Measuring the Effects of Ethanol and Flex-Fuel Vehicles on Brazilian Gasoline Supply and Demand: A Simultaneous Equations Approach

by
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Abstract
The focus of this paper is to investigate consumer response to supply and demand shifters in a transportation fuel market with a viable short-term substitute for traditional petroleum products. Many studies, using a variety of estimation techniques and studying dozens of countries, have confirmed inelastic price and income elasticities for gasoline. Transportation fuel substitution has been difficult due to the high costs and time needed to change fuel types. Flex-fuel technology reduces the barriers of substitution by providing a quick and cheap option for switching between gasoline dominant blends of fuel to ethanol dominant blends. In 2012, over 87 percent of all new vehicles sold in Brazil used flex-fuel technology, allowing Brazilian consumers to arbitrage between gasoline and ethanol. Brazil’s mature ethanol market lowers the substitutability barrier even further. Brazil has had a gasoline substitute, sugarcane based ethanol, since the 1980s. This paper extends the gasoline demand research by estimating gasoline supply and demand simultaneously in a market where the barriers to fuel substitution are considerably lower. Estimating the supply and demand curves simultaneously provides a unique insight into the effects of a well-developed ethanol market and flex-fuel technology on consumer behavior. The results have potential implications on consumer behavior in the United States, where the ethanol and flex-fuel vehicle markets are growing.

1. Introduction
Increasing concern about global carbon emissions has led to interdisciplinary research in the global transportation sector. More recently the focus has been on developing economies and countries emerging into the top ten global economies. In 2007, the United States signed the Energy Independence and Security Act, mandating increasing levels of blending of biofuels into gasoline and diesel products. The result has been rapid growth in the biofuel industry and feedstock agricultural industry. In Brazil, a renewable energy policy has been in place since 1974. The Pro-Alcool program subsidized investments in biofuel technology and mandated high levels of blending. The program mandates levels of blending, at close to 25 percent ethanol, of gasoline products. This program, along with recent developments in flex-fuel technology (vehicles that can burn different levels of blended fuel up to 100 percent ethanol), has provided a unique transportation fuels market that allows consumers to rapidly substitute fuel types. In 2011 total ethanol production was 332,902 thousand barrels per day, a 17.8 percent decline from 2010 production due to severe drought. In 2012 total production grew to 404,928 thousand
barrels per day. Brazilian ethanol production ranks second behind the United States, while Brazil is the world’s largest exporter of ethanol.

Brazil’s strategic investments in ethanol have influenced all sectors of the Brazilian economy, including transportation, petroleum resource production and petroleum product manufacturing. Vehicle manufactures producing and exporting vehicles to Brazil have developed special models to fit the fuel profile of Brazil. From 1983 to 1989 pure ethanol powered vehicles were more popular than gasoline vehicles with average annual new vehicle registrations of 558,879. During this time period ethanol prices were highly subsidized and controlled by the Brazilian government as part of the Pro-Alcool initiative. In the 1990s oil prices fell and ethanol became more expense relative to gasoline. Consumers switched to gasoline powered vehicles in response to lower gasoline prices. More recently, flex-fuel vehicles (FFVs) have been replacing pure ethanol vehicles. In 2012 87 percent of all new vehicle registrations are flex-fuel powered vehicles. Figure 1 shows the evolution of new vehicle registrations from 1970 to 2012. (Basso and Tae Hoon 2007)

The OPEC oil supply shock of the mid-1970s caused new vehicle registrations to reach an all-time low in 1975. This crisis was the primary motivation for the Brazilian investments in renewable fuel technology. The returns on these investments were realized beginning in the 1980s. By the mid-1980s ethanol powered vehicles peaked at almost 700,000 new registrations.
in 1986. Total vehicle registration began to increase exponentially during the 2000s coinciding with overall economic growth in Brazil. Vehicle manufacturers introduced flex-fuel vehicles during this decade, causing ethanol demand to increase along with total transportation fuels.

