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Impacts of the Biodiesel on the Brazilian Fuel Market

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Abstract

This paper investigates market effects of the Brazilian biodiesel law, which made the use of biodiesel, blended with petroleum diesel, mandatory in Brazil. The study estimates the demand curve for diesel fuel (biodiesel and petroleum diesel) and the industry supply curve of biodiesel. These two pieces of information have been used in a static analysis to draw scenarios with different biodiesel mandates. The results show that the current proportion of biodiesel in the diesel mixture (5%) increases consumers' price by 1.7% and decreases the consumption by 1.5% compared to the scenario without biodiesel. Also, an increase in the biodiesel percentage to 10% would raise the price by 3.5% and reduce the consumption by 3%.

Keywords: biodiesel, static analysis, demand estimation

1. Introduction

Recent concerns about the environment, high fossil fuels prices, and energy security led to the creation of biodiesel programs in several countries (<2>,<24>, <4>). In Brazil, biodiesel was introduced in 2005 <10>, mixed with mineral diesel to produce the BX blend, where X stands for the percentage of biodiesel.

During a transition period, from 2005 to 2007, a 2% addition of biodiesel to the mineral diesel (B2) was optional. After that, a certain percentage of biodiesel in all the diesel fuel[1] sold in Brazil was required. The biodiesel mandate has increased over time <10>. In the first six months of 2008 the commercial diesel fuel had to contain 2% of biodiesel (B2). The diesel proportion was required to increase to 3% (B3) on 1 July 2008, to 4% (B4) one year later, and to 5% (B5) since January 2010 (three years before the initial goal, <28>).

Brazilian federal government gave ecological, economic and social reasons to introduce the biodiesel mandate <28>. From the environmental perspective, the biodiesel is supposed to have smaller impact on greenhouses gases emissions since it is a renewable fuel produced mainly from vegetable oils (<4>). From the economic point of view, the fuel was expected to diminish petroleum diesel importation. In 2005 about 6% of the petroleum sold in the Brazilian was imported. Also, Brazil

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[1]The term "diesel fuel" in this article refers to the biodiesel-diesel mixture. The terms "mineral diesel", "petroleum diesel", and "oil diesel" are used as synonyms

could become an exporter of biodiesel since other countries are adopting similar programs. Finally, the biodiesel production could be an instrument to reduce regional inequality through income and employment generated by the biodiesel production chain. Fiscal benefits were implemented for all biodiesel producers who use raw materials from small farmers in poor regions.

However, biodiesel adoption may have negative impacts. First, it could increase the emissions of greenhouse gases if the production causes deforestation (<16>). Secondly, biofuel demand increases feedstock prices (<30>) and may cause land use change. For example, <1> show some evidence of substition of traditonal crops (such as oranges) to sugarcane in São Paulo state. Also, biodiesel may cause loss of welfare as its current production costs are higher than petroleum diesel (<2>). This is a non-exhaustive list as other problems might be caused by biodiesel use.

Since biodiesel adoption generates benefits and problems it is necessary to produce studies quantifying these effects. The need is even more evident when one analyzes the economic importance of the diesel. The fuel is the base of Brazilian transportation system, used in trucks, boats, buses, tractors and some power plants – the last mainly in North (Amazon) region. Even in small proportion, the biodiesel may have significant impacts on the Brazilian Economy.

The present paper contributes to the biodiesel literature by providing a measure of the welfare impact of biodiesel adoption. The empirical strategy consists in estimating the demand for diesel fuel and the costs of the biodiesel industry. With these two pieces of information it is possible to draw scenarios changing the biodiesel mandate. Then, the scenarios can be used to evaluate the effects of the biofuel plan and to predict the impact of future changes.

The economic impacts quantified in this paper are based on traditional partial equilibrium analysis: a change in the biodiesel policy changes the market equilibrium (price and quantity), which implies a change in the consumer and producer surplus [2]. <12> provide a general framework for the use of partial equilibrium analysis in the biofuel context.

The demand estimate is based on monthly Brazilian States panel data. The period analyzed spans from January 2003 to December 2009. The data includes diesel prices, amount of diesel sold (pure diesel before 2008 and BX mixture onwards), the fleet of heavy vehicles, and ICMS (tax on trade of products and services) as a proxy for economic activity.

The biodiesel industry supply curve was approximated with data from the last (17^{th}) biodiesel auction. This information is combined with the average price of the petroleum diesel in the refineries, and with the wholesale and the retail prices of the biodiesel mixture to simulate the impacts on price and quantity of BX sold caused by changes in the biodiesel mandate.

The results obtained show that the current proportion of biodiesel in the diesel mixture (B5) increases consumers' price by 1.7% and decreases the consumption by 1.5% when compared to the environment without biodiesel. An increase in the biodiesel percentage to 10% (B10) would raise the price by 3.5% and reduce the consumption by 3%. These all adds up to considerable welfare loss to consumers, retailers, and wholesalers.

The paper is a static approximation of a dynamic process: industry capacity and marginal costs are held constant over the simulations, and we ignore entry cost,

[2] A comprehensive introduction to the welfare analysis can be found in <26>

adjustment costs and strategic price behavior.

The biodiesel industry problem, however, is intrinsically dynamic. Firms have to decide whether to enter or not enter in the market. Once a firm has entered, it has to set the capacity, the technology, and the location and, in each period of time, it decides to continue or exits the market. Firms decisions will affect the market competition and consequently the prices. Therefore, a natural extension of this paper is a dynamic oligopoly model in the tradition of <15>, <27>. The model must deal with intrinsic heterogeneity in the industry regarding capacity, location and technology employed.

The paper is organized as follows. The next section describes the biodiesel market and shows the dataset used in the paper. Section 2 estimates the demand curve for diesel fuel. Section 4 recovers the costs and estimates the supply curve for the biodiesel industry. Section 5 presents the simulations results. Finally, section 6 concludes the paper, provides some directions for future works, and discusses some limitations of the approach.

2. The Biodiesel Market

Brazil has a long experience in the use of biofuels. During the 1970's the Proalcohol program (Brazil <7>) developed the bioethanol as a substitute to gasoline in automobiles. Even thought the legislation has experienced several changes over the last 4 decades, ethanol is still a very important part of Brazil's energy matrix (ANP <3>), and in 2006 ethanol represented 17% of Brazilian fuel supply (Almeida et al. <1>).

The biodiesel, on the other hand, was adopted later in Brazil. Silva César and Batalha <32> show that a first attempt to implement the biodiesel production was made in 1980. However, it was abandoned in 1986 due to reduction in the petroleum barrel price. During the 2000's new concerns about renewable energy led to the creation of the National Program for the Production and Use of Biodiesel (PNPB) (MME <28>). The main result of the program was the law n°11.097/2005 (Brazil <10>), which made the use of biodiesel mandatory from 2008.

It is worth noting that ethanol and biodiesel are not market competitors. Ethanol is a substitute to gasoline, used basically in automobiles. Biodiesel is a substitute to oil diesel, used mainly in trucks and buses. Since 1976, the use of diesel engines in automobiles has been forbidden by law (Brazil <8>). Therefore, the ethanol belongs to a different market and is not analyzed in the present paper.

The recent introduction of biodiesel generated a growing literature about the topic. Silva César and Batalha <32> summarize the history of the biodiesel in Brazil. Ayhan <4> discusses some benefits of biodiesel and governmental policies regarding biodiesel. Barbosa <5> and Pfuderer et al. <30> look at the impacts of the biofuels in the feedstock market. Fargione et al. <16> analyse the impact of biofuels in the greenhouse gases emissions.

