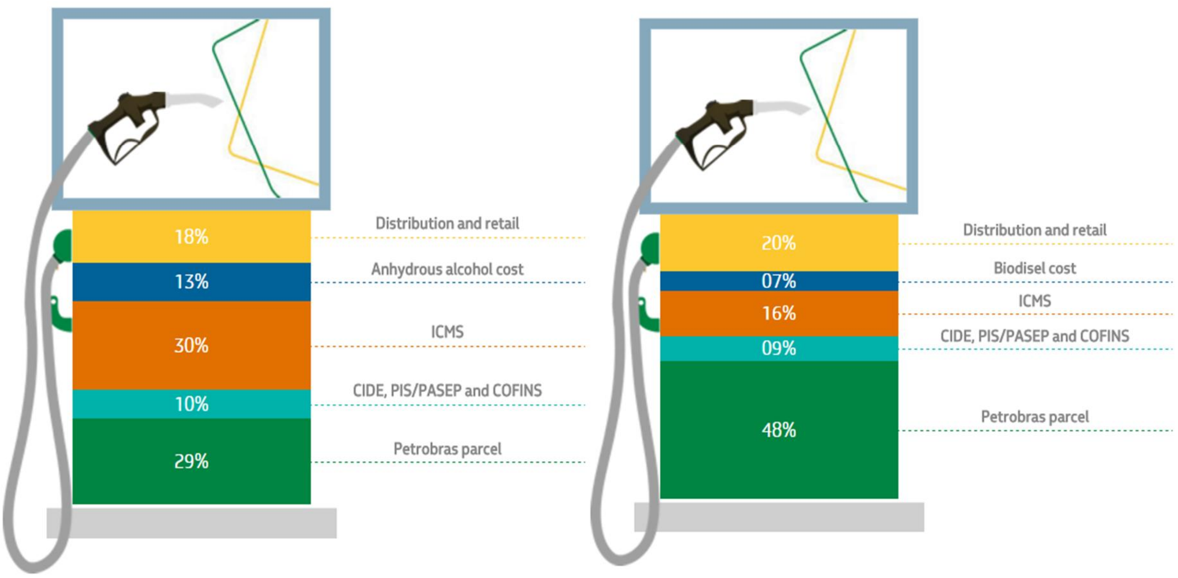

Figure 1. Consumer price composition for gasoline C (on the left) and diesel (on the right) in Brazil, referring to March, 2017. Source: Petrobras.

In the United States, the retail prices of gasoline and diesel are not regulated by the government. They are formed by the supply and demand conditions on the market and follow the fluctuations in the international price of crude oil. Fuel prices in the country include four main components: cost of crude oil, refining costs and profits, taxes, distribution and marketing costs and profits (see figure 2). The cost of crude oil is the major contributor to the final consumer price of fuels in the U.S., currently accounting for approximately 50% of this price.

Refining costs and profits vary seasonally and by region in the United States, partly because of the different gasoline formulations required to reduce air pollution in different parts of the country. Gasoline is more expensive in the Western States, mainly because of the requirements for cleaner fuel blends in this region due to concerns for air quality (EIA, 2016). Moreover, the increased demand for gasoline in the summer months generally results in higher prices and, thus, creates demand seasonality. Gasoline prices are also affected by the cost of other ingredients that may be blended with the fuel, such as ethanol.

Federal, state, and local government taxes also contribute to the retail price of fuels in the U.S. In 2015, the federal excise tax on gasoline was 18.34 cents/gallon, while for on-highway diesel it was 24.90 cents/gallon (EIA, 2016). There is an additional Leaking Underground Storage Tank fee of 1 cent/gallon. As of July 1, 2015, state and local government taxes and fees on gasoline averaged 26.49 cents/gallon, while for diesel this amount was 27.24 cents/gallon (EIA, 2016). County and city taxes can have a significant impact on the price of gasoline in some locations, as well.

In general, in the United States, the tax burden on diesel has been higher than on gasoline. This trend, however, has been reversed in the beginning of 2017, when the tax burden for both fuels was equalized and accounted for 20% of the final consumer price as it can be seen on figure 2. In comparison to Brazil, the tax burden on fuels in the U.S. is almost twice less.

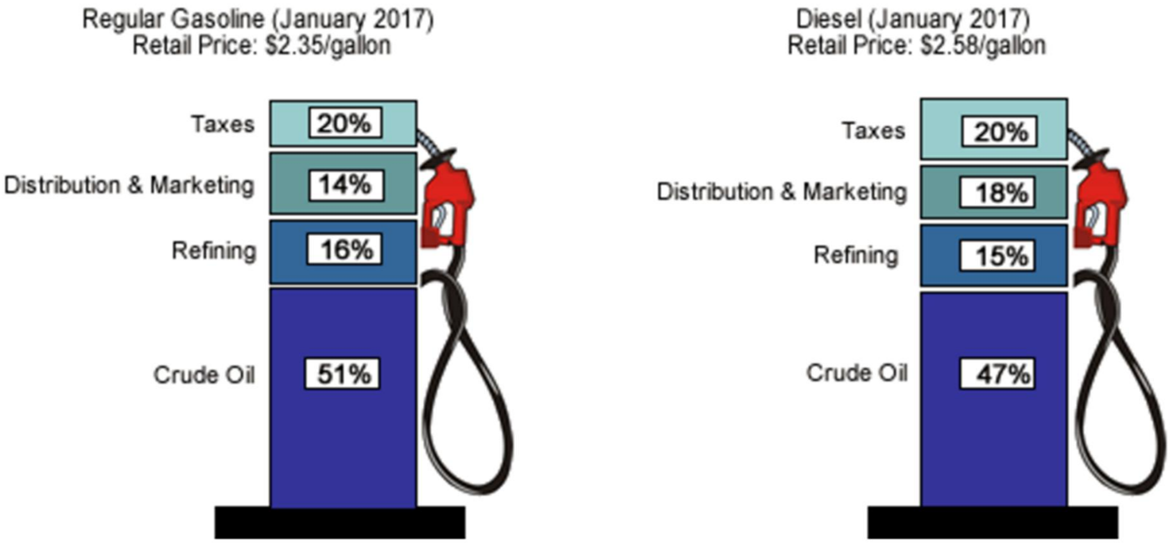

Figure 2. Consumer price composition for gasoline and diesel in the United States, referring to January, 2017.
Source: EIA.

Similar to the situation in the U.S., fuel pricing in Germany is not subject to government pricing regulations. Domestic gasoline and diesel station operators are free to choose at which time, in which direction and by which amount they change prices for all offered fuel types. The retail fuel market in the country is characterized by a considerable level of competition, mainly due to the introduction of price comparison websites, such as the Market Transparency Unit (Markttransparenzstelle), which publishes fuel prices in real time and ensures higher transparency for the final consumer.

The majority of fuel retailers in the country charge more than one price a day. Gasoline stations that belong to the big brands change their prices more frequently, possibly because they react more quickly to price adjustments of competitors. In addition, many stations increase prices in the evening hours, which typically remain valid during the night, resulting in lower average daytime fuel prices in the country (EIA, 2016). The price varies across regions, as well, with the South-West and North regions offering the lowest and the South-East region the highest average price quotes.

The fuel price in Germany consists of three components: commodity price, taxes and distributor and retail margins (see figure 3). The first component depends on the price for the particular product at the port of Rotterdam, which is the main market for fuels in Western Europe, where the benchmark prices of all types of gasoline and diesel are determined, depending on international market conditions. Since these prices are quoted in USD, the EUR/USD exchange rate is of importance for the final fuel price in Germany, as well. Margins in the fuel retail market in the country are small, accounting for approximately 10% of the final gasoline price.

The largest portion of the final consumer price of gasoline and diesel in Germany consists of the tax burden, which accounts for more than 50% of the retail price. This tax burden includes a fixed energy tax of roughly 0.65 EUR/liter on gasoline and 0.47 EUR/liter on diesel, as well a value-added tax of 19%. In comparison to Brazil and the U.S., Germany has a much higher tax burden on fuels. In the EU, however, the country does not have the toughest fuel tax system. The Netherlands, Italy and Denmark are the top three countries with highest fuel taxes in Europe (GLOBAL PETRO PRICES, 2017).

Figure 3. Consumer price composition for gasoline and diesel in Germany, referring to July, 2016.
Source: MWV.

2.2.4. Domestic fuel prices

Different government fuel pricing policies and taxation lead to domestic fuel prices that do not always follow international crude oil, but rather diverge significantly. The main argument used by governments in order to justify the use of pricing mechanisms on the domestic fuel market is the fact that oil products tend to have significant negative impact on inflation rates and fuel pricing policies are considered a useful tool for fighting inflation. In addition, the government policies that influence fuel prices lead to significant divergence of the domestic price levels across countries. Figures 4 and 5 illustrates the evolution of gasoline and diesel final consumer prices in Brazil, Germany and the United States expressed in USD/liter for the period between 2005 and 2016, as well as the international benchmark oil prices – Europe Brent and OK WTI spot prices.

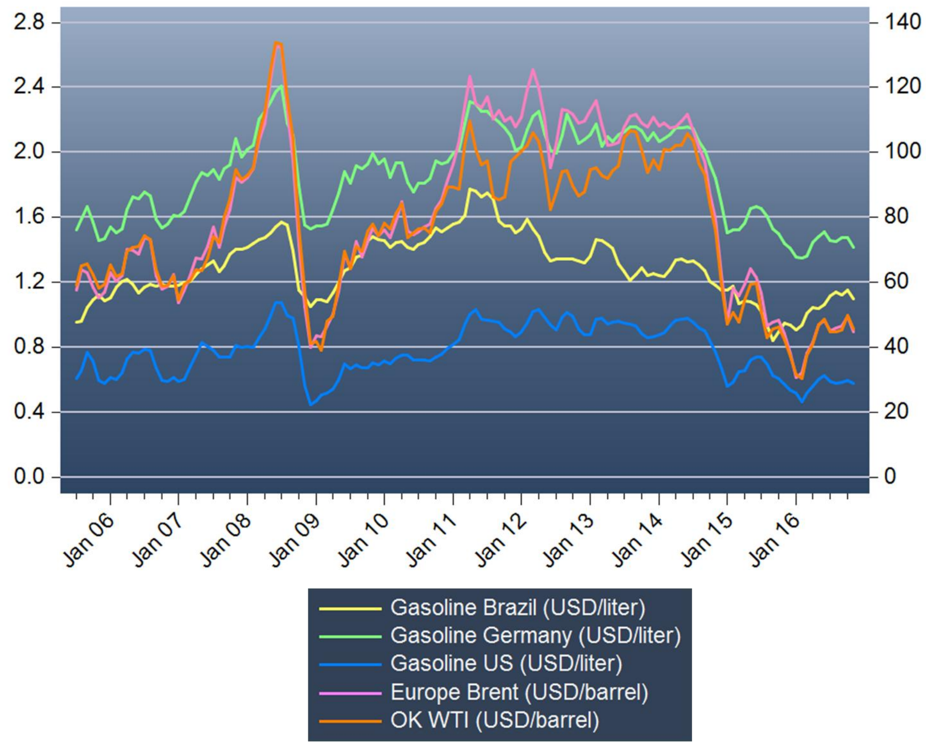

Figure 4. Monthly average consumer prices of gasoline in Brazil, Germany and the United States

Source: EIA, NPA, MWV.

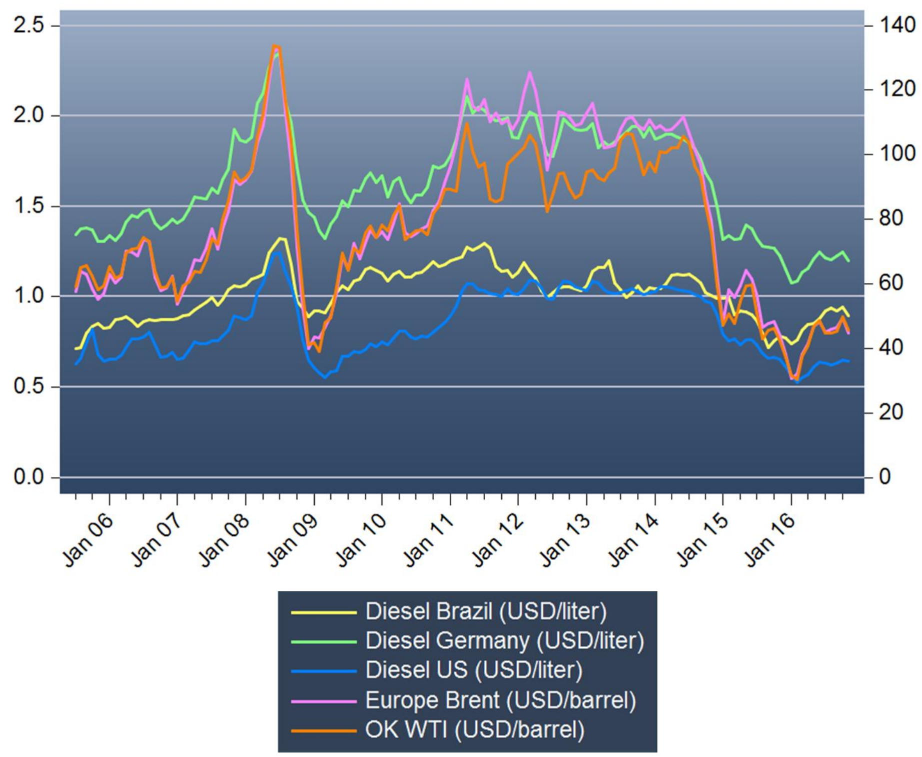

Figure 5. Monthly average consumer price of diesel in Brazil, Germany and the United States

Source: EIA, NPA, MWV.

The graphs show that the prices of both gasoline and diesel were the highest in Germany, followed by Brazil, and finally the U.S. with the lowest fuel prices among the three countries of interest during the observed period. This fact reflects the difference in the fuel tax burden in the three economies. As mentioned above, in Germany, the final consumer pays much more in the form of taxes for gasoline and diesel than in Brazil and in the U.S. In comparison to the rest of the world, the U.S. is among the countries with the lowest gasoline prices, while Germany ranks in the highest quantile (GLOBAL PETRO PRICES, 2017). Currently, the lowest gasoline price has been observed in Venezuela, while the highest – in Hong Kong. When it comes to Europe, however, the highest fuel prices are observed in Norway, Iceland and the Netherlands where gasoline is 25 to 30% more expensive than the European average (GLOBAL PETRO PRICES, 2017).

The type of government fuel pricing policy determines the extent to which the fluctuations in the international crude oil price are passed through to the domestic fuel sectors. As discussed above, in Brazil, the ex-refinery price of all petroleum derivatives is determined by Petrobras, while in the U.S. and in Germany gasoline and diesel prices are formed on the free market and are not subject to government interventions. As it can be seen on figures 4 and 5, the prices of both fuels in the U.S. and in Germany appear to fluctuate much more than in Brazil, especially when the price of diesel is concerned. This result is not surprising, since in Brazil the international crude oil price variations are not absorbed by domestic fuel prices.

2.3. Methodology and data description

2.3.1. Stationarity tests

This study relies on time series techniques for performing the analysis, which requires taking into account some general statistical properties of the time series data a priori (SERRA; ZILBERMAN, 2013). The first property to be considered is the stationarity of the examined variables. Stationary data is characterized by time-constancy of its statistical distribution and such a time series is considered to be a process integrated of order zero - I(0).

Common practices in time series modelling involve the application of the augmented Dickey-Fuller and the Phillips-Perron tests for determining whether a data series is stationary or not. The proposed by Elliott, Rothenberg and Stock (1996) DF-GLS test, however, has significantly greater power and better overall performance in terms of small-sample sizes, dominating the ordinary Dickey-Fuller tests (HATANAKA, 1996). This test represents a modified version of the augmented Dickey-Fuller test, in which the series has been transformed by a generalized least-squares regression. The DF-GLS test is performed fitting a regression of the following form (ELLIOTT; ROTHENBERG; STOCK, 1996):

$$y_t = \alpha + \beta y_{t-1} + \delta t + \zeta_1 \Delta y_{t-1} + \zeta_2 \Delta y_{t-2} + \cdots + \zeta_k \Delta y_{t-k} + u_t \quad (2.1)$$

where k is the number of lags of first-differenced, detrended variables. The number of lags of the process has to be chosen appropriately. Lags should be added to the model only until they are significant, i.e. until there is no serial correlation in the error term. For this purpose, information criteria like the Ng-Perron, the Schwarz Criterion and the Modified Akaike Information Criterion are used.

There are two forms of the DF-GLS test – GLS detrending (where the series to be tested is regressed on a constant and a linear trend) and GLS demeaning (where only a constant appears in the first-stage regression). The null hypothesis of the DF-GLS test assumes that the process y_t is a random walk. There are two alternative hypotheses depending on the chosen form of the test: y_t is stationary about a linear time trend, and y_t is stationary with a possible nonzero mean but with no linear time trend.

2.3.2. GARCH models

Another property of time series to be examined in this work is the changing volatility of the studied prices over time. The most common methodology for analyzing this aspect is the estimation of autoregressive heteroscedasticity (ARCH) models, which provide insights about the volatility structure of the time series. Contrary to the existing econometric models that consider the assumption of constant variance, Engle (1982) introduced a new class of models with zero mean, no serial correlation, constant unconditional variance, and non-constant variance conditional on the past. These are called autoregressive conditional heteroscedastic (ARCH) processes which allow the conditional variance of the process to change over time as a function of past errors, leaving the unconditional variance unchanged.

A natural generalization of the ARCH model, which allows for more flexible lag structure, was introduced by Bollerslev (1986) and is referred to as a GARCH process. Considering a real-valued discrete-time stochastic process ε_t and an information set available at time *t* (ψ_t), the GARCH (*p,q*) process defined by Bollerslev is given by:

$$\varepsilon_t|\psi_{t-1} \sim N(0, h_t) \quad (2.2)$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$$
$$= \alpha_0 + A(L)\varepsilon_t^2 + B(L)h_t \quad (2.3)$$

where $p \geq 0, q > 0, \alpha_0 > 0, \alpha_i \geq 0\ (i = 1, \ldots, q), \beta_i \geq 0\ (i = 1, \ldots, p)$. If $p = 0$, the GARCH (*p,q*) reduces to an ARCH (*q*) process, and if both *p* and *q* are zero, ε_t is just a white noise process. The main difference between the ARCH and the GARCH models is that the former considers the conditional variance as a linear function of past sample errors, while the latter allows the addition of the lagged conditional variances, as well.

The above presented model considers the volatility of a single time series variable. The multivariate GARCH models represent an extension of the univariate GARCH to an *n*-variable case, where H_t is the (*n x n*) conditional variance-covariance matrix of the *n*-dimensional zero mean random variable ε_t. This matrix is a function of the information set ψ_{t-1}, which allows each element of the matrix to depend on *q* lagged values of the squared and cross-products of ε_t, as well as on *p* lagged values of the elements of H_t. MGARCH models allow the conditional variance-covariance matrix of the dependent variables to follow a flexible dynamic structure and the conditional mean to follow a vector autoregression (VAR) process. The main advantage of this model is that it allows for the study of the relationships between the volatilities of multiple time series.

In general, MGARCH models differ depending on the specification of the conditional covariance function, each of them having its own characteristics and limitations. The focus of this work is the dynamic conditional correlations model (DCC) developed by Engle (2002), which is based on the decomposition of the matrix H_t. More specifically, for the process $r_t|\psi_{t-1} \sim N(0, H_t)$, this matrix can be written as:

$$H_t = D_t R_t D_t \quad (2.4)$$

where R is the correlation matrix containing the conditional correlations and D_t is a diagonal matrix containing the standard deviations of the process, i.e. D_t consists of the $\sqrt{h_{it}}$ elements on its main diagonal. The

DCC model allows for the R matrix to be time-varying. Moreover, the conditional variances can be modelled as univariate GARCH processes and the conditional correlations as functions of past market shocks.

Engle (2002) starts with considering the conditional correlation between two random variables r_{it} and r_{jt} as given by:

$$\rho_{ij,t} = \frac{E_{t-1}(r_{i,t}r_{j,t})}{\sqrt{E_{t-1}(r_{i,t}^2)E_{t-1}(r_{j,t}^2)}} \quad (2.5)$$

The returns r_t can be rewritten as the conditional standard deviation ($\sqrt{h_{i,t}} = \sqrt{E_{t-1}(r_{i,t}^2)}$) multiplied by the standardized disturbances ε_t, which have zero mean and variance equal to one for each series, in the following way:

$$r_{i,t} = \sqrt{h_{i,t}}\varepsilon_{i,t} \quad (2.6)$$

Furthermore, Engle defines the conditional covariance matrix of returns as $E_{t-1}(r_t r_t') \equiv H_t$, where H_t can be decomposed as in Equation (2.4). The correlation matrix R_t consists of all the equations in (2.6). In order to obtain this matrix, the $\rho_{ij,t}$' s have to be estimated. The author suggests the following correlation estimator:

$$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}q_{jj,t}}} \quad (2.7)$$

where the *q*'s are modelled as univariate GARCH processes in the following fashion (with $\bar{\rho}_{ij}$ being the unconditional correlation between the two random variables):

$$q_{ij,t} = \bar{\rho}_{ij} + \alpha\left(\varepsilon_{i,t-1}\varepsilon_{j,t-1} - \bar{\rho}_{ij}\right) + \beta(q_{ij,t-1} - \bar{\rho}_{ij}) \quad (2.8)$$

Engle assumes that the average of $q_{ij,t}$ will be $\bar{\rho}_{ij}$ and the average variance will be one. Moreover, the correlation estimator given by equation (2.8) will be positive definite as long as the covariance matrix Q_t, which consists of the elements $q_{ij,t}$, is a weighted average of positive definite and semidefinite matrices. To ensure the positive definiteness of Q_t, the condition $\alpha + \beta < 1$ must hold. The estimation of the developed MGARCH-DCC model, as proposed by Engle, relies on maximum likelihood techniques.

2.3.3. Data description

The data used in this paper consists of the following price series:

- Common gasoline monthly average price, resale, Brazil, BRL/liter (NPA);
- Diesel monthly average price, resale, Brazil, BRL/liter (NPA);
- Regular motor gasoline, all areas, retail price, U.S., USD/gallon (EIA);
- On-Highway diesel fuel price, including taxes, U.S., USD/gallon (EIA);
- Gasoline Super 95 E5 consumer price, Germany, EUR cents/liter (MWV);
- Diesel consumer price, Germany, EUR cents/liter (MWV);
- Europe Brent spot price, fob, USD/barrel (EIA);
- OK WTI spot price, fob, USD/barrel (EIA).

All data series were obtained from secondary sources and refer to monthly average consumer prices for the period July, 2005 - November, 2016. After 2005, biofuels started gaining considerable importance worldwide, which makes the chosen period of study rather relevant. According to Silveira and Mattos (2015), the increased global production and consumption after 2005 of biofuels altered the relationship between domestic fuel prices and crude oil. Moreover, the analysis is performed using consumer prices, in order to account for the combined effects of both government pricing policies (which have a direct impact on the ex-refinery price of fuels) and taxation (which impacts the final consumer price of fuels). The price of Europe Brent was used for the estimation of the models for Brazil and Germany, while for the U.S. the WTI oil price was included in the estimated system of prices.

In order to make the data comparable for the purposes of the study, all fuel prices were converted to USD/liter, using the monthly average BRL/USD and EUR/USD exchange rates published by OECD. All variables were transformed into log differences in order to work with price returns.

2.4. Results

2.4.1. Stationarity test

Prior to performing the analysis, the data series were tested for stationarity using the DF-GLS test. Both variations of the test were applied and the obtained results are reported in panel A., table 1. The number of lags was chosen using the Schwarz Information Criterion (SIC). All variables were found to be nonstationary in log form and stationary in log differences.

Table 1. DF-GSL stationarity test

Variable	Model 1		Model 2	
	Lag	DF-GLS Statistic	Lag	DF-GLS Statistic
ln(Gasoline Brazil)	1	-1.313693	1	-1.609520
Δln(Gasoline Brazil)	0	-7.837802	0	-7.964033
ln(Diesel Brazil)	1	-1.157250	1	-1.601780
Δln(Diesel Brazil)	0	-8.147026	0	-8.213816
ln(Gasoline U.S.)	1	-2.786858	1	-3.297559
Δln(Gasoline U.S.)	0	-4.954149	0	-6.265992
ln(Diesel U.S.)	1	-1.775985	1	-2.163413
Δln(Diesel U.S.)	0	-5.385869	0	-6.624598
ln(Gasoline Germany)	1	-1.641758	1	-1.822392
Δln(Gasoline Germany)	1	-4.766480	0	-7.999417
ln(Diesel Germany)	1	-1.447007	1	-1.523262
Δln(Diesel Germany)	0	-7.214243	0	-8.219388
ln(Brent oil)	1	-1.815444	1	-1.889856
Δln(Brent oil)	0	-5.630807	0	-7.217942
ln(WTI oil)	1	-2.255105	1	-2.395465
Δln(WTI oil)	1	-4.039960	0	-7.244452

Source: Results of the research.
Note: Model 1 – constant (critical values by MacKinnon (1996): 5% = -1.95; 1% = -2.58); Model 2 – constant and trend (critical values by Elliott, Rothenberg and Stock (1996): 5% = -3.2; 1% = -3.74).

2.5. MGARCH-DCC estimation results

The MGARCH-DCC (1,1) model was employed for calculating the time-varying conditional covariance matrix for the system of gasoline, diesel and crude oil prices in Brazil, in the United States, and in Germany. The resulting estimated coefficients of the MGARCH models for each country are plotted in tables 2, 3, and 4, respectively. The performed Wald test for the mutual significance of the adjustment parameters for the variance rejects the null hypothesis that $\lambda_1 = \lambda_2 = 0$ at all conventional levels for the three countries of interest, thus, suggesting that the DCC model fits better the data than the constant conditional correlation MGARCH model.

For Brazil, a heteroscedastic model with just an ARCH term was estimated, since the results of the performed standard likelihood ratio test gave a rejection of the model containing both ARCH and GARCH terms. As it can be seen in table 2, the ARCH term is significant for the three variables of interest, indicating that the variance of the price returns of gasoline, diesel and oil is affected by past error terms. The estimated conditional quasi-correlations are all positive, which implies that when the volatility of one variable increases, this leads to higher volatility in the other variables in the system. Gasoline and diesel prices were found to have a correlation of approximately 0.94, indicating that the two prices are highly related, while oil was found to be more correlated to the price of diesel than to the price of gasoline.