Total transportation fuel consumption is a function of the fleet composition, the fleet’s fuel efficiency, and the distance per vehicle driven. The introduction of pure ethanol powered vehicles in the 1980s has led to a unique fleet composition in Brazil. Other studies have estimated fleet composition using the ANFAVEA data (Du and Carriquiry 2013). This approach is prone to errors as the ANFAVEA fleet estimates are for automobiles and light-duty vehicles only. New vehicle registrations omit registrations and use of used vehicles. Understanding the turnover rate of older vehicles can also be difficult. To measure fleet composition, this chapter uses data from the RENAVAM database, a registry of all vehicles in Brazil. RENEVAM data is collected from local municipality departments of motor vehicles, aggregated to larger regions, and distributed by the Brazilian Department of Transportation (DENETRAN). Figure 2 provides a snapshot of the most recently available fleet data from the RENAVAM database:

Gasoline powered vehicles continue to dominate the Brazilian fleet, while flex-fuel vehicles gaining in popularity. Despite 87 percent of new light duty vehicle registrations being flex-fuel vehicles, gasoline powered vehicles maintain the largest market share at 55 percent. This is an
indication of low vehicle turnover. Older, gasoline powered vehicles remain in the fleet longer. Diesel powered vehicles make up 8% of the fleet, and the majority them are heavy duty commercial vehicles. Flex-fuel vehicles provide consumers the best opportunity to arbitrage across fuel prices.

Changing fleet composition dynamics are an indication of a need to study consumer behaviors in the transportation fuel market. Brazilian consumers have an increasing opportunity to substitute diesel for gasoline in the short term via flex-fuel vehicles. This type of flexibility will have a stronger impact on the domestic Brazilian transportation fuel demand market, and have a larger influence on international fuel markets. Policy makers, fuel suppliers and automobile manufacturers need to better understand consumer responses to relative price changes, income dynamics, input demands etc., to make the best policy and production decisions.

2. Brazilian Transportation Fuel Supply and Demand

Diesel, gasoline and ethanol dominate the transportation fuel market in Brazil. Recently Brazil has made significant investments in domestic crude production and refined petroleum products. Since 1995 Brazil has been a net-exporter of crude oil. In 2013, Brazil produced an average monthly production value of 2 million barrels per day of crude, 395,000 of which are for export. The discoveries of new oil fields along with a fast growing economy are contributing factors to Brazil’s recent boom in crude oil production. Investments in refineries, pipelines and terminals have also added to the petroleum manufacturing capacity of Brazil. Currently Brazil operates 16 national refineries with a total capacity of 2.1 million barrels per day. Three new refineries have come online from 2007 to 2010 adding approximately 47,000 barrels per day of capacity. The larger Brazilian refineries have an estimated capacity of 200-415 thousand barrels per day, and were built in the 1970s and 1980s. Figure 3 shows the evolution of crude production and exports from 1979 to 2013.
Diesel powered vehicles are only 8 percent of the total fleet, but diesel production amounts to an average of 54 percent of total transportation fuel production from 2006 to 2013. Almost all heavy duty commercial vehicles (trucks, busses, Lorries) are diesel powered. This sector of the vehicle fleet also has the least fuel efficient vehicles. The majority of Brazilian refineries are configured with hydrocrackers, and Brazilian crude production yields heavier crude grades, leading to a significant cost advantage to producing diesel. Brazil has relied heavily on diesel imports to meet demand during the same time period. Gasoline production amounts to about 28 percent of total transportation fuel production during the same time period.

Gasoline sold in Brazil is mandated to meet ethanol blending requirements of up to 25 percent.¹ To put that in perspective, the highest level of mandated ethanol blending in the United States is 10 percent. During the 1990s, prior the introduction of flex-fuel vehicles, the blending requirement had marginal effects on the total gasoline demand. The gasoline 25 percent of gasoline replaced by the ethanol in the final consumer product was offset by the lower energy content in ethanol. This required consumers to purchase more fuel to travel the same distance. With flex-fuel vehicles, the offsetting effect is negated by the substitutability of pure ethanol

¹ The executive branch of the Brazilian government has the authority to set the official blending requirements ranging from 20 to 25 percent depending on the availability of ethanol. In special circumstances, like the 2009/2010 drought conditions, the executive branch was able to set the blending requirement lower than 20 percent (17.5 percent during that period).
when prices ethanol prices are lower than gasoline prices. Figure 4 shows the evolution of transportation fuel production from 2006 to 2013 with imports.