From the economic perspective, it is possible to use the partial equilibrium analysis, a useful economic tool, to assess market outcomes of the use of biodiesel. De Gorter and Just <12> propose a general framework to analyze the impact of different biofuel mandates alongside taxes. The authors show how different mandates and tax schemes impact prices, and use data to recover supply elasticities from gasoline and ethanol. Similarly, Althoff et al. <2> use a partial equilibrium analyses to quantify the loses to the Indiana economy caused by a 2% biodiesel mandate. Their estimative shows a total cost ranging from $ 15.2 to 17.2 million.

In this tradition, the present paper contributes to this literature by using a partial equilibrium analysis to quantify the impacts of the biodiesel mandate in the market equilibrium outcomes. Due to the rich dataset employed in the paper it is possible to show how equilibrium prices and quantities are changed according to the biodiesel mandate, given that other factors remain constant (see section 5). This also provides some quantitative measures of welfare impacts of the biodiesel.

2.1. Commercialization

The Brazilian oil and biofuel market is regulated by ANP[3] (Brazil <9>). For biodiesel specifically, the agency is responsible for determining the biodiesel standards, inspecting the market (to assure that the correct biodiesel mandate is sold), and for collecting data. Also, ANP provides licences to construct new biodiesel

[3]National Agency of Petroleum, Natural Gas and Biofuels

plants, to change the capacity of existing ones, to produce, and to commercialize the biofuel.

ANP also plays a direct role in biodiesel commercialization. Wholesalers are responsible to mixing the biodiesel and the oil diesel (ANP <3>). However, they are not allowed to negotiate directly with the producers. Instead, they have to buy the biodiesel through actions organized by ANP.

ANP determines the amount of biodiesel that must be sold and the auction rules. The biodiesel producers are the bidders. They bid a mix of price and quantity according to the specific rules of the auction. The winners are those bidders with the lowest prices. The buyers are oil refineries[4]. Every refinery is assigned by ANP with a percentage of total biodiesel. After the auction the oil refineries resell the biodiesel to the wholesalers (ANP <3>).

17 auctions were performed from 2005 to the first quarter of 2010 (ANP <3>). From the 12^{th} onwards ANP divided each auction in two. The first of the split auctions were restricted, only the bidders that bought raw material from small farmers were allowed to participate. In the second one, all registered producers could participate as bidders (see Silva César and Batalha <32> for details). When necessary, the split auctions have a different notation through the paper: after the ANP number they have a (i) symbol, where $i = 1$ means that the auction is restricted and $i = 2$ means that the auction is non restricted. Also, they are considered different auctions because they have a separated dynamic.

Table 1 summarizes the results of the biodiesel auctions. It can be seen that the number of bidders and the volume auctioned increased over time, reflecting the increase in the biodiesel mandate. The prices, on the other hand, did not follow this pattern. Both the ceiling and the average price increased from the 6^{th} to the 12^{th} auctions and then the prices returned to the initial levels.

Empirical analysis of the biodiesel auctions is virtually impossible due their peculiarities [5]. Firstly, there were drastic changes in the auction format. The first 8 auctions were electronics auctions; ANP implemented live auctions for the following 8 auctions and returned to electronic format in the last one. Secondly, the bidding rules, the regularity of the auctions, the delivery schedule, and the guarantee of producers also changed over time. Finally, the number of actions is not large enough for empirical analysis.

However, even without an accurate analysis, the results of the auctions are used in section 4 to recover information regarding the supply curve of the biodiesel industry.

2.2. Market Data

ANP monthly collects fuel market data. The information includes the amount of each fuel sold by state, the total quantity of each fuel produced by oil refinery, the total of fuel imported, average fuel prices by state (price collected over a significant sample of gas stations) and the average price charged by producers and importers

[4] Technically, the buyers in the auctions are all the producers and importers with market share above 1%. In practise, the oil refineries of two companies (Petrobras and Refap) fulfill these conditions (ANP <3>).

[5] For empirical estimation of auctions see Guerre et al. <19>, Laffont et al. <23>, and Donald and Paarsch <14>

Table 1: Results of Biodiesel Auctions

Auction	Date	Price (R$ Jan 2003/m3)		Volume Auctioned (m3)	N° of Bidders
		Celing	Average		
1	23/11/2005	1624.80	1611.97	70000	8
2	30/03/2006	1593.16	1552.78	170000	12
3	11/07/2006	1588.07	1462.13	50000	6
4	12/07/2006	1587.79	1456.19	550000	25
5	13/02/2007	1555.97	1521.36	45000	7
6	13/11/2007	1907.07	1483.61	304000	26
7	14/11/2007	1907.07	1480.52	76000	30
8	10/04/2008	2165.74	2078.10	259000	24
9	11/04/2008	2165.74	2074.01	66000	20
10	14/08/2008	1977.55	1965.95	264000	21
11	15/08/2008	1977.55	1969.77	66000	20
12(1)	24/11/2008	1794.61	1784.83	264000	23
12(2)	24/11/2008	1794.61	1787.96	66000	23
13(1)	27/02/2009	1737.39	1636.30	252000	27
13(2)	27/02/2009	1737.39	1387.99	63000	32
14(1)	25/05/2009	1712.05	1673.58	368000	27
14(2)	25/05/2009	1712.05	1680.81	92000	32
15(1)	27/08/2009	1657.58	1631.36	368000	27
15(2)	27/08/2009	1657.58	1639.82	92000	32
16(1)	17/11/2009	1685.85	1670.46	460000	29
16(2)	17/11/2009	1685.85	1663.75	115000	34
17(1)	12/02/2010	1614.04	1572.47	419900	29
17(2)	12/02/2010	1614.04	1556.73	106000	43

Notes: The data is from National Agency for Oil and Biofuels <3>.

of petroleum products at regional level[6].

The data on quantity of fuel sold starts in January 2000. All wholesale fuel distributors have to report to ANP the amount of fuel monthly sold in each state. The data, therefore, covers all Brazilian territory and includes all types of liquid fuels used in the market.

Data on prices started being collected by ANP in July 2001 and the number of cities and gas stations consulted has increased over time. In July 2001 the research covered 411 cities, the total increased to 555 municipalities in May 2004.

Data on the total fleet of buses (including those used in public transportation), tractors and trucks by state from January 2003 to December 2009 were also collected. This information is from Denatran (National Department of Traffic) and it is available at the state level. Besides, as a measure of monthly economic activity level, Information was gathered on ICMS (Tax on Trade of Products and Services,) for the same period. All prices used in the paper are adjusted to January 2003 constant Reais (Brazilian currency).

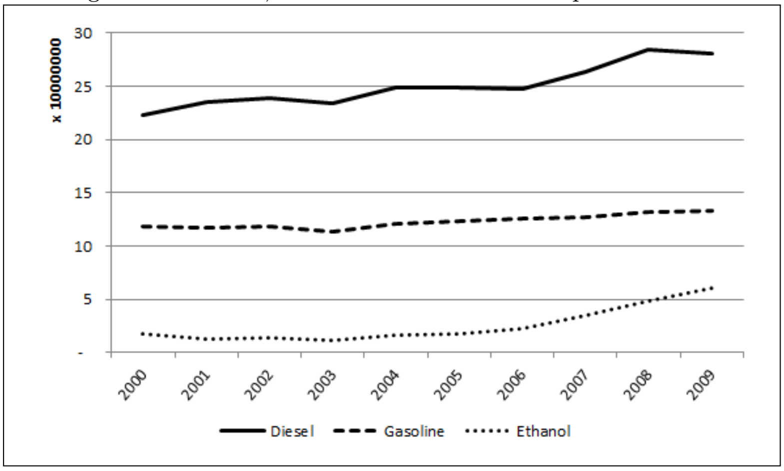
To serve as instruments for demand estimation I obtained data on the total value of petroleum imports and on the average wage of new employees in the wholesale fuel distribution and in the fuel retail industries. The value of imports is from ANP and is available with a monthly frequency at the National level. The wages are from Brazilian Ministry of Labour and Employment; this data has monthly frequency and it is available at the state level.