Table 2. Results of the estimated MGARCH-DCC model for Brazil

	Variables		
	Gasoline	Diesel	Oil
ARCH α	0.234019**	0.1955458**	0.5982747*
	(0.0928589)	(0.0825349)	(0.1734821)
Constant	0.001147*	0.0012406*	0.0035733*
	(0.0001692)	(0.0001713)	(0.0007212)
Corr(gasoline ,diesel)	0.9411468*	Adj. coef. λ_1	0.2821239*
	(0.0114379)		(0.090197)
Corr(gasoline, oil)	0.3801902*	Adj. coef. λ_2	0.11816
	(0.1078035)		(0.1036921)
Corr(diesel, oil)	0.4117312*	Log-likelihood	826.0598
	(0.1047976)		

Source: Results of the research.
Note: *significant at 1% level; **significant at 5% level; ***significant at 10% level. Standard errors in brackets.

Figure 6 plots the estimated dynamic volatilities of the three price series for Brazil, which showed strong time-varying behavior during the analyzed period. As it can be observed on the graph, the price of oil was much more volatile than the consumer prices of diesel and gasoline in the country. During the global financial crisis of 2008, the volatility of oil registered a significant jump, reaching historically high values. It returned considerably fast to its previous levels in the beginning of 2009. Moreover, after January, 2015, when the international price of oil fell to record low levels for the first time after the financial crisis, its price became much more volatile.

The volatility of domestic gasoline and diesel prices, on the other hand, remained rather stable during the observed period. It increased as well during the crisis years, but this response was rather small in comparison to international crude oil, thus, indicating that the artificially established fuel prices in Brazil did not allow international crude oil price volatility to be transmitted to the domestic fuel market. This result confirms the findings of Araújo (2006), who showed that domestic fuel prices in Brazil did not follow international crude oil price volatility between 2002 and 2006.

Figure 7 plots the estimated correlations between the fuel sector in Brazil and international crude oil, which showed strong time-varying behavior. The dynamic correlation between gasoline and diesel was found to be rather high, remaining in the range of 0.8-1.0 during the entire analyzed period, with the following few exceptions: in the end of 2008, as a result of the global financial crisis; in the beginning of 2011 - a period characterized by high international commodity prices and ethanol crisis in Brazil; in the end of 2013, when Petrobras started a wave of adjustments of the ex-refinery prices of both gasoline and diesel, and set the CIDE on fuels to zero in 2012.

The estimated oil-gasoline and oil-diesel dynamic correlations were found to move together and to vary significantly during the observed period. Both correlations were lower in the beginning of the period, registered an increase after the global financial crisis and showed more variation after October, 2014. This trend can be associated with the significant drop in international oil prices in the beginning of 2015, while Brazilian fuel prices were kept at the same levels and did not follow the decreasing international trend.

It is interesting to observe that the correlation between oil and the two fuels of interest in Brazil turned negative twice during the observed period – once in the end of 2015, and a second time in the first quarter of 2016. The main reason for this lies in the falling trend in the international crude oil price during these periods, while in Brazil domestic fuel prices were kept at levels higher than their international equivalents.

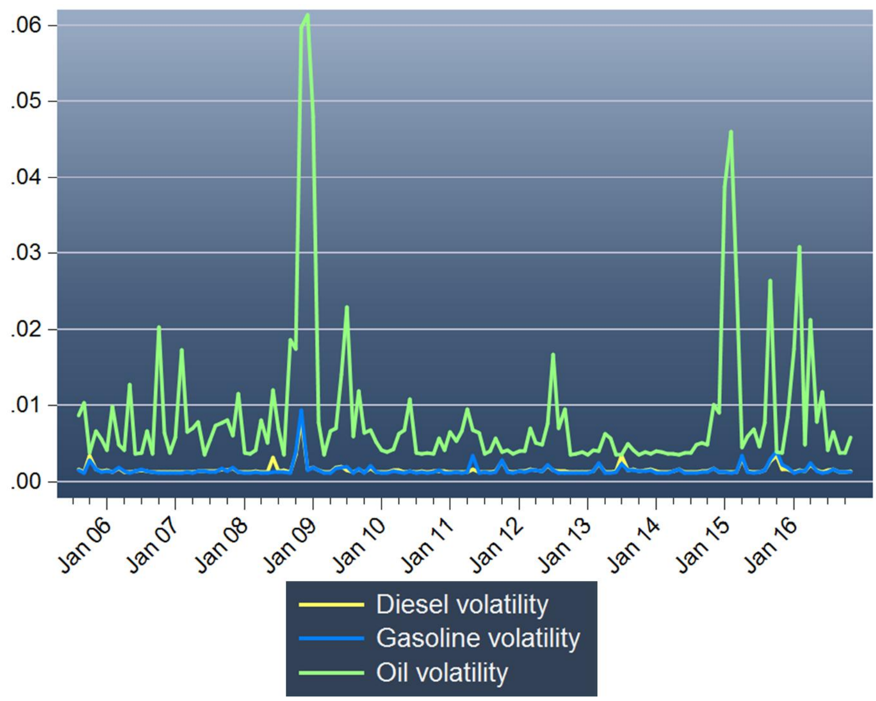

Figure 6. Estimated dynamic volatilities for Brazil

Source: Results of the research.

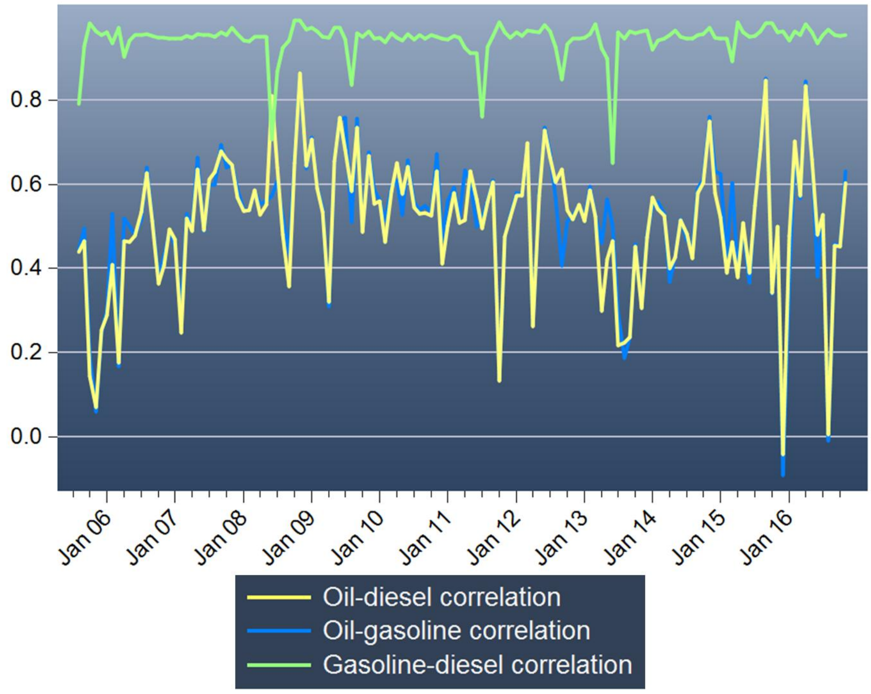

Figure 7. Estimated dynamic correlations for Brazil

Source: Results of the research.

The estimated MGARCH-DCC model for the United States results in significant ARCH and GARCH terms for all variables in the system, indicating that all variances are affected by both past error terms and past variances. The positive and significant GARCH terms imply that positive shocks increase volatility. The adjustment coefficients of the variance (λ_1 and λ_2) were found to be jointly different than zero, indicating that the variance of the variables is dynamic. All estimated correlations are positive and high – above 0.7, while for Brazil, the correlations between oil and the domestic fuel price returns were found to be less than 0.5, thus, indicating the influence of the government intervention in the domestic fuel price formation process. In addition, the price returns of oil and diesel in the U.S. appear to be more correlated than of gasoline and oil, which is a result similar to the one observed for Brazil. The domestic price returns of the two fuels of interest have the highest correlation among the three price pairs, with estimated value equal to 0.83.

Table 3. Results of the estimated MGARCH-DCC model for the United States

	Variables		
	Gasoline	Diesel	Oil
ARCH α	0.3609045*	0.3341871*	0.1955048*
	(0.0898413)	(0.0940148)	(0.0619498)
GARCH β	0.6016908*	0.6198705*	0.7153121*
	(0.0649956)	(0.0784156)	(0.0870745)
Constant	0.0004483**	0.0002362	0.0008299**
	(0.0002141)	(0.0001447)	(0.0004523)
Corr(gasoline ,diesel)	0.8314788*	Adj. coef. λ_1	0.074778
	(0.0326323)		(0.0590974)
Corr(gasoline, oil)	0.718828*	Adj. coef. λ_2	0.4995046**
	(0.0504732)		(0.2015766)
Corr(diesel, oil)	0.7219551*	Log-likelihood	681.0854
	(0.0510684)		

Source: Results of the research.
Note: *significant at 1% level; **significant at 5% level; ***significant at 10% level. Standard errors in brackets.

The graphs on figures 8 and 9 plot the estimated dynamic volatilities and correlations of the price series for the United States. Although the volatility of the diesel price returns was the lowest among the three variables, it is noticeable that the volatilities of the three prices moved together during the observed period and exhibited strong variation. This result is rather different than what was observed in Brazil, indicating how fuel pricing policies can alter the relationship between domestic fuel prices and the international oil market.

Moreover, the jump in the volatility of the price of oil in the end of 2008 was accompanied by a significant increase in the volatility of the U.S. fuel prices, with gasoline having an even stronger response than the price of oil. This result is similar to the findings of Rahman (2016), according to which, the growing international crude oil price volatility led to higher volatility of U.S. gasoline prices after the crisis years. In the end of the analyzed period, as a result of the turbulence on the international crude oil market due to the falling oil prices, the volatility of the three price series went up and registered much more variation than between 2010 and 2015, indicating the high responsiveness of the domestic fuel prices in the U.S. to fluctuations on the international oil market.

Figure 9 shows the estimated dynamic correlations between the examined prices for the U.S. market. The correlations between the international crude oil price returns and the domestic fuels for this country are higher than the calculated for the Brazilian market. They remained positive during the entire analyzed period - in the range of 0.6 and 0.8. The estimated dynamic correlation between the gasoline and diesel price returns was the highest among the three price pairs, which is in line with what was found for the Brazilian fuel market. For the U.S., however, this correlation remained in the range of 0.7 and 0.9, which is lower than the calculated for Brazil.

In the beginning of the analyzed period all estimated dynamic correlations were found to experience a significant jump. This result can be attributed to the fact that the American fuel sector went through some important changes at this point in time. The MTBE (Methyl Tertiary Butyl Ether) was banned as an additive to gasoline in 2004, the Energy Policy Act and the Renewable Fuel Standard (RFS1) were implemented in 2005, and a number of biofuel government policies, such as blending mandates, tax benefits and subsidies for biofuel production, were introduced by the government. All these measures stimulated the production and use of ethanol in the country after 2005 and helped the U.S. become the major player on the international biofuel scene, surpassing Brazil in terms of production and consumption.

The increased participation of ethanol in the energy mix in the U.S. altered the conditions on the domestic fuel market and can be associated with the significant jump in the oil-fuel correlation observed at the same period. Such an increase in the correlation, on the other hand, was not observed in Brazil in the end of 2005. The country went through a significant structural change of its domestic fuel sector earlier than the U.S. – in 2003, with the introduction of the flex-fuel vehicle which allowed the use of pure ethanol as a substitute to conventional fossil fuels.

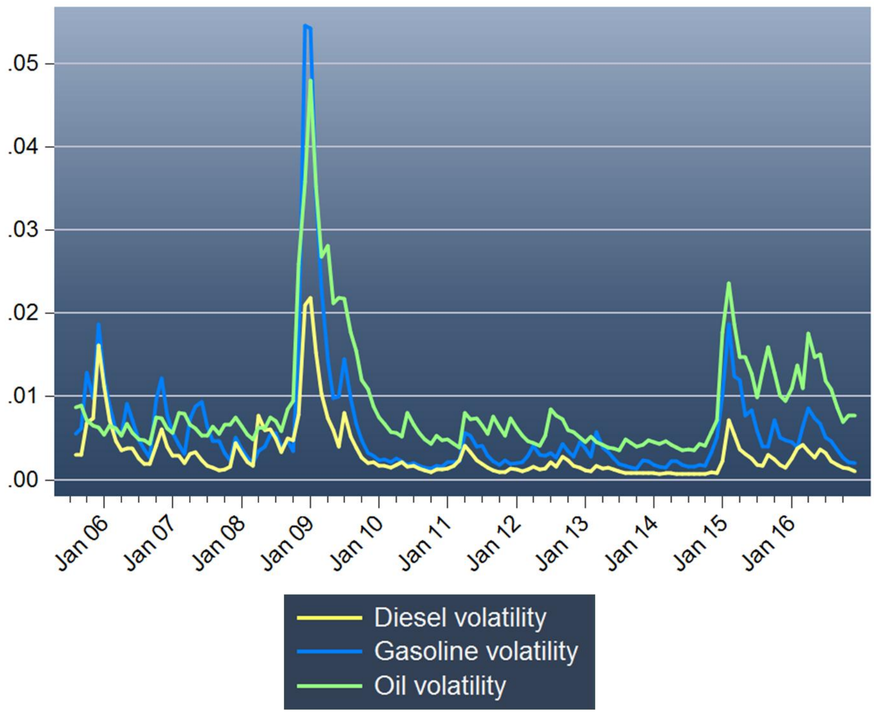

Figure 8. Estimated dynamic volatilities for the United States

Source: Results of the research.

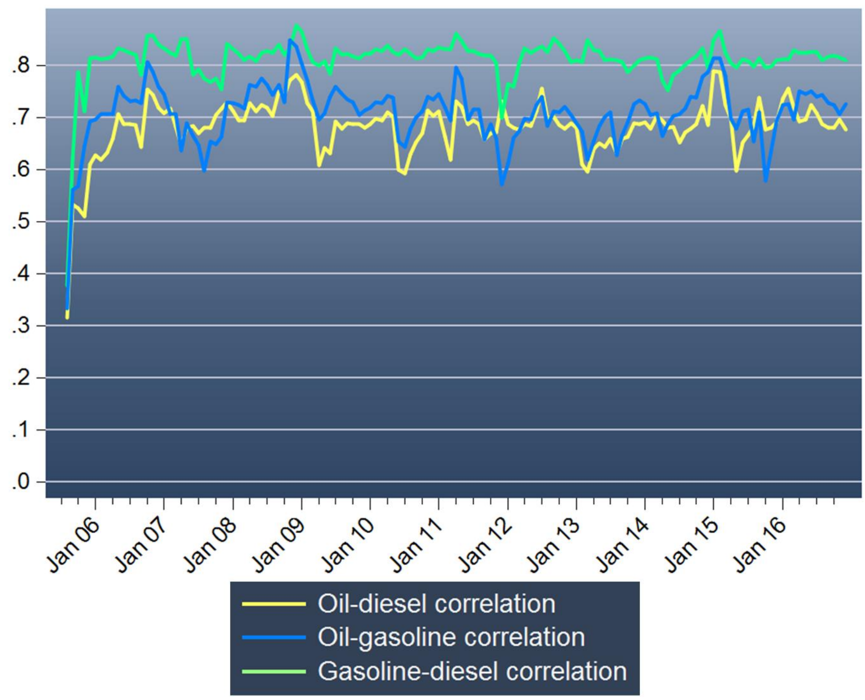

Figure 9. Estimated dynamic correlations for the United States

Source: Results of the research.

The results of the estimated MGARCH-DCC model for Germany show that the variances of all variables are influenced by past error terms and past variances. The positive and significant GARCH terms show that positive shocks led to higher volatility of the three examined prices. The quasi-correlations are positive and higher than the estimated equivalents for Brazil and the U.S. Gasoline and diesel were found to have the highest correlation, while diesel and oil are more correlated than oil and gasoline, which can be attributed to the importance that this type of fuel has for Germany.

Table 4. Results of the estimated MGARCH-DCC model for Germany

	Variables		
	Gasoline	Diesel	Oil
ARCH α	0.1803523*	0.146947*	0.3973654*
	(0.058861)	(0.0533708)	(0.1451133)
GARCH β	0.73295*	0.7560009*	0.5739932*
	(0.0839377)	(0.0780886)	(0.1347165)
Constant	0.0001837	0.0001846**	0.0006449
	(0.0001127)	(0.0000976)	(0.0004179)
Corr(gasoline ,diesel)	0.9050539*	Adj. coef. λ_1	0.017765
	(0.0176697)		(0.0348105)
Corr(gasoline, oil)	0.7936775*	Adj. coef. λ_2	0.6900377**
	(0.0355029)		(0.3460956)
Corr(diesel, oil)	0.8342254*	Log-likelihood	834.866
	(0.0292715)		

Source: Results of the research.
Note: *significant at 1% level; **significant at 5% level; ***significant at 10% level. Standard errors in brackets.

Figure 10 plots the estimated dynamic volatilities of the variables, showing that the domestic prices of gasoline and diesel exhibited stable and rather low volatility during the observed period, with small and almost insignificant adjustments in the end of 2008 and in the beginning of 2015 - the two major turbulent periods for the international crude oil price.

As it can be seen on the graph, the price of crude oil was much more volatile than the German diesel and gasoline price returns – a result in line with the one obtained for Brazil, but rather different than what was observed for the U.S. This indicates that free fuel pricing policy does not necessarily allow domestic fuel prices to follow the volatility of the international crude oil price. As discussed above, even in a situation when domestic fuel prices are formed on the market, governments can still influence the fuel sector through taxation mechanisms. Fuel tax burden in Germany constitutes more than 50% of the final consumer price of fuels, while the cost of crude oil accounts for only 25%, which can explain the rather stable price volatility of diesel and gasoline in the country. Thus, using flexible taxation on fuels, the government is able to stabilize the domestic fuel price without letting the international crude oil price fluctuations distort the domestic fuel sector.

When it comes to the estimated dynamic correlations between the variables, the results plotted on Figure 11 show that the correlation between gasoline and diesel is the highest among the three price pairs, which is in line with the results obtained for Brazil and the U.S. As it was found for the U.S., the correlation between the variables in Germany increased significantly in the beginning of the observed period, which can be attributed to the growing importance of the use of biofuels around the world after 2005. In Germany, in particular, there was a boom in biodiesel production after 2005, which reached record levels in 2007. Moreover, the German government started stimulating the use of biofuels in 2004 with the introduction of a new tax policy, which allowed full tax exemption for biofuels blended with conventional fuels.

The estimated correlations for Germany, however, remained rather stable after 2006 – in the range of approximately 0.75 and 0.9 - without registering any significant jumps during the crisis years. This result differs significantly from what was found for Brazil and the U.S., where the calculated correlations exhibit significant time-varying behavior. This result implies that different characteristics of the domestic fuel market together with different government policies and taxation alter the relationship between domestic fuel prices and the international crude oil market. In particular, taxation in Germany is rather different than in the other two examined countries. The heavy tax burden on fuel prices practiced by the German government is an instrument that helps keeping the domestic fuel sector rather stable. This result is in line with the existing literature, since, in general, Germany is considered a country that is not negatively influenced by the high volatility of international oil prices and one of the countries with the lowest oil vulnerability index (GUPTA, 2008).

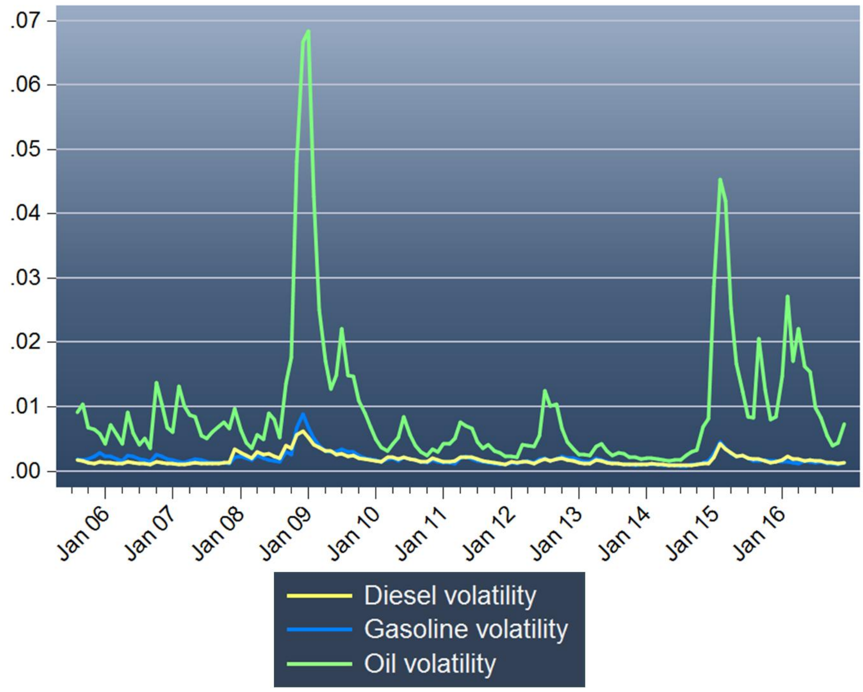

Figure 10. Estimated dynamic volatilities for Germany

Source: Results of the research.

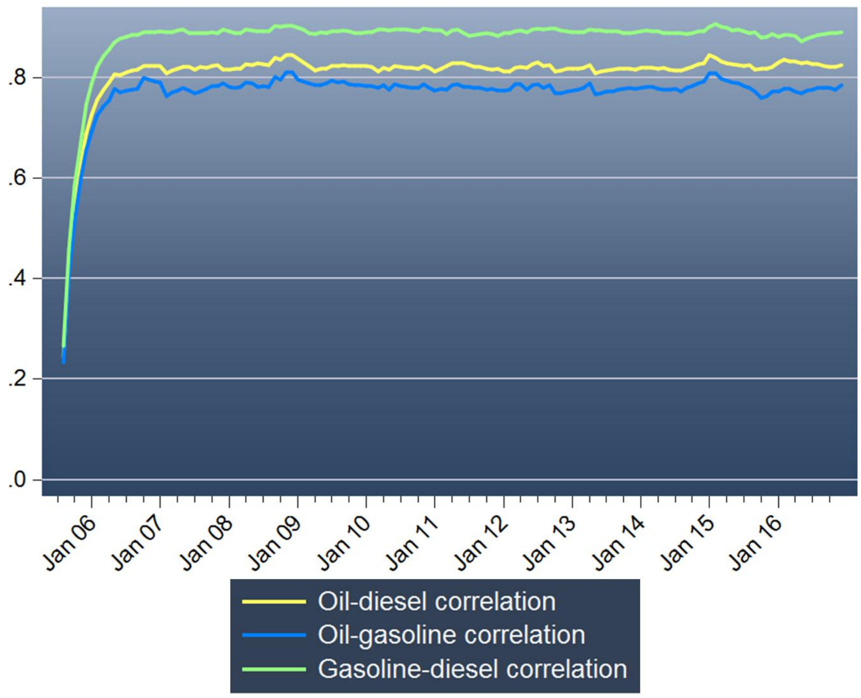

Figure 11. Estimated dynamic correlations for Germany

Source: Results of the research.

Germany is an example of a country where the fuel pricing policy of the government and the taxation regarding fuels work in a consensus. On the one hand, the free ex-refinery prices of fuels that are formed on the market and follow international crude oil price fluctuations induce competitiveness to the domestic fuel sector, while, on the other hand, the practiced fiscal policy on fuels keeps the final consumer price stable. The situation in the country should serve as an example for policy makers in Brazil, where the government attempts to diminish the negative effects of international crude oil price fluctuations on the domestic economy by establishing the ex-refinery price of all petroleum derivatives, while the practiced fiscal policy on fuels remains rather inadequate. Even though the original idea behind the flat-rate fuel tax CIDE was to be a flexible tool for stabilizing the domestic fuel sector, it was not implemented appropriately and currently the CIDE serves mainly as an additional instrument of the government for inducing disparity between domestic fuel prices and their international equivalents. Thus, the main negative aspect regarding the practiced policy in Brazil can be related to the lack of consensus between the two instruments in the hands of the government – fuel pricing policy and taxation.

2.6. Conclusions

This study focuses on a comparative analysis between the fossil fuel sectors in Brazil, in the United States and in Germany, with an emphasis on the evolution of the volatilities of domestic fuel prices and their correlation with international crude oil. A multivariate GARCH-DCC model was estimated for each of the three countries, using monthly average consumer prices of gasoline and diesel in addition to the WTI and the Europe Brent crude oil prices for the period July, 2005 - November, 2016.

The three examined countries differ significantly when it comes to specific characteristics of the domestic fuel sectors and government fuel pricing policy and taxation. These differences are behind the distinct estimated dynamic volatilities of the domestic fuel prices and their correlations with international crude oil in the three countries of interest.

The obtained price volatilities show that domestic fuel prices in Brazil and in Germany are not as volatile as the price of crude oil and do not accompany the variations in the volatility of the latter, while for the United States domestic fuel price volatilities were found to exhibit significant fluctuations similar to the international crude oil price. This results are in line with the existing differences between the three examined countries. In Brazil, the government fuel pricing policy does not allow the domestic price of fuels to adjust towards the fluctuations of crude oil, while in Germany the practiced taxation smooths out the volatility of domestic gasoline and diesel prices.

Moreover, the estimated dynamic correlations between crude oil and domestic gasoline and diesel prices in the U.S. and in Germany are almost double the correlations obtained for Brazil, which were found to be less than 0.5 for almost the entire analyzed period. This result is in line with the specific fuel pricing policy in Brazil, where the government does not allow the domestic prices to adjust to international crude oil price fluctuations.

Although the estimated correlations for Brazil and the U.S. show significant time-varying behavior, such a result was not found for the German fuel market, where the oil-gasoline and the oil-diesel correlations remained rather stable during the entire analyzed period. This finding indicates that the practiced policy in Germany, which is a combination of market fuel prices and flexible fiscal policy, permits the domestic fuel sector to be competitive, having prices that follow supply and demand conditions on the market, while at the same time, final consumer prices of fuels remain rather stable without inducing unnecessary instability to the domestic economy.

