IMPACT OF FLEXIBLE-FUEL VEHICLES ON BRAZIL'S FUEL MARKETS

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ABSTRACT OF THE THESIS

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Ethanol is a green and environment-friendly fuel that has been one of the most important fuels for Brazil's drivers for decades. Brazil has a strong and booming ethanol industry. Brazil's consumers are able to switch between ethanol and gasoline since the introduction of flex-fuel vehicles in March 2003, which alters both ethanol and gasoline markets. This paper's objectives are specified as follows:

a. Estimate the demand elasticity of ethanol, cross demand elasticity of ethanol to gasoline/sugar, the income elasticity of ethanol, the demand elasticity of ethanol to fleet;

b. Estimate the elasticities before and after the introduction of flex-fuel vehicles, and test if there is a significant difference between two periods;

c. Analyze the reasons for such differences as well as provide policy implications.

3-stage Least Squares Simultaneous Equations System is utilized for statistical analysis. Results of this study Show that: (1) demand for hydrous ethanol is more elastic after March 2003; (2) cross demand of ethanol to gasoline price is more elastic after March 2003; (3) income elasticity of ethanol is not statistically significant; (4) the relationship between sugar price and supply of ethanol is unimportant; (5) the growth in fleet leads to increase in the demand for hydrous ethanol, and this effect grew stronger after the introduction of flex-fuel vehicles.

My findings suggest that the invention and commercialization of flex-fuel vehicles alters Brazil's fuel market by enabling consumers to switch between two fuels. From a policy maker's view, demand for ethanol and gasoline are more sensitive to their prices, and their relationship is complicated with two reverse effects, which requires a more comprehensive model to evaluate any policy effect. From industrial standpoint, the results suggest that pricing strategy for ethanol and gasoline should be revised due to increasing elasticities. Future research about flex-fuel vehicles and fuel markets should incorporate tax rates, government policy, propaganda, education, and environmental impact.

Acknowledgement and/or Dedication

Dedication: Throughout my life one person has always been there during those difficult and trying times. I would like to dedicate this thesis and everything I do to my mother Hualin Tang. In addition to her I have always been surrounded with strong supportive women. I would not be who I am today without the love and support of my girlfriend Lynn Linhong Yao. Although our time together was brief, her contributions to my life will be felt forever

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IMPACT OF FLEXIBLE-FUEL VEHICLES ON BRAZIL'S FUEL MARKETS

1. Introduction and Background

Many countries have been investing billions of dollars on developing alternative energy, in which Brazil is a unique example of successfully developing ethanol industry and possessing enormous consumers' support for this industry. Apart from its natural advantages in producing sugarcane-based ethanol, the introduction and commercialization of flex-fuel vehicles since March 2003 also played an indispensable role and changed the Brazil fuels market by granting consumers the capacity of making choice between ethanol and gasoline, all of which eventually exerted influence on the basic market attributes of ethanol: elasticities. Elasticities are of great importance to both policy makers, for the purpose of evaluating tax burden and other government policies; and to the industry, as crucial market indicator and predictor.

The objectives of the paper are to (1) estimate the demand elasticity of ethanol, cross demand elasticity of ethanol to gasoline, supply elasticity of ethanol to sugar, the income elasticity of ethanol and the demand elasticity of ethanol to fleet; (2) estimate the elasticities before and after the introduction of flex-fuel vehicle, and test if there is a significant difference between these 2 periods; and (3) analyze the reasons behind such differences as well as provide policy implications.

This paper is structured in five parts (1) Introduction and Background, (2) Literature Review, (3) Data and Conceptual Framework, (4) Results and Interpretation, and (5) Conclusion, Policy Implications and Future Studies.

1.1 Ethanol as a Fuel

Ethanol, which is also known as alcohol, is a flammable and colorless liquid. The molecular formula is C_2H_5OH. It can be found in alcoholic beverages, and is used widely as a popular alternative fuel. Ethanol has a positive energy balance – that is, the energy content of ethanol is greater than the fossil energy used to produce it – and this balance is constantly improving with new technologies (USDOE 2010). As presented in Table 1, the energy content of ethanol is 23.5 MJ/L, which is lower than Gasohol[1]'s 33.18, Regular Gasoline's 34.8MJ/L, and Diesel's 38.6MJ/L (USDOE 2010). In other words, a driver needs more ethanol in volume to reach the same destination than other fossil fuels. As an alternative to fossil fuels, ethanol is considered to be safer, cleaner, more sustainable and inexpensive[2].

Table 1. Energy densities of some fuels

Fuel Type	**MJ/L**	**MJ/KG**	**Research Octane Number**
Ethanol	24	30[b]	108.6
E85 (85% ethanol, 15% gasoline)	25.65	33.1	100-105
Gasohol (90% gasoline, 10%	33.18	43.54	93/94

[1] Hereinafter, gasohol and gasoline in Brazil are synonyms unless specified.
[2] However, the costs of producing ethanol vary among different feedstock and methods.

ethanol)			
Regular gasoline	34.2	46.4	91
Diesel	37.3	48	25

a. Data source: the U.S. Department of Energy

b. Calculated from heats of formation. Does not correspond exactly to the figure for MJ/L divided by density.

Traditionally, ethanol is derived from feedstock containing natural sugar or starch that can be readily converted to sugar. There are many plants (feedstock) that could be used to produce ethanol worldwide. The United States uses corn as the major crop, due to its high content of starch. The EU grows sugar beet for ethanol production because of its high content of sugar. Brazil relies on sugarcane, and to be more specific, the Sucrose (Sugar) to derive fuel ethanol. Most of the industrial processing of sugarcane in Brazil is done through a very integrated production chain, allowing sugar production, industrial ethanol processing, and electricity generation from byproducts (Goldemberg 2008). The cellulose-rich bagasse (plant fiber) also has the potential for producing cellulosic ethanol; however, in Brazil it is often burnt directly to generate electricity. The generating capacity of bagasse-based power stations in Brazil reached 3.0 GW in 2007 and will grow to 12.2 GW in 2014. In 2008, sugarcane bagasse cogeneration accounted for 3.03 percent of the total Brazilian installed capacity of power. (Frost and Sullivan 2008)

There are two basic types of ethanol: hydrous and anhydrous. The former one contains 95% ethanol and 5% water, and can be used directly as fuel ethanol (E100).

The latter one is often blended with gasoline, for instance, gasoline (E25) sold in Brazil contains 25% of anhydrous ethanol and 75% of pure gasoline[3]. They are both available in most Brazil's gas stations. The US uses Gasohol (max 10% ethanol) and E85 (85% ethanol) ethanol/gasoline mixtures. In Brazil, mandatory blend is E25 since July 2007[4] (UNICA 2009).

1.2 Ethanol Production and Consumption in Brazil

Brazil is the world's largest producer of sugarcane and the largest exporter of sugar (FAO 2013). Brazil's ethanol production in 2010 (31 billion liters) (1 liter = 0.26 gallons) was equivalent to 38 percent of worldwide ethanol production, second only to the United States (49 billion liters), the world's leading producer since 2006 (EIA 2010b). Sugarcane serves as the exclusive source of feedstock for bioethanol production in Brazil, with more than 50% of Brazil's sugarcane production converted into fuel for automobile use (Schmitz et al. 2003). Brazil has a Federal District and 26 states, which are divided into five regions (Southwest, South, Center-West, North and Northeast). As presented in Table 2, sugarcane is cultivated in most Brazilian states, but the Southeast and Northeast regions contribute to more than 85% of national production. Sugar/ethanol mills in Brazil typically obtain 70% of their sugarcane from owned or leased farm land and the remaining 30% from independent producers (Crago et al. 2010). Since Brazil has built a competitive

[3] The ethanol blends in gasohol changed over time, for instance, in 2002 it was 24%-25%; in 2003 it was 20%-25%; in 2004-2006 it was 20%; in 2007 it was 23%-25%; in 2008-2009 it was 25%; in 2011-2012 it was 18%-25%. (Rico, 2007)

[4] but was reduced to E18 in April 2011

ethanol production and consumption industry (and keeps detailed record as well), it is relatively easy for us to model the market economically and statistically.

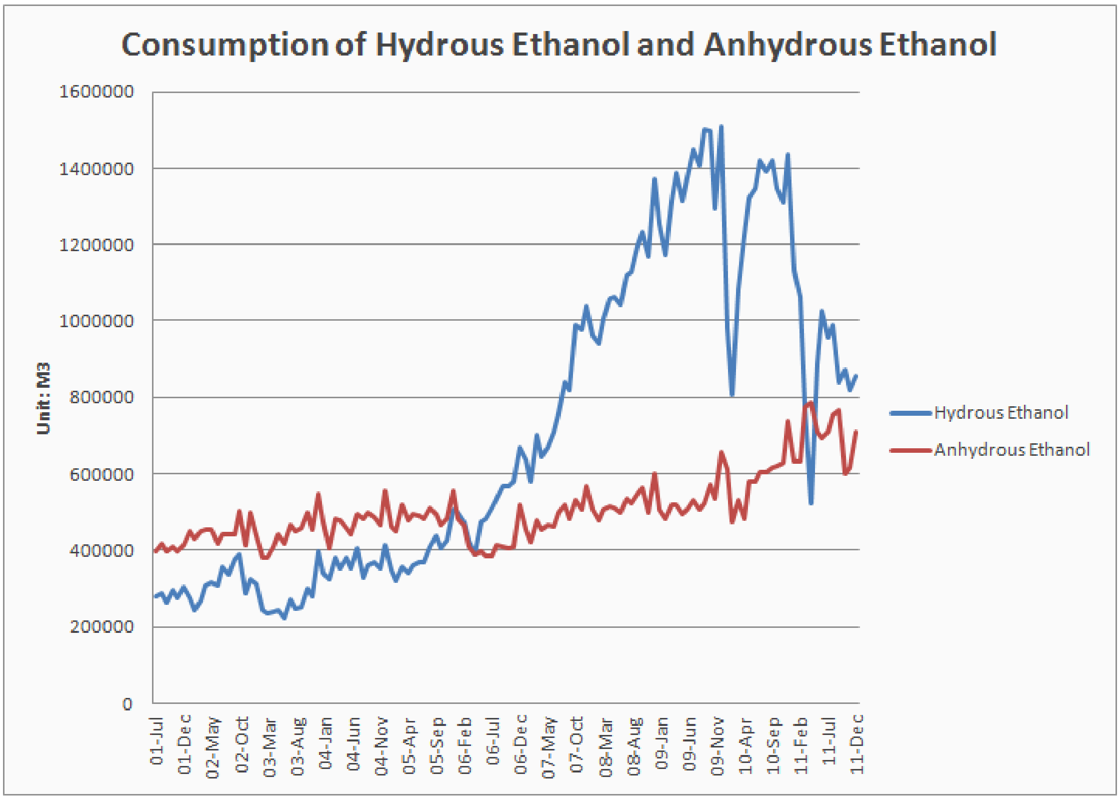
Table 2. Sugarcane area, yield and production in Brazil, by region

Major sugarcane region/States	Area planted to sugarcane				Yields, 2010	Production, 2010
	1990	2000	2010	Average annual growth, 1990-2010		
	Hectares (thousands)			Percent	Tons/ha	1000 tons
Brazil total	4,273	4,805	9,191	3.7%	79.7	729,561
Southeast	2,357	2,979	6,001	4.5%	83.4	500.639
Northeast	1,477	1,061	1,274	-0.5%	56.4	71,867
Center-West	216	373	1,200	8.4%	82.1	98,476
South	207	375	689	5.9%	82.4	56,817
North	16	16	27	3.1%	65.3	1,762

Source: Nassar and Moreira 2013

In 2008, the monthly consumption of fuel ethanol, including anhydrous ethanol for the mandatory E25 blend and hydrous ethanol for direct use, reached 1.432 billion liters, while pure gasoline consumption was only 1.411 billion liters (Agência Brasil, 2008). As shown in Figure 1, in December 2009, the monthly consumption of hydrous ethanol in Brazil reached a record-high of 1.508 billion liters, however, the consumption dropped dramatically to 0.806 billion liters in April 2011, which might be explained by the drop in international oil price. While the consumption of androus ethanol, which is an indicator of gasoline consumption, has been growing steadily and almost doubled in this decade,

Figure 1. Consumption of anhydrous ethanol in Brazil (in M^3), 2001 to 2011



Source:ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis

1.3 Flexible-Fuel Vehicles

As an alternative fuel, ethanol has long been marginalized as a result of its high production cost and low flexibility of vehicles. Brazilian consumers had to make a choice between conventional gasoline vehicle and ethanol vehicles, until the introduction and commercialization of Flexible-fuel Vehicles since 2003. A Flexible-fuel Vehicle (or Flex-fuel Vehicle) is designed to run on more than one fuel. The most common commercially available flex-fuel vehicle worldwide is the ethanol flex-fuel vehicle[5] which can run on either ethanol or gasoline or any blend of them, with 27.1 million automobiles, motorcycles and light trucks sold worldwide through December 2011, which are concentrated in four markets, Brazil (16.3 million), the United States (10 million), Canada (more than 600,000), and Europe, led by Sweden (228,522) (ANFAVEA 2011).