Diesel and gasoline production remained consistent during from 2006 to mid-2013 while ethanol production is very seasonal. Ethanol production coincides with harvest seasons, with peak ethanol production coming in Brazilian winter months (April – September). Gasoline imports spiked early 2011 in response to a severe drought. During this time period the president of Brazil loosened the gasoline-ethanol blending requirements, and Brazil increased imports to offset the lower ethanol production. Diesel imports remain relatively consistent as Brazil consumes more diesel than any other fuel, and lacks the production capability to meet demand.

Diesel consumption is greater than ethanol and gasoline consumption due to the heavy duty vehicle fleet. Heavy duty vehicles consume more fuel per mile traveled and make up a small percentage of the total vehicle fleet. Brazil is a net importer of diesel fuel as consumption outpaces total production. Brazil is a net exporter of ethanol, primarily exporting fuel to the United States. Ethanol exports are seasonal as production must align with sugarcane growing seasons. Ethanol exports are also highly dependent on other factors, including growing conditions and the price of sugar. Most ethanol plants in Brazil are capable of quickly changing production from ethanol to refined sugar using the same sugarcane feedstock. Figure 5 shows the evolution of transportation fuel consumption from 2006 to 2013 with exports.
3. Implications of Brazil Fuel-Market Research

The U.S. Energy Independence and Security act of 2007 aims to increase the market share of renewable fuels, mainly ethanol, in the U.S. transportation fuel market. Better fuel efficiency and changing driving patterns, along with annual increases to the ethanol-gasoline blending requirements, are putting pressure on the petroleum product markets. Policy makers and petroleum industry stakeholders are becoming increasingly aware of the implications of an emerging renewable fuel market in the U.S. Understanding the consumer behavior dynamics of a mature renewable fuels market like Brazil will be critical to informing policy decisions.

This chapter focuses on estimating the supply and demand relationship of the transportation fuel market in Brazil, with the goal of understanding consumer responses to demand shifters in a fuel market with viable short term substitutions for traditional petroleum products. Building on the work of previous research, this chapter adds new and more reliable data sources to the discussion, integrates endogenous fuel prices into a supply and demand model, and tests existing theoretical models about the shape of the Brazilian transportation fuel demand curve. The results of the models are likely to be applicable to any discussion regarding predicting future consumer behavior patterns in the U.S.

This chapter makes two major contributions to international fuel elasticity research. First, it uses a unique data set compiled from Brazilian National Petroleum agency (ANP), the Brazilian...
Ministry of Mines and Energy, the Central Bank of Brazil and the Brazilian National Department of Transportation. Together these sources provide a complete representation of the Brazilian light petroleum product market. Second, this paper is the first to consider the growing deregulation of petroleum product prices in Brazil. This is achieved by estimating supply and demand elasticities using a consistent model.

4. Literature Review

Alves and Silveria Bueno (2003) look at gasoline demand and how Brazil’s mature ethanol market affects the consumption of gasoline. The primary motivation of this paper is to estimate demand elasticities in response to increasing gasoline demand during the 1990s. Prior to the 1990s, Brazil dealt with extraordinary levels of inflation that hampered economic growth and prohibited a stable vehicle market from emerging. One of the causes of the high levels of inflation was the trade imbalance due to Brazil’s dependency on foreign oil imports. The Brazilian government invested in crude oil production and refinery capacity in the 1990s, and stabilized their financial markets, allowing a strong vehicle market to emerge.