The results of this paper are important for policy makers, since they provide empirical evidence that different government fuel pricing policies and taxation alter the correlation between domestic fuel prices and international crude oil. Artificially established by the government ex-refinery prices of petroleum derivatives, lead to lower correlation between domestic fuel prices and oil in comparison to countries where the government does not intervene in the formation of domestic fuel prices. This pricing policy, however, without an adequate fiscal policy on fuels, can lead to negative consequences for the domestic fuel sector and the entire economy, as observed in Brazil. The country is in need of a policy reform that considers not only the formation of petroleum derivatives' prices, but also adequate taxation on fuels, such as the one practiced in Germany, that protects the domestic economy from the fluctuations in the international crude oil price.

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3. PRICE TRANSMISSION IN THE BIOFUEL-RELATED SECTORS – A COMPARISON BETWEEN BRAZIL, GERMANY AND THE UNITED STATES

ABSTRACT

The main objective of the present study is to verify if there exist differences in the biofuel-related price transmission mechanisms in Brazil, in the United States and in Germany for the period 2005 – 2016, accounting for the effects of the global crisis of 2008. The performed time series analysis focuses on using data with the same frequency, level and time frame for the three economies in order to complement the existing literature with a comparative analysis of the relationships between the biofuel prices, their main fuel alternative and their major feedstock. The obtained results show that the German biofuel industry stands out among the three countries, especially when it comes to price transmission. While in Brazil and in the U.S. the ethanol sectors are characterized by a stable relationship between the prices of the biofuel-related commodities, in Germany such a strong and permanent link between biodiesel, diesel and rapeseed oil is not observed. Moreover, the results for the two sub-periods show that the price transmission changed significantly after the financial crisis. The three examined price series for Brazil and the U.S. became more integrated after 2008. The price of corn, however, remained exogenous during both sub-periods, implying that the relationship between the main feedstock and the domestic biofuel sector in the U.S. is rather different than the existing in Brazil. In Germany, on the other hand, the transmission between the three price series disappeared after the crisis period, which can be attributed to the changes in the policy regarding biofuels in the country, as well as to the specific characteristics of its biofuel-related sectors.

Keywords: Biofuels; Price transmission; Comparative analysis; VECM

3.1. INTRODUCTION

In recent years, rising fuel prices and growing environmental concerns about the harmful effects of conventional energy sources on global climate were the main drivers of the increased interest in biofuels as a substitute for fossil fuels in transportation. The growing production of this type of fuel alternative has changed the relationship between agricultural commodity prices and energy markets. According to Peri and Baldi (2010), higher energy prices stimulate biofuel production, which in turn leads to higher demand for agricultural crops used as feedstock for this fuel alternative, resulting in rising agricultural commodity prices. The potential existence of such a relationship between energy, biofuels and agricultural commodity markets makes the research on this topic highly relevant, especially considering the recent trends on international oil and agricultural commodity markets.

Crude oil prices reached historically high levels in 2008 as a result of the global financial crisis, which was followed by a dramatic drop in 2009. International agricultural commodity prices, on the other hand, exhibited significant increase after 2011 accompanied by considerable volatility, which raised the question if biofuels are to blame for this rising trend on the international agricultural market. Moreover, the recent trend of cheap crude oil that started in the beginning of 2015 affected biofuels, threatening the production of this commodity and making it less competitive as a substitute to conventional fossil fuels. Thus, the way these trends on the international market altered the existing price transmission mechanism between fuel, biofuel and agricultural commodity markets has become a widely discussed topic by energy, environmental and agricultural economists and has been examined thoroughly in the existing literature.

A better understanding of the fuels-biofuels-agricultural commodity price relationship is of particular importance for policy makers, since it directly influences the impact that energy and agricultural government policies would have on the domestic economy. Such an understanding of price relationships, can shed light on the currently popular food versus fuel debate raised by environmental groups criticizing biofuel stimulation policies. Comprehending the price dynamics among biofuel-related markets provides insights about the actual existence of a hazard for food security due to increased biofuel production. Moreover, knowledge of price transmission is crucial for many other economic agents as well, such as market operators and traders, agricultural producers, fuel and biofuel refiners, since it can affect their decisions to produce, invest and adopt mechanisms for protecting their production from price risks.

The interrelations among energy, biofuels and agricultural commodities are present mainly in the countries engaged in biofuel production and consumption, such as Brazil, the United States and some European countries, like Germany. The U.S. is currently the leading producer of biofuels in the world, focusing on ethanol derived from corn, which is used for blending with conventional gasoline in low percentages (from 5 to 15%).

Brazil is the second biggest global producer of ethanol and is one of the few countries in the world where ethanol and gasoline act as substitutes, since the wide use of flex-fuel vehicles allows the final consumer to choose between these two fuel alternatives. The use of sugarcane as main feedstock for the production of biofuels makes ethanol and sugar competitors on the supply side. Thus, there exists a specific relationship between the biofuel-related markets in Brazil, which cannot be observed anywhere else.

Germany is the major producers and consumer of biofuels in the European Union and a global leader in the production of biodiesel, which is derived mainly form rapeseed oil and is available as a blend with conventional diesel and in a pure form as a substitute. The country has a pioneering role in the promotion of biofuels and the adopted government policies stimulating the sector have served as an example for other EU member countries.

The three countries of interest exhibit significant differences when it comes to market specifications and government policies regarding biofuels. Thus, it is expected that the price transmission mechanisms in the domestic biofuel-related sectors in the three economies differ significantly as a result of the varying policies and market instruments. According to Kristoufek, Janda and Zilberman (2013): "*a shock on the price of ethanol in Brazil may differ considerably from a shock on the ethanol price in the U.S., and there may be a stronger link between biodiesel and fossil fuel prices in Germany that is greater than one would expect if considering fossil fuels and biofuels generically*."

The present work aims at performing a comparative analysis between the biofuel-related price transmission in Brazil, the U.S. and Germany, using the same methodology and data types in order to provide insights related to the argument of Kristoufek, Janda and Zilberman (2013). The main focus of the study is the examination of the linkages between the prices of the two most popular biofuels - ethanol and biodiesel, on the one hand, and the related to them feedstock and conventional fossil fuel prices, on the other. Emphasis is put on the possible causes for the identified differences among the three developed price transmission models, such as specific characteristics of the biofuel and fuel sectors and varying government policies.

The main contribution of this work is the fact that the analysis is not restricted to one particular country, but rather has an emphasis the comparison between the results obtained for the three chosen economies. Such a comparison can shed light on the impact that different policies and market instruments have on biofuel-related price transmission mechanisms and can provide knowledge and better understanding of the reasons underlying the possible divergence in the obtained results for the three examined countries. The findings could be particularly useful for policy makers, since the impacts of policy regimes can become clearer after comparing the situation across countries, and could help for the better understanding of how biofuel markets function under specific conditions.

The remainder of this work is organized as follows: Section 3.2 briefly reviews the related literature on biofuel price transmission; Section 3.3 presents the methodology used for performing the analysis; Section 3.4 describes the data used for the estimation; Section 3.5 is devoted to the result of the analysis; and, finally, Section 3.6 concludes with final remarks and suggestions for future research.

3.2. LITERATURE REVIEW

3.2.1. Price transmission literature – an overview

Before biofuels gained the importance they have nowadays, the majority of the research on price transmission in energy markets was focused on the interrelationships between fuel and agricultural commodity prices. The increased use of biofuels that served as an incentive for policy interventions, however, introduced this new factor that has an impact on agricultural markets. The price increase of agricultural commodities after 2011 raised the concern about the potential negative effects that biofuels have on the price levels and the volatility of these commodities. That is why most of the research in the area is focused on examining the price relationships between feedstock and food, on the one hand, and energy and bioenergy, on the other.

The existing studies on the presence and the direction of price relationships between the energy and agricultural markets usually differ in several aspects. First of all, the literature consists of both theoretical and time-series methodology, both having its advantages and disadvantages. The former has been developed using partial and general equilibrium models in order to analyze price level patterns, but not price volatility. These models, however, have been criticized for not being validated by historical data (SERRA; ZILBERMAN, 2013). Time-series analysis, on the other hand, is considered to be a relevant instrument for examining price transmission both in level and in volatility. Nevertheless, according to Abbott (2012) and Headey and Fan (2010) the results of time-series analysis have been rather inconclusive when it comes to the impact that biofuels have on agricultural commodity prices. The most common time-series methodology in the literature relies on cointegration and Granger causality tests, estimation of vector autoregression (VAR) and vector error-correction models (VECM).

Second of all, the data used in the econometric studies differs significantly across papers. The sources vary, as well as the period and the frequency of the data. Some authors examine the relationship between spot prices, others focus on futures prices. Some studies include only domestic prices, others incorporate international prices, as well. These differences in the literature justify the lack of consensus about the examined price relationships, and, in addition, do not allow the comparison of the obtained results across countries and regions.

The main conclusion in the majority of the existing studies is that biofuel and fuel price levels are strongly connected to agricultural commodity prices. Furthermore, a number of authors (GORTER; DRABIK; JUST, 2013) argue that price linkages depend significantly on the specific country that is being examined, on the agricultural development in this country, on the existing government supporting policies, and on the type of examined agricultural commodities.

3.2.2. Brazil

The case of Brazil is particularly interesting when it comes to price interrelations among the biofuel-related sectors. This is the result of a number of specific factors that play a role simultaneously: Brazil has a long history and experience in the biofuel industry; the country is one of the main producers and consumers of ethanol worldwide; biofuels are used as a substitute for gasoline and compete with sugar on the supply side. The price transmission literature in Brazil emerged after the liberalization of the sugarcane and ethanol sectors in the early 2000s. Till then the analysis of price linkages was inapplicable, since the government was administrating the prices of both sugar and ethanol.

In their review of biofuel-related price transmission literature, Serra and Zilberman (2013) point out two articles that study this price relationship in Brazil – Rapsomanikis and Hallam (2006) and Balcombe and Rapsomanikis (2008). The former suggests that international oil prices drive domestic sugar and ethanol prices in the long-run in an asymmetric manner, while there is no evidence for nonlinearity in the price transmission between sugar and ethanol, where sugar is found to be the dominant commodity. Balcombe and Rapsomanikis (2008), on the other hand, find evidence that international oil prices drive long-run domestic sugar prices, which in turn Granger-cause domestic ethanol prices.

Long-term relationship between ethanol and sugar and ethanol and gasoline is found by Rodrigues (2009), while Block, Coronel and Veloso (2012) provide evidence for the existence of a strong linkage between sugarcane, sugar and hydrous ethanol prices with the latter being the leader. Bentivoglio, Finco and Bacchi (2016), on the other hand, find a cointegration relation between the ethanol, sugar and gasoline prices in the country and show that in the short-run sugar and gasoline prices drive the main biofuel, while the latter has limited power in influencing the prices of the other two commodities.

Moreover, Capitani (2014) analyzes the price transmission between the Brazilian ethanol industry and a number of agricultural commodities for the period 2004-2014. The results show that sugarcane and ethanol do not have any significant negative effects on agricultural commodity prices. Therefore, according to the author, the increased production of biofuels in the country in recent years has had low influence on crop markets, which is in line with the results of Balcombe and Rapsomanikis (2008).

Chen and Shaghaian (2015) investigate the linkages among the price of ethanol in Brazil and the international prices of sugar and oil, accounting for structural breaks. According to the authors, before the crisis of 2008 there was only a short-term relationship among the price series, while after the breaking point they find evidence for cointegration between the three price series. Oil remained exogenous during the analyzed period, affecting significantly domestic ethanol and international sugar prices.

Some authors focus mainly on the relationship between fuel and biofuel markets in Brazil, without considering the effects they have on agricultural and feedstock markets. Cavalcanti, Szklo and Machado (2011), for instance, find that there is no effective price relationship between gasoline and international crude oil, while a long-term linkage exists between hydrous ethanol and gasoline in Brazil.

Although a large number of studies focus on cointegration tests and estimation of VECM, some authors turn to different models for performing their analysis on price transmission. Nunez and Otero (2015) examine Brazilian gasoline and ethanol prices, applying a pairwise procedure, which allows for the study of the spatial integration within and between the price series. The main findings suggest that the speed of adjustment of fuel and biofuel prices in the long-run depends on the distance between the States and on the tax regimes.

As it can be seen from this brief review of the literature on price transmission among the Brazilian biofuel-related markets, the majority of the findings suggest the existence of a long-term relationship between ethanol and sugar prices, and between ethanol and gasoline, but there is no consensus on the direction of the existing linkages.

3.2.3. United States

The majority of the works studying the topic of interest for the United States focus on the price transmission between biofuels and agricultural commodities. The main reasons for this trend is the fact that increasing food prices in the country have raised concerns about the negative impact that the high biofuel production has on agricultural commodity and food prices. A lot of works have been devoted to finding evidence in support or against the hypothesis that the stimulation of ethanol production after 2005 has something to do with the recent agricultural and food commodity price increase.

Zhang et al. (2009) use weekly prices for U.S. ethanol, corn, soybeans, gasoline and oil and conclude that although biofuels do not impact agricultural commodities in the long-run, they have a short-term negative impact on food prices. Moreover, Zhang et al. (2010) find no direct long-run relationship and only limited short-run linkages between agricultural and energy prices in the U.S. prior to 2008. The authors conclude that rising fuel prices are not directly leading to more expensive agricultural commodities, while sugar appears to be the driving force for the short-term increase in agricultural prices. When it comes to analyzing short-term effects, Cha and Bae (2011) find evidence that international oil price increases lead to elevated demand for corn for the production of ethanol in the U.S. and from there to higher corn prices in the country in the short-run.

Merkusheva and Rapsomanikis (2014) examine the price relationship between oil, ethanol, corn, wheat, and rice in the U.S. and show that oil prices are the long-run driver of ethanol and agricultural commodities. On the other hand, in the short-run the relationship between fuel and grain markets appears to be much weaker, which, according to the authors, is a result of external factors such as the biofuel mandate.

Although the main focus of researchers is spot price links, futures price relationships have been examined in the existing literature, as well. Papiez (2014), for instance, analyzes the causality among corn, crude oil and ethanol futures prices on NYMEX and CBOT. The obtained results suggest that causality relationships among these three price series change over time: corn prices influence crude oil futures prices till 2010 and ethanol till 2013, while oil prices have an impact on corn and ethanol only till 2010.

Myers et al. (2014) investigate the long- and short-run co-movements between U.S. fuel and agricultural commodity spot prices, while Myers et al. (2015) focus on analyzing the same relationship but using futures prices. These two works show that there is less co-movement between the futures prices of oil and feedstock used for biofuels than between the spot prices of these commodities – a rather important results, since it does not support the hypothesis that the excessive speculation on futures markets leads to tighter price links.

A number of researchers focus their attention on the impact that biofuel policies have on the price transmission mechanism. Baumeister and Kilion (2013), for instance, examine the price links for the U.S. accounting for a structural break in 2006 when the country expanded dramatically its ethanol production. The authors find no evidence in support of the idea that agricultural price increases lead to higher food prices. Oil price shocks do not appear to be causing any significant rise in retail food prices either. Moreover, McPhail (2011) finds that policy-driven demand shocks in the U.S. ethanol sector cause a significant decline in the world crude oil price, while ethanol supply shocks do not have any significant influence on the world oil market.

Furthermore, Drabik, Ciaian and Pokrivcak (2014) perform a simulation for the U.S. corn sector and its linkages with the ethanol and food sectors, comparing a benchmark scenario (world without biofuels) to scenarios, which account for the existence of biofuels under different regimes. The results suggest that biofuels affect the price transmission along the food chain but this impact depends on the policy regime for biofuels.

Koirala and Mishra (2015) examine the relationship between agricultural commodity and energy futures prices in the U.S., taking into account the recent legislation changes, such as the Energy Independence and Security Act of 2007 and the Renewable Fuel Standard Program of 2014. The obtained results suggest the existence of a high correlation and a positive and significant relationship between the two examined markets, thus, providing empirical support that higher energy prices lead to elevated agricultural commodity prices in the country.

Regarding changes in the existing price relationship between the biofuel-related sectors in the U.S. through time, Chiu et al. (2016) find that only between 2004 and 2006 there was a long-term relationship between the prices of ethanol, corn and oil. Corn is found to lead ethanol prices through all analyzed periods, while the policy-driven ethanol market does not have any significant impact on the other examined variables. Similar results are obtained by Bastianin, Galeotti and Manera (2016), who find that the price of ethanol was significantly influenced by the price of corn between 1978 and 2012, while an effect in the opposite direction was not found.

Apergis, Eleftheriou and Voliotis (2017) identify non-linearities and asymmetry in the price transmission between biofuel prices and a wide range of non-energy commodity prices in the U.S. The authors show that ethanol prices lead commodity prices and the latter have become more vulnerable to biofuel price fluctuations in recent years.

The majority of the reviewed works regarding the price transmission in the U.S. provide evidence for the existence of a short-term relationship between energy, biofuel and agricultural commodity markets, with energy and crop prices being the leader in most of the examined studies. There is no consensus, however, on the presence of a long-term link between the prices of these commodities in the country.

3.2.4. European Union

The biofuel-related price transmission for the Brazilian and U.S. markets has been thoroughly examined in the existing literature, but the same does not apply for the European biofuel sector, which has received much less attention from researchers. Since the predominant biofuel used in the countries from the EU is biodiesel produced from rapeseed oil or sunflower oil, the existing studies focus on the price relationships between this type of biofuel and the main crops used for its production. Peri and Baldi (2010), for instance, find a long-run cointegration relationship between rapeseed oil and diesel in the EU, with the adjustments of rapeseed oil prices being asymmetric and depending on the divergence between the two price series.

Some authors consider the EU ethanol prices in their research, instead of focusing on biodiesel. Zafeiriou et al. (2014) show that there exists a single long-run relationship between the prices of gasoline, ethanol and crude oil, with the latter being the exogenous variable. Crude oil prices are found to have a negative impact on ethanol, while gasoline has a positive effect on this type of biofuel.

Most of the reviewed studies, however, focus on a separate country from the EU with the main interest being on Spain and Germany, since they are among the major producers and consumers of biofuels in Europe.

Hassouneh, Serra and Gil (2011), for instance, concentrate on the energy-price relationships in Spain, examining the transmission among biodiesel, sunflower and international crude oil prices. The obtained results suggest a long-run relationship among the three price series, in which sunflower and crude oil are exogenous and biodiesel is the only one to adjust to deviations in the established long-run parity.

Pokrivcak and Rajcaniova (2011) study the relationship among ethanol and gasoline in Germany and Europe Brent crude oil prices. The authors find evidence for the existence of cointegration between oil and gasoline, but such a relationship is not found between the other two pairs - ethanol and gasoline, and ethanol and oil. Moreover, Busse, Bruemmer and Ihle (2012) examine on the price relationships between diesel and biodiesel, rapeseed oil, and soy oil in Germany and show that there exists cointegration between the examined price pairs.

Very few research has been focused on the relationship between futures prices in the EU. Ziegelback and Kastner (2011) analyze the linkages between European rapeseed futures price and conventional diesel futures prices. They find an asymmetric long-run relationship between the two time series, which is consistent with the findings of Peri and Baldi (2010) for the price relationship between rapeseed oil and diesel in the EU.

The reviewed works in this subsection reveal the existence of a long-term relationship between fuel and feedstock markets in the EU, in particular between diesel and rapeseed oil prices. Moreover, the majority of the results suggest the presence of cointegration between fuel, biofuel and feedstock markets, with fuel being the price-leader in most of the examined cases.

3.2.5. International and comparative studies

This subsection focuses on the biofuel-related price transmission literature, which studies international price relationships, as well as the existing research devoted to a comparison between the price transmission mechanisms across different countries. No consensus exists on the exact direction and the dynamics of the relationships for the global biofuel-related markets.

Ciaian and Kancs (2011) study the price dynamics for nine agricultural commodities traded internationally and develop a theoretical partial equilibrium model, which is further examined through time-series analysis. Their results provide evidence for the existence of a cointegration relation between the prices of all studied commodities and crude oil. The authors find that the effect that energy prices have on agricultural commodities is stronger in the presence of biofuels than without the use of bioenergy in transportation. Similar results have been obtained by Bracco (2014), who shows that biofuel production strengthened the relationship between global fuel and food markets, and that higher crude oil prices and increased biofuel production lead to elevated international food prices.

Drabik, Gorter and Timilsina (2014) examine how an international price shock in diesel will affect the world soybean and rapeseed markets under different regimes regarding bioenergy. The main findings show that under a mandate a diesel shock affects the international oilseed market less than under a tax exemption regime. When it comes to the effect on biodiesel, a diesel price increase under tax credit leads to higher biodiesel prices, but this is not the case under a blending mandate. Furthermore, the results of To and Grafton (2015) show that oil prices and biofuel production have statistically and economically significant impact on international and U.S. food markets both in the long- and in the short-run and were responsible for the food price increase after 2011.

In regards to different methodologies used in the international price transmission literature, Vacha et al. (2015) apply the wavelet coherence analysis, when examining the price relationships between international biofuels and a range of related commodities. The authors identify two strongly correlated pairs, which hold during the entire examined period – ethanol is strongly correlated to corn, and biodiesel to German diesel. Kristoufek, Janda and Zilberman (2013) provide further evidence for the results obtained by Vacha et al. (2015).

Although few studies focus on analyzing the biofuel-related price relationships between different countries, there exists a consensus in the existing literature that the U.S. is the main driver of energy and agricultural commodity prices around the world, and prices in other countries follow the U.S. price changes. Liu (2007), for instance, analyzes the integration among the three world ethanol markets – the U.S., Brazil and the EU. The obtained results suggest that both the American and the Brazilian ethanol markets Granger-cause the EU biofuel market, with the U.S. being the most influential. The EU, on the other hand, appears to have almost no effect on the ethanol industry in the other two countries.

Moreover, Rosa and Vasciaevo (2012) test the hypothesis of the existence of price transmission between the U.S. and the Italian energy and agricultural markets. They identify the existence of a long-term relationship between crude oil and the examined agricultural commodities in the U.S., as well as integration between the Italian and the American agricultural markets. The Italian commodity prices, however, do not show such a pronounced relation with international crude oil.

When it comes to comparing domestic price linkages across different countries, the existing research is rather scarce. Tokgoz and Elobeid (2006) perform a study in order to understand the dynamics between corn and ethanol markets in the U.S., and sugar and ethanol in Brazil. The authors find evidence for different effects of fuel prices on the ethanol industries in the two countries. An increase in gasoline prices leads to a rise in hydrous ethanol consumption in Brazil, while in the U.S. higher gasoline prices result in lower demand for ethanol, since the latter is used as a complementary product mainly for blending. Moreover, the authors show that increased corn prices in the U.S. lead to a reduction in ethanol production, while in the case of Brazil, higher sugar prices incentive the production of sugar from sugarcane in expense of the production of ethanol.

Silveira and Mattos (2015) perform a comparative analysis between the price and volatility transmission in the grain and livestock markets in the U.S. and in Brazil and find evidence for a long-term relationship between the two markets of interest in both countries. This relationship, however, was found to be different, due to the existing dissimilarities between the biofuel markets in the two examined countries.

In addition, Bentivoglio (2016) performs a comparative analysis between the price transmission of the biofuel-related sectors in Brazil and in the European Union, identifying a long-term relationship between the analyzed price series for both models. The obtained results provide evidence that between 2007 and 2013 the price of biodiesel in the EU was positively related in the long-run to the price of its main feedstock – rapeseed oil, while in Brazil the price of ethanol was found to be strongly related to the gasoline price instead of to the price of sugar, thus, indicating a different type of price transmission in the two analyzed contexts.

Kristoufek, Janda and Zilberman (2016) use the wavelet coherence methodology in order to examine the price transmission between anhydrous ethanol and sugar prices in Brazil and ethanol and corn prices in the U.S. They find evidence for a stable positive long-term relationship between the price series in both countries, thus, implying that there exist similarities in the behavior of the biofuel markets in Brazil and in the U.S. The main conclusion of the paper is that feedstock prices lead the price of biofuels in both economies in the short- and as well as in the long-run.

Filip et al. (2016) compare the price transmission between biofuel prices and 32 biofuel-related commodities and assets in Brazil, in the United States and in the European Union. Using a wavelet coherence framework, the authors identify strong, positive and stable long-term relationship between the price of biofuels and their main feedstock in Brazil and in the U.S., while such a stable relation was not identified between biodiesel and rapeseed oil in the EU, thus, indicating that biofuels have different positions in the fuel-food systems in the European countries, since biodiesel production does not depend on one single feedstock.

Based on the literature review presented in this subsection, it can be concluded that a thorough comparison between the biofuel-related price transmission mechanisms in Brazil, the U.S. and Germany has not been performed yet. Thus, the goal of the present study is to fill in this gap in the existing state-of-the-art literature.

3.3. METHODOLOGY

3.3.1. Stationarity tests

This study relies on time series techniques for performing the analysis, which requires taking into account some general statistical properties of the time series data a priori (SERRA; ZILBERMAN, 2013). The first property to be considered is the stationarity of the examined variables. Stationary data is characterized by time-constancy of its statistical distribution and such a time series is considered to be a process integrated of order zero - I(0).

Common practices in time series modelling involve the application of the augmented Dickey-Fuller and the Phillips-Perron tests for determining whether a data series is stationary or not. The proposed by Elliott, Rothenberg and Stock (1996) DF-GLS test, however, has significantly greater power and better overall performance in terms of small-sample sizes, dominating the ordinary Dickey-Fuller tests (HATANAKA, 1996). This test represents a modified version of the augmented Dickey-Fuller test, in which the series has been transformed by a generalized least-squares regression. The DF-GLS test is performed fitting a regression of the following form (ELLIOTT; ROTHENBERG; STOCK, 1996):

$$y_t = \alpha + \beta y_{t-1} + \zeta_1 \Delta y_{t-1} + \zeta_2 \Delta y_{t-2} + \cdots + \zeta_k \Delta y_{t-k} + \varepsilon_t \qquad (3.1)$$

where k is the number of lags of first-differenced, detrended variables. The number of lags of the process has to be chosen appropriately. Lags should be added to the model only until they are significant, i.e. until there is no serial correlation in the error term. For this purpose, information criteria like the Ng-Perron, the Schwarz Criterion and the Modified Akaike Information Criterion are used.