Flexible-fuel technology started being developed by Brazilian engineers near the end of the 1990s. The Brazilian flex-fuel vehicles are built with an ethanol-ready engine and one fuel tank for both fuels, and they are available in a wide range of models such as sedans, pickups, and minivans. Brazilian flex-fuel vehicles are capable of running on sole hydrated ethanol (E100), or just on a blend of gasoline with 20 to 25% anhydrous ethanol (the mandatory blend since 1993), or on any arbitrary combination of both fuels[6] (Goettemoeller and Goettemoeller 2007).

Flex-fuel vehicles were officially introduced to Brazil in March 2003. Although in the year of 2003, only roughly 50,000 flex-fuel light vehicles were manufactured nation-wide, which only accounted for 2.9% of the total light vehicles manufactured; in the year of 2011, 2,550,875 flex-fuel light vehicles were manufactured which accounted for 80.9% of the total light vehicles produced (ANFAVEA 2012), as presented in Table 3. As Figure 1 indicates, flex-fuel vehicle is the only type of vehicle that experienced a huge growth since 2003. By December 2009 they represented 39% of Brazil's registered Otto cycle light motor vehicle fleet (UNICA

[5] flex-fuel vehicle refers to ethanol-gasoline flex-fuel vehicle hereinafter, unless specified.
[6] In other words, flex-fuel engines cannot take pure gasoline.

2010). The three largest flex-fuel vehicles producers in 2010 are (1) Volkswagen (609,503), (2) Fiat (609,142), and (3) General Motors (561,871) (ANFAVEA 2010). In 2009 it is estimated that 35% of the total fleet of light vehicles had flex-fuel engines. At this pace, flex-fuel vehicles will be 78% of the total fleet of light vehicles in 2020 (Abranches 2010). They are also popular in the U.S. According to the U.S. Energy Information Administration, there are more than 8 million FFVs on U.S. roads today. However, many flex-fuel vehicle owners don't realize their car is an FFV and that they have a choice of fuels due to the identical exteriors as conventional vehicles (USDE 2013).

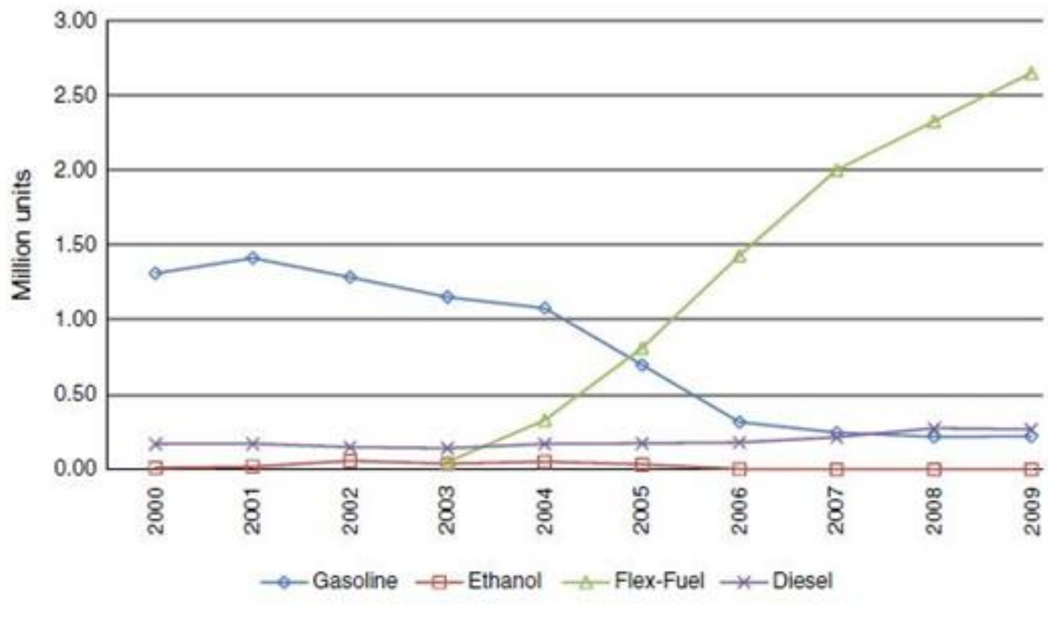
Flex-fuel vehicles have been proven to be successful in Brazil in the last decade. Before 2003, Brazilian drivers had to choose between traditional gasoline and ethanol vehicles, which were powered solely on one fuel. As a consequence, they were vulnerable to the fluctuations of fuel prices. The introduction and commercialization of flex-fuel vehicles offer consumers options depending on their market prices and combustion performance. Due to the gap in combustion performance, hydrated ethanol (E100) prices must remain lower to gasoline prices in order to be competitive. Technical estimations show that only when ethanol price is equal or lower than 70% of the gas price, it can be considered a better economic choice.

Table 3. Ethanol flex light vehicles manufacturing in Brazil, 2003-2011

Year	Flex autos produced	Flex light trucks produced	Total flex-fuel light vehicles produced	Flex vehicles as % total light vehicles produced
2003	39,853	9,411	49,264	2.9
2004	282,706	49,801	332,507	15.2
2005	776,164	81,735	857,899	36.1
2006	1,249,062	142,574	1,391,636	56.3
2007	1,719,745	217,186	1,936,931	69.1
2008	1,984,941	258,707	2,243,648	74.7
2009	2,241,820	299,333	2,541,153	84.0
2010	2,256,158	370,953	2,627,111	77.1
2011	2,165,534	385,341	2,550,875	80.9
2003-2011	12,715,983	1,815,041	14,531,024	60.2

Source: ANFAVEA yearly book 2012

Figure 2. Registration of new cars by fuel in Brazil, 1980-2009



Source: Anfavea (2010).

1.4 History of Fuel Ethanol in Brazil[7]

Brazil has a tradition of producing and consuming fuel ethanol. The first use of sugarcane ethanol as a fuel in Brazil dates back to the late twenties and early 1930s. Due to the lack of foreign oil, the mandatory blend became as high as 50% in 1943. After the end of the war cheap oil caused gasoline to prevail. Gasoline shortages and awareness of the dangers of oil dependence in the 1970s emerged in Brazil partially because of the first oil crisis in 1973.

As a result of the first oil crisis, the average price of crude oil increased from $2.91 per barrel in September 1973 to $12.45 per barrel in March 1975. Meanwhile the international sugar price is low. The National Alcohol Program -Pró-Álcool- (Portuguese: 'Programa Nacional do Álcool'), launched in 1975, aimed to develop its own ethanol industry and to compete with fossil fuels. Government helped construct distilleries adjacent to existing sugarcane mills, enabling managers to switch between sugar and ethanol as market price fluctuated. An initial target to blend anhydrous ethanol to gasoline was made up to 22.4% (by volume). In the beginning of the Program, ethanol production costs were close to $100 per barrel, falling to $50 per barrel 10 years later due to economies of scale and technological progress.

During the second oil crisis, the average price of crude oil increased from $15.85 per barrel in April 1979 to $39.50 per barrel over the next 12 months. Government

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[7] Also available in Appendix I

negotiated with car manufacturers to develop 100% alcohol fueled vehicles. A variety of incentives were designed to entice agricultural producers, distillers, car manufacturers, distributors, and others to adjust their operations and help meet the anticipated demand increase. Anhydrous and hydrated alcohol production levels increased from 500 million liters per year in the late 1970s to 15 billion liters per year in 1987. 92% new car sales between 1983 and 1988 were alcohol fueled.

Oil prices declined dramatically in the mid-1980s fell to below $10 per barrel in 1986; Government decreased the subsidies, thus decreased the production. Economic priority shifted to combating inflation, the currency was overvalued, which damaged ethanol's competitiveness. Brazil started importing ethanol due to the spread of alcohol fueled cars and insufficient domestic production; so Ethanol production stopped increasing in 1986. Major supply crisis in 1989 reduced the share of ethanol fueled cars to 1.02% only of new cars sold in the market by 1989.

International sugar prices were quite high in the 1990s, while oil price was low, generally under $25 per barrel. Price liberalization, deregulation and no direct subsidies were implemented since late 1990s. After 1999, market forces were the main drivers rather than public policies. The absence of a steady supply of hydrous ethanol weakened consumers' confidence in the Program;

Oil price rose above $30 in 2003 and reached $60 on August 11, 2005, and peaked at $147.30 in July 2008. There have been raising concerns of global warming, GHG emission and air pollution. World financial crisis occurred in 2008. Flexible-fuel vehicles were introduced to Brazil in March 2003, on which the government taxed a lower rate than regular cars. Within 18 months from March 2003, flex-fuel vehicles accounted for 73% of new car sales. In 2007, flex-fuel cars were already responsible for almost 80% of new car sales in the Brazilian market.

2. Literature Review

As any other fuel markets, Brazil's ethanol market is complex in many aspects, and calls for a comprehensive review of literatures. In this chapter, relevant literatures were categorized into 8 sections: (1) Taxes and Subsidies, (2) flex-fuel vehicles, (3) Theoretical Framework, (4) Consumer Behavior, (5) Elasticities in Empirical Research, (6) Environmental Impact, (7) Cost of Ethanol Production and (8) Social Welfare and Job Creation.

2.1 Taxes and Subsidies

Brazil's gasoline taxes are high, around 54%, while fuel ethanol taxes are lower and vary among states between 12% and 30%. As presented in Table 4, São Paulo has the lowest tax on fuel ethanol which is 12%, and Pará has the highest which is 30% (Eloy 2010). Compared with that, the average gasoline tax in the U.S. is 48.8 U.S. cents per gallon (as of January 2013), which is roughly 15% (API 2013).

Brazil's ethanol industry had been subsidizing for almost two decades (1979-1999) before it could independently develop, especially in 1970s and 1980s, ethanol production was heavily subsidized. Direct subsidies were given for the investment in mills and sugarcane plantation, through official credit at subsidized interest rates. In addition, price supports were given to producers in order to secure a fix return on investment, in which ethanol price was fixed at 60% of gasoline price. Property tax cuts to ethanol cars were also very significant (De Almeida et al. 2007).