Alves and Silveria Bueno conducted their study prior to the availability of “Flex” fuel vehicles, vehicles that run on a high ethanol blend or a low ethanol blend of fuel. Prior to the new technology, switching from gasoline to ethanol vehicles was more difficult. The authors used a co-integration model to estimate gasoline elasticities. They estimate a long-run price elasticity of -0.46. This value is very similar to other co-integration research, but is only significant at the 15 percent level. Given the very low number of observations, the authors conclude that significance at the 15 percent level is acceptable. The long-run income elasticity is estimated at 0.12. This value is considerably smaller than the literature suggests the income elasticity should be. The cross-price elasticity of ethanol is 0.48 at the 15 percent significance level. These results confirm that ethanol is a substitute for gasoline in Brazil, but that consumers still have some difficulty in substituting ethanol for gasoline. The short-run price elasticity is -0.09, considerably smaller than other research (although smaller than the long-run estimation. The short run income elasticity is 0.12, almost identical to the long-run elasticity. The short-run cross price elasticity is 0.22. They estimate the speed of adjustment parameter to be -1.48. The authors interpret the speed of adjustment parameter to mean that an increase in the demand of gasoline of 1 percent in period t-1 above what would be predicted by the long-run relationship (the co-integrating equation), would lead to a negative change in demand the following year of 1.48 percent.

Du and Carriquiry (2013) analyze the impact of flex-fuel vehicle adoption on the price of ethanol and gasoline. Since 2003 flex-fuel vehicles have been replacing single fuel (either ethanol only or gasoline only) vehicles. According to Du and Carriquiry, over 40% of Brazil’s vehicle stock had flex fuel vehicles. Du and Carriquiry estimated the share of flex-fuel vehicles using data from the Brazilian Association of Automotive and Vehicle Manufacturers (ANFAVEA). These results conflict with vehicle stock data from the Department of Transportation’s official vehicle
registration database. Nevertheless, the availability of flex-fuel vehicles allows consumers to arbitrage across the prices of different fuels. As a result, the authors argue that the relative fuel prices of ethanol and gasoline will reach equilibrium. They argue that the equilibrium will be an ethanol to gasoline price ratio of 0.7. The reason for this is because ethanol has approximately 70% of the energy content of gasoline.

The authors further develop the theoretical model introduced in Salvo and Huse (2011). Effectively, the market demand for ethanol is a function of domestic prices of substitute fuels, vehicle fuel economy, the size of the vehicle stock, and international exports. They describe a kinked demand curve for ethanol. The first section of the demand curve is very inelastic. This corresponds with a price ratio E/G greater than the theoretical equilibrium of 0.7. In this scenario fueling with ethanol is not cheaper than fueling with gasoline, so ethanol demand comes from ethanol powered vehicles and gasoline powered cars (gasoline powered cars use 20-25% blend of ethanol). When the price ratio is closer to the equilibrium, the elasticity of demand is higher. In this situation drivers can arbitrage between the two types of fuel, and are more sensitive to changes in price. If the price of ethanol is cheaper than gas, the elasticity will be somewhere between the other two scenarios.

This paper provides a good theoretical background to motivate my elasticity estimation of Brazil’s fuel market with modern data. The gasoline demand curve should be theoretically similar to the ethanol curve. When gasoline is more expensive than the equilibrium G/E ratio, the only demand for gasoline will be with the low gasohol blend in “pure” gasoline vehicles. When prices are close to equilibrium, gas will be used in both flex vehicles and regular vehicles. When G/E is lower than the equilibrium, gas will become more popular relative to ethanol vehicles and more gasoline vehicles will enter the market.

Salvo and Huse develop a stylized model for ethanol demand in Brazil. They argue the adoption of flex fuel vehicles has allowed consumers to take advantage of price differential between the fuels, leading to strong correlation in the price movements between ethanol and gasoline. Their model predicts that price of ethanol should be tied to and driven by the price of gasoline given world sugar prices (representing the opportunity cost of producing ethanol from sugarcane) and marginal production costs of ethanol. The implications of their model are that the market demand for ethanol will be kinked. Ethanol demand will be more inelastic when the energy equivalent price of ethanol is greater than the energy equivalent price of gasoline, and become elastic when the price ratios of ethanol to gasoline are close to 0.7, the ratio where a liter of ethanol provides the same energy output as a liter of gasoline.