There are two forms of the DF-GLS test – GLS detrending (where the series to be tested is regressed on a constant and linear trend) and GLS demeaning (where only a constant appears in the first-stage regression). The null hypothesis of the DF-GLS test assumes that the y_t is a random walk, possibly with drift. There are two alternative hypotheses depending on the chosen form of the test: y_t is stationary about a linear time trend, and y_t is stationary with a possible nonzero mean but with no linear time trend.

The price series of the biofuel-related markets in Brazil, the U.S. and Germany are tested for stationarity using the DF-GLS test before proceeding with the further analysis. Both models of the test are used in order to check if the results are robust. Moreover, in order to account for the global financial crisis of 2008, the entire sample is split into two sub-periods: 07/2005-12/2008 and 01/2009-11/2016. Thus, the stationarity test is applied for the entire sample, as well as, for each sub-period.

3.3.2. Cointegration and VECM

Another time series property that is tested in this work is the existence of a long-term relationship among the variables, or the so called cointegration. The formal development of this key concept was done by the Nobel laureates Clive Granger and Robert Engle (ENGLE; GRANGER, 1987). A vector time series y_t is said to be cointegrated if its individual elements are nonstationary but there exists a stationary linear combination of them - $\beta' y_t$, for some nonzero vector β called cointegration vector (HAMILTON, 1994). More precisely, the existence of cointegration implies that even though some permanent changes in the elements of y_t may occur, these elements are tied by the equilibrium relationship $\beta' y_t$ and tend to return to it in the long-run.

The proposed by Johansen (1988) and Johansen and Juselius (1990) cointegration test is based on a vector autoregression (VAR) model with *p* lags of a nonstationary *n*-dimensional process integrated of order one with independent and identically distributed (i.i.d.) Gaussian errors. The authors derive the maximum likelihood estimator of the cointegration vectors and perform a likelihood ratio test for the hypothesis that there exists a given number of cointegration vectors.

A VAR model of an I(1) process y_t describes the dynamic interactions among the set of variables collected in the vector y_t and takes the following form (HAMILTON, 1994):

$$y_t = c + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + \varepsilon_t \quad (3.3)$$

where Φ_j is the matrix of autoregressive coefficients, c is the constant term, and ε_t is a vector generalization of a white noise process with variance Ω, which is a symmetric positive definite matrix.

If the elements of the vector y_t are cointegrated, then the VAR model cannot be used to fit the data. Instead, an error-correction feature should be added to the VAR, which accounts for the existence of a long-term relationship between the variables. Such a model is called a vector error-correction model (VECM). VEC models are useful tools in time series, since they allow the direct estimation of the speed at which a dependent variable returns to its long-term equilibrium after a change in an independent variable. These models account not only for long-term relationships, but also for short-term interactions between the variables. Given the VAR process from equation (3.3) the VEC representation of this model takes the following form (LUTKEPOHL, 2005):

$$\Delta y_t = \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1} + \Pi y_{t-1} + u_t \quad (3.4)$$

where:

$$\Gamma_i = -I + \Pi_1 + \cdots + \Pi_i, \quad \text{i} = 1, 2, \ldots, p-1 \quad (3.5)$$

Thus, the matrix Π is a function of Γ ($\Pi = -\Gamma_p$) and consists of the coefficients that measure the long-term adjustments of the variables, while the Γ matrix contains the coefficients that measure the adjustments of the model in the short-run.

The rank of the matrix Π can be used to test for the existence and the number of cointegration vectors. If $rank(\Pi) = 0$, this means that there is no cointegration between the variables and a traditional VAR model can be used to examine their relationship. If $rank(\Pi) = n$, i.e. the matrix has a full rank, then the variables cannot be I(1), implying that y_t is a stationary process. Finally, if $0 < rank(\Pi) = r < n$, then the variables are cointegrated and the number of cointegration vectors is equal to the rank *r*. Consequently, there exist two (n *x r*) matrices - *a* and *β*, such that $\Pi = \alpha\beta'$, where the the *β*'s are the cointegration vectors and the linear combination $\beta' y_t$ is stationary, while the matrix *a* contains information on the speed of adjustment of the variables in the long-run. In this case, the application of the VAR model is inappropriate, and y_t can be interpreted as an error-correction model.

In order to test the hypothesis that there are at most *r* cointegration vectors, Johansen (1988) and Johansen and Juselius (1990) apply a likelihood ratio test where the null hypothesis being tested is the following:

$$H_0: rank(\Pi) \leq r \ or \ \Pi = \alpha\beta' \quad (3.6)$$

The Johansen cointegration test is applied to the price series data for the biofuel-related markets in the three selected countries in order to check for the existence of a long-term relationship between the variables during the entire analyzed period as well as during the two sub-periods. If such a long-term relationship is encountered, the analysis proceeds with the application of a VECM estimation, so that the cointegration vectors can be obtained and the coefficients for the short- and long-term adjustment of the variables in the system can be estimated. If the examined prices do not show any cointegration relationship, the analysis of their interrelations proceeds with the fitting of a VAR model with an appropriate number of lags, chosen by the results of the Akaike and Schwarz information criteria in their multi-equational form.

3.3.3. Granger causality test

Cointegration, however, does not say anything about the causality of series interdependencies, which is also an important aspect when analyzing price transmissions. The causality relationship between two time series can be examined applying the Granger causality test. According to Granger (1969), causality implies that a variable Y_t causes another variable X_t if $\sigma^2(X|\bar{X}) > \sigma^2(X|\bar{X},\bar{Y})$, where $\sigma^2(X|\bar{X})$ represents the minimum predictive error variance of X_t using only past values of this variable, and $\sigma^2(X|\bar{X},\bar{Y})$ is the variance of the prediction of X_t using past values of both X_t and Y_t. Granger (1969) denotes this causality as $Y_t \rightarrow X_t$.

Let's assume that Y_t and X_t are two stationary time series with zero means expressed in the following way:

$$X_t = \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + \varepsilon_t \qquad (3.7)$$

$$Y_t = \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + \eta_t \qquad (3.8)$$

where ε_t and η_t are two uncorrelated white noise series of errors. Under these assumptions, Granger (1969) shows that Y_t is causing X_t, if the coefficient b_j is non zero. Alternatively, X_t is causing Y_t, if the coefficient c_j is non zero. If both of these events occur, then there exists a feedback (or bidirectional) relationship between Y_t and X_t, denoted as $Y_t \leftrightarrow X_t$.

According to Hamilton (1994), testing for Granger causality can be done using F-test with null hypothesis $H_0: b_j = 0, c_j = 0$. One way of performing this F-test for checking if the variable Y_t causes X_t, for instance, is calculating the sum of squared residuals of equation (3.8) (RSS_1) and then comparing it with the sum of squared residuals of a univariate autoregression on X_t (RSS_0) in the following way:

$$S_1 = \frac{(RSS_0 - RSS_1)/p}{RSS_1/(T-2p-1)} \sim F(p, T-2p-1) \qquad (3.9)$$

If the test statistic S_1 is sufficiently large (exceeds the critical value of the F-test at the chosen significance level), the null hypothesis can be rejected, which implies that the variable Y_t Granger-causes the variable X_t. Another alternative is the application of the Wald test, which tests the hypothesis that in a VAR model each of the endogenous variables does not Granger-cause the dependent variable in that equation.

As mentioned above, for each country of interest a cointegration test is performed and, depending on its results, a VAR or a VEC model is estimated for the specific time period. For the cases when no long-term relationship is found between the variables, a VAR model is estimated in order to determine the short-term interactions between the price series and a Granger causality test is performed in order to verify the VAR results and to provide insights on the causality of the encountered short-term relationships between the variables.

3.3.4. Model specification

Assuming that evidence for the existence of a cointegration relationship between the variables was found from the Johansen cointegration test, the following VECM representations are estimated for Brazil, the U.S. and Germany, respectively:

$$\Delta P_t^B = \Pi_1 P_{t-1}^B + \Gamma_{11}\Delta P_{t-1}^B + \Gamma_{21}\Delta P_{t-2}^B + \cdots + \Gamma_{p-1,1}\Delta P_{t-p+1}^B + \mu_1 + u_{t,1} \quad (3.10)$$

$$\Delta P_t^{US} = \Pi_2 P_{t-k}^{US} + \Gamma_{12}\Delta P_{t-1}^{US} + \Gamma_{22}\Delta P_{t-2}^{US} + \cdots + \Gamma_{p-1,2}\Delta P_{t-p+1}^{US} + \mu_2 + u_{t,2} \quad (3.11)$$

$$\Delta P_t^G = \Pi_3 P_{t-k}^G + \Gamma_{13}\Delta P_{t-1}^G + \Gamma_{23}\Delta P_{t-2}^G + \cdots + \Gamma_{p-1,3}\Delta P_{t-p+1}^G + \mu_3 + u_{t,3} \quad (3.12)$$

where P_t^B is a vector consisting of the price of hydrous ethanol ($P_{E,t}^B$), the price of gasoline C ($P_{G,t}^B$), and of sugar ($P_{S,t}^B$) at period *t*, which refer to the Brazilian market; P_t^{US} is a vector consisting of ethanol ($P_{E,t}^{US}$), gasoline ($P_{G,t}^{US}$), and corn ($P_{C,t}^{US}$) prices for the U.S. market at period *t*; and P_t^G consists of biodiesel ($P_{B,t}^G$), diesel ($P_{D,t}^G$), and rapeseed oil ($P_{R,t}^G$) prices for Germany.

Taking into account the specific characteristics of the Brazilian fuel and biofuel sectors, it is expected that the results will provide evidence for the existence of a tight long-term relationship between hydrous ethanol and sugar prices, since the two commodities are derived from sugarcane and are competing on the supply side. Moreover, evidence for price transmission is anticipated for the domestic prices of gasoline and ethanol, due to the fact that the two fuels act as substitutes on the Brazilian market. The relationship between the prices of these fuels is assumed to be amplified by the fact that they act as complements as well, since pure gasoline is not available in the country, but rather a blend with 27% of anhydrous ethanol.

For the U.S. market, it is expected that the obtained results will show the existence of transmission between the prices of ethanol and corn, since the use of this feedstock for the production of biofuels directly influences the amount of corn that goes for feeding and alimentation and its price levels. Moreover, a tight relationship between ethanol and gasoline prices is anticipated, since ethanol is highly used for blending. The substitutability between fuels and biofuels in the U.S., however, is restricted by the automobile fleet, because the majority of cars in the country is not suited for running on high blends of ethanol. This fact constitutes the main difference between the biofuel industries in Brazil and in the U.S., implying that the price transmission in the two countries will be rather different.

The results of the price transmission analysis for Germany are presumed to indicate a relationship between the prices of biodiesel and rapeseed oil, since the latter is considered a major feedstock for biodiesel production in the country. This relationship, however, is assumed to be rather different than what is observed in the other two examined countries, mainly because rapeseed oil is not the single feedstock for the production of biofuels, as is the case with sugarcane in Brazil and corn in the U.S. In addition, for the three countries of interest, it is expected that the price relationship between the biofuel-related sectors changed after the financial crisis of 2008, which is assumed to have tightened the linkages between the examined variables.

3.4. Data description

The data used in this paper consists of the following price series:

- Hydrous ethanol monthly average distribution price, Brazil, BRL/liter (NPA);
- Gasoline C monthly average distribution price, Brazil, BRL/liter (NPA);
- Sugar producer price for São Paulo, Brazil, daily, BRL/sack (Center for Advanced Studies on Applied Economics/"Luiz de Queiroz" College of Agriculture - CEPEA/ESALQ);
- Ethanol price, Iowa, U.S., monthly, USD/gallon (U.S. Department of Agriculture – USDA);
- Gasoline price, U.S., monthly, USD/gallon (USDA);
- Corn price, Iowa, U.S., monthly, USD/bushel (USDA);
- Biodiesel wholesale price, Germany, monthly, EUR cents/liter (Union for the Promotion of Oil and Protein Plants - UFOP);
- Diesel wholesale price, Germany, monthly, EUR/hectoliter (Federal Statistical office of Germany - Destatis);
- Rapeseed oil wholesale price, Germany, monthly, fob, EUR/t (UFOP).

All data series were obtained from secondary sources and consist of fuel and biofuel related prices for Brazil, Germany and the United States, referring to the period July, 2005 - November, 2016. The choice of the analyzed period is justified by the fact that the production and use of biofuels started gaining international importance only after 2005, as pointed out by Silveira and Mattos (2015). In addition, the examined period was split into two sub-periods in order to account for the effects of the global financial crisis of 2008. The price transmission analysis is performed for the entire sample, as well as for the two separate sub-periods referring to July, 2005 - December, 2008, and January, 2009 - November, 2016.

The price of sugar was used in the model for Brazil as a proxy of the price of the main feedstock for the production of biofuels in the country. The choice is justified by the fact that sugarcane prices in Brazil do not fluctuate freely and are calculated at regular time periods, while the production of ethanol and sugar from the same raw material implies a tight relationship between the two commodities that act as substitutes on the supply side. For Germany, the price of rapeseed oil was included in the analysis. Even though different feedstock is used for the production of biofuel in this country, such as sunflower, palm and soybean oil, according to Flach et al. (2016), rapeseed oil is the major raw material for biodiesel.

In order to make the data comparable for the purposes of the study, all prices were transformed into monthly average and converted to USD, using the monthly average BRL/USD and EUR/USD exchange rates published by OECD. More precisely, the prices of fuels and biofuels were converted into USD/liter in order to facilitate the analysis. All data was transformed into log terms, which allows the interpretation of the estimated coefficients of the VEC and VAR models as elasticities of price transmission. The figures below plot the studied price series for the three countries of interest.

Examining the historical evolution of ethanol, gasoline and sugar prices in Brazil (figure 12), it can be noticed that the prices of the two fuel alternatives experienced strong co-movements, especially after the global financial crisis. During the entire period, the gap between the gasoline and ethanol prices remained rather stable. Concerning sugar and ethanol, the two series appeared to be moving together before 2008 and especially after 2012. The price of sugar registered significant fluctuations and followed an increasing trend between 2011 and 2013, which corresponds to a period of high international commodity prices. The observed trends on the graph, however, can significantly differ from the short-term dynamics between the variables.

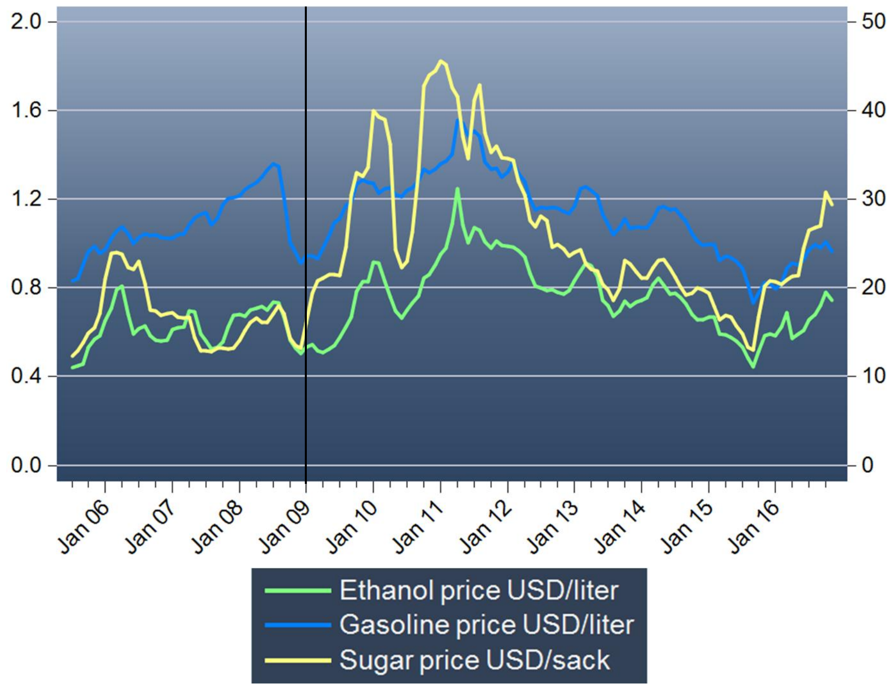

Figure 12. Monthly average producer prices of hydrous ethanol, gasoline C and sugar for Brazil between July, 2005 and November, 2016

Source: NPA, CEPEA/ESALQ.

Figure 13 plots the biofuel-related prices for the U.S. market. As it can be seen on the graph, ethanol and gasoline exhibited mild co-movements during the observed period. The price of gasoline reacted significantly to the global financial crisis of 2008, following the fluctuations in the international crude oil price from this period. The reaction of the ethanol price to the financial crisis was not as prominent as of gasoline. The prices of the two fuels for the U.S. market appeared to be more related after the crisis years and to exhibit strong co-movements especially after January, 2014.

The price of corn, on the other hand, appeared to be rather independent than the other two price series. It registered a significant upward trend after 2011, which persisted until 2013. Afterwards, the price of corn remained rather stable - between 3 and 4 USD/bushel. As it can be seen on the graph, corn and ethanol prices moved together only between 2008 and 2013.

The differences between the situation in Brazil and in the U.S. are rather prominent when figures 12 and 13 are compared. It is noticeable that the biofuel-related prices oscillated much more in the U.S. than in Brazil, which can be explained by the fact that in this country there is no government intervention in the domestic fuel sector, while in Brazil the government determines the ex-refinery price of all petroleum derivatives. In addition, considering the results of the graphic analysis, the prices of both fuels in Brazil exhibited a close and stable relationship during the entire period, while such a noticeable transmission between the two price series in the U.S. cannot be observed on figure 13.

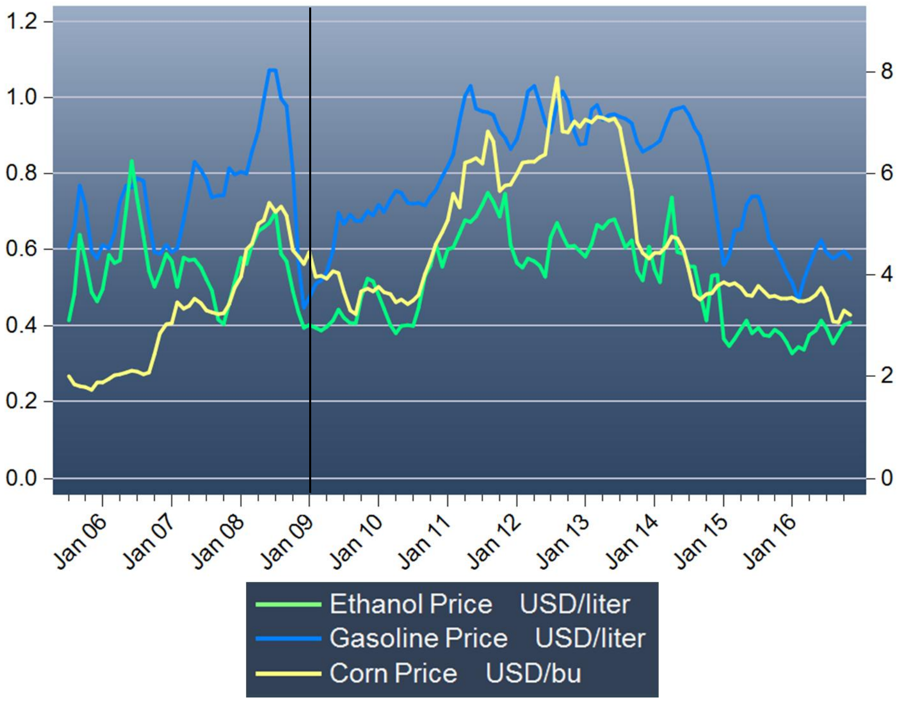

Figure 13. Monthly average producer prices of ethanol, gasoline and corn for the United States between July, 2005 and November, 2016

Source: USDA, EIA.

For Germany, strong co-movements between the three prices of interest can be observed on figure 14 for the period before the financial crisis. Biodiesel, diesel and rapeseed oil showed a clear relationship during the first sub-period. After 2008, however, no significant co-movements between the price series can be observed for the German market. The tight relationship between the biofuel-related prices in the country was broken after the crisis years.

Until 2011 German biodiesel remained cheaper than diesel, but since January, 2013, the domestic biodiesel price surpassed the diesel price and remained at higher levels ever since. The rapeseed oil price, on the other hand, started a downward trend in 2011, which went on until the end of the analyzed period. Moreover, it is noticeable that after 2015 the German diesel price registered a significant drop, which followed the fall in the international crude oil price from the same period. When compared with Brazil and the United States, the case of Germany is rather different. Instead of a stronger relationship between the examined price series after the financial crisis, as it is observed on the graphs of the other two countries, German biofuel-related prices do not appear to follow the same trends after 2008.

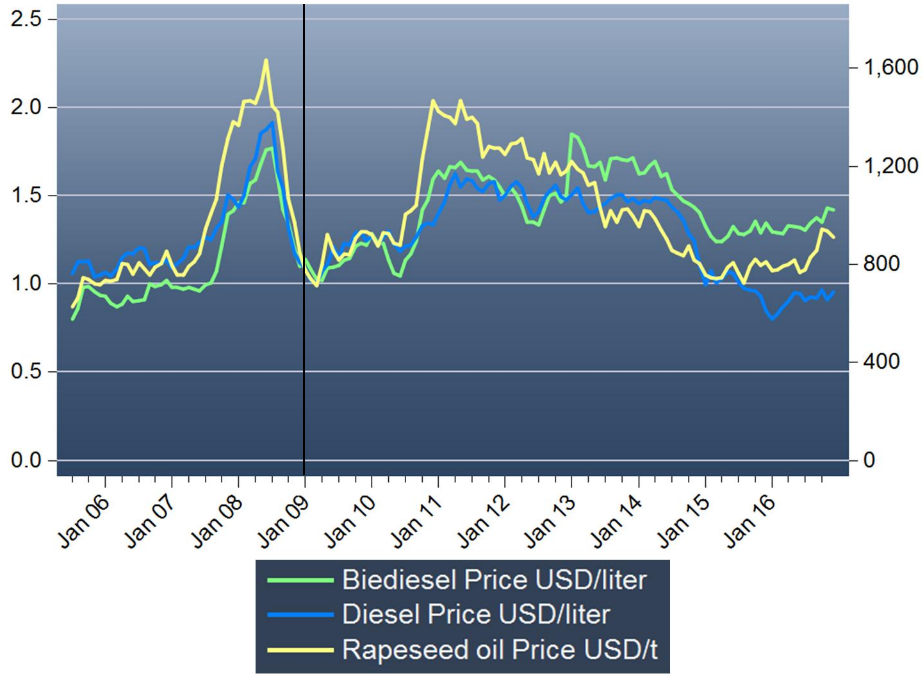

Figure 14. Monthly average producer prices of biodiesel, diesel and rapeseed oil for Germany between July, 2005 and November, 2016

Source: UFOP, Destatis.

3.5. Results

3.5.1. Stationarity test

Prior to performing the analysis, the data series were tested for stationarity using the DF-GLS test. Both models of the test were used and the number of lags was chosen using the Schwarz information Criterion (SIC). The results for the entire sample are shown in table 5. All variables were found to have a unit root in level, but they are stationary in their first difference (all data series are I(1)). Same results hold for the two sub-periods, the results for which are presented in tables 1 and 2 in Appendix A.

Table 5. DF-GLS stationarity test: 07/2005-11/2016

	Model 1		Model 2	
Variable	Lag	DF-GLS Statistic	Lag	DF-GLS Statistic
$P^{B}_{E,t}$	1	-1.391256	1	-2.314875
$\Delta P^{B}_{E,t}$	0	-7.791517	0	-7.871718
$P^{B}_{G,t}$	1	-1.386959	1	-1.716708
$\Delta P^{B}_{G,t}$	0	-7.509620	0	-7.598518
$P^{B}_{S,t}$	2	-0.960694	2	-1.768374
$\Delta P^{B}_{S,t}$	1	-7.090987	1	-7.663410
$P^{US}_{E,t}$	0	-2.139114	0	-2.376397
$\Delta P^{US}_{E,t}$	2	-2.858829	0	-8.229921
$P^{US}_{G,t}$	1	-2.756499	1	-3.223957
$\Delta P^{US}_{G,t}$	0	-4.980617	0	-6.253613
$P^{US}_{C,t}$	1	-0.801720	1	-0.995061
$\Delta P^{US}_{C,t}$	1	-3.636458	0	-6.797735
$P^{G}_{B,t}$	1	-0.653341	1	-1.967116
$\Delta P^{G}_{B,t}$	1	-3.577037	0	-7.263096
$P^{G}_{D,t}$	1	-1.402888	1	-1.421621
$\Delta P^{G}_{D,t}$	1	-3.744151	0	-7.946378
$P^{G}_{R,t}$	1	-1.020326	1	-1.503328
$\Delta P^{G}_{R,t}$	2	-3.407383	0	-8.593714

Source: Results of the research.

Note: Model 1 – constant (critical values by MacKinnon (1996): 5% = -1.95; 1% = -2.58); Model 2 – constant and trend (critical values by Elliott, Rothenberg and Stock (1996): 5% = -3.2; 1% = -3.74).

3.5.2. Cointegration test and VECM estimation results

The Johansen cointegration trace statistic test results for the three countries of interest are reported in table 6. For Brazil, one cointegration relationship is found when the entire sample is considered. This long-term link is prominent during the first sub-period, while after the financial crisis the results of the performed test point towards the existence of two cointegration equations. This finding is in line with the common conclusion in the literature that there exists a long-term relationship between the biofuel-related prices in Brazil (RODRIGUES, 2009; BLOCK; CORONEL; VELOSO, 2012; BENTIVOGLIO; FINCO; BACCHI, 2016).

For the United States, the hypothesis of the existence of a long-term link between the variables in the system cannot be rejected when the entire analyzed period is considered. Evidence for such a cointegration relationship is found between 2008 and 2016, while it disappears when the first sub-period is considered.

For the German data, the results of the performed Johansen trace statistic test presented in table 6 show that the price series are cointegrated of order one during the first sub-period. Such a long-term link, however, cannot be identified between 2005 and 2016 and during the period after the crisis.

The results of the performed cointegration test provide evidence in support of the hypothesis that the financial crisis of 2008 has altered the relationship between the examined variables in the three countries of interest. The analysis proceeded with the fitting of a VECM to the data during the periods when long-term relationships were identified, while for the situations where no evidence for cointegration was found, the estimation was performed by fitting a VAR model to the data and applying the Granger causality test.