It is intricate for economists to estimate total amount of subsidies that Brazilian authorities have invested on ethanol industry. Goldemberg (2007) estimated that the overall subsidies are around $30 billion in 20 years. Other authors agreed that the cost of the Pró-Álcool program to the Brazilian government was about $4 billion (BNDES 2008). Moreover, the consulting firm DATAGO estimated that subsidies through loans and price support totaled approximately $ 16 billon (in 2005 dollars) from 1979 to the mid 1990s, when this type of direct subsidy was totally terminated (Bear Stearns 2006).

Although official government subsidies were terminated in 1999, according to Schmitz et al. (2003), Brazil's fuel policy provided a hidden subsidy to Brazilian sugarcane farmers, which eventually influenced the ethanol price. They suggested that changes in the ethanol program, in the direction of increasing blend ratios, transferred more than 100 million U.S. dollars annually in the form of hidden subsidies.

Calvalcanti et al. (2011) analyzed the taxation of liquid fuels used in light vehicles in Brazil and concluded that, even though Brazil’s ethanol is no longer directly subsidized, heavy taxation still contributes to keep ethanol price competitive. Moreover, this revision of fuel tax rates would avoid excessive transfer of income from society to ethanol producers and internalize the external costs resulting from GHG emissions from the consumption of fossil fuels.

Table 4. ICMS value-added tax on fuel ethanol

Region	State	Tax Rate for Fuel Ethanol
North	Pará	30%
	Others	25%
Northeast	Alagoas, Serpipe	27%
	Bahia	19%
	Others	25%
Center-West	Goiás	15%
	Others	25%
Southeast	Espírito Santo	27%
	Rio de Janeiro	24%
	São Paulo	12%
	Others	25%
South	Paraná	18%
	Others	25%

Source: FAZENDA (2008)

2.2 Flex-fuel Vehicles

A recent paper by Freitas and Kaneko (2011b) evaluated the demand for ethanol in Brazil after the introduction of flex-fuel vehicles using a cointegration approach and autoregressive distributed lag bounds tests over the period 2003-2010 (with estimations using unrestricted error correction model (UECM) equations), and concluded that during the last decade, ethanol had strengthened its position as an independent fuel and gasoline's substitute. Moreover, they also proved that the growth of Brazil's flex-fuel vehicles is a major driving factor of long-run ethanol demand.

Another research by Schünemann (2007) identified the introduction of flex-fuel vehicles as an inhibitor of gasoline consumption in Brazil. He estimated the elasticity between gasoline consumption and fleet of flex-fuel vehicles to be -0.012, that is, every 1% increase in the fleet of flex-fuel vehicles will lead to 0.012% decrease in gasoline consumption. Moreover, the income elasticity of demand for gasoline, in his paper, was estimated as 1.749 from Jan 1991 to February 2007, and 0.537 from July 2001 to February 2007, showing (1) the income demand elasticity for gasoline is positive, and (2) a trend of decreasing over time.

The work of Taylor (2006) indicated that despite the fact that the new flex-fuel vehicles were approximately R$ 950 (which is 320 US dollars) more expensive than their single-fuel counterparts, they were still a more economical option in the long term due to the capacity to switch between two fuels. For most of time, ethanol was a cheaper option; however, when gasoline price dropped considerably or pure ethanol was not available in some areas, flex-fuel vehicles drivers' capability of shielding against risks would be helpful.

Kamimura and Sauer (2008) agreed that the introduction of flex-fuel vehicles in 2003 recovered the ethanol producer market (a spectacular recovery of ethanol use during 2003-2007) and brought environmental benefit. However, they suggested that government must pay attention for a potentially hazardous socio-economic situation if such fuel market becomes a totally ‘‘liberal’’ economic environment and call for government regulation.

2.3 Theoretical Framework

De Gorter and Just (2007) developed a framework to evaluate the welfare effects of a biofuel consumer tax and the interaction effects with a price contingent farm subsidy， particularly for the U.S. They basically built a model including corn market and fuel market, analyzing their interaction effects, as well as the Deadweight loss. It could be utilized to evaluate the welfare effects of subsidies for ethanol production (thus, the ProAlcool program in Brazil), in order to get the transfers and deadweight loss of government subsidies. De Gorter and Just analyzed both fuel market and corn market (which is the raw material of ethanol production in this case) simultaneously, which enables us to estimate the effects of tax and subsidies on both markets. In Brazil, there were basically two kinds of ethanol-related fuel sold in gas stations, that is, E100 and E25, from which they were able to estimate the ethanol assumption. The sugarcane market in Brazil’s case was the raw material market. Their model was based on perfect competitive market. In Brazil it was basically also the case because there werenumberless refineries and gas stations, and the industry had never been monopolistic or nationalized.

Boff (2011) modeled the Brazilian ethanol market in the long term, especially focusing on the role of price rates ethanol/sugar and ethanol/gasoline. He carried a cointegration analysis to describe the price behavior in the retail market of São Paulo and Rio de Janeiro, and concluded that after the introduction of flex-fuel vehicles in 2003, the estimated price transmission elasticity of ethanol with respect to gasoline (and sugar) increased over time, which demonstrates that the introduction of flex-fuel vehicles (1) enabled customers to switch between ethanol and gas, and (2) made ethanol price more vulnerable to fluctuation of international sugar price. Moreover, the current ethanol price adjusted to meet the long run equilibrium level within a cycle period of about one year. Boff estimated the elasticity by running a logarithm regression based on empirical data.

Freitas and Kaneko (2011a) analyzed the characteristics of ethanol demand at the regional level. They divided Brazil into two regions: developed center-south and developing north-northeast regions. A panel cointegration analysis with monthly observations from Jan 2003 to Apr 2010 was employed to estimate the long-run demand elasticity, carried out using a log-log regression model to conveniently and naturally estimate the elasticities. Their results showed that the demand for ethanol differs between regions. In the developed center-south, the price elasticity for both ethanol and alternative fuels was high; in the north-northeast region, consumption was more sensitive to the change of flex-fuel vehicles and income. In other words, the pattern of ethanol demand in the center-south region closely resembled that in developed countries, while the pattern of ethanol demand in the north-northeast region closely resembled that in developing countries. Another Freitas and Kaneko (2011b) paper used an Unrestricted Error Correction Model (UECM) which is a combination of cointegration approach and error correction models to estimate the influence of some factors on the demand for ethanol in Brazil market. This approach followed a dynamic specification including lags of the dependent variables, lagged and contemporaneous values of the independent variables as explanatory factors. Breusch–Godfrey LM test was carried out to check the serial correlation in the residuals. They only estimated the elasticities after flex-fuel vehicles was introduced to the Brazilian market, and their results suggested that the demand elasticity of ethanol is -1.413, the cross demand elasticity of ethanol to gasoline was 0.948, and the income elasticity of ethanol was not significant.

Figueira et al. (2012) provided two highly accurate and efficient consumption forecasting tools based on time series analysis. Box–Jenkins forecasting methods were used to forecast Brazilian hydrated ethanol fuel consumption series, and transfer functions were used to forecast the anhydrous ethanol consumption. The data was converted into average quarter series to improve the identification and adjustment of the ARIMA model, since monthly oscillation of the series could be reduced. Box–Jenkins univariate model could incorporate both moving average and autoregressive approaches. As seasonal ARIMA, an extra seasonal component was compared with nonseasonal time series models. Stage 2 involved estimating model parameters; stage 3 was for diagnostic checks for model adequacy. Transfer function model was similar to Box–Jenkins univariate procedure except that exogenous variable is included and the evaluation of cross correlation between exogenous and dependent variables must be considered through the stages of model selection. The results showed that if the country's GDP sustains a 4.6% yearly growth rate, domestic consumption of fuel ethanol would increase to 25.16 billion liters through this period, which was close to the forecasted gasoline consumption of 31 billion liters. At a lower GDP growth of 1.22% a year, gasoline consumption would be reduced and domestic ethanol consumption in Brazil would be no higher than 18.32 billion liters.

In order to estimate the impact of flex-fuel vehicles on demand for ethanol, Salvo and Huse (2011) provided a stylized model of the vertical sugarcane/sugar/ethanol industry which predicted the equilibrium price of ethanol should increasingly move with the price of gasoline with two assumptions: (1) sugar/ethanol industry exerted market power in domestic markets but much less so on the world market; and (2) price of gasoline was (largely) exogenous to the sugar/ethanol industry. Moreover, they statistically examined the relationship between ethanol and gasoline prices by using a Vector Autoregressions (VARs) that control world prices of sugar and oil.

Bromiley et al. (2008) evaluated the factors that influence the E85 sales in Minnesota, U.S. using a multivariate random effects least squares regression model. The dependent variable was E85 volume sales, and independent variables included: (1) E85 price, (2) gasoline price, (3) percent difference, (4) interaction of E85 and gasoline price, (5) E85 price sign, (6) station age, (7) number of stations, (8) flex-fuel vehicles, (9) square of flex-fuel vehicles, (10) green (2002 green party governor votes in station’s county), (11) transportation (transportation funding votes in station’s county), (12) corn production, (13) ethanol in county, (14) ethanol in adjacent county, (15) twin cities, (16) population, (17) income, (18) education. Several variables such as E85 price and gasoline price were proved to be significantly correlated to ethanol sales, and several were not.

Kim et al. (2007) analyzed consumer preferences for alternative fuel vehicles based on preference data in the state level in South Korean. A mixed logit model using the Bayesian approach was carried out for estimation, including 5 fuel type vehicles: (1) gasoline vehicles, (2) diesel vehicles, (3) hybrid vehicles, (4) hybrid electric vehicles, and (5) electric vehicles. Results suggested heterogeneity for the preferences regarding fuel type and body, and homogeneity for preferences for cost and horsepower. Elasticity results showed that fuel and maintenance costs were the most important factors influencing preference among alternative fuel vehicles. In other words, as long as fuel and maintenance costs were reduced, people were willing to purchase more alternative fuel vehicles.

2.4 Consumer Behavior

Previous studies have pointed out that cost is the main factor determining the consumer choice for environmentally friendly solutions in transportation (Kim et al., 2007; The Royal Society, 2008). According to Pacini and Silveira (2010), Bioethanol had been generally the most cost-efficient fuel in Brazil; however, it was not the case for all states. Brazilian consumers had opted for fuel ethanol even when it was not the economically optimal choice. Moreover, the comparison of the Brazilian and Swedish fuel markets revealed that consumer behavior differed among established

(Brazil) and new (Sweden) markets for ethanol. Possible reasons include: (1) Brazil has a long and lasting tradition of producing and consuming ethanol; (2) Swedish gasoline prices reacted faster to international oil price, while in Brazil gasoline price was controlled by the state oil company Petrobras who delayed price adjustments to the market; and (3) Brazil government granted ethanol consumers more incentives compared to Sweden.

Research by Freitas and Kaneko (2011a) indicated that the consumption of ethanol demonstrated similar patterns between two Brazilian regions: the developing north-northeast and developed center-south. In other words, the difference in the level of development between the north-northeast and center-south did not lead to gap in the pattern of ethanol consumption. However, there were still some differences across regions. The coefficients for ethanol demand in the center-south region was consistent with those observed in developed countries (higher price elasticities), and the values for north-northeast region was similar to those observed in developing countries (lower price elasticities).

There is also a big market of ethanol and flex-fuel vehicles in the U.S. E85 (85% ethanol, 15% gasoline) was introduced to Minnesota, U.S. in 1997 to provide ethanol blend fuel to flex-fuel vehicle drivers. Bromiley et al. (2008) used multivariate statistical model to estimate the significance of factors that influence the volume of E85 fuel sales to the general public in Minnesota from 1997 to 2006, including the prices of E85 and gasoline, FFV vehicle ownership, population demographics, and other variables. They found that those factors are contributing to an increasing E85 volume sales: (1) Decreasing E85 price and increasing regular gasoline price, or the price difference therein; (2) Number of local stations; (3) Selling E85 for longer time periods; (4) Selling E85 at a branded station. Moreover, Consumer attitudes towards "green" issues and progressive transportation issues, evaluated by voting patterns, along with income level and education, were proved to have no significance for E85 sales.