Figure 1 shows the consumption of three main liquid fuels used in land transport

[6]Each region is formed by groups of States with Geographical, historical and Economic similarities.

in Barrel of Oil Equivalent (BOE) from 2000 to 2009. As said before, gasoline and ethanol are not substitutes to diesel in the Brazilian Market. However, the graph illustrates the importance of diesel fuel. Diesel is more consumed than gasoline and ethanol put together. Nevertheless, ethanol has the highest increase in the consumption (250% in the period), followed by the diesel (26%) and gasoline (12%).

Figure 1: Gasoline, Ethanol and Diesel consumption in BOE



Source: Elaborated based on data from the National Agency for Oil and Biofuels <3>.

Table 2 shows the Consumption of diesel by Brazilian Region in 2007. In terms of absolute consumption, the Southeast uses most of the diesel, approximately 43% of the total consumption. Among the states, São Paulo, in the Southeast region, has the highest consumption, about 22% of the national consumption. However, considering the Consumption per capita, Central-West region has the highest use of diesel followed by the South region. The Southeast region has the second lowest per capita consumption. Table 2 provides evidence that the regional effects are important for the diesel fuel demand.

Table 2: Diesel Consumption by Region

	Consumption (1000000 BOE)	Consumption Per Capita
North	3.87	0.26
Northeast	6.23	0.12
Central-West	4.67	0.35
Southeast	18.10	0.23
South	8.68	0.32

Notes: The data is from National Agency for Oil and Biofuels <3>.

Figure 2 shows the diesel fuel price dynamic in Brazil. The left hand side of the figure shows the Average price charged by retailers, the minimum and the maximum price found in the survey and the average retail margin (the difference between the price charged by the gas stations and the wholesale price). The right hand side of the figure shows the standard deviation of the prices.

One can see that the movements of the average, minimum and maximum price are similar with a reasonably stable difference among them. The variance of the price reinforces this feature. It is small compared to the average, less than 0.05

Figure 2: Price (R$ January 2003)

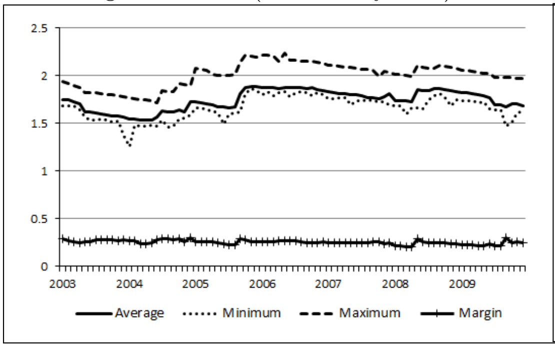
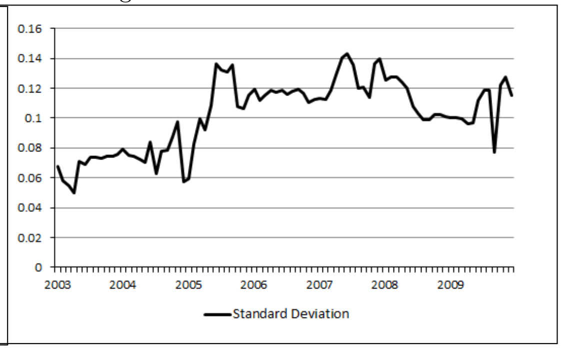


Figure 3: Standard Deviation



Source: Elaborated based on data from the National Agency for Oil and Biofuels <3>.

most of the time, with a slightly increase at the end of the period.

The average retail margin is stable during the whole analyzed period, indicating that the gas stations are able to transfer the positive shocks on costs to consumers. Conversely they do not retain a negative shock on prices. The figure indicates that the gas stations are charging a fixed markup over the marginal cost.

If one does not consider the retail margins of the other fuels, the result on stable margins differs from those found by Hosken et al. <20>. The authors discovered a substantial variability in the retail margins. This difference, however, may be explained by data aggregation and might not reflect the individual behavior of the retailers.

Table 3 shows some basic statistics regarding the Biodiesel Industry. All the indicators have grown over the period. The number of plants in 2009 is more than nine times the total number of factories in 2005. The production experienced an even higher increase, more than 2000 times the initial quantity. In 2005 the production of Brazilian biodiesel industry was only 756 m^3 in 2005 and it rose to 1.6 million m^3 in 2009.

Table 3: Industry Summary Statistics

	2005	2006	2007	2008	2009
Production (1000 m^3)	0.7	69.0	404.3	1,167.1	1,607.8
Number of Plants	7	18	45	62	64
Capacity (1000 m^3)	84.7	638	2,475.1	3,315.3	4,629.8
Capacity Utilization (%)	0.9%	10.8%	16.3%	35.2%	34.7%

Source: Elaborated based on data from the National Agency for Oil and Biofuels <3>.

The capacity, on the other hand, had a much slower increase when compared to the production. The capacity was around 85,000 m^3 in 2005 and increased to about 460,000 m^3 in 2009 (almost 55 times the initial capacity). The capacity utilization, however, is still low, around 35% in 2009.

This growth in the indicators was expected as the percentage of biodiesel in the BX also increased. However, the low percentage of the capacity utilization raises questions about the firms' strategy and about the future of the industry market structure. The capacity production of biodiesel is enough to attend levels of BX higher than 5%. Therefore, in the absence of new increases in the biodiesel mandate, some firms are expected to exit the industry.

3. Demand Estimation

The demand for diesel is a result of a number of different maximization processes. Diesel is used as input in several industries: agriculture, land transportation (freight and passengers), ship transportation and energy generation. Besides industrial use, diesel can also be utilized by domestic consumers for idiosyncratic reasons (for example, small boats for recreational fishing). In this sense, the diesel estimation cannot rely on a structural model based on agent's optimization.

Following the considerations above, the demand for diesel can be seen as a function of variables such as economic activities and fleet level.

$$lnQ_{it} = f\left(p_{it}, X_{it}\right) + \varepsilon_{it} \tag{3.1}$$

Where lnQ_{it} represents the natural logarithm of the quantity (m^3) of diesel sold in state i in period t, p_{it} is the average price charged by gas stations in state i during the period t. The vector X_{it} is composed by covariates that influence demand. It includes the logarithm of ICMS as a measure of economic activity level, the logarithm of the total fleet (the sum of the buses, tractors and trucks by state) to capture the importance of diesel in the transportation, and state dummies since regional characteristics may affect the demand for diesel fuel. To mitigate endogeneity problems with the variable ICMS, it is net of fuel taxes. ε_{it} is the error term. $f(.)$ is a demand function.