Table 6. Johansen cointegration test results (trace statistic method)

	2005-2016		2005-2008		2009-2016	
Null hypothesis	Eigenvalue	Trace statistic	Eigenvalue	Trace statistic	Eigenvalue	Trace statistic
			BRAZIL			
r=0	.	33.3727	.	32.0019	.	36.8247
r<=1	0.13674	13.5222*	0.35366	14.5449*	0.17882	18.1086
r<=2	0.05491	5.8978	0.25076	2.9969	0.14537	3.1854*
			UNITED STATES			
r=0	.	31.8674	.	23.6419*	.	42.6866
r<=1	0.15462	9.0236*	0.35254	6.2542	0.26035	14.0373*
r<=2	0.04000	3.4715	0.12315	0.9976	0.12852	0.9693
			GERMANY			
r=0	.	25.2939*	.	32.5742	.	19.1053*
r<=1	0.10765	9.8045	0.41375	10.6795*	0.11925	7.0416
r<=2	0.06051	1.3151	0.18493	2.2956	0.06606	0.5487

Source: Results of the research.

Note: 5% critical values: r<=0: 29.68; r<=1: 15.41; r<=2: 3.76; * denotes acceptance of the null hypothesis of r cointegration relations at 5% level.

The obtained coefficients for the estimated VECM for Brazil for all analyzed periods are reported in table 7. Two lags were included in the three estimated systems, in line with the results of the Akaike and Schwarz information criteria in their multi-equational form. The R^2 and the F-statistic of the models show that the data fits well and the inclusion of error-correction terms is necessary.

When the entire sample is considered, the estimated long-term adjustment coefficients for all variables were found statistically significant and negative, implying that the prices of ethanol, gasoline and sugar in Brazil participate in the adjustment process towards long-run equilibrium. This result is rather in line with the expected, since the characteristics of the Brazilian biofuel-related sectors imply a strong long-term relation between the three prices of interest. The negative sign of the estimated coefficients means that when the system is above its long-term equilibrium, the prices of ethanol, gasoline and sugar must fall in order to restore the cointegration relationship.

The obtained values of the coefficients show that ethanol adjusts faster than gasoline and sugar, with 0.25% of the ethanol price being adjusted in the long-run. Moreover, the estimated cointegration equation for the entire analyzed period: $P^B_{E,t} = 0.4487\ P^B_{G,t} + 0.3438\ P^B_{S,t}$, implies that a positive shock in the prices of gasoline and sugar has a positive long-term effect on the price of ethanol. Similar results have been obtained by Rodrigues (2009) and Bentivoglio, Finco and Bacchi (2016).

During the first sub-period, the estimated long-term adjustment coefficients of the VECM show that only the price of ethanol participated in the adjustment process towards the cointegration relationship, while after 2008 the prices of gasoline and sugar entered the long-term adjustment process. These results indicate that the price transmission between the biofuel-related sectors in Brazil became stronger after the global financial crisis. Moreover, during the second sub-period, the price of sugar was found to adjust faster to the long-term equilibrium than the prices of the other two analyzed commodities, while ethanol had the highest speed of adjustment between 2005 and 2008.

The obtained results for the Brazilian market show that the long-term relationship between the examined price series changed after the financial crisis, when ethanol, gasoline and sugar became more interrelated. This finding can be attributed to the existing differences between the two examined periods. During the first sub-period, international sugar prices were relatively stable, the Brazilian ethanol sector was flourishing, and the BRL/USD exchange rate was decreasing. The second sub-period, on the other hand, was characterized by record high levels of international sugar prices, especially between 2011 and 2014, crisis in the Brazilian ethanol sector associated with insufficient supply and a need of imports from the U.S., and high BRL/USD exchange rate indicating weak national currency. Thus, the unfavorable conditions after 2008 brought distortions to the domestic biofuel-related sectors and induced a change in the long-term relationship between the price series.

Table 7. VECM estimation results for Brazil

	2005-2016 (VECM)		
	$\Delta P^{B}_{E,t}$	$\Delta P^{B}_{G,t}$	$\Delta P^{B}_{S,t}$
Const.	-0.00068	-0.000	0.001
Long-term adj. coef. α_1	-0.2526*	-0.1060*	-0.1602*
$\Delta P^{B}_{E,t-1}$	0.3916*	0.1474**	0.1638
ΔP^{B}_{Gt-1}	-0.2272	0.2415**	-0.5644**
$\Delta P^{B}_{S,t-1}$	0.0980	-0.0398	0.4583*
Cointegration equation	1	-0.4487*	-0.3438*
	2005-2008 (VECM)		
	$\Delta P^{B}_{E,t}$	$\Delta P^{B}_{G,t}$	$\Delta P^{B}_{S,t}$
Const.	0.000	0.000	0.000
Long-term adj. coef. α_1	-0.4977*	-0.0355	0.05073
$\Delta P^{B}_{E,t-1}$	0.3469**	0.0118	0.3014
ΔP^{B}_{Gt-1}	0.0825	0.4946**	0.0684
$\Delta P^{B}_{S,t-1}$	0.3541**	0.0572	0.7331*
Cointegration equation	1	-0.7477*	-0.3863*
	2009-2016 (VECM)		
	$\Delta P^{B}_{E,t}$	$\Delta P^{B}_{G,t}$	$\Delta P^{B}_{S,t}$
Const.	0.000	0.000	0.000
Long-term adj. coef. α_1	-0.2355*	-0.1079*	-0.2510*
Long-term adj. coef. α_2	0.1048**	0.03175	0.3364*
$\Delta P^{B}_{E,t-1}$	0.4422*	0.1994**	0.5356*
ΔP^{B}_{Gt-1}	-0.4905**	0.0754	-1.0321*
$\Delta P^{B}_{S,t-1}$	0.0475	-0.0580	0.4227*
Cointegration eq. 1	1	0.000	-0.6694*
Cointegration eq. 2	0.000	1	-0.7173*

Source: Results of the research.

Note: * significant at 1%; ** significant at 5%; *** significant at 10%. The estimated models include only a constant. For the interpretation of the cointegration equations, the signs of the coefficients need to be inverted.

When it comes to the short-term interactions between the variables for the Brazilian market, the results show that all prices reacted significantly and positively to changes in their own lagged values, with the only exception of gasoline in the second sub-period. Regarding the short-term transmission between the different price series, between 2005 and 2008 only the price of sugar was found to affect significantly the price of ethanol. A 1%-increase in the price of sugar at period *t-1* caused a 0.35%-increase in the price of ethanol at period *t*. When the entire sample is considered, the estimated coefficient for the short-term impact of gasoline on the price of ethanol was found to be negative. This coefficient, however, is not statistically different than zero.

The situation changed after the financial crisis, when variations in the prices of both ethanol and gasoline were found to have a significant impact on the price of sugar. In addition, the obtained results provide evidence for a bidirectional short-term relationship between the two fuel alternatives for the period after 2008. A 1%-increase in the price of gasoline led to a 0.49%-decrease in the price of ethanol, while a 1%-change in the price of the biofuel, caused a positive response of approximately 0.2% in the price of its substitute.

The estimated short-term coefficients for Brazil show that the price relationship between the biofuel-related sectors in the country changed after 2008, suggesting more interaction between the examined variables, with sugar becoming more dependent on the domestic price fluctuations of gasoline and ethanol after the crisis years. This change in the short-term price transmission in the country can be attributed to a number of negative trends observed in the Brazilian biofuel-related sectors, especially after 2011. The use of ethanol in the country lost its competitiveness and the sector entered a supply crisis, while Petrobras was importing gasoline and diesel at high BRL/USD exchange rate in order to satisfy domestic fuel demand. Meanwhile, international sugar prices reached record levels, which impacted the Brazilian market, stimulating the production of sugar from sugarcane instead of ethanol, thus, creating a tighter link between the prices of the two commodities competing for the same feedstock. These results show that the price transmission between the biofuel-related sectors in the country is influenced by international factors when it comes to sugar, since Brazil is a major global producer and consumer of this commodity and its domestic market is highly related to the international sugar sector.

For the United States, a VECM with two lags and one rank was estimated for the entire sample and for the second sub-period. The values of the R^2 and the F-statistic show that the data fits well the estimated models. No cointegration relationship was found for the period between 2005 and 2008, thus, a VAR model with one lag of the first difference of the data was estimated for this sub-period followed by a Granger causality test. The estimated results are presented in table 8.

Table 8. VECM and VAR estimation results for the United States

	2005-2016 (VECM)		
	$\Delta P_{E,t}^{US}$	$\Delta P_{G,t}^{US}$	$\Delta P_{C,t}^{US}$
Const.	-0.002	-0.001	0.0029
Long-term adj. coef. α_1	-0.0752	0.1226*	-0.0232
$\Delta P_{E,t-1}^{US}$	0.0326	-0.1117**	0.0961
ΔP_{Gt-1}^{US}	0.2548**	0.5800*	-0.1352**
$\Delta P_{C,t-1}^{US}$	0.2847**	0.1718**	0.2897*
Cointegration equation	1	-1.6230*	0.4305*
	2005-2008 (VAR)		
	$\Delta P_{E,t}^{US}$	$\Delta P_{G,t}^{US}$	$\Delta P_{C,t}^{US}$
Const.	-0.016	-0.021***	0.0132
$\Delta P_{E,t-1}^{US}$	0.1360	-0.0246	0.0780
ΔP_{Gt-1}^{US}	0.2793	0.6072*	-0.1221
$\Delta P_{C,t-1}^{US}$	0.6171**	0.6499*	0.3657*
	Granger causality test		
H_0	Chi^2	df	$Prob.>chi^2$
$P_{G,t}^{US} \rightarrow P_{E,t}^{US}$	1.9522	1	0.162
$P_{C,t}^{US} \rightarrow P_{E,t}^{US}$	5.5518	1	0.018
$P_{E,t}^{US} \rightarrow P_{G,t}^{US}$	0.0402	1	0.841
$P_{C,t}^{US} \rightarrow P_{G,t}^{US}$	11.519	1	0.001
$P_{E,t}^{US} \rightarrow P_{C,t}^{US}$	0.72931	1	0.393
$P_{G,t}^{US} \rightarrow P_{C,t}^{US}$	1.2571	1	0.262
	2009-2016 (VECM)		
	$\Delta P_{E,t}^{US}$	$\Delta P_{G,t}^{US}$	$\Delta P_{C,t}^{US}$
Const.	0.001	0.001	-0.001
Long-term adj. coef. α_1	-0.1698**	0.1494*	-0.0333
$\Delta P_{E,t-1}^{US}$	0.0206	-0.1399**	0.1197
ΔP_{Gt-1}^{US}	0.1468	0.4078*	-0.131
$\Delta P_{C,t-1}^{US}$	0.1725	0.0981	0.2037**
Cointegration eq. 1	1	-1.1922*	0.0570

Source: Results of the research.

Note: * significant at 1%; ** significant at 5%; *** significant at 10%. The estimated models include only a constant. For the interpretation of the cointegration equations, the signs of the coefficients need to be inverted.

For the entire analyzed period, the estimated long-term adjustment coefficient for the U.S. market is statistically different than zero only for the price of gasoline, while the other two commodities were not found to adjust towards the long-term equilibrium. After the financial crisis, however, ethanol entered the cointegration relationship, implying that the prices of the two fuels become more tightly connected after 2008. The price of corn, on the other hand, remained exogenous in the long-run during all analyzed periods.

The obtained results for the U.S. market show that the long-term relationship between the biofuel-related markets in the country strengthened after the financial crisis. This finding is in line with Rajcaniova, Drabik and Ciaian (2013) and Gorter, Drabik and Just (2015) which provide evidence for a tight relationship between the biofuel-related prices in the U.S. in recent years as a result of the establishment of blending mandates and the suppression of tax incentives.

The main feedstock in the U.S., however, remained exogenous during both sub-periods – a result rather different than what was observed in Brazil. This finding can be attributed to the fact that the country is the number one producer, consumer and exporter of corn worldwide (USDA, 2016), which implies that its corn sector is highly related to the international market of this commodity. Thus, the exogeneity of the domestic corn price in the long-run is a result rather in line with the expected, considering the position of the country in the international context. In contrast, for the case of Brazil, the price of sugar became more interrelated with the domestic biofuel market after 2008, indicating a different effect of the crisis period on the price transmission mechanisms in these two countries.

In the short-run, for all analyzed periods, the results show that gasoline and corn prices adjusted to changes in their own lagged values. The price of the main feedstock was found to have a significant and rather strong positive impact on the prices of both ethanol and gasoline between 2005 and 2008, while such a short-term effect was not found after the financial crisis, when none of the estimated short-term adjustment coefficients for the effects of the price of corn on the two fuel alternatives was statistically significant. During the first sub-period, a 1%-increase in the price of corn in period *t-1* caused a 0.6171%-increase in the price of ethanol in period *t* and a 0.6499% increase in the price of gasoline.

When it comes to the price of the main fossil fuel in the U.S., it was found to be affected in the short-term by all other prices in the system when the entire sample is considered. When the analysis is performed only for the data between 2005 and 2008, the Granger causality test results show that there existed a unidirectional transmission from corn to gasoline prices. This short-term effect, however, disappeared after the crisis period.

Regarding the response of the price of corn in the short-run, it was found to be negatively affected by shocks in the price of gasoline when the entire period is analyzed, while this effect disappeared when the two sub-periods are considered separately. None of the variables was found to Granger-cause the price of corn before 2008 and it remained exogenous after the financial crisis, as well. This finding provides insights on the food vs. fuel debate, showing that ethanol production did not have a significant direct negative impact on corn prices in the U.S., which is in line with the conclusions of other studies in the existing literature (ZHANG et al., 2010; CHIU et al., 2016; BASTIANIN; GALEOTTI; MANERA, 2016).

The obtained results for the U.S. market, indicate that the relationship between the domestic gasoline and ethanol prices tightened after the financial crisis. This finding can be attributed to the trends in the American biofuel sector from that period. After 2005, ethanol gained significant importance in the domestic fuel market due to the introduction of the Energy Policy Act together with the Renewable Fuel Standard (RFS) program. This boosted domestic ethanol production, making the country the number one player on the international biofuel scene in terms of ethanol production, which registered record high levels first in 2011 and later on in 2014 (EIA, 2016). In addition, the second RFS program was introduced in 2010 and the different degrees of credit offered to the participants in the ethanol sector, such as the Volumetric Ethanol Excise Tax Credit (VEETC) and the Small Ethanol Producer Credit were eliminated in 2011. Moreover, the period between 2009 and 2016 was rather turbulent when the international price of crude oil is considered. It reacted significantly to the global financial crisis, established itself on higher levels in the following years and registered a dramatic drop in the beginning of 2015. These trends affected the domestic fuel market in the U.S., since the country is a major crude oil consumer and importer and its domestic fuel prices follow the international oil price fluctuations. Thus, the rather turbulent period between 2009 and 2016 can be considered the main reason for the altered relationship between the biofuel-related sectors in the country.

For Germany, no cointegration was identified when the entire sample is considered, as well as during the second sub-period, thus, a VAR model on the log differences of the data was estimated for these two periods and a Granger causality test was performed in order to verify the results. A VECM with one rank and one lag was estimated for the period before the financial crisis, in accordance with the results of the Johansen cointegration test presented above. The obtained coefficients of the estimated models for the German market are presented in table 9.

Regarding the entire analyzed sample, the estimated results of the VAR model show that the price of biodiesel responded positively to changes in the other two variables in the system. A 1%-increase in the price of diesel led to a 0.25%-increase in the price of biodiesel, while a positive shock in the price of rapeseed oil caused a 0.19%-increase in the price of this type of biofuel. Moreover, biodiesel remained endogenous in the system, without causing any significant response in the other variables. The price of diesel, on the other hand, was found to be significantly affected by the price of rapeseed oil, while the latter reacted positively to changes in the price of this type of fuel from the previous period.

The performed Granger causality test supports the results of the estimated VAR model, indicating a unidirectional causality from the price of rapeseed oil and diesel towards the price of biodiesel, as well as a bidirectional relationship between rapeseed oil and diesel prices. These results provide evidence for the tight short-term linkage existing between the prices of fuel and feedstock in Germany, while the price of the main biofuel was not found to have such a strong position as observed in Brazil and in the United States.

Table 9. VECM and VAR estimation results for Germany

	2005-2016 (VAR)		
	$\Delta P^{G}_{B,t}$	$\Delta P^{G}_{D,t}$	$\Delta P^{G}_{R,t}$
Const.	0.0031	-0.0022	0.0022
$\Delta P^{G}_{B,t-1}$	0.0597	0.1093	0.0234
$\Delta P^{G}_{D,t-1}$	0.2521*	0.1086	0.3240*
$\Delta P^{G}_{R,t-1}$	0.1918**	0.1684**	0.1185
	Granger causality		
H_0	Chi2	df	Prob.>chi2
$P^{G}_{D,t} \rightarrow P^{G}_{B,t}$	7.1872	1	0.007
$P^{G}_{R,t} \rightarrow P^{G}_{B,t}$	5.2511	1	0.022
$P^{G}_{B,t} \rightarrow P^{G}_{D,t}$	1.1474	1	0.284
$P^{G}_{R,t} \rightarrow P^{G}_{D,t}$	4.0503	1	0.044
$P^{G}_{B,t} \rightarrow P^{G}_{R,t}$	0.03366	1	0.854
$P^{G}_{D,t} \rightarrow P^{G}_{R,t}$	7.602	1	0.006
	2005-2008 (VECM)		
	$\Delta P^{G}_{B,t}$	$\Delta P^{G}_{D,t}$	$\Delta P^{G}_{R,t}$
Const.	0.0006	-0.0031	0.0015
Long-term adj. coef. α_1	-0.6371*	-0.3934*	-0.2167*
Cointegr. Equation	1	-0.3404**	-0.5564*
	2009-2016 (VAR)		
	$\Delta P^{G}_{B,t}$	$\Delta P^{G}_{D,t}$	$\Delta P^{G}_{R,t}$
Const.	0.0033	-0.0021	0.0017
$\Delta P^{US}_{E,t-1}$	-0.0106	0.1551	-0.1455
ΔP^{US}_{Gt-1}	0.1533	0.0562	0.2045
$\Delta P^{US}_{C,t-1}$	0.1355	0.0428	0.1123
	Granger causality test		
H_0	Chi^2	df	Prob.>chi^2
$P^{G}_{D,t} \rightarrow P^{G}_{B,t}$	1.7768	1	0.183
$P^{G}_{R,t} \rightarrow P^{G}_{B,t}$	1.8472	1	0.174
$P^{G}_{B,t} \rightarrow P^{G}_{D,t}$	1.7181	1	0.190
$P^{G}_{R,t} \rightarrow P^{G}_{D,t}$	0.20228	1	0.653
$P^{G}_{B,t} \rightarrow P^{G}_{R,t}$	0.93799	1	0.333
$P^{G}_{D,t} \rightarrow P^{G}_{R,t}$	2.1482	1	0.143

Source: Results of the research.

Note: * significant at 1%; ** significant at 5%; *** significant at 10%. The estimated models include only a constant. For the interpretation of the cointegration equations, the signs of the coefficients need to be inverted.

Before the global financial crisis, one cointegration relation was identified between the biofuel-related prices in Germany. The long-term adjustment coefficients of the estimated VECM with one lag were statistically significant and negative for the three price series, implying that if the system is above its equilibrium level, the prices of the three commodities must decrease in order to bring it back to stability. The price of biodiesel was found to adjust the most between 2005 and 2008, with a long-term adjustment coefficient equal to 0.63%. Moreover, the estimated cointegration equation shows that diesel and rapeseed oil had a positive long-term impact on the domestic price of biodiesel.

This long-term relationship between the three price series for the German market, however, disappeared after the crisis. The estimated VAR model and the results of the Granger causality test for the second sub-period show that there was no short-term relation between the examined variables. None of the short-term coefficients was found to be statistically significant. The null hypotheses of no Granger causality between the variables could not be rejected, implying no short-term price transmission between the biofuel-related sectors in Germany after 2008. This result is in line with the conclusion of Pokrivcak and Rajcaniova (2011), according to which no cointegration exists between the biofuel-related sectors in this country.

The estimated results for the German market show that the prices of biodiesel, diesel and rapeseed oil in Germany were tightly related between 2005 and 2008, which can be attributed to the fast growth of the biofuel sector in the country during this period as a result of the adopted policy changes stimulating the production of this fuel alternative. The European Union approved the Directive 2003/30/EC in 2003, in response to the rising concerns regarding climate change and the highly volatile international oil prices. This Directive introduced a blending mandate for all member countries, which were required to guarantee that a minimum share of biofuels was sold on their domestic market. Furthermore, in 2004, there was a change in the German tax policy, allowing full tax exemption for biofuels blended with conventional fossil fuels. This stimulated the production and consumption of biodiesel in the country and increased the share of renewable fuels in transportation.

Afterwards, however, the situation in Germany changed significantly. In 2007, due to the high weight that the tax exemption was imposing on the national budget, it was eliminated by the government and replaced by quota obligations and tax discounts with the introduction of the Energy Tax Law in 2006 and the Biofuel Quota Law in 2007. These changes in the legislation resulted in an immediate decrease in the production of biofuels in the country. According to Pires and Schechtman (2010), the German biodiesel production decreased by 12% between 2007 and 2008. The idle capacity of the production plants reached 85% and half of the companies involved in the biodiesel sector had to exit the market due to financial difficulties. These changes that occurred in the German biofuel legislation distorted the domestic market and the price transmission observed during the first sub-period disappeared after 2008. Moreover, the highly fluctuating EUR/USD exchange rate after the financial crisis might have introduced additional turbulence to the German biofuel-related sectors, distorting the long-term relationship between the examined prices.

3.5.3. Comparison of the results

Comparing the results of the estimated models for the three countries of interest during the entire analyzed period, it can be observed that only in Brazil all variables of interest adjusted in the long-run. In the U.S., just the price of gasoline was found to adjust towards the long-term equilibrium, while for Germany no long-term relationship was found between the price series. This result is rather in line with the expected, since Brazil has the most developed biofuel sector from the three countries of interest, characterized by the wide use of ethanol produced from sugarcane in its pure form as substitute for gasoline, which implies tighter relation between the prices of the examined commodities.

Regarding the short-term interactions between the variables during the entire analyzed period, the obtained results show that in the U.S. and in Germany the biofuel price was significantly influenced by the prices of its fossil fuel alternative and the main feedstock for its production, while, for the case of Brazil, the price of ethanol was found to be rather independent in the short-term, indicating the self-sufficiency of the biofuel industry in this country. In addition, both in Brazil and in the U.S., the price of gasoline was significantly affected by the domestic price of ethanol, while for Germany, the results indicate that biodiesel did not have a significant impact on the price of its fossil fuel alternative, thus, implying a significant degree of endogeneity of the biofuel sector in this country.

The obtained results for the two sub-periods indicate that the relationship between the biofuel-related sectors changed after the financial crisis of 2008 in the three examined countries. This change can be attributed to a number of factors characterizing the period between 2009 and 2016, such as turbulent exchange rates, increasing international commodity prices, highly volatile international crude oil prices, and changes in the domestic biofuel policies. The findings for Brazil and the U.S. show that after the crisis the long-term relationship between the price series strengthened significantly.

In Germany, on the other hand, both the short- and the long-term transmission between the variables from the first sub-period disappeared after 2008, which is a result of the changes in the country's government policy regarding biofuels. This finding is rather important, since it shows how crucial the government support is for the development of the German biofuel sector and it indicates that policies play a significant role when it comes to price transmission in the biofuel-related sectors. Although similar policy changes were observed in the U.S. after 2008, with the expiration of the tax credit and the import tariffs on ethanol in 2011, the relationship between the biofuel-related prices in this country remained rather strong and stable. As pointed out by Kristoufek, Janda and Zilberman (2012), however, the biofuel-related policies in the U.S. and in Germany are rather different. In Germany, for instance, there is no well-defined blending mandate and policy makers have relied mainly on tax exemption and tax credits in order to stimulate the production and use of biofuels, while in Brazil and in the U.S. there exist well defined blending mandates, which provide additional stimulus for the development of the domestic biofuel industry.

Regarding the relationship between the examined variables in the short-run, it is important to mention that in Brazil the price transmission between the price series increased significantly after 2008. Before the crisis, both gasoline and sugar were found to be exogenous in the short-run, while afterwards the sugar price entered the transmission mechanism, becoming significantly affected by the prices of the other two commodities. In the U.S., on the other hand, fewer short-term adjustment coefficient were found to be statistically significant after 2008, with the price of corn remaining highly exogenous during both sub-periods. These findings reflect the different position the main feedstock for the production of ethanol has in the two examined countries. In Brazil, the price of sugar is tightly linked to the domestic biofuel industry, while in the U.S. the price of corn appears to be rather independent and influenced mainly by trends on the international market.

The most noticeable difference between the two sub-periods, however, was found for Germany, where after 2008 none of the estimated short-term coefficients were statistically different than zero. Thus, while in Brazil and in the U.S. the biofuel-related sectors became more tightly linked after the financial crisis, the opposite was observed for the German market. This finding can be attributed to the fact that there is no single feedstock used for the production of biodiesel in Germany. In general, the feedstocks for the production of biofuels in the EU differ by region. Rapeseed oil and sunflower oil are the most common, but soybean oil and palm oil are used for this purpose, as well. In recent years, the use of palm oil as biofuel feedstock has become widely spread in the EU mainly because of its price discounts (FLACH, et al., 2014). This trend might have shaken the position of rapeseed oil as major feedstock in Germany and disturbed the link it had with the biofuel sector before the crisis years.

The lack of a single feedstock in Germany results in a different relationship between the biofuel-related prices in the country, reflecting that the domestic biodiesel sector is not tightly dependent on the rapeseed oil price – a result similar to what was found by Filip et al. (2016). In contrast, when the industry depends on a single feedstock for the biofuel production, this creates strong dependence between the prices of the input and the final product. Unfavorable climate conditions can influence the harvest and the crop of the main feedstock, and without an alternative, the supply of biofuel might suffer, which can affect significantly its final price. In Germany the high substitutability of different feedstocks justifies the lack of a tight price relationship between the biofuel-related sectors.