However, consumers are not always so "rational" and price is not the only factor influencing their purchasing choice. Salvo and Huse (2013) observed roughly 20% of flex-fuel vehicle drivers choosing gasoline even when gasoline is priced 20% higher than ethanol in energy-adjusted terms ($/mile), and similarly, 20% of them choosing ethanol even when ethanol price is 20% higher than gasoline. Their results suggested that there was heterogeneity among consumers. Some people were willing to pay for the "greenness". For example, an environmentally concerned Rio De Janeiro consumer facing an ethanol price of 0.34R$/km had 50% probability of choosing ethanol compared with a non-environment-invoking Rio consumer facing a lower ethanol price of 0.25R$/km. The 0.09R$/km (0.08$/mile) could be interpreted as the "willingness to pay for greenness" for a subset of consumers. Likewise, some consumers had a strong taste for gasoline because it made the vehicle more powerful. With transaction-level data, they investigated the characteristics of these two fuels that differentiated them in different groups of consumers, and concluded that (1) education level was not a significant determinant; (2) an established habit was significant; (3) concern with the engine. Their results seemed counterfactual, since we assume that consumers will always choose the most economic option. As policy implications, they suggested that other than tax reduction and subsidies, policy makers who want to promote fuel ethanol must also make non-price characteristics into consideration. For example, TV commercials which promoted ethanol as the "green" fuel, the "home" fuel and the "boosts your vehicle's power" fuel, would address these benefits of ethanol to regular consumers. And such advertisement was adopted by UNICA, a Brazilian sugar industry trade association in late 2012.

Fuel ethanol in Brazil (E100) has approximately 34% less energy per unit of volume than gasoline. In average, E100 is considered to deliver 70% of the mileage of gasoline, for the same volume of fuel. However, the cost-benefit of ethanol compared with gasoline is not solely based on the energy content. The opportunity cost of choosing ethanol as the fuel for flex-fuel vehicle drivers is even higher than the gasoline, which some economists explained in the assumption as that consumers did not have perfect perception of the price differential when the relative price approaches (or surpasses) 0.7. In other words, consumers may choose ethanol even when this is not the optimal choice (Pacini and Silveria 2011).

2.5 Elasticities in Empirical Research

With considerable restrictions and uncertainty (for example, the reliability of data, externality and internality, proper modeling), it is difficult to estimate an accurate demand elasticity for fuel ethanol. Using the regional approach, Freitas and Kaneko

(2011b) estimated that in the short run, the elasticity for the price of ethanol was -1.413, and the cross effect of the price of gasohol was 0.948. As shown in Table 5, many other economists have estimated the demand elasticity in Brazil, and their results varied from -0.459 to -1.413; the cross demand elasticity of ethanol to gasoline ranged from -0.364[8] to 1.374, which shows a significant divergence even on the direction of elasticity; the income elasticity ranged from 0.130 to 1.255. Some other economists estimated the demand elasticity of gasoline (E25), ranging from -0.313 to -0.945; the cross demand elasticity of gasoline to ethanol ranged from 0.049 to 0.480; the income elasticity of gasoline ranging from 0.122 to 0.535. Different researches brought out significantly different results, which support the complexity of estimating elasticity.

Table 5. Demand elasticities of ethanol and cross demand elasticities of ethanol to gasohol in Brazil from empirical literature

Reference	**Dependent Variable** [a]	**Period**	**Explanatory variables and elasticity** [b]		
			Ethanol	Gasohol	Income
Freitas & Kaneko (2011b)	*Ethanol*	1.2003-7.2010	-1.413	0.948	
Pontes (2009)	*Ethanol*	7.2001-10.2008	-0.934	1.374	1.255
Azevedo (2007) [c]	*Ethanol*	1.2002-6.2006	-0.459	-0.364	0.137
Azevedo (2007) [d]	*Ethanol*	1.2002-6.2006	-0.857	1.017	0.130
Azevedo (2007) [e]	*Ethanol*	1.2002-6.2006	-1.250	1.251	0.002
Silva et al. (2009)	*Gasohol*	4.2001-12.2006	0.049	-0.945	0.154
Schünemann (2007)	*Gasohol*	7.2001-2.2007		-0.313	0.535

[8] Which is in doubt since it is negative and deviant from others;

Alves and Bueno (2003)	*Gasohol*	1984-1999	0.480	-0.464	0.122

[a] *Refers to fuel consumption*

[b] *Eprice, Gprice and Inc refer to real ethanol price, real gasohol price and real income, respectively. Coefficients refer to long-term elasticities*

[c] *Results for Brazil*

[d] *Results for the southern region*

[e] *Results for the northern region*

[f] *Author provided several combinations of variables. The select results is from the model most similar to that proposed in the present research*

2.6 Environmental Impact

Ethanol produced from sugarcane provides renewable energy, and less carbon intensive than oil. Bioethanol reduces air pollution thanks to its cleaner emissions, and also contributes to mitigate global warming by reducing Green House Gases (GHG) which is a main driving force for the world to develop clean and green fuels. Since pure ethanol (E100) does not contain sulfide or nitrogen, along with other toxic substances and carcinogens, vehicles that driven by it will not pollute the air (Smeets et al. 2006).

There are a lot of literatures supporting the environmental benefit of sugarcane-based ethanol. Studies showed that GHG emission reduction due to one liter of ethanol replacing one liter of gasoline ranged from 19% to 47% per kilometer (well-to-wheels, from biomass production to the vehicle) in the case of corn ethanol, from 35% to 56% in the case of sugar beet and of 92% in the case of sugarcane ethanol, because of its more favorable energy balance (Macedo 1998). U.S. Department of Energy reported that greenhouse gas emissions were reduced approximately 15% when ethanol produced from corn was used (USDE, 2010). De

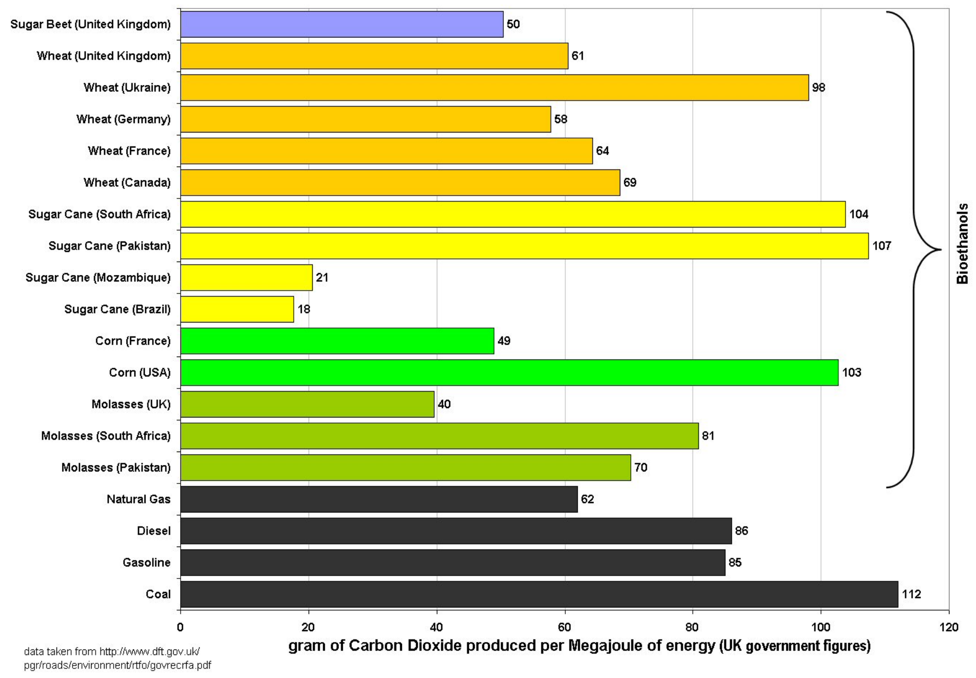
Almeida et al. (2007) claimed that sugarcane ethanol could reduce more than 80% of GHG emissions; in contrast, ethanol derived from other crops could only reach 50% deduction in the best scenario. Crago et al. (2010) estimated the GHG emissions from corn and sugarcane ethanol and concluded that the total emission from corn ethanol is 1173 kg CO_2-eq per M^3, while the emission from sugarcane ethanol was only 550 kg CO_2-eq per M^3, showing a great reduction of GHG emission.

Zhai et al (2009) evaluated differences in fuel consumption and tailpipe emission of flex-fuel vehicles driven by E85 versus gasoline, and concluded that the differences of E85 versus gasoline emission rates were -22% for carbon monoxide (CO), 12% for hydrocarbon (HC) and -8% for nitrogen oxides (NO_X). In other words, switching from gasoline to E85, based on the same energy released, would reduce CO and NO_X emission, but increase HC emissions. However, on a fuel life cycle basis for corn-based ethanol versus gasoline, CO emissions were estimated to decrease by 38%, CO_2 emissions decrease by 25%, HC emissions decrease by 18%, and NO_X emissions decrease by 82%.

A recent study found that the use of sugarcane ethanol in Brazil resulted in a reduction of 600 million tons in CO2 emissions since 1975, an amount equivalent to about 7 percent of Brazil’s total CO2 emissions from the consumption of energy over the same period (UNICA 2010a; EIA 2010a). Moreover, the Environmental Protection Agency (EPA) deemed sugarcane ethanol an advanced biofuel that reduces GHG emissions by 61 percent, compared with gasoline GHG emissions

(EPA 2010). During the production and use of fuel ethanol from cane in Brazil for 2005/2006, the total GHG emission was 436 kg CO^2/M^3, and it will decrease to 436 kg CO^2/M^3 in the 2020 year scenario. For every M^3 of E100 use in Brazil, 2181 kg CO^2 emission was avoided; for every M^3 of E125 use in Brazil, 2323 kg CO^2 emission was avoided. (Macedo 2005). As presented in Figure 2**,** The UK government figures indicated that bioethaol derived from sugarcane in Brazil by far had the lowest gram of carbon dioxide per megajoule, which was only 18 G/MJ compared to 103 G/MJ for bioethanol derived from corn in the U.S. and 50 G/MJ for bioethanol derived from sugar beet in the UK. It was surprising to find that the CO^2 emission of bioethanol derived from corn in the U.S (103 G/MJ), was even higher than that of gasoline (85 G/MJ). It also implied that biofuel is not always the most environmental friendly choice.

Figure 3. Gram of carbon dioxide produced per megajoule of energy



Wills and Rovere (2010) predicted that flex-fuel vehicles would outnumber solely gasoline-powered vehicles, and in 2030 they will make up 91% of the total fleet. As a result, Brazil's consumption of energy of light vehicle fleet will be reduced from 2 to 1.8 million TJ in 2030, and in the most optimistic scenario it will be reduced to 1.4 million TJ. The efficiency of fuel/emission will also be raised from 145.89 g CO_2/km in 2000 to 53.70 g CO_2/km in 2030 in the best scenario.

Smeets et al. (2006) compared the Dutch sustainability criteria and the current Brazilian practice, quantification of the consequences for ethanol production in terms of production method and production costs if these sustainability criteria were applied. Results suggested that despite too many uncertainties of land-use and environmental impact, Brazilian ethanol derived from sugarcane scored from average to (very) positive in many impact categories, demonstrating a decent level of sustainability. However, there were still some problems identified to differ among plants that could be improved using proper measures.

Although the bio-ethanol production in Brazil is generally considered 'green', it also has some social and environmental costs. Araujo (2011) mentioned the state of Alagoas in Brazil, in which only 13.1% of the state's original rainforest had survived the sugarcane ethanol program. As a consequence, heavy rainfall in the region led to severe floods and destroyed thousands of buildings. Smeets et al. (2006) also mentioned that Brazil was intensifying its agricultural production, which could be either accomplished by technology improvement or cultivation more land in native forest area which would be socially and ecologically devastating.