A similar approach to estimate gasoline demand has been used in many studies as summarized by Basso and Oum <6>. The traditional approach takes the demand for gasoline as a function of price, income and controls. Also, it is pointed that most of the specifications rely on log linear forms and Greene <17> and Dahl and Sterner <11> support the selection of the log-linear form. Based on that, the present paper also estimates a log-linear specification for the demand function. 3.1 becomes:

$$lnQ_{it} = \alpha_0 + \alpha_1 ln(p_{it}) + X_{it}\beta^{'} + \tau_i + \lambda_t + \upsilon_{it} \tag{3.2}$$

ln represents the natural logarithm and the error $\varepsilon_{i,t}$ is decomposed in three terms: an individual specific term τ_i, a time specific term, λ_t, and a individual time specific term ,$\upsilon_{i,t}$.

In order to assure the consistency of demand parameters estimated one assumption is necessary:

D1: *Consumers are only interested in the amount of energy the fuel produces.*

Assumption **D1** says that consumers see any biodisel mandate as the same product [7]. This assumption assures that the coefficients of equation 3.2 are stable, they do not change according to the diesel mandate.

Table 4 presents the results of the demand estimation. The first column of the table is the result of the OLS regression with the use of state dummies, which is equivalent to the fixed effects estimator [8]. The coefficient of the price is negative, as expected. The value is approximately 0.6 indicating that an increase of 1% in the real price of the diesel implies a reduction of 0.6% in the consumption of diesel.

[7] Tests conducted by the Ministry of Science and Technology indicated that there are no loss of efficiency in diesel engines due the use of any BX blend up to B5 ANP <3>

[8] See Greene <18> and Wooldridge <37> for details about panel methods

The variable fleet has an unexpected negative signal: an increase in the number of heavy vehicles decreases the use of biodiesel. However, the coefficient is statistically insignificant. On the other hand, the log of ICMS has the expected signal. A one percent increase in the total tax collected causes an increase of 0.03% in the total consumption of diesel. Since ICMS is charged on products and services effectively traded, the results show a positive relation between the economic activity and diesel consumption.

The second entry in table 4 is the results of the random effect estimation. One can see that the price and the economic activity effects are stronger under the random effects hypothesis. Besides, the fleet has the expected sign and it is significant at 5%. However, the Hausman test rejects the hypothesis of no systematic differences between the random and fixed effects.

Instrumental variables are used to control the endogeneity problem caused by simultaneous equations. The instruments are supply-side cost shifters: the log of the wholesale average price, the log of the wage of new employees in the fuel distribution industry (retail and wholesale), and the log of average import price of the m^3 of petroleum. All the instruments affect the supply of diesel fuel, as they affect the marginal cost of the industry. However, they have no effects on the demand side. In other words, the instruments do not alter the consumers' decisions. Therefore, the instruments can be considered exogenous. Besides, the regression of the retail price on the instruments (table 5) has an F-Statistic equal to 9496, considerably higher than the 10 or 20 value pointed by Stock et al. <33> to rule out weak instruments.

The results for the IV with states dummies are in the third entry in the table 4. The price elasticity is considerably higher when compared to OLS regression, the value of the parameter is now about -0.9, 50% higher than the estimation without instruments. The log of fleet continue to be insignificant and with the wrong sign. The log of ICMS is almost the same when compared with the OLS regression.

Finally, the fourth column in table 4 presents the random effects estimation of the model using instrumental variables. The price elasticity is around 1 and the log of fleet is significant and with the right sign. The log of ICMS is close to the value obtained in the random effects estimation with no instruments and higher than the fixed effects estimations. This difference between the estimators with instruments is strongly significant according to the Hausman test (qui-square value of 407.12).

One can draw two conclusions based on the diesel fuel demand estimation. First, the regional effects are important. The Hausman test strongly rejects the equality among the fixed and the random effects estimator [9]. Second, the use of the instrumental variables changed the results considerably. The OLS seems to underestimate the price elasticity.

Based on the conclusions above, the coefficients obtained in the fixed effects IV estimation are used to construct the simulations in section 6.

[9] The random effects estimator is consistent and efficient under the hypothesis of independence of the individual characteristics. The fixed effects estimator does not need this assumption to achieve consistence. Therefore the fixed effect is a more robust estimator. See Wooldridge <37> for the use of the Hausman test in the panel context.

Table 4: Demand Estimation

	OLS	RE	IV	RE-IV
Log Price	-0.5599*	-0.6398*	-0.8594*	-1.0573*
	(0.1701)	(0.1760)	0.1998)	(0.1998)
Log Fleet	-0.0123	0.0535*	-0.0109	0.0521*
	(0.0171)	0.0171)	0.0170)	(0.017)
Log ICMS	0.0394*	0.0730*	0.0417*	0.0748*
	(0.0126)	(0.0128)	(0.0125)	(0.0127)
State Dummies	Yes	No	Yes	No
Time Dummies	Yes	Yes	Yes	Yes
Number of Observations	2259	2259	2257	2257
R-Squared	0.9864	0.6723	0.9866	0.6634
Hausman	402.98		407.12	

Notes: Dependent Variable is the log of of the total m^3 of diesel. Standard errors in parentheses. *Significante at 5%. Instruments are log of the wholesale price, log of the import expenditure of Petroleum and log of the wage of new employees in the fuel distributor industry.

Table 5: Regression of the instruments on the logarithm of the price

	OLS
Ln whole Sale Price	0.9111*
	(0.0063)
Ln New wages	0.0020
	(0.0004)
Ln Oil Import Price	-0.0073*
	(0.0027)
F-Statistic	9496

Notes: Dependent Variable is logged diesel price. Standard errors in parentheses. *Significante at 5%.

4. The Production Side

Data on the last two auctions (17(1) and 17(2)) was used to approximate the industry supply curve. The are two reasons for this choice. First, these two auctions are electronic and therefore have better information regarding the bids; it is possible to access all the bids of every firm. Second, the paper relies on a static exercise and to include the past auctions I should make considerations regarding the capacity adjustments cost and the entry costs of the firms.

Since the cost structure of the firms is not observed, some assumptions are required to recover the supply curve. First, I assume a strategic interaction among the firms and a feature of the non-observed cost structure:

P1: *Firms are in perfect competition.*

P2: *Marginal cost is constant and firms can produce up to 100% of their capacity.*

Assumption **P1** is based on the low capacity utilization in 2009, around 36%. The firms are obliged to enter into a fierce competition in order to sell their production. The first part of assumption **P2**, constant marginal costs, is a standard assumption in both theoretical[10] and empirical[11] economic literature. The second part of the assumption **P2** refers to the fact that firms do not waste money building a capacity that they will not use.

Assumptions **P1** and **P2** are, however, not enough to characterize the supply curve as some firms did not enter in the the last two auctions. To overcome this difficulty, the firms are divided in four groups, according to their participation in the auction, and specific assumptions are made for each group.

4.1. Group 1

The first group is composed by the firms that had license to produce but not to commercialize. They could not have participated in the auctions. For this group the following assumption is made:

P3: *The marginal cost is equal to the auction ceiling price. Therefore, firms in group 1 can offer any amount of biodiesel between zero and their full capacity at the ceiling price.*

Formally:

$$s_i(b) = \begin{cases} q_i = 0 & \text{if } b < b_c \\ 0 \leq q_i \leq C_i & \text{if } b = b_c \\ q_i = C_i & \text{if } b > b_c \end{cases} \tag{4.1}$$

Where, $s_i(b)$ is firm i's supply function, C_i is firm i's capacity, q_i is firm i's quantity supplied, b_c is the auction celling price, and b is a given price.