3.6. Conclusion

The main objective of the present study is to verify if there exist differences in the biofuel-related price transmission mechanisms in Brazil, in the United States and in Germany, with emphasis on the specific characteristics of the biofuel and fuel sectors and the varying government policies regarding these industries in the three countries of interest. The performed time series analysis focuses on using data with the same frequency, level and time frame for the three economies in order to complement the existing literature with a comparative analysis of the relationships between the biofuel prices, their main fuel alternative and their major feedstock. The analysis is performed for two separate time periods, which account for the effects of the global financial crisis of 2008.

The obtained results show that the relationship between the biofuel-related sectors is different in the three examined countries. For Brazil, the ethanol, gasoline and sugar prices were found to adjust towards the long-term equilibrium when the entire sample is considered, while in the U.S. only the price of gasoline participated in the long-term adjustment process. For Germany, on the other hand, no evidence for a long-term relationship between the variables was found, which implies less dependent biofuel-related sectors in this country.

Furthermore, the analysis for the two sub-periods shows that the price transmission between the biofuel-related sectors in the three countries changed significantly after the financial crisis. In Brazil, the examined price series became more integrated after 2008, with gasoline and sugar prices joining the long-term adjustment process. For the U.S. market, the estimated results show that the price series exhibited a long-term cointegration relationship after the crisis period, which was not observed between 2005 and 2008. The price of corn, however, remained exogenous during both sub-periods, implying that the relationship between the main feedstock and the domestic biofuel sector in the U.S. is rather different than the existing tight link between ethanol and sugar prices in Brazil.

The situation in Germany, however, is rather different than what was found for the other two examined countries. While the prices of biodiesel, diesel and rapeseed oil were tightly related between 2005 and 2008, after the crisis neither short- nor long-run transmission was observed between the three analyzed price series. This result can be attributed to the changes in the policy regarding biofuels in the country, as well as to the specific characteristics of its biofuel-related sectors, which include the existence of alternative feedstocks for biofuel production. While in Brazil and in the U.S. the industry is characterized by a stable price transmission between the biofuel-related commodities, in Germany such a stable link is not observed.

The main contribution of the present paper lies in the performed comparative analysis which sheds light on the existing differences between the price transmission mechanisms related to biofuels in Brazil, Germany and the United States. The findings of the study contribute to the existing discussion regarding biofuel policies by stressing the fact that price transmission depends significantly on the specific characteristics of the domestic biofuel industry as well as on the government policies regarding this fuel alternative.

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4. HYPOTHETICAL EFFECTS OF FREE GASOLINE PRICES ON THE ETHANOL SECTOR IN THE STATE OF SÃO PAULO

ABSTRACT

Brazil is a particularly interesting country when it comes to the study of fuel prices and their effects on the domestic economy, since the oil-related sectors have some specific characteristics, such as the wide use of ethanol as a substitute for gasoline and the practiced fuel pricing policy by the government. The goal of the present study is to analyze how the situation in the state of São Paulo would have looked like between 2007 and 2016 if fuel prices were not administrated by the government and what the hypothetical effects of such a change in the government fuel pricing policy would have been on biofuel prices and demand. For the purposes of the analysis, a hypothetical consumer gasoline price was constructed, using the provided by DATAGRO "interned" gasoline price series. The fuel demand elasticities were estimated by fitting a structural VEC model to the data. The obtained results show that gasoline prices that incorporate the price fluctuations on the international crude oil market would have led to higher hydrous ethanol prices in the state of São Paulo, making it more profitable for sugarcane producers to engage into the production of ethanol instead of sugar. Moreover, gasoline prices without government intervention would have caused lower demand for this type of fuel, breaking the artificial demand created by the practiced fuel pricing policy. These findings show that the ethanol sector could have benefitted from a freely fluctuating gasoline prices, especially between 2011 and 2014 when the industry faced a severe crisis. There is a need for reformulating the practiced fuel pricing policy in Brazil in order to help ethanol regain its previous competitiveness as a substitute for conventional fossil fuels and to reestablish itself in the country's energy matrix.

Keywords: Fuel pricing policy; Free fuel prices; Ethanol; Demand estimation

4.1. Introduction

Crude oil and conventional fossil fuels remain the main energy source worldwide. They are internationally traded goods and their prices are formed following the basic rules of supply and demand on the world market. Nevertheless, the prices of fuels in some countries do not follow the international price of crude oil, but rather diverge significantly. This trend is the result of two main factors that play a role simultaneously: government fuel pricing policies and taxation. In general, fuel price fluctuations are considered to have a significant negative impact on inflation rates, especially in developing countries, which is the main reason why governments adopt different fuel pricing mechanisms which involve some degree of intervention in the formation of the domestic fuel price.

The case of Brazil is particularly interesting when it comes to the study of fuel prices and their effects on other sectors of the economy, since the oil-related industry in the country has some specific characteristics, such as the wide use of ethanol produced from sugarcane as a substitute for gasoline and the practiced fuel pricing policy by the government. Until 1997, the state-controlled company Petrobras held a monopoly on all oil-related activities in the country, fuel imports were not allowed and the price of all petroleum derivatives was established by the government. Moreover, the price of ethanol was artificially established and kept at 60% of the domestic price of gasoline (FARINA et al., 2010). In the late 1990s, the first steps towards the liberalization of the fuel industry were taken: the sector was opened for competition, subsidies were removed, and the refinery price was liberalized. This process was effectively completed in 2002 and currently there is no official government control over the fuel sector.

Nevertheless, fuel prices in Brazil are not entirely free to follow international crude oil price fluctuations. The ex-refinery price of all petroleum derivatives is set by Petrobras, which uses as a reference for the price adjustments the variations in the Brent crude oil price and the USD exchange rate published by the Central Bank of Brazil. The established pricing system in the country aims at diminishing the negative effects that volatile fuel prices would have on the inflation rate. Thus, Petrobras plays the role of a price-setter and assists the Brazilian government by ensuring that the supply and the price of petroleum derivatives in the country meet the consumption requirements (FATTOUH; OLIVEIRA; SEN, 2015). Another measure used by the government as a way to control domestic fuel prices is taxation, which has been frequently adjusted in order to maintain the price of fuels stable in times of expensive international crude oil.

This pricing policy has been an important decision for the government, since the country has a history of periods with extremely high inflation. Moreover, in Brazil the distribution system of goods relies mainly on road transportation, which implies that higher fuel prices will be passed on to the final consumer price of goods, since the majority is transported by trucks. In 2014, for instance, more than half of all goods transported was carried by road (CUNHA, 2015). The inadequate infrastructure for using cheaper types of transportation makes the country dependent on road transport and almost all sectors of the economy become vulnerable to fuel price fluctuations.

The practiced pricing policy in Brazil resulted in a significant divergence of the domestic fuel prices from the international price of crude oil, as shown on figure 15. As it can be observed on the graph, the domestic monthly average consumer prices of gasoline and diesel remained rather stable during the period between 2005 and 2016, with small and insignificant adjustments occurring mainly after 2012. According to Fattouh, Oliveira and Sen (2015), the gasoline price has been adjusted 12 times in the last 11 years, while the diesel price – 14 times. The Europe Brent price, on the other hand, measured in R$/barrel, varied significantly between 2005 and 2015. These fluctuations on the international oil market, however, were not absorbed by the gasoline and diesel prices in Brazil.

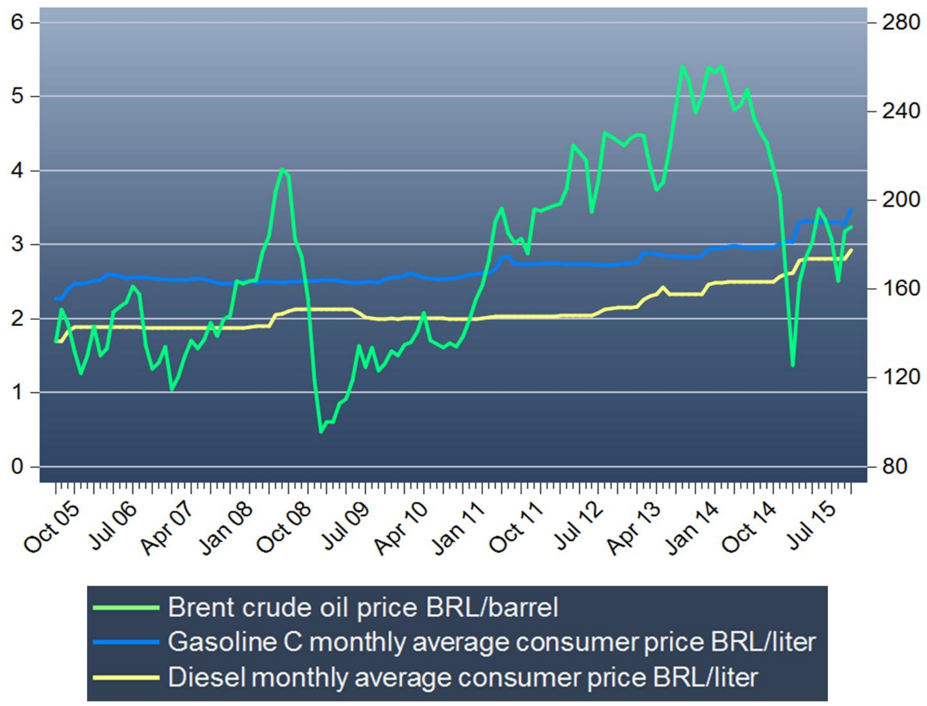

Figure 15. Monthly average consumer prices of gasoline C and diesel for Brazil and Europe Brent crude oil price between January, 2005 and January, 2016

Source: NPA, EIA.

In general, ad hoc fuel pricing policies, as the one existing in Brazil, lower the vulnerability of the domestic market to outside oil price shocks, but they can also have severe consequences for the domestic economy. Artificially low domestic petroleum product prices in times of expensive international crude oil can lead to financial difficulties for fuel suppliers and importers, fuel supply shortages and lack of investment in the fuel sector (KOJIMA, 2009). For the specific case of Brazil, the artificially established petroleum product prices have brought imbalances to the domestic economy and especially to Petrobras (SERIGATI, 2014). The profitability of the company has deteriorated significantly, which, in turn, has undermined the value of its shares and increased its indebtedness. Between 2011 and 2014 Petrobras lost over 23 billion BRL by importing gasoline, diesel and LPG at higher prices than it was selling domestically and its debt increased by 70% (OLIVEIRA; ALMEIDA, 2015).

Other sectors of the economy, especially the ethanol industry, suffered as well in the past few years. The prevailing trend of the consumers' preference for ethanol as a result of the introduction of the flex-fuel vehicle in 2003 was reversed in 2009, due to the artificially low gasoline price established by Petrobras. The attractiveness of the ethanol sector reduced, pushing away investors and leading to migration to sugar production from sugarcane instead of ethanol. In general, Brazil has a major international comparative advantage in the production of ethanol and large domestic demand potential, which can be activated once the price of the product becomes competitive when compared to gasoline (ARAUJO, 2013). Keeping the price of fuels artificially low, however, undermined the competitiveness of the biofuel sector in recent years and the potential of this fuel alternative weakened significantly.

The negative consequences of the established pricing policy in Brazil raise some fundamental questions: Who is covering the losses of Petrobras and is the burden transferred to the final consumer? Should the government let the price of fuels adjust to international crude oil price fluctuations? What would the potential impact of such a pricing policy be on the domestic economy and especially on the ethanol sector? These important questions have not been answered yet, thus, the study of how the situation in Brazil would look like if fuel prices were not administrated and what their level would have been during the past decade, represents a relevant topic of research, which is addressed in the present paper.

The main objective of this work is to provide insights on the issue by examining the hypothetical effects of a change in the government fuel pricing policy in Brazil on the fuel and biofuel prices and demands in the state of São Paulo for the period January, 2007 - June, 2016. For this purpose, a hypothetical freely fluctuation consumer gasoline price was constructed, using the provided by DATAGRO series of "interned" gasoline A price. The proposed method for performing the analysis is based on fitting a structural vector autoregression (SVAR) model to the data that incorporates the specific characteristics of the fuel and biofuel sectors in the country, in order to estimate the price elasticities of ethanol and gasoline demand. The estimated contemporaneous responses of the variables to changes in the price of gasoline are used afterwards for the calculation of the hypothetical ethanol price for a scenario with no government intervention in the domestic fuel sector and the consecutive effects on the demanded quantities of ethanol and gasoline.

The remainder of this work is organized as follows: Section 4.2 briefly reviews the literature on fuel pricing policy and ethanol demand estimation in Brazil; Section 4.3 focuses on the methodology for performing the analysis; Section 4.4 develops the theoretical model applied in the paper and describes the used data; Section 4.5 presents the results of the research; Section 4.6 concludes with final remarks and suggestions for future research.

4.2. Literature Review

4.2.1. Fuel pricing policy and simulation of free fuel prices

There is no consensus in the existing literature whether the Brazilian government should move to a fuel pricing policy, which allows the prices of petroleum derivatives to be determined entirely by the market, or not. Some authors (VIEGAS, 2011) argue that the total liberalization of the price of gasoline is essential for the country, especially for the ethanol industry, while others (OLIVEIRA; ALMEIDA, 2015; ALMEIDA; OLIVEIRA; LOSEKANN, 2015) think that a market-based approach for fuel prices is unfeasible. The majority of the reviewed works, however, conclude that a change in the practiced fuel pricing mechanism in Brazil is essential for the country.

Almeida, Oliveira and Losekann (2015), for instance, perform a comparative analysis of internationally practiced fuel pricing policies and their application for Brazil. The authors conclude that the full liberalization of fuel prices, as in Canada and the United States, is not the best option for a country like Brazil, which has great concerns of the impacts of international price variations on the level of inflation. Thus, some level of government control is needed and a policy of stabilization funds, such as the practiced in Chile and Peru, appears to be the better option for Brazil.

According to Azevedo and Serigati (2015), the adopted strategy by the government of the President Dilma Rouseff of administrating prices as an instrument for reducing inflation in Brazil has been inefficient, has had negative impacts on investment and consumption decisions, and, in addition, has been used as a strategy for winning elections. The authors propose two alternative policies. The first one establishes clear and transparent rules for price adjustments, whose change represents a cost for the government in office, in order to limit its power and reduce any kind of abuse. The second option is removing the administrated prices from the composition of the inflation index IPCA, which will change the motives of the government when exercising control on price levels.

The negative effects of the practiced fuel pricing policy in Brazil on the ethanol sector have received attention in the existing literature, as well. Santos, Garcia and Shikida (2015), for instance, discuss the main factors that led to the crisis of the ethanol sector in the country from 2011, namely, the elevation of the production costs, the increase in the costs for external financing, the reduction in the margins, and the control of the price of gasoline. The authors raise the question of the potential effects of liberalization of the price of gasoline on the ethanol sector in the country and suggest this research question as an interesting continuation of their work.

When it comes to the potential impact of free fuel prices in Brazil on the ethanol industry, Araujo (2013) analyzes how the variation of the price of gasoline in the country affects the performance of the ethanol sector. The author estimates the GDP of the sugar and ethanol industries for the period 2002-2012, using the actual gasoline prices for the studied period and a benchmark price of gasoline of the Gulf of North America. The obtained results show the existence of significant impact of the gasoline price on all variables of the biofuel industry in Brazil, which include production of hydrous and anhydrous ethanol, GDP of the sugar and ethanol sectors, and indebtedness of the industry. The article provides evidence that the fuel pricing policy of the government has negative impact not only on the performance of Petrobras, but also on the performance of all sugar and ethanol-related sectors in the country.

A simulation of free gasoline price for Brazil was performed by Serigati (2014), who used two different approaches. The first originates in the calculation of a viable price of hydrous ethanol, from which the price of gasoline is derived, assuming that the effective price ratio of 0.7 between the two prices is maintained. The second one is based on a simulation of an average gasoline price following the variations in the international crude oil price from where the arbitrary fair price of ethanol is derived. Serigati (2014) concludes that the policy of controlling fuel prices has decreased the competitiveness of ethanol over time but at the same time has helped control inflation.

More thorough analysis of the potential effects of free fuel prices on the inflation rate in Brazil was performed by Corrêa and Teixeira (2014). The authors used U.S. gasoline and diesel prices as a proxy for free fuel prices in Brazil, in order to calculate the historical IPCA for the hypothetical situation of no government intervention in the fuel sector for the period 2003-2008. The authors do not find any significant hypothetical negative impact on the index of inflation. The obtained results show that only in 2003 and in 2008 the inflation rate would have been higher due to the free prices of gasoline and diesel in comparison to the actually observed rate of inflation in the country.

Furthermore, Cunha (2015) developed a method for analyzing the direct and indirect effects of administrated fuel prices on the inflation index in Brazil for the period 2005-2013. The obtained results show that the policy of controlling fuel prices was successful for mitigating the level of inflation in some of the studied years, but at the same time was associated with social costs and economic distortions related to this type of pricing policy. Moreover, Cunha (2015) emphasizes the negative effects of the practiced fuel pricing policy in the country, indicating the distortions in the domestic price system, the deterioration of Petrobras' financial situation, the reduced attractiveness of the oil-related sector for investment, the negative impact on the ethanol sector and the environmental costs. The proposed alternative policy by the author is the adoption of a measure of core inflation as an official index, which is supposed to exhibit less variation than the plain inflation index and, thus, can serve as a better signal for adopting different economic policies.

Khanna, Nunez and Zilberman (2016) develop a partial-equilibrium model of the fuel, biofuel, and sugar sectors in Brazil in order to analyze the impacts of the practiced fuel policies in the country. The authors simulate five alternative policy scenarios and compare their hypothetical effects on the prices and the demanded and supplied quantities of sugar, ethanol and gasoline. The main findings show that the status-quo policy scenario that considers the existing mix of policies, including blending mandate, gasoline tax, ethanol tax credit and oil price cap, leads to higher consumer fuel and biofuel prices, higher production and consumption of ethanol, lower sugar supply and gasoline demand, in comparison to the baseline scenario of no policy. Moreover, the authors conclude that the choice of fuel policies in Brazil has not been guided by the pursuit of economic efficiency, but rather by policy objectives such as tax revenue, increasing oil exports, and the well-being of various interest groups.

Analysis of the impacts of the practiced fuel pricing policy in Brazil on the price of ethanol has been performed by Costa and Burnquist (2016). They use annual data for the period 2006-2015 for the estimation of a freely fluctuating gasoline price based on the import price of this commodity. The authors find that between 2006 and 2010, as well as in 2015, the observed ethanol and gasoline prices in Brazil were approximately 10% higher than the simulated prices without government intervention, while between 2010 and 2014 the simulated prices were found to be 7% above the observed ones. The obtained results show that the government intervention in the domestic fuel sector has at certain periods stimulated the consumption of biofuels and at other periods it has discouraged ethanol demand. The authors, however, do not examine the effects of the total liberalization of the domestic fuel sector on the demanded fuel and biofuel quantities.

4.2.2. Price transmission in the biofuel-related sectors and ethanol demand estimation

For the purposes of the proposed study, it is crucial to understand the interrelations between the ethanol sector and the sugar and gasoline markets in Brazil. Moreover, it is important to take into consideration the existing link between the hydrous and anhydrous ethanol markets. First of all, sugar and ethanol in Brazil are produced from the same feedstock – sugarcane, which makes the two products competing on the supply side. Since most of the production plants in the country are specialized in producing both products, it is up to the producer to decide how to distribute its production, depending on market conditions. This specific characteristic of the sugar and ethanol sectors makes them closely interrelated, especially when it comes to price linkages. The findings of the empirical literature provide evidence for the existence of a long-term relationship between the prices of sugar and ethanol in Brazil (RAPSOMANIKIS; HALLAM, 2006; BALCOMBE; RAPSOMANIKIS, 2008; BLOCK; CORONEL; VELOSO, 2012; BENTIVOGLIO; FINCO; BACCHI, 2016).

Another important characteristic of the Brazilian biofuel sector is the fact that there are two types of ethanol produced in the country – hydrous ethanol, which is used in its pure form as a substitute for gasoline, and anhydrous ethanol, which is derived after dehydration and is used only for blending with gasoline. Since the latter is a derivation of the former, the prices of the two products are highly interrelated (ELOBEID; TOKGOZ, 2008).

When it comes to the relationship between hydrous ethanol and gasoline in Brazil, the two products act as substitutes on the demand side due to the existence of the flex-fuel vehicle, introduced in 2003, which allows the consumer to choose what fuel to use – gasoline C (a blend of gasoline with 27% of anhydrous ethanol) or pure hydrous ethanol fuel. Since ethanol is less efficient than gasoline, it makes sense to use the biofuel as a substitute as long as its price constitutes 70% of the price of gasoline. This specific characteristic of the fuel and biofuel sectors, which is rather unique for Brazil, implies that they are closely interrelated. The results of the existing empirical literature on the topic show that there exists a long-term relationship between the prices of hydrous ethanol and gasoline in the country (CAVALCANTI; SZKLO; MACHADO, 2011; BENTIVOGLIO; FINCO; BACCHI, 2016).

Ethanol demand estimation in Brazil has been a relevant research topic since the introduction of the flex-fuel vehicle in 2003, which made it possible for the consumer to choose between gasoline and ethanol as fuel alternatives. Table 10 provides synthesized information on the estimated ethanol demand elasticities in the empirical literature for Brazil. In the majority of reviewed studies on the topic, ethanol consumption is used as dependent variable, while various independent variables, such as own price and the price of the main substitute, income and vehicle fleet, are included in the estimation of the equation for ethanol demand. Three major methodology approaches can be distinguished in the examined literature – time series analysis based on cointegration and vector error-correction model (VECM) estimation; least-squares (OLS) regression estimation; and spatial panel model estimation.

As it can be seen from table 10, the estimated own price elasticities of ethanol demand from all of the reviewed studies have a negative sign, reflecting the rules of the Law of Demand, while the estimated cross-price elasticities have a positive sign, implying that ethanol and gasoline act as substitutes. The estimated own short-term price elasticities remain in the range between 0.55 and 1.96, while in the long-run this range is between 1.11 and 11.26 in absolute terms, indicating that ethanol demand is more sensitive to its own price changes in the long-run (PONTES, 2009; RANDOW; FONTES; CARMINATI, 2010; SANTOS; FARIA, 2012; CARDOSO; BITTENCOURT; PORSSE, 2013). Similar conclusions can be derived for the cross-price elasticity with gasoline:

the estimated values are higher in the long than in the short-run, implying higher substitutability between the two fuel alternatives in the long-run. Moreover, the results of the reviewed studies show that ethanol demand is more sensitive to changes in the price of gasoline than to its own price variations.

There is a consensus in the literature that after the introduction of the flex-fuel vehicle in 2003, ethanol strengthened its position as a fuel and as a substitute for conventional fossil fuels (FREITAS; KANEKO, 2011; SERIGATI; CORREIA; PEROSA, 2010), which led to an increase in price and cross-price elasticities of the demand for this type of biofuel (SOUZA, 2010). In addition, ethanol demand is found to be more income elastic and more sensitive to changes in the vehicle fleet than gasoline demand (PONTES, 2009; CARDOSO; BITTENCOURT; PORSSE, 2013).

Table 10. Studies on ethanol demand estimation for Brazil

Reference	Model	Period	Short-run Variables and elasticities				Long-term Variables and elasticities			
			$P_{ethanol}$	$P_{gasoline}$	Y	F	$P_{ethanol}$	$P_{gasoline}$	Y	F
AZEVEDO (2007)		2002-2006	-0.93	1.30	0.40	-	-0.46	-0.36	0.14	-
PONTES (2009)	Cointegr., VECM	2001-2008	-0.75	0.87	1.31	-	-0.93* -0.19**	1.37	1.25	-
RANDOW, FONTES and CARMINATI (2010)	Cointegr., VAR/VEC	2001-2009	-0.55	not signif.	1.10	-	-11.26	12.79	0.46	-
SERIGATI, CORREIA and PEROSA (2010)	3SLS	2001-2009	-1.28* -2.18**	1.33* 1.98**	0.69	1.44	-	-	-	-
SOUZA (2010)	2-stage OLS (instruments)	2001-2006 and 2006-2009	-1.26 -1.83	0.75 2.03	0.45 0.21	1.56 4.48	-	-	-	-
FREITAS and KANEKO (2011)	Cointegr.	2003-2010	-1.42	0.95	not signif.	1.68	-1.8	1.99	-	4.4
DIEHL (2012)	SVAR and VEC	2001-2011	-0.932	1.2	0.551	-	-	-	-	-
SANTOS (2013)	1-step GMM	2001-2010	-1.25	1.18	0.55	-	-8.46	7.99	3.72	-
CARDOSO, BITTENCOURT and PORSSE (2013)	Spatial panel (HP-SAR)	2001-2011	-1.96	2.56	1.00	0.49	-3.45	4.50	1.76	0.87
MELO and SAMPAIO (2014)	SVAR	2001-2011	-0.95	0.80	-	-	-	-	-	-
SANOTS and FARIA (2014)	Spatial panel (Random effects)	2001-2010	-	-	-	-	-1.11	1.27	0.14	-

Source: Results of the literature review.
Note: *period before the introduction of the flex-fuel vehicle in 2003; **period after the introduction of the flex-fuel vehicle.

Based on the literature review presented in this section, it can be concluded that a thorough study of the potential effects of free fuel prices in Brazil on the ethanol sector has not been previously performed. There exists no consensus on whether the government should adopt a market-oriented fuel pricing policy or not, but the majority of researchers point out the necessity of a new pricing mechanism that is more transparent, does not allow abuse by the government, and does not have significant negative impact on the domestic economy, and especially on the ethanol sector.

4.3. Methodology

4.3.1. Stationarity tests

This study relies on time series techniques for performing the analysis, which requires taking into account some general statistical properties of the time series data a priori (SERRA; ZILBERMAN, 2013). The first property to be considered is the stationarity of the examined variables. Stationary data is characterized by time-constancy of its statistical distribution and such a time series is considered to be a process integrated of order zero - I(0).