2.7 Cost of Ethanol Production

Ethanol is an inexpensive alternative to fossil fuels. A World Bank report concluded that in 2005, ethanol from sugarcane grown in the center-south region of Brazil was the cheapest biofuel today, with the average production cost ranging from $0.23-0.29 per liter (Exchange rate is fixed to R $2.40 to the US dollar). Biodiesel had higher production costs—at least $0.50 per liter (or $79 per barrel of biodiesel) or, in many cases, higher. (Kojima and Johnson 2005).

In 2010, the average ethanol production in the United States was 3,200l/ha/year, while in Brazil this figure was more than twice higher (6,800 l/ha/year.). This was reflected in production costs: US$ 0.20/l in Brazil against US$ 0.47/l in the United States, who was still strongly subsidizing the production of ethanol with less favorable energy and GHG balances as in comparison to the Brazilian case (Rovere et al. 2011).

Based on the cost data in 2005, which was derived using a method called Life Cycle Assessment and Costing, the gasoline production cost was calculated to be 0.59 $/kg, while the ethanol production costs are ranging from 0.30 $/kg (base case) to 0.26 $/kg (future case). The cost of 1 km driving for all the fuel alternatives in both cases are presented in Table 6, which demonstrates that the cost of 1km driving for ethanol was 25.5% lower than gasoline, and 24.2% lower than E85. (Van der Voet & Huppes, 2009)

Table 6. Cost of 1km driving for all the fuel alternatives Case

Costs	Gasoline	E10	E85	Ethanol	Unit
Base case	0.0393	0.0388	0.0313	0.0294	$/km
Future case	0.0393	0.0385	0.0282	0.0254	$/km

source: Van der Voet & Huppes 2009

The production cost of ethanol in Brazil can be divided into four categories: (1) Operating cost, (2) Feedstock cost, (3) Refinery cost and (4) Transportation cost. Different from most studies, Crago et al. (2010) found that at an exchange rate of US$1=R$2.15, the cost of corn ethanol was 15% lower than the cost of Brazilian ethanol derived from sugarcane (with FOB but without tariffs). However, Sugarcane ethanol had lower GHG emissions than corn ethanol but a price of over $113 per ton of CO2 was needed to affect competitiveness.

To summarize, the costs of ethanol production varied among countries, states and even plants. Most literatures supported that ethanol derived from sugarcane had the lowest production cost, which made it competitive in international and domestic markets. However, it is noticeable that ethanol producers in Brazil had been subsidized or offered low interest loan to keep the ethanol price competitive, compared with gasoline that were heavily taxed by the government, therefore the comparison of costs here was potentially biased.

2.8 Social Welfare and Job Creation

As a labor-intensive and comprehensive industry, ethanol industry is expected by the government to create jobs and generate social welfare. Hofstand (2009) observed that sugarcane production required hand labor at harvest, which created a large group of migrant workers who could only find work a couple of months a year during sugarcane harvest. A skilled harvester could cut 1,000 pounds of sugarcane in an hour. However, there are two problems: (1) those jobs were often seasonal which could not provide workers stable income and welfare package, and (2) machines were replacing traditional human labor such as harvesting cane.

An ethanol refinery plant can be identified as a primary economic target generating jobs and economic benefits to the local community. A report by Urbanchuk (2010) analyzed the social welfare and job creation of ethanol industry, and found that in 2011, the production of 13.9 billion gallons of ethanol supported 90,200 direct jobs and 311,400 indirect jobs all across the U.S. An 85 million gallon per year ethanol biorefinery provided the following economics benefits to the local economy: (1)The goods and services bought and sold as a result of the operation of the ethanol facility add $274 million to the local GDP; (2) The economic activity resulting from the ethanol biorefinery helps create 1,540 new jobs across all sectors including nearly 40 at the biorefinery and more than 1,500 in the agricultural sector; (3) The increase in good paying jobs as a result of the facility boosts local household incomes by $49 million. While according to Ethanol Across America (2006), a typical 40 million gallon ethanol plant in Nebraska would (1) provide a one-time boost of $71 million U.S. dollars to the local economy during construction; (2) expand the local economic base of the community by $70.2 million U.S. dollars each year through the direct spending of $59 million dollars; (3) create at least 35 full-time jobs at the plant and a total of at least 120 jobs throughout the local economy; and (4) increase household income for the community by $6.7 million dollars annually. The 2010 U.S. Ethanol Industry Salary study estimated nearly a half million direct and indirect jobs generated by the ethanol industry nationally (Voegele, 2009).

Goldemberg et al. (2008) stated that in Brazil, the investment needed for job creation in the sugarcane sector was much lower than that in other industrial sectors. The creation of one job in the ethanol agro industry required on average US$ 11,000, while a job in the chemical and petrochemical industry costed 20 times more. In this sense, the ethanol and related industries might be the most efficient job creator which could potentially ease the unemployment problem.

Everything has two sides, so does ethanol industry. Although the sugarcane sector creates many jobs, many of them are related to child labor, unsafe working environment, low wage and benefit and other social issues. However, it was not possible to collect all data necessary for analysis (Smeets et al. 2006). Moreover, the U.S. had developed a mammoth ethanol industry derived from corn and mandate policy[9] to support this industry, which was believed by some to be one of the reasons for sharp price increase of corn between 2006 and 2011. In 2011, about 40% of all corn harvested in the U.S. went into ethanol production, therefore the supply of corn for food use was decreasing which jeopardizes millions of people living in developing countries fed on cheap imported corn from the U.S. (McNeil, 2012)

[9] In 2007 the Renewable Fuel Standard was established, which mandated a steadily increasing percentage of renewable fuel in U.S.

3. Conceptual Framework

3.1 Conceptual Framework

Freitas and Kaneko (2011b) have estimated similar elasticities in Brazil's ethanol market, their methods and results are summarized in Chapter 2.3. Although their methodology is very instructive, it still suffers from some weaknesses that may weaken the credibility of research. I am trying to avoid their weaknesses in my methodology and make more accurate and sound estimates. The comparison between their paper and mine is summarized in Table 7. Their weaknesses and my suggestions include:

(1) They only estimated demand elasticities of ethanol, while supply side also should be included since the market price is the outcome of the equilibrium between these two sides. They are both taken into consideration in my model;

(2) They only estimated the hydrous ethanol market, yet ignored the fact that gasoline sold in Brazil contains 17%-25% of anhydrous ethanol, which makes their estimation incomplete and biased. For flex-fuel vehicle drivers, hydrous ethanol and gasoline are not simple substitute fuels whose cross price elasticity is positive. Furthermore, their prices are positively correlated since they share the same ingredient. In my model, the hydrous and anhydrous ethanol market are estimated along with the supply of total ethanol in a 3-stage least squares simultaneous equations system, which is expected to be more accurate and comprehensive;

(3) In Freitas and Kaneko's model, average family income was chosen as income variable. However, since their dependent variable was total ethanol consumption, the average income could not reflect total income which was determined by both average income and population. While in my model, the income variable is the product of average income and economically active population, in order to generate a dependable total income for my analysis.

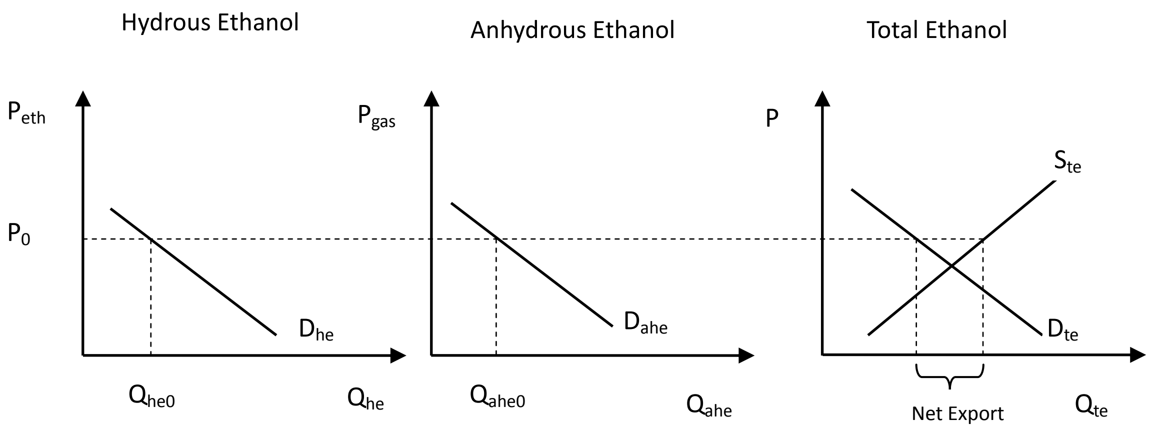
Table 7. Comparison of Freitas and Kaneko (2011b) and my thesis

Researcher(s)	**Freitas and Kaneko (2011b)**	**Yifan He (2013)**
Markets	Demand markets of Ethanol and Gasoline, not including the Anhydrous Ethanol;	Demand markets for Hydrous Ethanol and Anhydrous Ethanol, and Supply Market for Total Ethanol;
Model	Unrestricted Error Correction Model (UECM);	3-stage Least Squares (3SLS) Simultaneous Equations;
Income	Average Income.	Average Income * Economically Active Population.

Note: Comparison is based on Freitas and Kaneko (2011b) and this thesis.

This thesis analyzes the ethanol market from the equilibrium between demand and supply. On the demand side, hydrous and anhydrous ethanol are estimated simultaneously because they are correlated; on the supply side, total ethanol is estimated by including domestic consumption of hydrous ethanol, anhydrous ethanol (in gasoline which contains 17%-25% anhydrous ethanol) and net export (or net import after 2011). Fixing one curve and shifting the other one can help estimate the former one, as visualized in Figure 4.

Figure 4. Equilibrium of demand for hydrous ethanol, anhydrous ethanol and supply of total ethanol



Although taxes and subsidies are discussed in the previous chapter (2.1), they are not included in my model. First of all, taxes and subsidies data are unavailable. The table of ICMS Value-added Tax on Fuel Ethanol lists the tax rates in some states; however, it is far from comprehensive and can only represent the tax rate in 2008. Moreover, the data of tax rates on fuel gasoline is also unavailable. After 1999, the Brazilian authorities no longer directly subsidized the ethanol industry, which makes subsidies not relevant to our model, not mention lacking access to detailed data. Furthermore, since the data of Fleet of flex-fuel vehicles, ethanol-driven vehicles and gasoline vehicles are unavailable, they are not included in my empirical analysis, although their presence could be of great help in analyzing reasons for change in elasticities.

3.2 3-Stage Least Squares Simultaneous Equations

A 3-stage least squares simultaneous equations system is chosen to estimate elasticities based on the fact that in this case, Brazil's hydrous ethanol market and anhydrous ethanol market are highly correlated in a complex way: First of all, hydrous ethanol and gasoline are substitute fuels for flex-fuel vehicles therefore the increase in one's price will lead to the increase in the other's consumption; However, since gasoline sold in Brazil contains a certain amount of anhydrous ethanol, the increase in one's price will lead to the increase in the other's price (as opportunity cost increases), and subsequently causes a decrease in the other's consumption. These two reverse effects take place simultaneously; as a result the coefficients cannot be estimated by simple linear regression or other independently estimating methods. A 3-stage least squares simultaneous equations system is able to analyze both effects simultaneously with instruments which are independent and external to the price and demand/supply of different fuels.