Equation 4.1 may underestimate or overestimate the supply function of the plants in this group as no information about the price behavior is known. However, this problem is minimized as a small fraction of firms belong to this group (see appendix I)

[10]For exemple, Sutton <34>, Krugman <22> Dixit and Stiglitz <13> and Tirole <35>

[11]For example,Ryan <31>, Nevo <29>, and Jia <21>

4.2. Group 2

The second group is formed by firms that could have entered in the auction (they have the commercialization license) but decided not to enter. The assumption made for this group is exactly equal to **P3**:

P4: *The marginal cost is equal to the auction ceiling price. Therefore, firms in group 2 can offer any amount of biodiesel between zero and their full capacity at the ceiling price.*

Formally:

$$s_i(b) = \begin{cases} q_i = 0 & \text{if } b < b_c \\ 0 \leq q_i \leq C_i & \text{if } b = b_c \\ q_i = C_i & \text{if } b > b_c \end{cases} \tag{4.2}$$

Where, $s_i(b)$ is firm i's supply function, C_i is firm i's capacity, q_i is firm i's quantity supplied, p_b is the auction celling price, and b is a given price.

For this group the minimum offer price maybe be higher than the ceiling price. The ceiling price can be seen as a lower bound for the minimum offer price. **P3** implies that the lower bound is actually equal to the minimum offer price for group 2 and the firms did not enter in the auction due to entry costs [12].

4.3. Group 3

This group incorporates the firms that entered in the auction but did not win. For group 3 the following assumption is made:

P5: *The marginal cost is equal to the firm's lowest bid. Therefore, firms in group 3 can offer any amount of biodiesel between zero and their full capacity at a price equal to their lowest bid.*

Formally:

$$s_i(b) = \begin{cases} q_i = 0 & \text{if } b < b_m^i \\ 0 \leq q_i \leq C_i & \text{if } b = b_m^i \\ q_i = C_i & \text{if } b > b_m^i \end{cases} \tag{4.3}$$

Where, $s_i(b)$ is firm i's supply function, C_i is firm i's capacity, q_i is firm i's quantity supplied, p_m^i is the firm i's lowest bid, and b is a given price.

Assumption **P3** is a good approximation of the marginal cost, since the firms signalized their intention in providing biodiesel at this price level. Also, assumption **P2** assures that this marginal cost is the same for the entire capacity.

4.4. Group 4

This group is formed by firms that won the auction. For this group the following assumption is assumed:

P6: *The marginal cost is equal to the firm's lowest winning bid. Therefore, firms in group 4 can offer any amount of biodiesel between zero and their full capacity at a price equal to their lowest winning bid.*

[12] see <25> for entry costs in auctions

Formally:

$$s_i(b) = \begin{cases} q_i = 0 & \text{if } b < b_w^i \\ 0 \leq q_i \leq C_i & \text{if } b = b_w^i \\ q_i = C_i & \text{if } b > b_w^i \end{cases} \tag{4.4}$$

Where, $s_i(b)$ is firm i's supply function, C_i is firm i's capacity, q_i is firm i's quantity supplied, b_w^i is the firm i's lowest winning bid, and b is a given price.

For this group the minimum offer price may be be lower than the winning bid. Therefore, their marginal cost might be overestimated.

In the next subsection we combine the assumptions made above to recover the industry supply curve.

4.5. Industry Supply

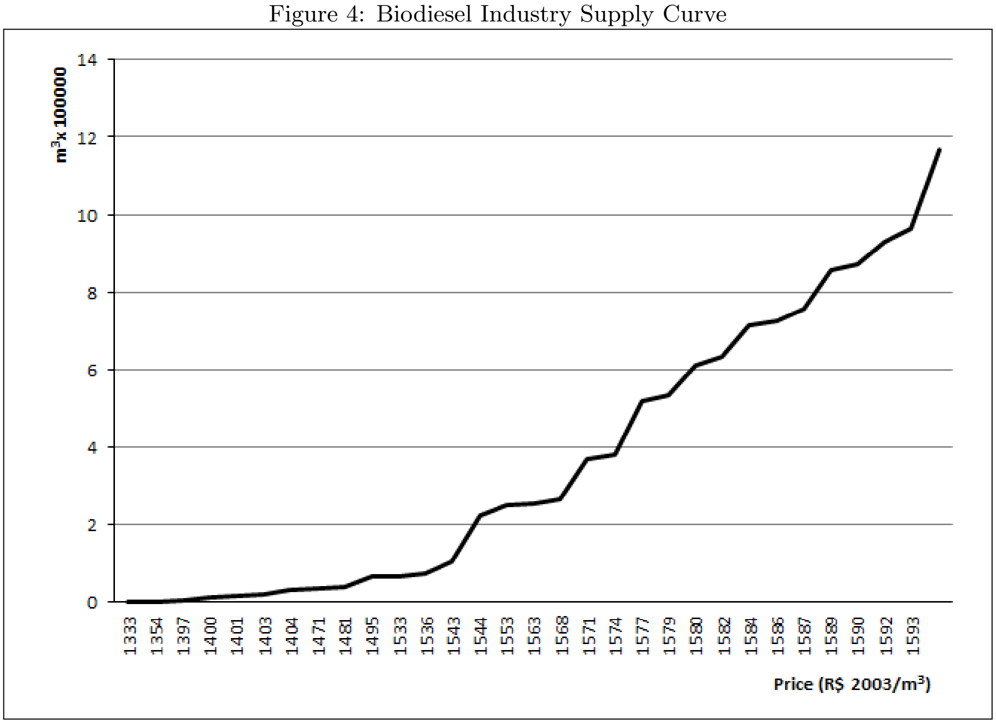
The industry (or market) supply curve is the horizontal sum of firm supply curves (Mas-Colell et al. <26>). For the biodiesel industry it can be defined as follow:

$$S_i(b) = \sum_{i=1}^{J} s_i(b) \tag{4.5}$$

Where, $S_i(b)$ is the market supply function, $s_i(b)$ is firm i's supply function, b is a given price, and J is the total number of producers.

Due the discontinuous characteristics of the firms supply, the industry supply function does not have a closed form. However, under the assumptions assumed, it is possible to compute the amount offered at any given price. Figure 4 shows the biodiesel supply curve.

Figure 4: Biodiesel Industry Supply Curve



Source: Elaborated based on data from the National Agency for Oil and Biofuels <3>.

The supply curve express a *ceteris paribus* condition, it shows the relations between the price of a good and its quantity supplied, given that the other factors are constant. Therefore, a change in the these other factors shifts the position of the supply curve. A linear cost reduction for all firms, for example, shifts the demand to the left. For any given price there a reduction in the quantity offered. The opposite happens if the costs increase.

The factors that affects the biodiesel supply include the raw material price, the opportunity cost of the producer, the labor cost, and the technology. Biodiesel is produced by a chemical reaction of lipids (vegetable oil or animal fat) with an alcohol(Ayhan <4>). Therefore, if the price of a feedstock used in the biodiesel production increases, the supply curve shifts to the right. Also, if the producer can use the plant to produce oils for non-fuel purposes, a decrease in the price of this alternative option would shift the supply curve to the right. A similar reasoning can be made for all the relevant factors shifting the supply curve.

Even though the factors affecting the supply curve are very important, they are not addressed in this paper for two reasons. First, there is not data available to map the factors to the cost structure. In other words, the quantitative result of these changes cannot be determined. Second, the paper makes a short run partial equilibrium analysis. I analyze how the market outcomes change with a change in the biodiesel mandate given that the other factors are constant (see section 5). The hypothesis of all the other factors remaining constant is not strong in the short run, as the producer of other goods would take time to adjust prices.