Common practices in time series modelling involve the application of the augmented Dickey-Fuller and the Phillips-Perron tests for determining whether a data series is stationary or not. The proposed by Elliott, Rothenberg and Stock (1996) DF-GLS test, however, has significantly greater power and better overall performance in terms of small-sample sizes, dominating the ordinary Dickey-Fuller tests (HATANAKA, 1996). This test represents a modified version of the augmented Dickey-Fuller test, in which the series has been transformed by a generalized least-squares regression. The DF-GLS test is performed fitting a regression of the following form (ELLIOTT; ROTHENBERG; STOCK, 1996):

$$y_t = \alpha + \beta y_{t-1} + \delta t + \zeta_1 \Delta y_{t-1} + \zeta_2 \Delta y_{t-2} + \cdots + \zeta_k \Delta y_{t-k} + u_t \quad (4.1)$$

where k is the number of lags of first-differenced, detrended variables. The number of lags of the process has to be chosen appropriately. Lags should be added to the model only until they are significant, i.e. until there is no serial correlation in the error term. For this purpose, information criteria like the Ng-Perron, the Schwarz Criterion and the Modified Akaike Information Criterion are used.

There are two forms of the DF-GLS test – GLS detrending (where the series to be tested is regressed on a constant and a linear trend) and GLS demeaning (where only a constant appears in the first-stage regression). The null hypothesis of the DF-GLS test assumes that the y_t is a random walk. There are two alternative hypotheses depending on the chosen form of the test: y_t is stationary about a linear time trend, and y_t is stationary with a possible nonzero mean but with no linear time trend.

4.3.2. Structural vector autoregression (SVAR)

A vector autoregression process of a vector y_t containing *n* variables with *p*-lags can be expressed in the following form (HAMILTON, 1994):

$$y_t = c + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + \varepsilon_t \quad (4.2)$$

where y_t is a vector of stationary variables whose interrelations are analyzed, c denotes an $(n \times 1)$ vector of constants, Φ_j is an $(n \times n)$ matrix of autoregressive coefficients and ε_t is a vector of independent and identically distributed (i.i.d.) error terms with variance-covariance matrix Ω.

A structural vector autoregression is a VAR(p) process subject to short- or long-run restrictions placed on the contemporaneous relations in the VAR system, based on economic theory. According to Hamilton (1994) an SVAR representation of equation (4.2) takes the following form:

$$B_0 y_t = k + B_1 y_{t-1} + B_2 y_{t-2} + \cdots + B_p y_{t-p} + u_t \quad (4.3)$$

where B_0 is an (*n x n*) matrix of contemporaneous relationships between the variables, B_i's are (*n x n*) matrices of coefficients, and u_t is an (*n x 1*) vector of structural innovations.

Assuming that B_0 is invertible, equation (4.3) can be multiplied by B_0^{-1} on the left and solved for y_t, which results in the following reduced form of the SVAR:

$$y_t = B_0^{-1}k + B_0^{-1}B_1 y_{t-1} + B_0^{-1}B_2 y_{t-2} + \cdots + B_0^{-1}B_p y_{t-p} + B_0^{-1}u_t \quad (4.4)$$

Equation (4.4) represents the short-term SVAR form, where the imposed restrictions on the B_0 matrix model the contemporaneous relationships between the variables. Moreover, for the identification of the SVAR model, an orthogonality restriction should be imposed on the variance-covariance matrix of the residuals (Ω). This matrix should be diagonal, implying that the covariances between the residuals is restricted to be zero. The estimation of the coefficients of the SVAR model is based on maximum likelihood method of estimation.

4.3.3. Cointegration and SVECM

Another time series property that is tested in this work is the existence of a long-term relationship among the variables, or the so called cointegration. The formal development of this key concept was done by the Nobel laureates Clive Granger and Robert Engle (ENGLE; GRANGER, 1987). A vector time series y_t is said to be cointegrated if its individual elements are nonstationary but there exists a stationary linear combination of them - $\beta' y_t$, for some nonzero vector β called cointegration vector (HAMILTON, 1994). More precisely, the existence of cointegration implies that even though some permanent changes in the elements of y_t may occur, these elements are tied by the equilibrium relationship $\beta' y_t$ and tend to return to it in the long-run.

The proposed by Johansen (1988) and Johansen and Juselius (1990) cointegration test is based on a vector autoregression (VAR) model with *p* lags of a nonstationary *n*-dimensional process integrated of order one with independent and identically distributed (i.i.d.) Gaussian errors. The authors derive the maximum likelihood estimator of the cointegration vectors and perform a likelihood ratio test for the hypothesis that there exists a given number of cointegration vectors.

If the results of the cointegration test point towards the existence of a long-term relationship between the variables of the vector y_t, then the VAR model in equation (4.2) cannot be used to fit the data. Instead, an error-correction feature should be added to the VAR, which accounts for the existence of a cointegration relationship between the variables. Such a model is called a vector error-correction model (VECM). VEC models are useful tools in time series, since they allow the direct estimation of the speed at which a dependent variable returns to its long-term equilibrium after a change in an independent variable. These models account not only for long-term relationships, but also for short-term interactions between the variables. The VECM representation of the VAR model in equation (4.2) without constant and without a deterministic trend takes the following form (LUTKEPOHL, 2005):

$$\Delta y_t = \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1} + \Pi y_{t-1} + u_t \quad (4.5)$$

where:

$$\Gamma_i = -I + \Pi_1 + \cdots + \Pi_i, \quad \text{i}= 1,2, \dots, p-1 \quad (4.6)$$

Thus, the matrix Π is a function of Γ ($\Pi = -\Gamma_p$) and consists of the coefficients that measure the long-term adjustments of the variables, while the Γ matrix contains the coefficients that measure the adjustments of the model in the short-run.

The rank of the matrix Π can be used to test for the existence and the number of cointegration vectors. If $rank(\Pi) = 0$, this means that there is no cointegration between the variables and a traditional VAR model can be used to examine their relationship. If $rank(\Pi) = n$, i.e. the matrix has a full rank, then the variables cannot be I(1), implying that y_t is a stationary process. Finally, if 0< $rank(\Pi) = r < n$, then the variables are cointegrated and the number of cointegration vectors is equal to the rank *r*. Consequently, there exist two (n *x r*) matrices - *a* and *β*, such that $\Pi = \alpha\beta'$, where the the *β*'s are the cointegration vectors and the linear combination $\beta' y_t$ is stationary, while the matrix *a* contains information on the speed of adjustment of the variables in the long-run. In this case, the application of the VAR model is inappropriate, and y_t can be interpreted as an error-correction model.

In order to test the hypothesis that there are at most *r* cointegration vectors, Johansen (1988) and Johansen and Juselius (1990) apply a likelihood ratio test where the null hypothesis being tested is the following:

$$H_0: rank(\Pi) \leq r \; or \; \Pi = \alpha\beta' \quad (4.7)$$

The VEC model presented in equation (4.5) does not include assumptions from economic theory and can be considered the reduced form of a structural VEC model which incorporates restrictions based on theory. A structural VEC model (SVECM) without deterministic trend and exogenous variables takes the following form (LUTKEPOHL, 2005):

$$A\Delta y_t = \Gamma_1^* \Delta y_{t-1} + \Gamma_2^* \Delta y_{t-2} + \cdots + \Gamma_{k-1}^* \Delta y_{t-p+1} + \Pi^* y_{t-p} + B\epsilon_t \quad (4.8)$$

The matrix of contemporaneous effects A allows the incorporation of a structure reflecting a theoretical model in the VECM. For the estimation of the structural form parameters of the model, restrictions should be imposed on the matrix of contemporaneous effects. The estimation of the SVECM is done using maximum likelihood estimation.

4.4. Theoretical model and data description

For the purposes of the present study, a slightly modified version of the theoretical model developed by Diehl (2012) is used as the basis for the estimation of the price elasticities of ethanol and gasoline demand. This theoretical model captures the specific characteristics of the fuel and biofuel sectors in Brazil and consists of the following nine equations:

1. Hydrous ethanol demand:

$$D_{HE,t} = \alpha_0 + \alpha_1 P_{HE,t} + \alpha_2 P_{G,t} + \alpha_3 Y_t + \alpha_4 F_t + \varepsilon_{1,t} \quad (4.9)$$

2. Domestic consumer price of hydrous ethanol:

$$P_{HE,t} = \beta_0 + \beta_1 P_{G,t} + \beta_2 P_{AE,t} + \varepsilon_{2,t} \quad (4.10)$$

3. Gasoline C demand:

$$D_{G,t} = \delta_0 + \delta_1 P_{HE,t} + \delta_2 P_{G,t} + \delta_3 Y_t + \delta_4 F_t + \varepsilon_{3,t} \quad (4.11)$$

4. Domestic consumer price of gasoline C (exogenous):

$$P_{G,t} = \varepsilon_{4,t} \quad (4.12)$$

5. Anhydrous ethanol price:

$$P_{AE,t} = \varphi_0 + \varphi_1 P_{S,t} + \varepsilon_{5,t} \quad (4.13)$$

6. Domestic sugar price:

$$P_{S,t} = \gamma_1 P_{IS,t} + \varepsilon_{6,t} \quad (4.14)$$

7. International sugar price (exogenous):

$$P_{IS,t} = \varepsilon_{7,t} \quad (4.15)$$

8. Income (exogenous):

$$Y_t = \varepsilon_{8,t} \quad (4.16)$$

9. Flex-fuel vehicle fleet (exogenous):

$$F_t = \varepsilon_{9,t} \quad (4.17)$$

where, $D_{HE,t}$ is the quantity sold of hydrous ethanol at period *t*; $D_{G,t}$ is the quantity sold of gasoline C; $P_{HE,t}$ is the consumer price of hydrous ethanol; $P_{G,t}$ is the consumer price of gasoline C; $P_{AE,t}$ is the domestic producer price of anhydrous ethanol; $P_{S,t}$ is the domestic producer price of sugar; $P_{IS,t}$ is the international price of sugar; Y_t is income; and F_t is the number of alcohol and flex-fuel vehicles in use.

These nine equations form the matrix of contemporaneous relations between the variables. Equations (4.9) and (4.11) model the demand for hydrous ethanol and for gasoline C, respectively. The independent variables in the demand equations include price of the fuel of interest, price of its substitute, income, and alcohol and flex-fuel vehicle fleet. In equation (4.10) the independent variable is the consumer price of hydrous ethanol, which is modelled as a function of the price of gasoline C and the price of anhydrous ethanol, which can be considered a proxy for the producer price of ethanol, as pointed out by Elobeid and Tokgoz, (2008).

Moreover, the developed theoretical model accounts for the formation of the domestic sugar price, which is modeled as dependent on the international sugar price (equation 4.14), since Brazil is a major player on the international sugar market, implying that its domestic sugar sector is highly influenced by international factors.

The domestic sugar price, on the other hand, is considered to influence the domestic producer price of anhydrous ethanol (equation 4.13), since the two products are derived from the same raw material and are considered competing on the supply side. The consumer price of gasoline, as well as the international price of sugar, the income and the vehicle fleet are considered to be exogenous variables in the model.

Table 11. Matrix of contemporaneous effects.

	$D_{HE,t}$	$P_{HE,t}$	$D_{G,t}$	$P_{G,t}$	$P_{AE,t}$	$P_{S,t}$	$P_{IS,t}$	Y_t	F_t
$D_{HE,t}$	1	(-)	0	(+)	0	0	0	(+)	(+)
$P_{HE,t}$	0	1	0	(+)	(+)	0	0	0	0
$D_{G,t}$	0	(+)	1	(-)	0	0	0	(+)	(-)
$P_{G,t}$	0	0	0	1	0	0	0	0	0
$P_{AE,t}$	0	0	0	0	1	(+)	0	0	0
$P_{S,t}$	0	0	0	0	0	1	(+)	0	0
$P_{IS,t}$	0	0	0	0	0	0	1	0	0
Y_t	0	0	0	0	0	0	0	1	0
F_t	0	0	0	0	0	0	0	0	1

Source: Elaborated by the authors.

The restrictions on the matrix of the contemporaneous relationships between the variables of the theoretical model are presented in table 11. The expected signs of the coefficients are shown in brackets. In the demand equations for hydrous ethanol and gasoline C, the expected sign of the coefficient on income is positive.

The price of the respective product is expected to influence the demanded quantities in a negative way, while the price of the substitute product is considered to have a positive impact on fuel demand. The alcohol and flex-fuel vehicle fleet is assumed to have a positive sign in the demand equation for ethanol and to influence negatively the demand for gasoline.

In the price equation for hydrous ethanol, the expected signs are positive for the effects of changes in both the price of gasoline and in the producer price of anhydrous ethanol. In turn, the price of anhydrous ethanol is considered to be positively influenced by the price of sugar, since the two products are competitors on the supply side. Finally, the international price of sugar is assumed to have a positive effect on the domestic producer price of this product.

As it can be seen in table 11, the matrix of restrictions presumes that the consumption of fuels is contemporaneously influenced by all other relevant variables in the model, but at the same time, it is not considered to have any contemporaneous impact on the prices included in the system. This structure follows the logics of the majority of studies examining fuel demand, which assume that the price variables are exogenous. According to Rodrigues (2015), this way of modelling demand for fuels is based on the fact that domestic fuel prices more often than not are subject to government policies and regulations, on the one hand, and are tightly linked to the international price of oil, on the other. In the specific case of Brazil, the ex-refinery price of all crude oil derivatives is established by the state-owned company Petrobras, while the price of ethanol has a ceiling given by the price of gasoline. These specifics of the fuel and biofuel sectors in the country justify the modelling of the fuel prices as unaffected by the demanded quantities.

The data used for the empirical analysis consists of the following series:

- Hydrous ethanol sales by distributors in liters (National Agency of Petroleum, Natural Gas and Biofuels - NPA);
- Gasoline C sales by distributors in liters (NPA);
- Consumer price of hydrous ethanol in BRL/liter (NPA);
- Consumer price of gasoline C in BRL/liter (NPA);
- Producer price of anhydrous ethanol in BRL/liter (Center for Advanced Studies on Applied Economics/"Luiz de Queiroz" College of Agriculture - CEPEA/ESALQ);
- Producer price of sugar in BRL/sack (CEPEA/ESALQ);
- International sugar price – futures contract for first delivery for Sugar No. 11 converted into BRL/sack (The New York Stock Exchange - NYSE);
- Real average monthly income in BRL (Brazilian Institute of Geography and Statistics - IBGE);
- Alcohol and flex-fuel vehicle fleet in units (Brazilian Automotive Industry Yearbook - ANFAVEA).

All variables are obtained from secondary sources and consist of monthly regional data for the state of São Paulo for the period January, 2007 - July, 2016. In order to make the data comparable for the purposes of the study, all prices were converted into Brazilian currency, using the monthly nominal USD/BRL exchange rate published by the Central Bank of Brazil. All price data was transformed into real terms using as a deflator the IGP-di for December, 2015, and all volumes were converted to liters. All variables were transformed into log terms, which allows the interpretation of the estimated coefficients of the SVAR (SVEC) model as elasticities.

The simulated free gasoline price was constructed using the provided by DATAGRO series of daily producer prices of gasoline A that accompany the fluctuations in the international crude oil price. The company publishes regularly such a hypothetical free price of fuels in Brazil denoted as "interned price". All costs incurred in importing fuels to the domestic market are considered. More precisely, the calculation of the "interned price" for gasoline is based on the following formula:

RBOB Gasoline spot price NYMEX FOB*Exchange rate + trade margin + ocean freight + insurance + customs costs + inland freight

The simulated daily prices for gasoline A were transformed into monthly final consumer prices by adding federal (CIDE, Pis/PASEP, Cofins) and state taxes (ICMS for São Paulo), costs for blending with anhydrous ethanol, distribution and retailer transportation costs and margins. The price composition formula for gasoline C published by NPA was used as a basis for the price calculation (see Appendix B). The quotas of the federal taxes were provided by DATAGRO. For the calculation of the ICMS for São Paulo, the margin of aggregate value - MVA (for the period before March, 2014) and the weighted average final consumer price - PMFP (for the period afterwards) published by CONFAZ were used as a reference for the calculation of the tax burden. In addition, the anhydrous ethanol price provided by CEPEA/ESALQ was added to the gasoline A price, as well as a freight cost of 0.05 BRL/liter. The reported by NPA retailer margin was included in the simulated consumer gasoline C price, in addition to the distribution margin and transportation costs, calculated by decomposing the observed final consumer price of gasoline C for the period of interest.

The evolution of the simulated free gasoline price in comparison to the observed price of this product for the state of São Paul and the Europe Brent oil price is shown on figure 16. As it can be seen on the graph, the hypothetical free price accompanies the fluctuations in the international crude oil price and varies significantly during the analyzed period. The actually observed domestic gasoline price, on the other hand, did not exhibit the same level of variation and did not move together with the price of oil. What draws attention, is the significant gap existing between the two gasoline price series through time. In most of the analyzed months, the simulated free gasoline price remained higher than the observed one, with the exception of the period between October, 2008 and June, 2009, and in the beginning of 2015. Both sub-periods are related to significant drops in the international crude oil price.

Before 2010, the goal of the government with the intervention in the domestic fuel sector was primarily stimulating the production and use of biofuels (COSTA; BURNQUIST, 2016). Thus, the domestic gasoline price was kept rather stable at a low level of round about 2.4 BRL/liter. Between 2010 and 2014, however, the goal of the government changed and the domestic consumer price of gasoline went through several adjustments, following a steady increasing trend, while the calculated hypothetical free price of this type of fuel is fluctuating significantly during this period. The average difference between the two price series increased significantly after 2011, reaching approximately 17%. This is a rather high value, which suggests that the effects of the hypothetical free price on the fuel and biofuel markets in the country would have been significant during this period, as well.

In 2015, the goal of the government with the intervention in the domestic fuel sector went back to the previously established goal before 2010 of stimulating the domestic biofuel consumption, as well as helping the financial performance of the indebted Petrobras (COSTA; BURNQUIST, 2016). The government adjusted the domestic gasoline price and set it at levels higher than the international equivalent that followed the drop in the international crude oil price. Thus, while some nations were benefiting from the low petroleum product prices in the beginning of 2015, Brazil did not.

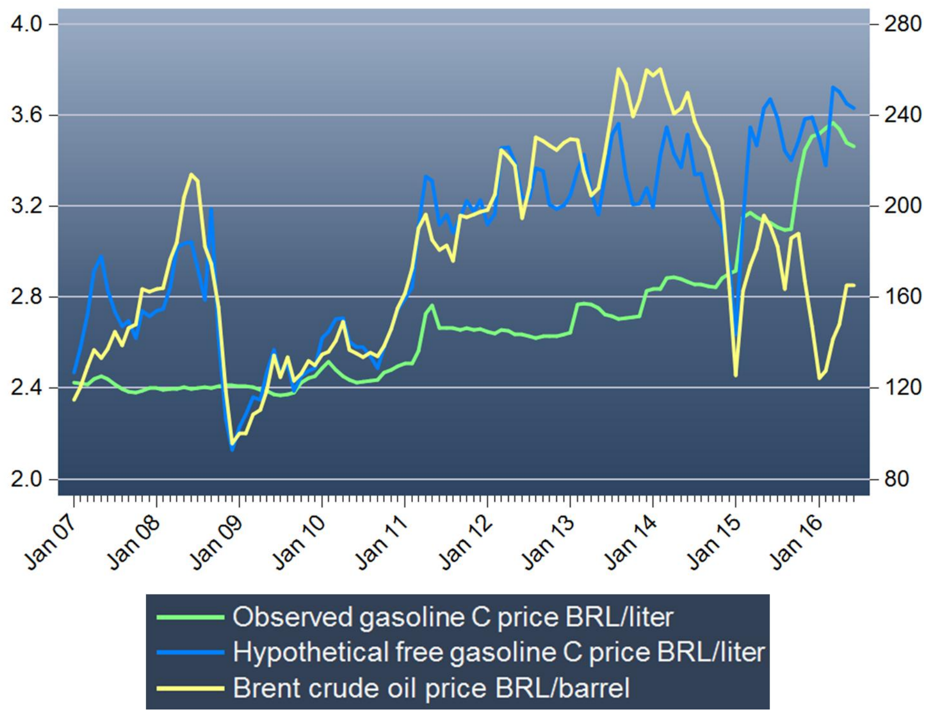

Figure 16. Observed versus hypothetical monthly average gasoline C prices for the state of São Paulo and Europe Brent crude oil price between January, 2007 and July, 2016

Source: Elaborated by the author using data from NPA, DATAGRO, EIA

4.5. Results

Prior to performing the analysis, the data series were tested for stationarity using the DF-GLS test. Both models of the test were applied. The choice of number of lags was based on the Akaike and Schwarz information criterion. The results of the performed stationarity test are shown in table 12. All variables were found to have a unit root in level, but they are stationary in their first difference for both models of the test at the 1% significance level, with the exception of the price of anhydrous ethanol and the salary, which were found to be I(1) when model 1 is considered, and the fleet, for which the hypothesis of a unit root at level could not be rejected for the model without a deterministic trend.

Table 12. DF-GLS stationarity test

	Model 1		Model 2	
Variable	Lag	DF-GLS Statistic	Lag	DF-GLS Statistic
$D_{HE,t}$	4	-0.268216	4	-1.519483
$\Delta D_{HE,t}$	0	-10.61157	3	-6.383753
$P_{HE,t}$	9	-1.329930	9	-1.584902
$\Delta P_{HE,t}$	6	-6.157524	6	-6.188643
$D_{G,t}$	12	-0.255994	12	-1.601919
$\Delta D_{G,t}$	1	-10.17106	0	-12.26557
$P_{G,t}$	2	-0.322581	1	-1.583657
$\Delta P_{G,t}$	1	-6.897795	1	-7.236627
$P_{AE,t}$	0	-3.158345	0	-3.421390
$\Delta P_{AE,t}$	0	-8.895727	0	-9.398764
$P_{S,t}$	2	-2.045449	2	-2.071289
$\Delta P_{S,t}$	1	-5.976928	1	-6.631899
$P_{IS,t}$	12	-1.904739	12	-2.188538
$\Delta P_{IS,t}$	0	-6.584537	0	-6.938452
Y_t	0	-0.689860	0	-2.874143
ΔY_t	11	0.149272	1	-3.742816
F_t	12	-2.199103	12	-5.693281
ΔF_t	12	-4.572845	12	-3.673875

Source: Results of the research.
Note: Model 1 – constant (critical values by MacKinnon (1996): 5% = -1.95; 1% = -2.58); Model 2 – constant and trend (critical values by Elliott, Rothenberg and Stock (1996): 5% = -3.2; 1% = -3.74).

All series were found to be integrated of the same level, thus, the analysis proceeded with the Johansen test for cointegration, the results of which are presented in table 13. Two cointegration equations were identified based on the maximum eigenvalue test, which implies that a VECM with rank 2 should be estimated, instead of a VAR model.

Table 13. Johansen cointegration test results (maximum eigenvalue method)

Null hypothesis	Eigenvalue	Max-Eigenvalue Statistic	5% Critical value
r=0	0.476584	67.97483	58.43354
r<=1	0.426901	58.45308	52.36261
r<=2	0.345655	44.53262*	46.23142
r<=3	0.233198	27.88024	40.07757
r<=4	0.192575	22.46008	33.87687
r<=5	0.131171	14.76400	27.58434
r<=6	0.106438	11.81665	21.13162

Note: * denotes acceptance of the null hypothesis of r cointegrating relations at 5% level.

After the identification of the existence of a long-term relationship between the variables, an SVEC model was fitted to the data and the matrix of contemporaneous effects was estimated. The restrictions imposed on this matrix, which are necessary for the identification of the structural model, are shown in table 11 above. Two lags were included in the system, based on the results of the Akaike and Schwarz information criteria in their multi-equation version. Moreover, a dummy variable accounting for the imposed ceiling on the price of hydrous ethanol was included in the model, which equals 0 when the observed ratio between the ethanol and gasoline prices was lower or equal to 0.7, and 1 otherwise.

The estimated coefficients of the contemporaneous effects matrix presented in table 14, have the expected signs and are statistically significant with the exception of the fleet in the equation for hydrous ethanol demand and the sugar price in the equation for the anhydrous ethanol price, which were not found to be statistically different than zero.

Table 14. Estimated matrix of contemporaneous effects.

	$D_{HE,t}$	$P_{HE,t}$	$D_{G,t}$	$P_{G,t}$	$P_{AE,t}$	$P_{S,t}$	$P_{IS,t}$	Y_t	F_t
$D_{HE,t}$	1	-1.386*	0	1.027**	0	0	0	1.159**	-0.2700
$P_{HE,t}$	0	1	0	0.893*	0.276*	0	0	0	0
$D_{G,t}$	0	1.080*	1	-1.828*	0	0	0	0.914**	-1.013*
$P_{G,t}$	0	0	0	1	0	0	0	0	0
$P_{AE,t}$	0	0	0	0	1	0.2084	0	0	0
$P_{S,t}$	0	0	0	0	0	1	0.336*	0	0
$P_{IS,t}$	0	0	0	0	0	0	1	0	0
Y_t	0	0	0	0	0	0	0	1	0
F_t	0	0	0	0	0	0	0	0	1

Source: Results of the research.
Note: * statistically significant at 1% probability; ** statistically significant at 5% probability; *** statistically significant at 10% probability; _ statistically insignificant.

In the demand equation for hydrous ethanol, the magnitude of the estimated coefficient for the price of gasoline C indicates that ethanol consumption responds considerably to contemporaneous variations in the price of its substitute in this market segment. A 1%-change in the consumer price of gasoline C causes approximately 1.027% increase in the demanded quantity of hydrous ethanol, which is a result in line with the existing literature, where the short-term cross-elasticity of ethanol demand lies between 0.75 and 2.56 (see table 10).

The consumption of hydrous ethanol responds significantly to changes in its own price, as well. A 1%-change in the consumer ethanol price causes 1.386% decrease in the demand of this commodity. This estimated value is close to the short-term elasticities of ethanol demand in the existing literature, which remain in the range of 0.55-1.96 in absolute terms when it comes to its own price (see table 10). Regarding the sensitivity of ethanol consumption to income, a positive elasticity of 1.159 was estimated by the model.

In the equation for the consumer price of hydrous ethanol, all coefficients are statistically significant. An increase of 1% in the price of gasoline C is found to cause a contemporaneous response in the price of ethanol of 0.893%. This elasticity is in line with the results of previously published studies, which estimate the effect of the price of gasoline on the price of ethanol between 0.79% (COSTA; BURNQUIST, 2016) and 1.12% (BACCHI, 2005). Moreover, a 1%-increase in the price of anhydrous ethanol, which was used as a proxy for the producer market segment, was found to have a 0.276% impact on the price of its hydrous equivalent - a result very similar to the obtained by Diehl (2012).