On the demand side of hydrous ethanol, based on literatures such as Fritas and Kaneko (2011b), Salvo and Huse (2011) and Bromiley et al. (2008), several factors are considered to be relevant: (1) Ethanol price; (2) gasoline price; (3) income (4) fleet of total vehicles;

On the demand side of anhydrous ethanol, i.e. the demand for gasoline, several factors are considered to be relevant:

(1) Ethanol price; (2) gasoline price; (3) income (4) fleet of total vehicles;

On the supply side of total ethanol, several factors are considered to be relevant:

(1) Ethanol price; (2) gasoline price (anhydrous ethanol in gasoline); (3) sugar price (as the opportunity cost of producing ethanol); (4) international crude oil price

Among all variables listed above, endogenous variables are (1) consumption of hydrous ethanol, (2) consumption of anhydrous ethanol, (3) hydrous ethanol price, (4) gasoline price and (5) supply of ethanol. They are correlated in error terms.

Some instruments or exogenous variables are selected for estimating the simultaneous equations. They are crucial for an accurate and unbiased estimation. Two main characteristics are required like independence (uncorrelated with error terms) and correlation (correlated with endogenous variables). Some potential instruments that meet these requirements include (1) GDP of Brazil; (2) income; (3) fleet of total vehicles (4) international sugar price; (5) international crude oil price; (6) seasonality; (7) number of days in a month. They are varying independently from the demand and price of ethanol/gasoline, yet having effect on them, which makes them candidates for instruments.

3-Stage Least Squares Simultaneous Equations

In order to estimate the elasticities in two periods within one equations system, a dummy variable D is introduced to my model. It is set as 0 in the first period (07/2001-02/2003) and 1 in the second period (03/2003-12/2011). The coefficient of interactions of dummy variable and independent variables represents the significance and magnitude of change inelasticities between two periods.

The 3-stage least squares simultaneous equations system consists three equations. On the demand side of hydrous ethanol:

$$Q_{hydrous-eth}^{demand} = \beta_{1,0} + \beta_{1,1} * P_{eth} + \beta_{1,2} * P_{gas} + \beta_{1,3} * Income + \beta_{1,4} * Fleet_{TV} +$$

$$\beta_{1,5} * D * P_{eth} + \beta_{1,6} * D * P_{gas} + \beta_{1,7} * \mathrm{D} * Income + \beta_{1,8} * D * Fleet_{TV} + \epsilon_{1,0} \qquad (1)$$

On the demand side of anhydrous ethanol:

$$Q_{anhydrous-eth}^{demand} = \beta_{2,0} + \beta_{2,1} * P_{eth} + \beta_{2,2} * P_{gas} + \beta_{2,3} * Income + \beta_{2,4} * Fleet_{TV} +$$

$$\beta_{2,5} * D * P_{eth} + \beta_{2,6} * D * P_{gas} + \beta_{2,7} * D * Income + \beta_{2,8} * D * Fleet_{TV} + \epsilon_{2,0} \qquad (2)$$

On the supply side of ethanol:

$$Q_{total-eth}^{supply} = \beta_{3,0} + \beta_{3,1} * P_{eth} + \beta_{3,2} * P_{gas} + \beta_{3,3} * P_{sugar} + \beta_{3,4} * P_{oil}^{Int} + \beta_{3,5} * D * P_{eth} +$$

$$\beta_{3,6} * D * P_{gas} + \epsilon_{3,0} \qquad (3)$$

(in which $Q_{total-eth}^{supply} = Q_{hydrous-eth}^{demand} + Q_{anhydrous-eth}^{demand} + Netexport$)

Endogenous Variables: $Q_{total-eth}^{supply}, Q_{hydrous-eth}^{demand}, Q_{anhydrous-eth}^{demand}, P_{eth}, P_{gas}$

Exogenous Variables:

$Fleet_{TV}, P_{sugar}, P_{oil}^{Int}, month, number\ of\ days\ in\ the\ month$[10]

Since all variables are already in logarithms, the coefficients could be directly interpreted as elasticities. For example, $\beta_{1,1}$ is the demand elasticity of hydrous ethanol in the first period, and $\beta_{1,1} + \beta_{1,5}$ is the demand elasticity of hydrous ethanol in the second period. If $\beta_{1,5}$ is statistically significant, the change in elasticity between two periods is supported.

[10] The last two variables are additional exogenous that are included in none of the system equations, yet involved in the estimating process. For more information, check the Stata manual http://www.stata.com/help.cgi?reg3

3.3 Data Source

All the data used in this thesis are listed in Table 7, with description and source. All price data have been adjusted based on inflation. In order to estimate elasticities, price and quantity data would be transformed to logarithmic form in the next section.

Table 8. Data Description and Source

Variable	Description	Source	Descriptive Statistics
$Q_{hydrous}^{demand}$	Monthly Consumption of hydrous ethanol, in cubic meter	ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis	Min: 160259.193 Max: 1164383.199 Mean: 529002.7788
$Q_{anhydrous}^{demand}$	Monthly Consumption of anhydrous ethanol, in cubic meter		Min: 257082.4555 Max: 609915.0092 Mean: 379782.7928
P_{eth}	Price of Ethanol(Hydrous, 95% ethanol), in 2011 Brazilian R$/ cubic meter		Min: 1649.847096 Max: 2948.497392 Mean: 2093.80831
P_{gas}	Price of Gasoline(18-25% ethanol), in 2011 price R$/ cubic meter		Min: 2750 Max: 3933.688438 Mean: 3380.266831
$P_{oil}^{International}$	International Crude Oil Price, in 2011 price US $/Barrel	World Bank Global Economic Monitor (GEM) Commodities	Min: 18.60473684 Max: 133.8730435 Mean: 61.51123013
P_{sugar}	International Price of Sugar, in 2011 price R$/ton		Min: 557.5125559 Max: 1302.486806 Mean: 856.3972865
Income	Monthly income per capital in Brazil, 2011 price, R$/month	IBGE (The Brazilian Institute of Geography and Statistics), 2012.	Min: 1392.442985 Max: 1793.503717 Mean: 1570.949386

		Monthly employment survey	
$Fleet_{TV}$	Fleet of Total Vehicles	Denatran (National Transit Department)	Min: 30408573.83 Max: 70543535 Mean: 47127748.85
Month	11 dummy variables representing January to December		

Note: Monthly data from 07/2001 to 12/2011;
126 observations in total.

3.4 Hypotheses

This section formulates the hypotheses: (1) the absolute value of demand elasticity of hydrous ethanol increased after the introduction of flex-fuel vehicles; (2) the significance of cross demand elasticity for hydrous ethanol to gasoline increased after the introduction of flex-fuel vehicles; (3) the cross supply elasticity for hydrous ethanol to sugar is negative; (4) the income elasticity of ethanol is not statistically significant; and (5) the fleet of total vehicles has a positive effect on the demand for hydrous ethanol, and this effect is intensified after 2003. Justifications of these hypotheses are given in the following sections;

(1) H1: Demand elasticity of hydrous ethanol is negative, and increases significantly in absolute value after the introduction of flex-fuel vehicles.

$$\beta_{1,1} < 0; \;\; \beta_{1,1} + \beta_{1,5} < 0; \;\; \beta_{1,5} < 0$$

Before March 2003, ethanol-driven vehicles were popular in Brazil. Drivers then did not have options when ethanol price was fluctuating. As a consequence, demand for hydrous ethanol is expected to be inelastic. After the introduction of flex-fuel vehicles, drivers are able to switch between ethanol and gasoline, depending on their market prices and energy densities, which generates an unfixed demand for ethanol. In other words, the introduction of flex-fuel vehicles made the hydrous ethanol more elastic.

(2) H2: Cross demand elasticity for hydrous ethanol to gasoline was positive, and was not significant before the introduction of flex-fuel vehicles, but significant after that.

$$\beta_{1,2} > 0;\ \beta_{1,2} + \beta_{1,6} > 0;\ \rho_{\epsilon}^{a} < 0.95, \rho_{\epsilon}^{b} > 0.95$$ [11]

H2 (a): If both elasticities are statistically significant, the elasticity after March 2003 is assumed to be larger in absolute value.

$$\beta_{1,2} > 0;\ \beta_{1,2} + \beta_{1,6} > 0;\ \beta_{1,6} > 0$$

Before the introduction of flex-fuel vehicles, Brazilian drivers were not able to switch between ethanol and gasoline, unless owning both types of vehicles. Therefore, the cross demand elasticity for hydrous ethanol to gasoline was assumed not to exist. In such case, the cross demand elasticity existed even before March 2003. Flex-fuel vehicles enable drivers to make choice between two types of fuels and generate the cross demand elasticity. Even if the cross demand elasticity existed

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[11] ρ_{ϵ}^{a} is the significance of cross demand elasticity of for ethanol to gasoline in the first period (July 2001 – February 2003), ρ_{ϵ}^{b} is the significance of cross demand elasticity of for ethanol to gasoline in the second period (March 2003 – December 2011).

before March 2003[12], it would increase in absolute value after that due to consumers' enhanced interchangeability between ethanol and gasoline.

(3) H3: Cross demand supply for hydrous ethanol to sugar is negative.

$$\beta_{3,3} < 0$$

Since sugar and ethanol are both derived from sugarcane (sugar is an intermediate product of ethanol), sugar price can be regarded as the opportunity cost of producing ethanol. When sugar price increases, it is more profitable to produce sugar rather than ethanol from sugarcane, which will reduce the supply of ethanol. Hence the cross supply elasticity for hydrous ethanol to sugar is assumed to be negative.

(4) H4: Income elasticity of demand for hydrous ethanol is not statistically significant.

$$\rho_{\epsilon} < 0.95$$

Since ethanol is not a Giffen good whose demand decreases with growing income, it is expected to have a positive income elasticity of demand, which means the demand increases along with growing income. However, since many economists have observed statistically insignificant coefficients (Freitas & Kaneko, 2011b; Azevedo, 2007; Silva et al., 2009), it is realistic to assume that income elasticity estimated in

[12] Possible reasons include (1) owner of both gasoline and ethanol vehicles; (2) government control.

this paper is also not significant[13].

(4) H5: the fleet of total vehicles has positive effect on the demand for hydrous ethanol, and the effect increased after March 2003.

$$\beta_{1,4} > 0;\ \beta_{1,4} + \beta_{1,8} > 0;\ \beta_{1,8} > 0$$

First of all, it is logical to speculate that the relationship between fleet of total vehicles and demand for ethanol is positive. This positive relationship has been confirmed by some economists like Freitas and Kaneko (2011b). Second, the wide commercialization of flex-fuel vehicles allows more drivers to consume hydrous ethanol, and this change in fleet structure would have influence on the demand elasticity of hydrous ethanol to fleet. I am assuming that the effect increased after March 2003, which means that the growth in fleet now leads to more growth in the demand for hydrous ethanol. However, this effect requires statistical analysis to support.

[13] Yet in this paper, income is evaluated by total income (product of average income and population) rather than average family income used by Freitas & Kaneko (2011), which might be different and not necessarily generating the same results.

4. Results and Interpretations

In this section, Stata 10.1 is utilized to execute all statistical analyses. Raw results from statistical regressions are summarized into Table 9-11 and interpreted later in Chapter 4.3.

4.1 OLS of Q-hydrous ethanol to endogenous variables

First of all, a simple OLS regression was executed between the demand for hydrous ethanol and the endogenous variables (instruments) to check the correlation between them. The results demonstrated in Table 9 can initially prove that the coefficients of sugar price and fleet of total vehicles are significant, while others are not that significant (p value ranging from 0.116 to 0.172), but it is still worthy keeping them in the model.