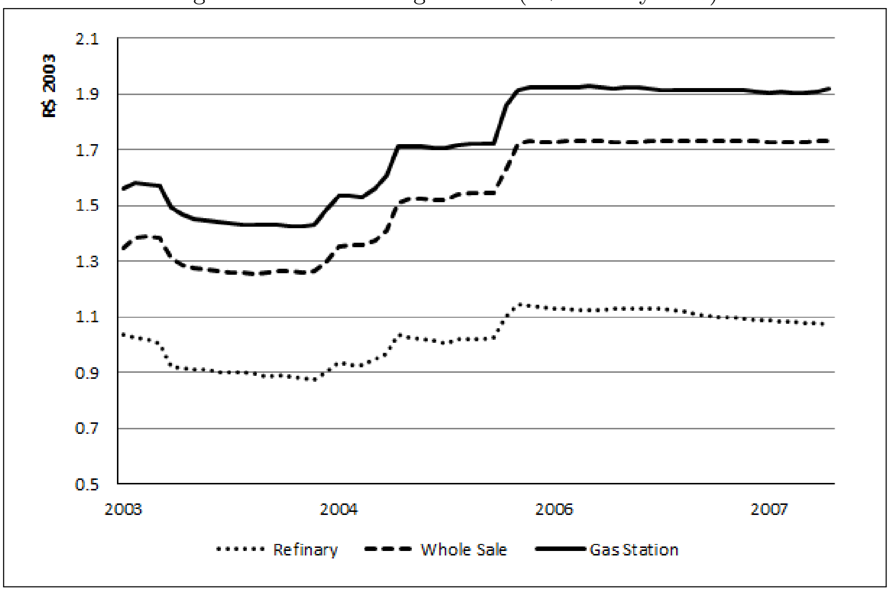
5. Welfare Analysis

Biodiesel producers are part of a broader fuel industry which includes wholesalers, retailers, oil refineries and fuel importers. To analyze the impacts of the biodiesel mandates on the retail prices it is necessary to consider the interactions among all these agents. More specifically, it is necessary to know how all the agents in the market react to a change in the biodiesel mandate.

It is useful to divide the agents in the market according to their position in the diesel fuel supply chain. The firms involved in the direct production or importation of the fuel (oil refineries, fuel importers and biodiesel producers) form the upstream part of the supply chain. On the other hand, the firms that commercialize the fuel previously produced (wholesalers and retailers) form the downstream part of the supply chain.

The analysis is made backwards. The first step is to see what happens in the downstream part of the market. In other words, how retailers and wholesalers react to a given change in the prices of usptream firms [13]. Figure 5 shows the average prices of petroleum diesel charged by retailers, wholesalers, producers and importers in Brazil between January 2003 and December 2007, before the mandatory adoption of biodiesel. The lines of the three prices show a quite similar pattern, besides the distance between the retail and the wholesale price is stable over the period. It corroborates the discussion made in the data description about the retail markups. The wholesaler margin is not so stable; it seemed to increase in the last months of the analyses.

Figure 5: Diesel Average Prices (R$ January 2003)



Source: Elaborated based on data from the National Agency for Oil and Biofuels <3>.

Figure 5 provides the base for the following hypothesis:

S1: *(i) Wholesalers and retailers charge a markup (margin) over their acquisition costs; (ii) wholesalers buy petroleum diesel, while biodiesel and retailers buy*

[13]See Tirole <35> for a more detailed idea of vertical restraints

the BX blend; (iii) the markup in a given point in time is composed by a time invariant part and a time specific noise iid with zero mean.

Hypothesis **S1** provides the best response of retailers and wholesalers to any price chosen by firms in the upstream market. It is worth noting that the hypothesis fits the data and simplifies the strategies of the downstream firms.

For the upstream market the following hypothesis is made:

S2: *Oil refineries and the diesel importers do not react (change prices) to a change in the biodiesel mandate.*

Hypothesis **S2** is reasonable since it cannot be seen in the data any change in the oil diesel producers' price caused by the introduction of biodiesel. Therefore, it is assumed that the oil diesel price is constant in all the simulations.

5.1. Counterfactuals

Given assumptions **S1** and **S2**, the diesel fuel price paid by the consumers (BX price) in a given month can be written as:

$$p_{it} = \alpha b_{it} + (1-\alpha)d_{it} + \mu^r_{it} + \mu^w_{it} \tag{5.1}$$

Where, b_t stands for the biodiesel producers' price in period t, d_t stands for the oil diesel producers' price in state i in period t, $\mu^r_{,i,t}$ is the retailers' markup in state i in period t, $\mu^w_{,i,t}$ is the wholesalers' markup in state i in period t, and α is the biodiesel mandate.

Equation 5.1 assumes that the one price law holds for biodiesel in all Brazilian territory and at regional level for the oil diesel. Also, it implies that the fuel is not commercialized through auctions but directly negotiated between buyers and sellers.

The elements necessary to perform the simulation are given by equations 3.2, 4.5 and 5.1. Basically the exercise consists in finding an market equilibrium price for each biodiesel mandate keeping the other factors constant. For a given level of markup, oil diesel price and α, equation 5.1 gives the fuel diesel price as a function of the biodiesel price. Therefore, for the market equilibrium it is necessary a biodiesel price that equates the quantity supplied (equation 4.5) and the quantity demanded (equation 3.2).

The computational details are as follow. First, I used just a month in the simulation to minimize possible dynamic distortions. The variables fleet, ICMS and petroleum diesel prices are those observed in November 2009. Second, the markup is the average margin for the period between January 2003 to December 2007 for the retailers and between January 2007 and December 2007 for the wholesalers. I used only one year to estimate the wholesalers' margin to capture its increase observed in the data. Finally, the coefficients for the demand are those estimated through fixed effects with IV (Table 4).

The algorithm used for the simulations is simple (the code is presented in appendix II). It starts with a low biodie sel price and calculates the the demand and supply for this price. If the difference between the supply and the demand is high, the price increases by a small amount and a new demand a new supply are calculated. The algorithm continues till the difference between the quantity supplied and the quantity demanded becomes negligible.

5.2. Results

The simulations results are shown in table 6. The chart presents the scenarios with different mandatory percentages of biodiesel. The baseline is the scenario without biodiesel (100% of petroleum diesel). The second scenario has a 5% biodiesel mandate. For the others scenarios, the mandate was increased from 1% up to 15% and then simulated with a 20% mandate. In all the simulations the possible loss of efficiency in the diesel engines due the increase of the biodiesel proportion is not considered.

It should be noted that the biodiesel price presented in the table corresponds to the producer price, free of wholesalers' and retailers' margins. The BX price, on the other hand, is the consumer's final price considering both margins and the proportion of biodiesel and petroleum diesel in the fuel. Furthermore, the BX price is the Brazilian average price. Since equation 3.2 allows for state effects, an equilibrium price and quantity is obtained for each state and the equilibrium quantity is used as a weight to calculate the national average price.

Table 6: Simulation Results

	Biodiesel		BX		Capacity
%	Price *	Quantity**	Price*	Quantity**	Utilization (%)
0%	-	-	1.75	3,459.70	0%
5%	1.57	170.5	1.78	3,409.20	44%
6%	1.58	203.9	1.78	3,398.70	52%
7%	1.58	237.2	1.79	3,388.40	61%
8%	1.59	270.2	1.80	3,377.90	70%
9%	1.59	303.1	1.80	3,367.60	78%
10%	1.59	335.7	1.81	3,357.10	86%
11%	1.59	368.2	1.97	3,347.30	95%
12%	2.14	388.5	2.07	3,237.20	100%
13%	3.47	388.5	2.09	2,988.20	100%
14%	4.62	388.5	2.26	2,774.70	100%
15%	5.64	388.5	2.45	2,589.70	100%
20%	9.33	388.5	3.58	1,942.30	100%

Notes: (*)R$ Jan 2003/L, (**) 1000 m^3. Values obtained thought simulation based on equilibrium conditions. The first line (B0) presents the petroleum diesel price.