In the gasoline demand equation, all estimated coefficients are statistically significant. A 1%-increase in the price of ethanol generates a positive response of 1.080% in the consumption of gasoline C, while an increase in the price of gasoline by 1% causes a drop in its sales of 1.828%. These results show that domestic demand for gasoline in Brazil was rather elastic during the observed period. The obtained values are in line with the results of Silva et al. (2009), who estimated short-term own price elasticity of gasoline demand equal to -1.505%.

The estimated coefficients of contemporaneous effects between the variables of the SVEC model are used for the calculation of the hypothetical responses of the ethanol price and the demanded quantities for fuel and biofuel to the simulated gasoline price that accompanies the fluctuations in the international crude oil price. Figures 17, 18 and 19 plot the observed values of the three variables of interest in comparison to the calculated hypothetical values for a situation without government intervention in the domestic fuel sector.

It is important to mention that the ceiling on the price of ethanol was accounted for when the hypothetical price of this product was calculated. For the periods when the calculated hypothetical price ratio of ethanol and gasoline was above 0.7, the simulated hydrous ethanol price was set to be equal to 70% of the hypothetical price of gasoline.

As shown on figure 17, free domestic gasoline prices would have resulted in higher hydrous ethanol prices than the observed ones during the analyzed period, with the only exceptions in the end of 2008 and during the first few months of 2015 and of 2016. This result is rather different than the findings of Costa and Burnquist (2016), according to which free gasoline prices has led to lower simulated ethanol prices than the observed ones between 2006 and 2010, and in 2015, and higher simulated prices than the observed ones between 2011 and 2014.

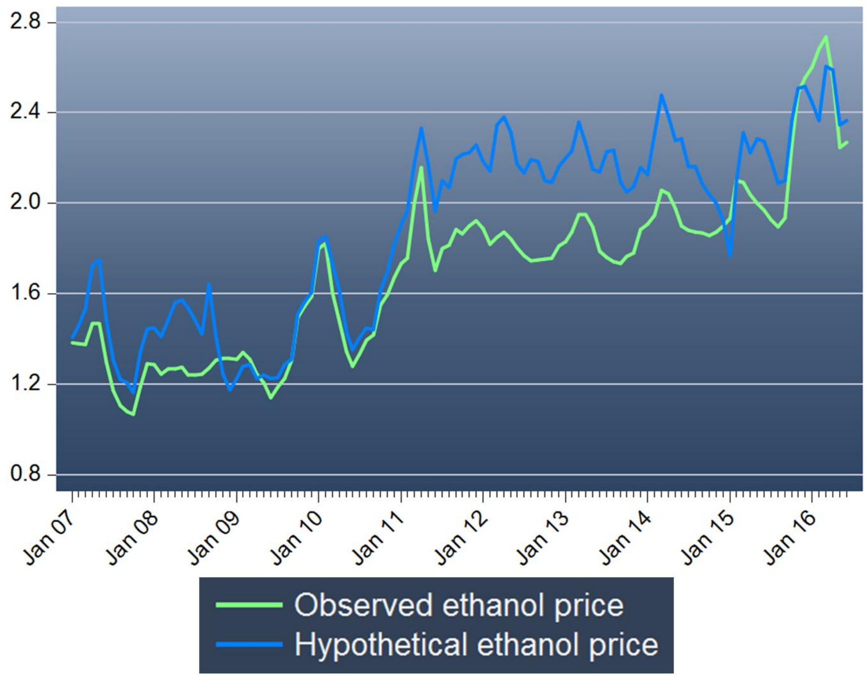

Figure 17. Observed versus hypothetical monthly average consumer price of hydrous ethanol for the state of São Paulo between January, 2007 and July, 2016

Source: Results of the research.

The beginning of the observed period corresponds to the burst of the global financial crisis, when the international price of crude oil registered a significant increase. The incorporation of the fluctuations in the oil price in the domestic fuel sector in Brazil, would have led to approximately 17% higher domestic gasoline prices than the observed ones, which would have resulted in a difference of approximately 15% between the actual and the hypothetical consumer hydrous ethanol prices in the state of São Paulo.

In the beginning of 2009, however, when the historically high international oil price registered a dramatic drop, the simulated gasoline price remained approximately 5% below the observed one. This resulted in hypothetical price of hydrous ethanol during the first months of 2009 approximately 1.9% lower than the observed price of this commodity, indicating that the final consumer was paying for the government intervention in the fuel sector during these months, while the ethanol producers were gaining from the practiced pricing policy. Hence, the controlling of the gasoline price during this period can be interpreted as a subsidy for ethanol producers, as pointed out by Costa and Burnquist (2016).

The highest percentage difference between the observed and the hypothetical hydrous ethanol prices was observed between October, 2010 and December, 2014, when the former was found to be approximately 17% lower than the latter. Thus, during this period, the consumer stopped paying for the government intervention in the fuel sector. The lower observed ethanol price played the role of a discouragement factor for ethanol producers, for whom the price difference with the hypothetical values can be interpreted as a loss of revenue. This result can be attributed to a number of factors that played a role simultaneously between 2010 and 2014.

First of all, the Brazilian ethanol sector suffered a severe crisis in the beginning of 2011 due to unfavorable climatic conditions, increased sugar production as a result of growing international prices, increased production costs for ethanol, lack of financing, and insufficient government stimuli towards the biofuel sector. During this period, the practiced fuel pricing policy was focused on keeping the price of gasoline at artificially lower levels than the international equivalents. The government adjusted the domestic gasoline price 5 times between 2011 and 2014, and changed the flat-rate fuel tax CIDE four times, including making it 0 in June, 2012 (NPA, 2017). The government control of the domestic fuel price is considered one of the main reasons for the underperformance of the ethanol industry in Brazil between 2011 and 2014, making this fuel alternative more vulnerable and less competitive (SANTOS; GARCIA; SHIKIDA, 2015). In addition, according to Cesca, Araújo and Bottrel (2016), the ethanol crisis and the government intervention changed the demand elasticity of this biofuel towards a more elastic behavior in the short-run.

Moreover, the BRL/USD exchange rate reached extremely high levels between 2011 and 2014 making imports rather expensive. This had significant negative impact for the domestic economy and especially for Petrobras, which had to cover the price gap between the expensive imported gasoline and the low domestic price of this fuel during a period when gasoline imports reached significantly high levels. In addition, higher exchange rate means bigger gap between observed and hypothetical gasoline prices, since the latter is directly affected by the cambial variations, and in turn, bigger difference between the actual and simulated hydrous ethanol prices, as shown on figure 17.

The obtained results for the period between 2011 and 2014 show that the ethanol market could have been stimulated and most probably the crisis could have been avoided if the government was not intervening in the domestic fuel sector. If the higher hypothetical hydrous ethanol prices were actually observed during this period, they would have provided a stimulus for sugarcane producers to increase the supply of biofuel instead of sugar, which could have mitigated at least some of the negative effects of the ethanol crisis. This result is particularly interesting for everyone involved in the biofuel sector in Brazil, since it provides evidence for the advantages of a free fuel pricing policy for the ethanol industry.

During the first months of 2015, however, the hypothetical hydrous ethanol price was found to be approximately 5% lower than the actual one. This period was characterized by a significant change in the international crude oil sector caused by the dramatic drop of the WTI and the Brent oil prices, which resulted in a simulated free gasoline price lower than the observed one for the state of São Paulo. Moreover, the focus of the Brazilian fuel pricing policy changed in the beginning of 2015. The domestic gasoline price was adjusted and set to a level higher than the international equivalent in an attempt to stimulate the use of biofuels and to improve the financial performance of Petrobras (COSTA; BURNQUIST, 2016). These trends led to higher observed hydrous ethanol prices than the hypothetical ones without government intervention. This result shows how sensitive the price of ethanol would have been to changes in the international crude oil price if it was not indirectly controlled by the government through the setting of the ex-refinery price of gasoline.

After calculating the hypothetical price of hydrous ethanol for a situation in which the government set free the price of gasoline in 2007, the analysis proceeds with the calculation of the hypothetical effects this fuel pricing policy would have had on the demand for fuels. Since demanded quantities respond to changes in both their own price and in the price of their main substitutes, the net effect of the hypothetical gasoline and ethanol prices was accounted for when the new fuel demand was calculated.

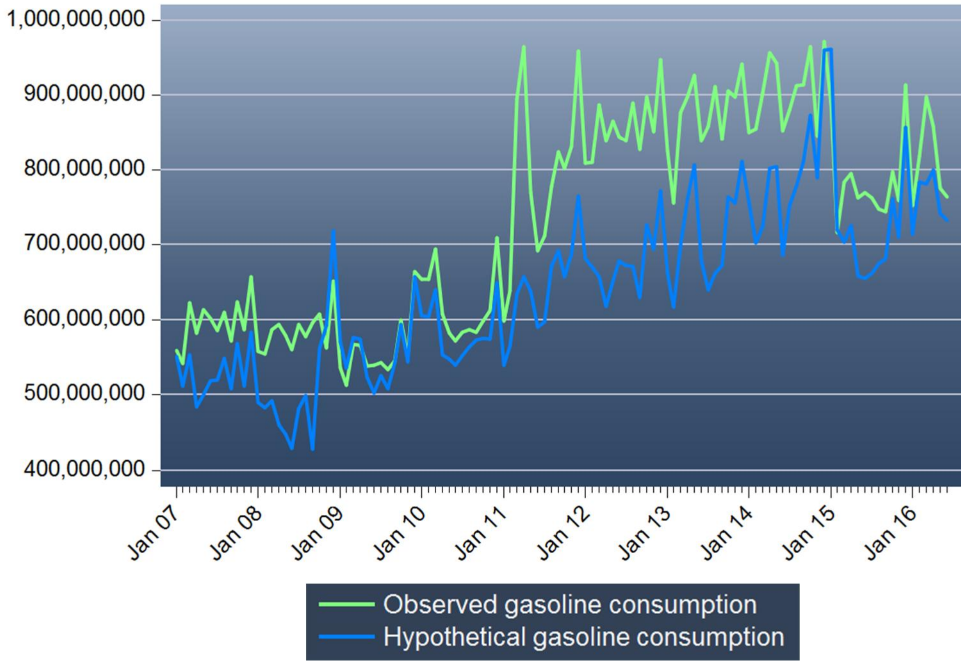

Figure 18. Observed versus hypothetical consumption of gasoline C in the state of São Paulo between January, 2007 and July, 2016

Source: Results of the research.

The observed and the calculated hypothetical demanded quantities for gasoline C between 2007 and 2016 for the state of São Paulo are shown on figure 18. As it can be seen on the graph, the hypothetical gasoline demand is lower than the observed with the only exception between October, 2008 and April, 2009 and in the beginning of 2015, when it actually surpassed slightly the observed gasoline consumption.

In the beginning of the period, the higher simulated gasoline prices without government intervention would have caused approximately 14% lower gasoline demand than the artificially established by Petrobras fuel prices. The following significant drop of the international crude oil price in the beginning of 2009 as a result of the global financial crisis would have been incorporated in the domestic fuel market as well, resulting in lower simulated prices and higher gasoline demand by approximately 4% in comparison to the actually observed demand in the state of São Paulo during this period.

The years of the ethanol crisis in Brazil, which correspond to a period of high international commodity prices, would have looked rather different if the domestic gasoline price was allowed to adjust to the fluctuation on the international crude oil market. No government intervention between 2009 and 2014 would have resulted in approximately 17% lower gasoline demand. This trend would have been reversed in the beginning of 2015 due to the historically low international crude oil price from this period, which would have made domestic gasoline rather cheap and would have resulted in approximately 4% higher demanded quantities.

The obtained results show that the higher simulated gasoline price accompanying international crude oil price fluctuations would have caused lower gasoline consumption – an effect that could not have been outweighed by the higher hypothetical hydrous ethanol price. Thus, the artificially created demand for gasoline in Brazil, supported by the government intervention in the fuel sector between 2011 and 2014, would have been broken if the domestic gasoline price was allowed to fluctuate freely.

The absence of government intervention in the domestic fuel sector would have had an impact on the demand for hydrous ethanol in the state of São Paulo, as well. The hypothetical consumption of hydrous ethanol if the domestic gasoline price was freely fluctuating between 2007-2016 is calculated using the net effect of the simulated gasoline and ethanol prices. The obtained results are shown on figure 19.

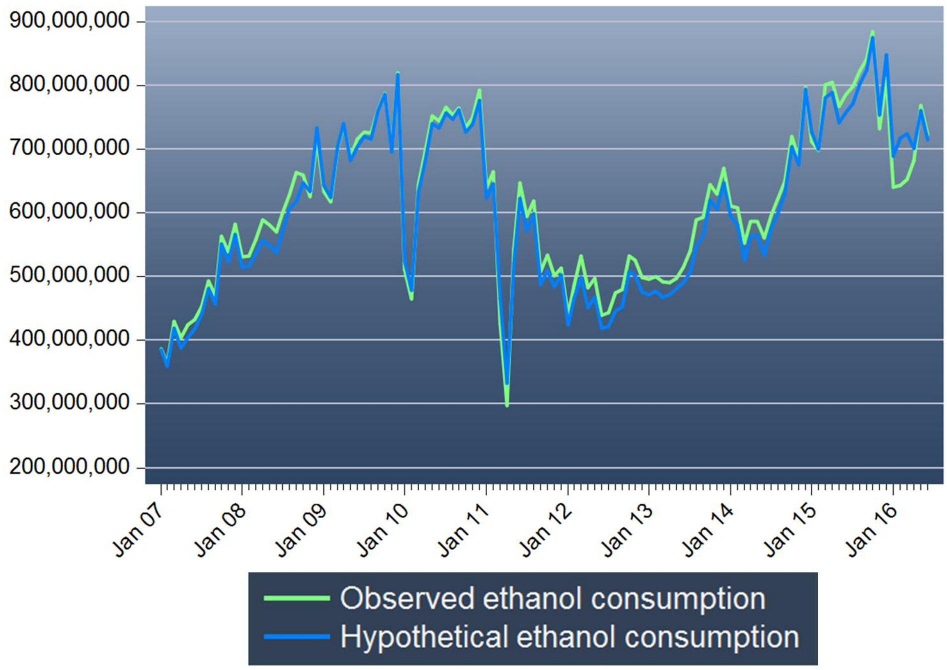

Figure 19. Observed versus hypothetical consumption of hydrous ethanol in the state of São Paulo between January, 2007 and July, 2016

Source: Results of the research.

As it can be seen on the graph, free market gasoline prices would have resulted in slightly different ethanol demand during the analyzed period in comparison to the actually observed demanded quantities. During 2007 and 2008, the observed ethanol demand remained approximately 3.5% higher than the calculated hypothetical demand for this commodity. This trend was reversed in the end of 2008, when the calculated biofuel consumption in the absence of government intervention in the domestic fuel sector would have been approximately 1.2% higher than the actual consumption in the state of São Paulo. During the ethanol sector crisis between 2011 and 2014, however, the hypothetical demand for ethanol would have been lower than the observed one as a result of the higher simulated ethanol prices – a trend reversed in 2015 when the price of ethanol in the absence of government intervention in the Brazilian fuel sector would have been lower than the observed one pushing domestic demand for this commodity up.

4.6. Conclusions

The present work analyses the hypothetical effects of a gasoline price that accompanied the movements in international oil prices between 2007 and 2016 on the fuel and biofuel sectors in the state of São Paulo, Brazil. The specific characteristics of these sectors were taken into account when fitting an SVEC model with two cointegration relationships, identified by the Johansen cointegration test, to the used data series. The results of the estimated matrix of contemporaneous effects show that the consumer price of hydrous ethanol and the demanded quantities of ethanol and gasoline respond significantly to the contemporaneous variations in the consumer price of gasoline. The obtained price elasticities were used for the calculation of the hypothetical effects of the absence of government intervention in the domestic fuel sector on the variables in the system. For the purposes of the analysis, a simulated free consumer gasoline price was constructed, using the provided by DATAGRO series of "interned" prices.

The obtained results show that free gasoline prices that incorporate the fluctuations in the international crude oil price would have led to higher hydrous ethanol price in the state of São Paulo, making it more profitable for sugarcane producers to engage in the production of ethanol instead of sugar. Moreover, the hypothetical gasoline price without government intervention would have caused lower demand for gasoline, breaking the artificial demand for this fuel created by the practiced fuel pricing policy of keeping the domestic fuel prices at lower levels than their international equivalents. These findings show that the ethanol sector could have benefitted from a freely fluctuating gasoline price between 2011 and 2014 and the negative effects of tin the industry during this period could have been mitigated at least to some extent.

The performed analysis provides empirical evidence that the practiced fuel pricing policy in Brazil has had negative impact on the ethanol sector in the state of São Paulo for the analyzed period. The artificially established by the government domestic gasoline price has reduced the competitiveness of ethanol as a substitute for conventional fossil fuels and undermined the performance of this important sector, in which Brazil has been a worldwide leader both in terms of production and exportation till the mid-2000s. There is a need for reformulating the fuel and biofuel policy in the country, otherwise the ethanol sector will not be able to recover from the crisis. The Brazilian ethanol sector has tremendous potential but it needs political incentives in order to regain its previous competitiveness as a substitute for conventional fuels and to reestablish itself in the country's energy matrix.

The results of the present research are limited to the state of São Paulo. Thus, estimating the hypothetical effects of free gasoline prices for other regions in Brazil, as well as for the country as a whole is considered to be an important step for further research. Moreover, the analysis of the effects of no government intervention in the fuel sector on the production of ethanol and sugar, as well as on the domestic economy as a whole constitute interesting topics for continuation of the present research.

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5. CONCLUSION

The recent trends in the international crude oil price have brought back the interest of researchers to the importance of the practiced by the government fuel pricing policy for the domestic economy, especially in developing countries. In addition, the existing food vs. fuel debate raised by the concerns about the increasing agricultural commodity and food prices as a result of the stimulating policies for the production of biofuels has received significant attention in the existing literature.

Brazil constitutes a particularly interesting case when it comes to the government participation in the domestic fuel and biofuel sectors. The intervention in the fuel pricing mechanism in the country is indirect, with the government influencing the formation of the domestic prices of petroleum derivatives through participation in the organization and decision making of the national oil company Petrobras and through irregular adjustments in the flat-fuel tax rate CIDE. The lack of consensus between the practiced fuel pricing mechanism in Brazil and the fiscal policy on fuels has been the reason for the increasing concerns about the negative effects on the domestic fuel and biofuel sectors. The severe crisis that the Brazilian ethanol industry experienced after 2011 was to some extent caused by the practiced by the government fuel pricing and fiscal policies, which created artificial demand for gasoline by keeping the price of this commodity at lower levels than its international equivalents.

The recent crisis of the biofuel industry in Brazil should serve as a lesson for the government. It reflects the need for reformed fuel price adjustment mechanisms that are coherent and transparent and take into account the negative consequences that administrating fuel prices has on the domestic economy. A free fuel pricing policy might not be the best option for Brazil due to its history of high inflation. The example of Germany, however, shows that market fuel prices in combination with a flexible fiscal policy can lead to a competitive domestic fuel sector without inducing instability from the international crude oil market to the domestic economy. Thus, this combination of policy alternatives should be considered carefully by the Brazilian government.

Further research, however, is needed for the establishment of an accurate and better serving the needs of the country fuel pricing policy, especially in combination with adequate fiscal measures. A comparison with other developing economies and an analysis of the potential impacts of implementing their pricing regimes on the Brazilian economy and on the use of biofuels is considered a relevant topic for future research. Knowledge about the experience of other countries and the degree of success of their fuel pricing mechanisms is crucial for the development of a suitable policy for Brazil.

APPENDIX

APPENDIX A.

Table 1 - DF-GLS stationarity test: 07/2005-12/2008

Variable	Model 1 Lag	Model 1 DF-GLS Statistic	Model 2 Lag	Model 2 DF-GLS Statistic
$P^{B}_{E,t}$	1	-2.144483	1	-2.931143
$\Delta P^{B}_{E,t}$	0	-3.727151	0	-3.987809
$P^{B}_{G,t}$	1	-1.651107	1	-2.252536
$\Delta P^{B}_{G,t}$	0	-3.280599	0	-3.791677
$P^{B}_{S,t}$	1	-1.932549	1	-2.358091
$\Delta P^{B}_{S,t}$	0	-3.177952	0	-3.467894
$P^{US}_{E,t}$	1	-2.416292	1	-3.025446
$\Delta P^{US}_{E,t}$	0	-3.824994	0	-4.460136
$P^{US}_{G,t}$	1	-2.643150	1	-3.171712
$\Delta P^{US}_{G,t}$	0	-2.457798	0	-2.851770
$P^{US}_{C,t}$	1	-0.713850	2	-2.786272
$\Delta P^{US}_{C,t}$	0	-3.219939	0	-3.962482
$P^{G}_{B,t}$	1	-1.361191	1	-2.135086
$\Delta P^{G}_{B,t}$	0	-2.853735	0	-3.233722
$P^{G}_{D,t}$	2	-1.884583	2	-2.775757
$\Delta P^{G}_{D,t}$	0	-3.744700	0	-4.160553
$P^{G}_{R,t}$	3	-2.130091	3	-2.693337
$\Delta P^{G}_{R,t}$	0	-3.304237	0	-3.716984

Note: Model 1 – constant (critical values by MacKinnon (1996): 5% = -1.95; 1% = -2.58); Model 2 – constant and trend (critical values by Elliott, Rothenberg and Stock (1996): 5% = -3.2; 1% = -3.74).

Table 2 - DF-GLS stationarity test: 01/2009-11/2016

Variable	Model 1 Lag	Model 1 DF-GLS Statistic	Model 2 Lag	Model 2 DF-GLS Statistic
$P_{E,t}^{B}$	1	-1.394765	1	-1.756105
$\Delta P_{E,t}^{B}$	0	-6.774759	0	-6.945305
$P_{G,t}^{B}$	1	-1.273844	1	-1.558762
$\Delta P_{G,t}^{B}$	0	-6.651948	0	-6.754643
$P_{S,t}^{B}$	2	-1.171884	1	-1.940525
$\Delta P_{S,t}^{B}$	0	-3.370146	0	-4.897849
$P_{E,t}^{US}$	0	-1.625494	0	-1.779641
$\Delta P_{E,t}^{US}$	1	-8.944630	1	-9.033052
$P_{G,t}^{US}$	1	-1.080393	1	-1.258001
$\Delta P_{G,t}^{US}$	0	-4.524208	0	-6.107679
$P_{C,t}^{US}$	1	-1.151403	1	-1.339562
$\Delta P_{C,t}^{US}$	2	-2.233597	0	-5.676405
$P_{B,t}^{G}$	0	-1.005242	0	-1.404015
$\Delta P_{B,t}^{G}$	0	-6.127505	0	-6.982590
$P_{D,t}^{G}$	0	-0.655711	0	-0.808698
$\Delta P_{D,t}^{G}$	0	-4.999512	0	-6.674074
$P_{R,t}^{G}$	0	-0.986505	0	-1.192196
$\Delta P_{R,t}^{G}$	1	-4.805122	0	-8.342202

Note: Model 1 – constant (critical values by MacKinnon (1996): 5% = -1.95; 1% = -2.58); Model 2 – constant and trend (critical values by Elliott, Rothenberg and Stock (1996): 5% = -3.2; 1% = -3.74).

APPENDIX B. Gasoline price formation - NPA

Composition of the price of gasoline A (pure, without blending with anhydrous ethanol - EAC) paid to producers or importers:

A. Realization price (1)

B. Federal tax CIDE - Contribuição de Intervenção no Domínio Econômico (2)

C. Federal taxes - PIS/Pasep and Cofins (3)

D. Price without state taxes D = A + B + C

E. ICMS for the producer E = [(D / (1 - ICMS%)] - D (6)

F. Price with ICMS (without the ICMS for tax substitution) F = D + E

G. (i) ICMS for tax substitution (with PMPF) G = (PMPF x ICMS% / (1 - MIX (9)) - E (7) or (ii) ICMS for tax substitution (without PMPF) G = F x % MVA x ICMS% (8)

H. Producer price without freight (ex-refinery price) with ICMS H = F + G(i)(G(ii))

Composition of the price of anhydrous ethanol to be blended with gasoline A:

I. Price of anhydrous ethanol (1)

J. Federal tax – Cide (2)

K. Federal taxes - PIS/Pasep and Cofins (3)

L. Producer price without freight and ICMS (the ICMS for the anhydrous ethanol was included in the formation of the price of gasoline A as shown above in item G) L = I + J + K + L (5)

Composition of the price of gasoline C paid to distributors (mixture of gasoline A with anhydrous ethanol):

M. Freight of gasoline A to distributor

N. Freight of EAC to distributor

O. Acquiring costs of distributor O = M + N + (H x (1- MIX (9)) + (L x MIX (9))

P. Distributor margin

Q. Freight from distributor to retailer

R. Distributor price R = O + P + Q

Composition of the final consumer price of gasoline C:

S. Acquisition costs of retailer S = R

T. Retailer margin

U. Final price of gasoline C U = S + T

Observations:

(1) FOB price (without freight and taxes) including the margin of the economic agent.
(2) Law n° 10.336, from 12/12/01, and its alterations, in combination with the Decree n° 5.060, from 30/04/04, and its alterations.
(3) Law n° 10.865, from 30/04/04, and its alterations, in combination with the Decree n° 5.059, from 30/04/04, and its alterations.
(4) Law n° 11.727, from 23/06/08, and its alterations, in combination with the Decree n° 6.573, from 19/09/08, and its alterations.
(5) In general, it is said that there is tax deferral, when the payment of a certain tax is transferred to a later stage of the chain. In

the case of anhydrous ethanol, the producer or importer of gasoline A collects the tax on the production stage of anhydrous ethanol, in the cases when the latter is used for the composition of gasoline C.

(6) Rates established by the state governments (with reductions in the calculation bases, if any) plus the "Poverty Fund" (if any).

(7) Average price for final consumer Final (PMPF) established by the Act Cotepe/PMPF.

(8) Margin of aggregated value (MVA) established by the Act Cotepe/MVA (only when PMPF is missing) (7)

(9) MIX: Law n° 8.723, from 28/10/93, and its alterations, in combination with the Cima Resolution that defines the percentage of the blending of gasoline with anhydrous ethanol.