Table 9. Coefficients of some instruments from OLS, hydrous ethanol consumption as the dependent variable

Variable	Comment	Coefficient	p value
logincome	Logarithmic price of Brazil's domestic hydrous ethanol, in R$/L	-1.891604	0.116[a]
logpsugar	Logarithmic price of international sugar, in 2011 Real $	-.2057929	0.068[b]
logpoil	Logarithmic price of International crude oil, in 2011 Real $;	-.1770626	0.172[a]
logpethus	logarithm price of U.S. ethanol, in 2011 Real $;	-.1871484	0.159[a]

logtv	Logarithmic fleet of total vehicles in Brazil	.7009971	0.000[c]

a: statistically insignificant;

b: statistically significant at 90% significance level;

c: statistically significant at 99% significance level;

Note: 126 observations.

4.2 Results of 3-stage Least Squares Simultaneous Equations

As Table 10 shows, given that the coefficients of *D*Peth*, *D*Pgas* and *D*Fleet* are statistically significant at 95%, we can assert that the demand elasticity of hydrous ethanol, cross demand elasticity of hydrous ethanol to gasoline and cross demand elasticity of hydrous ethanol to fleet changed significantly between Period 1 and Period 2. However, income elasticity of hydrous ethanol is very small and not statistically significant, which is consistent with my hypothesis. The only result inconsistent with my hypothesis is the statistically insignificant supply elasticity of hydrous ethanol to sugar.

Table 10. Coefficients from 3-stage least squares regression，hydrous ethanol consumption as the dependent variable

Variable	Coefficient	P-value	Variable	Coefficient	P-value
Peth	-0.9286	0.000[c]	*D*Peth*	-0.7462	0.015[b]
Pgas	0.8764	0.001[c]	*D*Pgas*	0.5964	0.023[b]
$Fleet_{tv}$	1.9321	0.003[c]	*D*Fleet*	1.5733	0.006[c]
Income	0.1853	0.375[a]			
Psugar[d]	0.0484	0.855[a]			

a: Statistically insignificant

b: Statistically significant at 95% level

c: Statistically significant at 99% level

d: the dependent variable here is the supply of ethanol, and the elasticity is supply elasticity of ethanol to sugar

Note: R^2=0.8698;

126 observations.

Test for Overidentification

Hansen-Sargan Overidentification Test (or Sargan Test) is used to check overidentification of instruments. The Sargan Test is based on the observation that the residuals should be uncorrelated with the set of exogenous variables if the instruments are truly exogenous. The null hypothesis is that error term is uncorrelated with the instruments. In this model, the p-value of test statistic is 0.2622, showing that we cannot reject the null hypothesis. In other words, the model does not suffer from severe overidentification problem.

4.3 Summary and Interpretation:

Raw results are summarized into Table 11, and based on which interpretations and further analysis are given in the next section.

Table 11. Elasticities estimated by 3-stage least squares regression，hydrous ethanol consumption as the dependent variable

Elasticity	Period 1 (07/2001-02/2003)	Period 2 (03/2003-12/2011)
Demand elasticity of hydrous ethanol	-0.9286[a]	-1.6748[b]
Cross demand elasticity of hydrous ethanol to	0.8764[a]	1.4728[b]

gasoline		
Cross Demand elasticity of hydrous ethanol to fleet of total vehicles	1.9321[a]	3.5054[a]
Income elasticity of hydrous ethanol	Statistically insignificant	
Cross supply elasticity of hydrous ethanol to sugar		

a: Statistically significant at 99%.
b: Statistically significantly at 95%;
c: Elasticities in Period 2 are calculated by adding two coefficients together, if both of them are statistically significant.
Note: 126 observations.

Interpretation of Results

(1) The demand elasticity of ethanol changed from -0.9286 before March 2003 to -1.6748 aftewards, which might be (or partially) caused by the massive use of flex-fuel vehicles. Since flex-fuel vehicle drivers are now able to choose between ethanol and gasoline depending on their prices and energy densities, the absolute value of demand elasticity of fuel ethanol is assumed to increase. In other words, before March 2003, ethanol-driven vehicles could only consume ethanol even if ethanol price was high (relatively inelastic); while they now can switch to gasoline in the same situation (relatively elastic). The result is consistent with my hypothesis H1, which expects a negative and increasing (in absolute value) elasticity. It is also not deviant from the results in empirical researches (-0.459 to -1.413). [14]

(2) The cross demand elasticity of ethanol to gasoline changed from 0.8764 before

[14] Which could be found in section 2.5

March 2003 to 1.4298 afterwards, which could also be explained by the effect of flex-fuel vehicles. When flex-fuel vehicles were not on Brazil's market, the substitution between ethanol and gasoline was not well-establish and the cross price elasticity was supposed to be insignificant. However in this case, the significance of cross demand elasticity before March 2003 might be explained by: (1) Some Brazilian consumers owned both ethanol-driven and gasoline-driven vehicles, which enabled them to switch between fuels to cope with price fluctuations; (2) Some researchers have estimated statistically insignificant results as well (such as Alves and De Losso da Silveiria Bueno 2003) before 2003, which they believed that ethanol and gasoline were substitutes then. Since flex-fuel vehicle drivers are able to switch between ethanol and gasoline depending on their prices and energy densities, the gasoline price would have more influence on the demand for ethanol, therefore the cross demand elasticity is assumed to increase. It is consistent with hypothesis H2(a). Compared to the literature (1.012 to 1.374)[12], my estimates are also not deviant.

(3) The income elasticity of hydrous ethanol is not statistically significant in both periods. It does not contradict with my hypothesis H3 that assumes an insignificant relationship between income and demand for ethanol; moreover, it is also consistent with some literatures such as Azevedo (2007) and Silva et al. (2009). Freitas & Kaneko (2011b) for example, reported that income plays a relatively lesser role as an explanatory factor for ethanol demand, in which the income elasticity is close to zero. A potential reason behind the insignificance of income elasticity is that: since

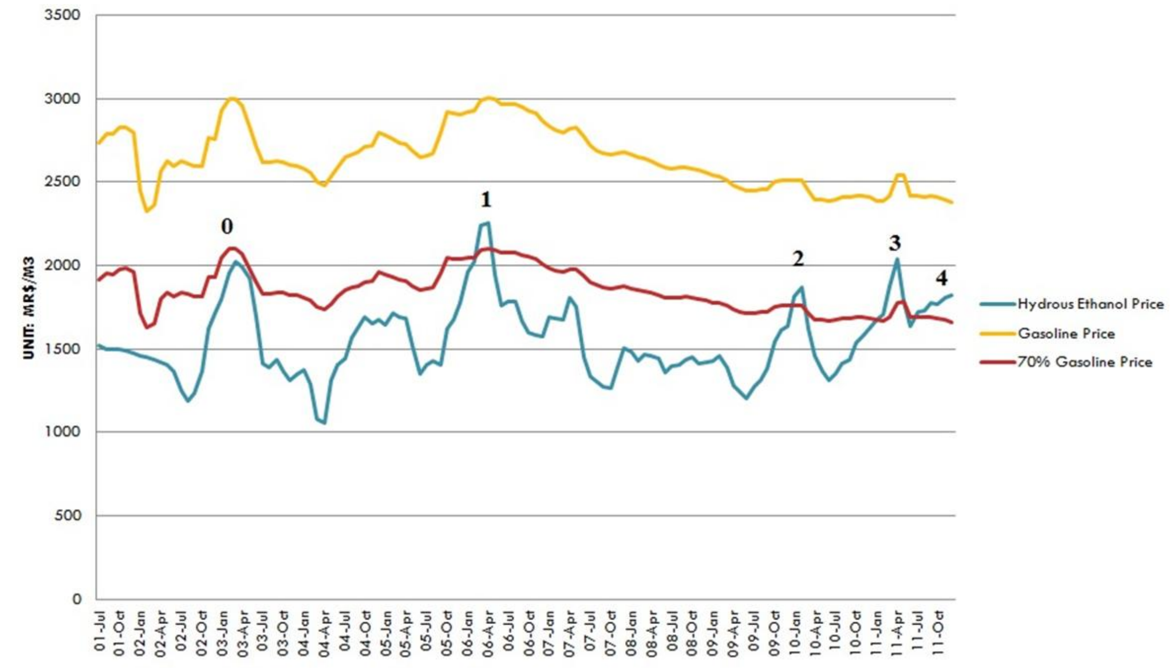
ethanol is a relatively cheap alternative for gasoline, it may show some characteristics of a Giffen Good: While income is decreasing, people consume less fuel with higher proportion of hydrous ethanol; while income is increasing, people consume more fuel with lower proportion of hydrous ethanol. However, this theory requires more evidence and research to prove.

(4) Before March 2003, the cross demand elasticity of ethanol to the fleet of total vehicles was 1.9321, which means every 1% increase in total fleet would lead to 1.9321% increase in the consumption of hydrous ethanol (possibly indicating that ethanol-driven vehicles have a higher utilization rate). While after March 2003, the cross demand elasticity of ethanol to the fleet of total vehicles is 3.5054, which means every 1% increase in total fleet leads to 3.5054% increase in the consumption of hydrous ethanol. The change of fleet structure might be the reason for that change. Research by Freitas and Kaneko (2011b) indicates that in the long run, each 1% growth in the fleet results in a 4.4% increase in ethanol demand, which is similar to my estimate (3.5%).

(5) The cross supply elasticity of hydrous ethanol to sugar is not significant during both periods. This result is against my hypothesis that sugar price has a positive effect on the supply of ethanol (including hydrous and anhydrous). Videlicet, according to my findings, sugar price is not correlated with the supply of ethanol. This assertion is not conclusive since several crucial factors are absent from the model: tariff and tax rates, sugarcane production, new technology and government

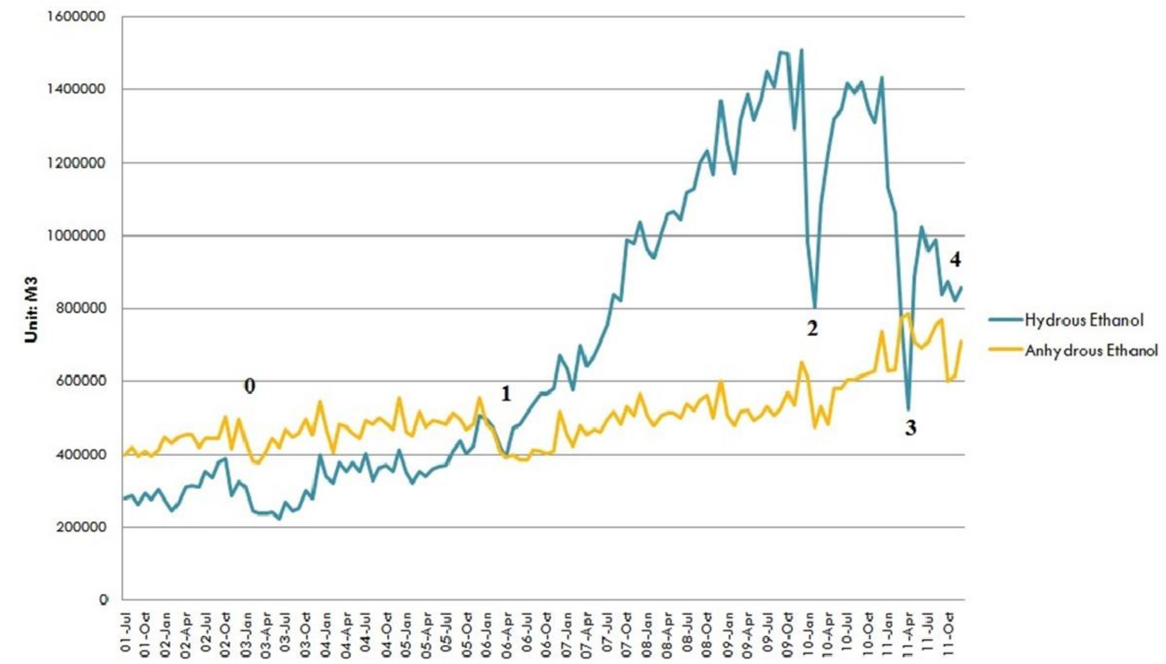
policy. Speaking of substitution between hydrous ethanol and gasoline enabled by flex-fuel vehicles, Figure 4 is a very good presentation of relative prices. As mentioned in previous chapter, the hydrous ethanol's energy density is roughly 30% less than gasoline's, and equivalently 70% gasoline price is equated with hydrous ethanol price. In Figure 4, we could find that there are four times (1-4) when hydrous ethanol price was higher than 70% of gasoline price, and they all happened after the introduction of flex-fuel vehicles. Before March 2003, there was another time point when they were very close (0). It is rational to speculate that for a flex-fuel vehicle driver, the purchasing decision at a gas station is based on the energy-density-adjusted prices of these two fuels. When hydrous ethanol price was higher than 70% of gasoline price, it was no longer the most economical choice, which would be opted out by consumers. From Figure 6 we observe that in these four periods (1-4) when hydrous ethanol was not economical for flex-fuel vehicles, ethanol consumption went through dramatic falls and the fluctuations were bigger and bigger. While before March 2003 when the substitution between two fuels was not established, although the hydrous ethanol price was fluctuating violently, its consumption did not fluctuate accordingly, which demonstrates inelasticity in demand for hydrous ethanol.