One can see that the B5 increases the consumer price in 1.7%, from R$ 1.75 to R$ 1.78. The raise in the price leads to a reduction in consumption of about 50.000 m^3, around 1.5%. If one doubles the current biodiesel mandate, from 5% to 10%, the price effect is more than proportional: fuel diesel price increases 3.6% reaching R$ 1.82. The consumption, on the other hand, decreases by 3% due the use of B10.

The simulations also allow understanding of the relations among capacity utilization, price and consumption. The increase in the capacity utilization from 44% (with B5) to 95% (with B11) increases the producer price in R$ 0.02 (about 1%). Therefore, the supply curve of the industry seems to be smooth on price up to 95% of its full capacity.

As stated before, the B5 drives the capacity utilization to 44%. When one doubles the compulsory percentage, the capacity utilization goes to 86%. This less than proportional increase in the capacity utilization is due to the increase in price that reduces the consumption of the total mixture.

Further increases in the compulsory proportion of biodiesel increases the capacity utilization and leads to operation of firms with higher marginal costs. The effects on prices are higher after 11% of biodiesel. The biodiesel price increases 34% when B11 is substituted for B12. It happens because with a 12% biodiesel mandate the industry starts to work to its full capacity, the price need to go up to equalize the demand and the offer. Since the biodiesel is a small proportion of the total BX, its price needs a great increase to generate a significant drop in the BX demand. At a mandatory 20% blend, the price to the consumer is more than the double of the pure petroleum diesel, and the total consumption falls about 44%.

The impacts of different diesel mandates in the consumer surplus, and in the profits[14] are also analyzed. The focus is the difference between the baseline scenario (no biodiesel) and the alternative scenarios with different percentages of biodiesel. Also, since there is no closed form for the consumers' utility, it is not possible to analyze the equivalent and the compensating variations. Alternatively, the consumer surplus[15] is used as a measure of consumers' loss of welfare due the change in the price of the diesel fuel caused by the biodiesel mandates. Finally, oil refineries profits were not considered since no information regarding their costs is available. The results are summarized in table 7.

The second column in table 7 shows the total consumer surplus (the sum over Brazilian states). The current proportion of biodiesel (B5) causes a loss of R$ 104 million to the consumers. An increase to 10% in the mandatory percentage of biodiesel would costs R$ 212 million to consumers in terms of welfare. The loss increases very fast after 11% and achieve the impressive number of R$ 2 billion with B15 and R$ 4 billion with B20.

For biodiesel proportion up to 10% the biodiesel industry's profits are quite small when compared to the consumer loss. At the current percentage (5%) the profits of all producers are around R$ 5 million. The double of the present percentage of biodiesel would increase the profits to 10 million. After that, however, one can observe a remarkable increase in the total profits; they achieve R$ 3.3 billion when one considers the scenario with 20% of biodiesel. The retailers and wholesalers are also affected by the introduction of biodiesel. Together they have a reduction of R$ 39 million in the total profit at the current level of biodiesel. At a 20% level of biodiesel the total profit loss to retailers and wholesalers is above one billion.

In sum, the losses to consumers, wholesalers and retailers outweigh the profits for the biodiesel producers in any level of biodiesel proportion considered. However, other benefits created by the use of biodiesel could make the adoption of biodiesel a socially optimal decision. For example, environmental benefits, such as reduction in the greenhouse gases emissions, or improvement in the air quality may generate a significant welfare. Also, the income transfer to small farmers might be socially desirable. These considerations are above the scope of this paper and may be included in future works.

[14] For biodiesel producers, Fixed costs are not considered. Therefore, profit is equal to revenue (price times quantity) minus marginal costs times quantity. If one consider the presence of fixed costs, the profit in the table becomes producer surplus. For retailers and wholesalers the variations in profits are equal to the margin times the change in the quantity sold.

[15] See Varian <36>.

Table 7: Simulation Results

Biodiesel Mandate	Consumer Surplus(*)	Biodiesel Producers Profit(*)	Δ Retailers' Profit(*)	Δ Wholesalers' Profit(*)
5%	-104	5	-9	-30
6%	-125	7	-11	-36
7%	-146	8	-13	-42
8%	-168	9	-15	-49
9%	-190	10	-16	-55
10%	-212	10	-18	-61
11%	-233	254	-20	-67
12%	-470	801	-40	-133
13%	-1042	1272	-84	-281
14%	-1579	1682	-122	-408
15%	-2077	2044	-155	-519
20%	-4241	3365	-271	-905

Notes: (*)R$ Jan 2003/L. Results obtained by simulation.

6. Conclusions and Future Research

The compulsory adoption of biodiesel in the Brazilian fuel market can bring many changes to the economy. Most of these changes are, however, still unknown. This paper addresses market equilibrium outcomes: the effects on price, consumption and welfare in the short run.

The analysis of the demand shows that even though the diesel is a important raw material in the transport and agriculture industry (with almost no substitute in the short run) it has a considerable high price elasticity when controlled by other factors.

The industry supply estimation was based on the results of the last two auctions in the dataset. This simplification was adopted to avoid capturing possible dynamic effects on the static analyses made in the paper. The supply curve constructed is considerably smooth up to the industry total capacity. After that, a change in the compulsory proportion has a huge impact on prices due to capacity constraints.

The simulations show that the current level of biodiesel raises the final price to consumers by 1.7% and decreases the consumption by 1.5%. If the government doubles the compulsory proportion the new price would be 3.5% higher with a decrease in consumption of 3%. Besides, the welfare analyses showed that the consumers, wholesalers and retailers have a huge loss in consumer surplus and in profits due to the adoption of the biodiesel. With a 5% biodiesel blend, the total loss is about R$ 143 million.

The paper, however, could not explore all the aspects of this broad field. For example, it is unknown how the increase in the oil production and oil refining in Brazil affects the biofuel programs (the country is a net exporter of oil and may become a net exporter of petroleum diesel). Also, more studies are necessary to understand the economic impacts of biodiesel in the other parts of the supply chain. This includes the effects of biodiesel in feedstock, land use, employment and the expenditure in subsidies. Besides, the paper did not apply a dynamic framework. Future works should improve the analysis in this aspect in order to create more realistic scenarios. Combined, all this information could be a better guide for energy policy decisions.

[1] Almeida, E. F. d., Bomtempo, J. V., and Silva, C. M. d. S. e. (2008). *Biofuels: Linking Support to Performance.* OECD.

[2] Althoff, K., Ehmke, C., and Gray, A. W. (2003). Economic analysis of alternative indiana state legislation on biodiesel. Technical report, Center for Food and Agricultural Business, Department of Agricultural Economics, Pardue University.

[3] ANP (2010). National agency for oil and biofuels. www.anp.gov.br. [In Portuguese].

[4] Ayhan, D. (2007). Importance of biodiesel as transportation fuel. *Energy Policy*, 35(9):4661 – 4670.

[5] Barbosa, M. Z. (2011). Disponibilidade de oleo de soja para energia e alimentos no brasil. *Informações Econômicas*, 41(9).