Coyle, Debacker and Prisinzano implement a simultaneous equation model for the United States gasoline market using excise tax data. Their approach is unique in that they use excise tax data for gasoline consumption per capita (instead of EIA published data generated from survey results). They also account for the endogeneity in estimating quantity demanded and price, as
they are determined simultaneously. Their approach is strictly an estimation of short-run gasoline demand, using a static log-linear model.

Coyle, Debacker and Prisinzano find that a three-stage least squares estimator corrects for the downward bias of an OLS model. Their approach is also one of the few to simultaneously estimate price elasticity of supply for gasoline. They confirm that U.S. gasoline consumption is relatively inelastic from 1990 to 2011, with an own price elasticity of demand equal to -0.0752. They estimated price elasticity of supply at 0.289. The supply price elasticity was dramatically different than the EIA’s anecdotal estimate of 2.0. They argue that these supply-side results provide insight to policy regarding the effects of taxation on gasoline demand. For example, a proposed tax holiday on gasoline will generate more surplus for the producers than consumers, and will not have the desired effects on gasoline consumption.

Gasoline Demand Literature Surveys

Gasoline demand has been a popular topic for researches dating back to the first supply shocks during the 1970s. Since then there have been hundreds of papers implementing a variety of methods to estimate gasoline demand in the United States and internationally. While every paper produces unique results dependent on the method and the data, many of survey research has identified important trends in the results.

Basso and Oum focused on the variation of results based on the methodology used. They grouped static, dynamic, time-series and structural models into groups, and only compared the results of a study with other studies using similar methodology. They grouped models into the following categories: reduced-form demand models with aggregate data, co-integrated models, models that use household-level data, and structural models.

Reduced-form demand models using aggregate data are most common, and the papers vary in results depending on the data and methodology. Models can be grouped into dynamic and static categories. Dynamic models often include a lagged endogenous variable (typically gasoline consumption) in the set of explanatory variables. Such a model is used to capture the fact that consumer’s responses to changes in income and price take time. Dynamic models are said to capture both short-run and long-run demand elasticities. The partial adjustment model is a popular approach for a dynamic model. Other models include variables on vehicle characteristics and vehicle use patterns.

Basso and Oum argue that short run price elasticity for models using reduced-form aggregate data are between -0.2 and -0.3, and short-run income elasticity ranges from 0.3 to 0.5. Long-term price elasticities range from -0.6 to -0.8 and income elasticities range from 0.9 to 1.30

Basso and Oum also look at the results from co-integration models. They recognize that many authors use time-series data but fail to test for non-stationarity in their series. A co-integration approach assumes an inherent long-term relationship between the endogenous and explanatory
variable, and estimates the reaction to a deviation from the long-term relationship. Basso and Oum argue that these models have the advantage of simultaneously estimating long-run and short-run elasticities. Long-run price elasticities were typically more elastic using a co-integration approach instead of partial adjustment approach.

Dahl and Sterner provide another look at gasoline demand research and related price and income elasticities. They also broke the surveyed studies into 10 model types based on data and methodology. Average short-run price elasticities ranged from -0.12 to -0.41 while short-run income elasticities were from 0.14 to 0.58. Long-run price elasticities were from -0.23 to -1.05 while income elasticities were from 0.60 to 1.31.

Goodwin et al. completed a review of 69 unique studies related to road traffic and fuel consumption elasticities in developed economies. Their review includes studies with periods ranging from 1929 to 1991, and was intended to serve as an update to earlier literature reviews. Although Goodwin et al. did not provide results for specific methodologies used in their review, they did provide summaries of elasticities for different variables using dynamic and static estimation methods. The average short-term price elasticity using dynamic methods was -0.25, while the average long-term estimate was -0.64. The average short-run income elasticity was 0.39, while the long-term elasticity was 1.08. The static method produced a short-run price elasticity ranging from -0.28 to -0.55 depending on the data-type (cross-section, panel, or time-series) with an overall average of -0.43. The average short-run income elasticity ranged from 0.44 to 0.51 with an overall average of 0.49.