Figure 5. Hydrous ethanol price, gasoline price, and 70% gasoline price in Brazil, 2001 - 2011



Source: ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis

Figure 6. Monthly consumption of hydrous ethanol and anhydrous ethanol in Brazil, 2001-2011



Source: ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis

5. Conclusions, Policy Implications and Future Study

5.1 Conclusions

As the second largest ethanol producer in the world, Brazil also has the highest level of market penetration of flex-fuel vehicles, which makes it a good example of how biofuel market works and reacts to a new technology. The invention and commercialization of flex-fuel vehicles changed the Brazilian ethanol and gasoline markets by enabling Brazilian drivers to switch between ethanol and gasoline, depending on their prices and energy densities. My methodology was developed based on 3-stage simultaneous equations to estimates the elasticities from three markets: demand for hydrous ethanol, demand for anhydrous ethanol and supply of total ethanol.

Generally speaking, the results are consistent with literatures and my hypotheses. According to my study, the demand elasticity of ethanol changed from -0.9286 (July 2001-February 2003) to -1.6748 (March 2003-December 2011), demonstrating that the introduction of flex-fuel vehicles made the fuel ethanol more elastic. The cross demand elasticity of ethanol to gasoline varied from 0.8764 to 1.4728, which is owing to the drivers' capability to choose fuels associated with flex-fuel vehicles. The cross supply elasticity of ethanol to sugar, showing that the relationship between sugar price and supply for ethanol lacks evidence to support. Income has no significant effect on the demand for ethanol. The fleet of flex-fuel vehicles is proved to be correlated to the demand for ethanol, and the elasticity changed from 1.9321 in the first period to 3.5054 in the second period. This change can also be explained by the change in fleet structure with flex-fuel vehicles. In summary, flex-fuel vehicles reconstructed the Brazilian ethanol market in many ways.

5.2 Policy Implications

We have been using fossil fuels for centuries, and they are still serving as the foundation of our civilization; however, fossil fuels also have been generating many global issues: air pollution, global warming, unsustainability of resources, dependence on foreign countries and fluctuating prices. Although alternative fuels are drawing our attentions, none of them are capable of challenging fossil fuels so far due to their high production cost or inconvenience of storing. Brazil seeks biofuel, or bioethanol particularly, as a solution, which so far seems the most applicable one. The development of Bioethanol industry requires huge amount of subsidies to producers/consumers and investment on R&D as well as infrastructure construction. But above all, consumers need an economic and convenient technology to consume the new fuel, and flex-fuel vehicle serves as such a technology. It offers consumers options, which make them less vulnerable to fluctuating oil and ethanol prices. For any authorities planning to develop their own biofuel industry and consuming market, several policy implications can be given based on my findings and previous literature:

(1) To policy makers, the increasing demand elasticity of ethanol and cross price elasticity of ethanol to gasoline show that the ethanol market is more sensitive to price fluctuations than it used to be. Hydrous ethanol and gasoline are both substitute fuels in consumption market (due to flex-fuel vehicles) and competitive goods in

supply market (since gasoline in Brazil contains 15%-25% ethanol), which require a more comprehensive model to estimate the effect of a government policy. For example, a tax reduction on gasoline would have two reverse effects on the demand for itself: on one side, the demand for gasoline would grow due to the decline in price; one the other side, the hydrous ethanol price would also decline (since gasoline and ethanol are competitive in supply market), consequently the demand for gasoline would as well decline (since they are substitute goods in consumption market). The final effect is therefore ambiguous.

(2) The biofuel industry needs tax credits or subsidies to survive and thrive. Hitherto, no alternative fuels could compete with fossil fuels without tax credit, subsidies, financial and policy support from government----not to mention the huge amount of investment spent on research and development of new fuels and vehicles. In Brazil's case, the authorities used to spend billions of dollars on subsidies[15], and are still granting a tax advantage to sustain the competitiveness of fuel ethanol.

(3) It is important for policy makers to make decisions based on their competitive advantages and disadvantages. Brazil has unique natural advantages in cultivating sugarcanes; therefore it is economical and efficient for it to develop a sugarcane-based ethanol industry, which cannot be copied by any others. Every country has its own natural advantages to develop alternative energy, for examples, Iceland has ample geothermal energy resources which has been utilized to generate electricity; the U.S. has wide cultivated land in the mid-west for corn farming and

[15] By the Pró-Álcool program, until 1999

corn-based ethanol derivation; China recycles millions of tons of waste oil from catering industry to refine biodiesel.

(4). A new alternative fuel will not thrive unless consumers are able to use it economically, conveniently and risklessly. An unconventional technology always comes with uncertainty, and rational consumers are not willing to take the risk. In Brazil's case, the flex-fuel vehicles act as such an effective linkage between fuel ethanol and consumers. In the 1980s, ethanol-driven vehicles took over more than 90% of the new vehicles market due to relatively low ethanol price (ANFAVEA 2012). However, its sales dropped dramatically to less than 0.1% in 1995 and eventually disappeared from Brazil's market, which hit the ethanol industry very hard along with low oil price. Consumers feel secure to own a flex-fuel vehicle for the reason that the risk and uncertainty caused by fluctuating fuel prices is minimized. Moreover, they are inexpensive (Taylor 2006), convenient to drive and are identical to traditional vehicles. The commercialization of flex-fuel vehicles is actually a major driving force of long-run demand for ethanol (Freitas and Kaneko 2011b). An unsuccessful example of alternative vehicle is electric vehicles, which are not yet widely used because of several deficiencies like high cost, inconvenience of charging and insufficient travel range. Consumers are willing to pay for the new technology[16] and eventually contribute to develop a green industry, even when their income does not increase[17].

(5) Consumers are mostly 'rational', for instance, they are prone to choose the most

[16] In the period of 2009 to 2011, flex-fuel vehicles account for 80% of light vehicles produced in Brazil.
[17] Since in this paper and literature, income effect on demand for hydrous ethanol is not statistically significant.

economical fuel when relative prices fluctuate. However, they are also ‘irrational’ due to personal preference (Salvo and Huse 2013), for instance, concern for the environment (towards ethanol), or the love for more power (towards gasoline). In order to promote green fuel such as hydrous ethanol, the authorities should invest in environmental education and advertisement to the public.

5.3 Shortcomings and Future Studies

Although my research is well-designed, it inevitably has several shortcomings. First of all, the observations in the dataset before the introduction of flex-fuel vehicles (20) are way less than those after (106) which could possibly impede the reliability of regression results. Second, the reliability of study would be improved with more variables introduced to the model such as tax rates (which can be used to analyze the change in tax burdens between two periods), the fleet of flex-fuel vehicles, ethanol-driven and gasoline-driven vehicles, and number of ethanol/gasoline stations (convenience of fueling). Third, control for heteroskedasticity is absent in this thesis.

The flex-fuel vehicles is a brand new product and economic phenomena with which many issues are worthy of investigation. Potential future studies could include (1) the impact of flex-fuel vehicles on Brazil’s GHG emission, (2) the impact of flex-fuel vehicles on international sugar price, and (3) the feasibility of widely commercializing flex-fuel vehicles in the United States and its consequences.

APPENDIX I - Phases of Brazilian National Alcohol Program (PROALCÓOL)

Phases	Time Period	Government Policies	Results	Background
Pre-PROALCÓOL	Before 1975	None	None	➢ The first use of sugarcane ethanol as a fuel in Brazil dates back to the late twenties and early 1930s; ➢ The mandatory blend became as high as 50% in 1943; ➢ After the end of the war cheap oil caused gasoline to prevail; ➢ Gasoline shortages and awareness of the dangers of oil dependence in the 1970s;
1	1975 to 1979	➢ Government helped construct distilleries adjacent to existing sugarcane mills, enabling managers to switch between sugar and ethanol as market price fluctuated; ➢ Government effort launched with an initial target to blend anhydrous ethanol to gasoline up to 22.4% (by volume).	➢ In the beginning of the Program, ethanol production costs were close to \$100 per barrel, falling to \$50 per barrel 10 years later due to economies of scale and technological progress; ➢	➢ The first oil crisis, the average price of crude oil increased from \$2.91 per barrel in September 1973 to \$12.45 per barrel in March 1975; ➢ Low international sugar prices.
2	1979 to 1986	➢ Government negotiated with car manufacturers to develop 100% alcohol fueled vehicles; ➢ Government designed a variety of incentives to entice agricultural producers, distillers, car manufacturers, distributors, and others to adjust their operations and help meet the anticipated demand increase.	➢ Anhydrous and hydrated alcohol production levels increased from 500 million liters per year in the late 1970s to 15 billion liters per year in 1987; ➢ 92% new car sales between 1983-88 were alcohol fueled.	➢ The second oil crisis, the average price of crude oil increased from \$15.85 per barrel in April 1979 to \$39.50 per barrel over the next 12 months.

3	1986 to 1989	➢ Government decreased the subsidies, thus decreased the production; ➢ Economic priority shifted to combating inflation, the currency was overvalued, which damaged ethanol's competitiveness; ➢ Started importing ethanol due to the spread of alcohol fueled cars and insufficient domestic production.	➢ Ethanol production stopped increasing in 1986; ➢ Major supply crisis in 1989 reduced the share of fuel ethanoled cars to 1.02% only of new cars sold in the market by 1989.	➢ Declining oil prices in the mid-1980s, fell to below $10 per barrel in 1986; ➢
4	1989 to 2003	➢ Ethanol is mixed up to 24% with gasoline. ➢ Price liberalization, deregulation and no direct subsidies since late 1990s; ➢ After 1999, market forces are the main drivers rather than public policies.	➢ The absence of a steady supply of hydrous ethanol weakened consumers' confidence in the Program;	➢ Increased international sugar prices; ➢ Low oil price, generally under $25 per barrel.
5	from 2003 on	➢ The introduction of Flex-fuel Vehicles in March 2003, which the government taxed at a lower rate than regular cars; ➢ Since July 2007 the mandatory blend is 25%(E25).	➢ Within 18 months from March 2003, Flex-fuel Vehicles accounted for 73% of new car sales; ➢ In 2007, Flex-fuel cars were already responsible for almost 90% of new car sales in the Brazilian market.	➢ High oil price, rose above $30 in 2003, reached $60 by August 11, 2005, and peaked at $147.30 in July 2008; ➢ Raising concern of global warming, GHG emission and air pollution; ➢ World financial crisis since 2008.

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