[6] Basso, L. J. and Oum, T. H. (2007). Automobile fuel demand: A critical assessment of empirical methodologies. *Transport Reviews*, 27(4):449–484.

[7] Brazil (1975). Law number 76.593. Diário Oficial [da] República Federativa do Brasil.

[8] Brazil (1976). Law number 76.593. Diário Oficial [da] República Federativa do Brasil.

[9] Brazil (1997). Law number 9.478. Diário Oficial [da] República Federativa do Brasil.

[10] Brazil (2005). Law number 11.097. Diário Oficial [da] República Federativa do Brasil.

[11] Dahl, C. and Sterner, T. (1991). Analysing gasoline demand elasticities. *Energy Economics*, 3(13):203–210.

[12] De Gorter, H. and Just, D. R. (2009). The economics of a blend mandate for biofuels. *American Journal of Agricultural Economics*, 91(3):738–750.

[13] Dixit, A. and Stiglitz, J. E. (1977). Monopolistic competition and optimum product diversity. *American Economic Review.*

[14] Donald, S. and Paarsch, H. (1993). Identification, estimation, and testing in empirical models of auction within the independent private values paradigm. UWO Department of Economics Working Papers 9319, University of Western Ontario, Department of Economics.

[15] Ericson, R. and Pakes, A. (1995). Markov-perfect industry dynamics: A framework for empirical work. *The Review of Economic Studies*, 62(1):53–82.

[16] Fargione, J., Hill, J., Tilman, D., Polasky, S., and Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. *Science*, 319(5867):1235–1238.

[17] Greene, D. (1982). State level stock system of gasoline demand. *Transportation Research Record*, (801):44–51.

[18] Greene, W. H. (2003). *Econometric Analysis.* Prentice Hall.

[19] Guerre, E., Perrigne, I., and Vuong, Q. (2000). Optimal nonparametric estimation of first-price auctions. *Econometrica*, 68(3):525–574.

[20] Hosken, D. S., McMillan, R. S., and Taylor, C. T. (2008). Retail gasoline pricing: What do we know? *International Journal of Industrial Organization*, 26(6):1425 – 1436.

[21] Jia, P. (2006). Estimating the effects of global patent protection in pharmaceuticals: A case study of quinolones in india. *American Economic Review*, 96(5):1477–1514.

[22] Krugman, P. (1978). Increasing returns, monopolistic competition and international trade. *Journal of International Economics*.

[23] Laffont, J.-J., Ossard, H., and Voung, Q. (1995). Econometrics of first-price auctions. *Econometrica*, 63(4):953–980.

[24] Lamers, P., McCormick, K., and Hilbert, J. A. (2008). The emerging liquid biofuel market in argentina: Implications for domestic demand and international trade. *Energy Policy*, 36(4):1479–1490.

[25] Li, T. and Zheng, X. (2009). Entry and competition effects in first-price auctions: theory and evidence from procurement auctions. *Review of Economic Studies*, 76(4):1397–1429.

[26] Mas-Colell, A., Whinston, M. D., and Green, J. R. (1995). *Microeconomic Theory*. Oxford University Press.

[27] Maskin, E. and Tirole, J. (1988). A theory of dynamic oligopoly, i: Overview and quantity competition with large fixed costs. *Econometrica*, 56(3):549–569.

[28] MME (2005). Ministerio das minas e energia. Programa Nacional de Produção e Uso do Biodiesel. Available in: http://www.mme.gov.br/programas/biodiesel/. [In Portuguese].

[29] Nevo, A. (2001). Measuring market power in the ready-to-eat cereal industry. *Econometrica*, 69(2):307–342.

[30] Pfuderer, S., Davies, G., and Mitchell, I. (2009). The 2007/08 agricultural price spikes: Causes and policy implications. Technical report, HM Government.

[31] Ryan, S. P. (Forthcoming). The costs of environmental regulation in a concentrated industry. *Econometrica*.

[32] Silva César, A. d. and Batalha, M. O. (2010). Biodiesel in brazil: History and relevant policies. *African Journal of Agricultural Research*, 5(11).

[33] Stock, J. H., Wright, J. H., and Yogo, M. (2002). A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business & Economic Statistics*, 4(20):518–529.

[34] Sutton, J. (1991). *Sunk Costs and Market Structure*. Cambridge, MA: MIT Press.

[35] Tirole, J. (1988). *The Theory of Industrial Organization*. MIT University Press.

[36] Varian, H. R. (1992). *Microeconomic Analysis, Third Edition.* W. W. Norton & Company, 3rd edition.

[37] Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data.* MIT University Press.

7. Appendix I – Plant Characteristics

Table 8: Add caption

Plant	Monthly capacity	Marginal Cost	Group
Biolix	900	1592.92	1
Brasil ecodiesel 1	9000	1592.92	1
Brasil ecodiesel 2	8100	1592.92	1
Coomisa	360	1592.92	1
Cooperfeliz	200	1592.92	1
Ouro verde	510	1592.92	1
Abdiesel	72	1592.92	2
Agrenco	19608	1592.92	2
Big Frango	1200	1592.92	2
Bionorte	2451	1592.92	2
Cooperbio	120	1592.92	2
Fusermann	900	1592.92	2
Granol	7500	1592.92	2
Grupal	300	1592.92	2
Kgb	150	1592.92	2
Nutec	72	1592.92	2
Rondobio	300	1592.92	2
Soyminas	1200	1592.92	2
Taua	3000	1592.92	2
Tecnodiesel	330	1592.92	2
Usibio	600	1592.92	2
Vermoehlen	150	1592.92	2
Araguassu	3000	1533.34	3
Bio Oleo	300	1494.74	3
Brasil Ecodiesel 3	10800	1543.09	3
Clv	3000	1570.53	3
Innovatti	900	1552.78	3
Ssil	150	1396.85	3

Notes: (**) m^3,(*)R$ Jan 2003/L,. Values obtained thought simulation based on equilibrium conditions. The first line (B0) presents the petroleum diesel price.

8. Appendix II – Code Used to Compute Equilibrium

```
---------------------------------------------------------------------
SUMMARY
DESCRIPTION: Simulate Equilibrium for different biodisel mandates
INPUTS: sim.mat
OUTPUT: p (vector of prices) and q (vector of quantities)
INPUTS DETAILS:
ela: price elasticity
m1il: retaleir's markup
m2il: wholesaler's markup
ps: diesel prices
const: states' constant
s: quantity supplied for the industry at each price
---------------------------------------------------------------------
clear
load sim
d = zeros(11,1)
d1=zeros(27,1);
of=810*(ones(11,2)); % Initial offer
p = ones(11,1);
p=1590*p; % Initial price
i =1;
j=1;
pie = .05; % biodiesel mandate
for i=1:16;
   while abs(d(i)-of(i))>1
        p(i) = p(i)+.1;
        for j = 1:27
          d1(j) = (pie*p(i)+(1-pie)*1000*pd(j)+1000*m1il(j)+1000*mi2(j))^ela;
        end
        d(i) = const'*d1;
        d(i)=d(i)*pie;
        max = max(s(:,1)<=p(i))
        of(i,1) == s(max(s(:,1)<= p(i)),2);
        if d(i)>of(i,2) & d(i)<of(i,1)
          of(i,1) = d(i);
        end
        of(i,2) = of(i,1);
   end
   if d(i)<388459.2255 % Maximum Capacity
      p(i+1)=p(i)-1;
   else
      p(i+1)=p(i)+100;
   end
   pie = pie + .01;
end
```