5. Description of Data

All data are monthly series from September 2001 to July 2013. Each series represents national level aggregate data for Brazil. This study uses total gasoline consumption as the endogenous variable instead of gasoline consumption per capita. Gasoline consumption, gasoline prices and ethanol prices are published by the National Petroleum Agency (ANP). Gasoline consumption is published as thousands of barrels per day. All price data is originally published in terms of Real per liter. Prices were adjusted for inflation using the Brazilian CPI published by the Central Bank of Brazil, and converted into USD using the Real – USD exchange rate published by the Federal Reserve. Prices used in this analysis are in terms of USD/gallon.

Gasoline production data is a monthly summation of gasoline output from Brazilian refineries in barrels. The production data was converted to barrels per day. ANP produces monthly production data by product and refinery for each of Brazil’s active refineries. Local production does not equal total consumption, as Brazil has needed to augment production with gasoline imports to meet incremental demand.

Income data represents real per capita income and is published by the Brazilian Statistical and Geographic Institute (IBGE). Income was converted to USD using the exchange rate published
Crude oil prices are the average monthly global spot price of Brent crude. These prices were converted to real prices using the CPI published by the Central Bank of Brazil. Brent crude is a specific type of crude oil that is used as a measure for the general movements of all crude prices. Brent crude is more appropriate than other measures like WTI (West Texas Intermediate) or Dubai since it is used more globally. In reality, the actual crude slates of Brazilian refineries will be considerably different than the widely used global crude pricing types. However, the Brazilian refinery feedstock prices will move with the variations of Brent prices, making Brent a simple. Refining costs are estimated using a model created by the energy consulting firm, Energy Analysts International. The model produces variable refining costs for refineries that use a similar crude slate as the Brazilian refineries. These variable costs include the operational costs of producing gasoline. Refining costs do not include fixed costs, the cost of feedstock, or labor costs. Previous research (Alves and Silveria Bueno 2003) used data from the 1974 to 1999. During this time gasoline and ethanol prices were subject to regulation by the Brazilian government. The data set used in this study captures a period of deregulation in both ethanol and gasoline.

6. Model and Estimation

The models used in this study follow the basic principles of previous research. For example Dahl (Dahl, Gasoline demand survey 1986) performed Box-Cost tests to test for the correct functional form of the equation:

\[ G^D = f(P, I, X) \]

The left-hand side of the equation represents gasoline demand, \( P \) represents the price of gasoline and \( I \) represents a measurement of income and \( X \) a matrix of all other measures. Dahl found evidence to use the log-linear form. Other studies (Hsing 1990) argue the linear functional form is more correct, while some studies (Dahl and Sterner, Analysing gasoline demand elasticites: a survey 1991) argue that there is little difference between the forms.

The gasoline demand equation is:

\[
\ln G^D_t = \beta_0 + \beta_1 \ln P^D_t + \beta_2 \ln Y^D_t + \beta_3 \ln E^D_t + \beta_4 \ln M^D_t + \epsilon^D_t
\]

where \( G^D_t \) is gasoline consumption (in thousands of barrels per day), \( P^D_t \) is the real price of gasoline (in dollars per gallon), \( Y^D_t \) is the average monthly real income (in dollars), \( E^D_t \) is the real price of ethanol (in dollars per gallon), \( M^D_t \) is the average monthly total employment and \( \epsilon^D_t \) is the disturbance term. The time index represents a month ranging from 09/2001 to 07/2013. Other studies (Du and Carriquiry 2013) and (Alves and Silveria Bueno 2003) have treated gasoline prices as exogenous. They justified the exogenous treatment of gasoline prices due to the
government intervention of gas prices through the Brazilian state-owned oil corporation, Petrobras. Effective January 20, 2002 the Brazilian federal government officially deregulated prices for crude oil, oil products and natural gas (PETROBRAS 2012). Demand elasticity estimation using data after the deregulation of prices will require supply-side consideration. This study uses a simultaneous equations model to estimate supply and demand curves in market equilibrium to avoid problems of endogeneity that arise when an explanatory variable is correlated with the disturbance term. In this case the price variable in the demand equation above will be correlated with the disturbance variable as price and quantity demanded are simultaneously determined in equilibrium.

Gasoline supply is assumed to be a function of the price of gasoline, the price of feedstock, and variable refining costs:

$$\ln G^S_t = \alpha_0 + \alpha_1 \ln P^S_t + \alpha_2 \ln Z^S_t + \alpha_3 \ln V^S_t + \epsilon^S_t$$

where $G^S_t$ is the supply of gasoline (in thousands of barrels per day), $P^S_t$ is the real price of gasoline (in dollars per gallon), $Z^S_t$ is the real price of Brent crude (in dollars), $V^S_t$ is the real variable refining costs (in dollars) and $\epsilon^S_t$ is the disturbance term. In equilibrium $G^D = G^S$. Both equations lack lagged gasoline consumption (or production) as an explanatory variable. This implies estimated coefficients will represent short-term demand and supply elasticities.

A simultaneous equations approach is necessary to avoid estimation bias using OLS. Models that estimate gasoline demand in a free market, where the price of gasoline is determined by optimization behavior among both consumers and producers, need to incorporate supply-side considerations. In a free market, quantity demanded is simultaneously determined by the price. A model that estimates the demand curve independently of the supply curve is vulnerable to estimation bias when using OLS because the price variable will be correlated with the disturbance term.

Instrumental variables for each equation act as supply and demand shifter, but must not affect the other equation. For example, income is a demand shifting variable that does not directly shift the supply curve, but only has in impact on the supply equation through the price. A three stage least squares estimator is appropriate in this situation because the disturbance term from each equation will be correlated since they both depend on the price of gasoline (Zellner and Theil 1962). The price of ethanol is a critical demand shifter that is independent of gasoline supply. Gasoline is produced through a complicated refining process using crude oil as a feed stock, while ethanol is produced from sugarcane with a different refining process. Income and employment will only affect supply indirectly through prices, and are good demand shifters. The price of crude oil and refining variable costs are supply shifters that will affect gasoline demand through the price of gasoline.

7. Results and Discussion
The 3SLS results for the demand equation are presented in the following figure.

| Dependant Variable = ln(MBPD Gasoline Consumption) | Estimate  | Std. Error | t value | Pr(>|t|) |
|---------------------------------------------------|-----------|------------|---------|---------|
| (Intercept)                                       | -3.95674  | 1.135862   | -3.48346| 0.000669|
| ln(Gasoline Price)                                | -1.00834  | 0.151393   | -6.66041| 6.45E-10|
| ln(Ethanol Price)                                 | 0.524758  | 0.096789   | 5.42166 | 2.66E-07|
| ln(Income)                                        | 0.48405   | 0.077486   | 6.24695 | 5.17E-09|
| ln(Employment)                                    | 0.778257  | 0.150904   | 5.1573  | 8.80E-07|

The short-term price of gasoline is considerably more elastic than price elasticity estimations in other countries. These results support the conclusion by (Du and Carriquiry 2013) that the price elasticity of a fuel in an environment with cheap and efficient substitutability is greater than a market prohibitive of quick substitutions. The mechanism of the quick substitution between gasoline and ethanol is the flex-fuel vehicle. Flex-fuel vehicles accounted for 87 percent of 2012 new vehicle registrations, increasing the Brazilian consumer’s ability to substitute fuels. Alves and Silveria Bueno (2003) estimated price elasticity at -0.09 using data predating the flex-fuel technology. Their results are inline with gasoline demand research in other countries using similar data.

The cross-price elasticity of ethanol is positive and significant, at 0.52. This supports the argument that ethanol is a substitute for gasoline as a transportation fuel. Silveria Alves and Sliviera Bueno (2003) estimated the cross-price elasticity between gasoline and ethanol at 0.48. The degree of substitutability appears to be consistent pre-flex fuel vehicles and after flex fuel vehicles. Both sets of results support the argument that ethanol is an imperfect substitute for gasoline, an argument also supported by the energy efficiency differential of each fuel type.

The short-term income elasticity is 0.48, which falls in the range of comparable estimates (0.3 to 0.5). In most countries lacking ethanol infrastructure and flex-fuel vehicles, consumers are more responsive to income changes than gasoline prices. The advantage of Brazilian ethanol production from sugarcane, a technique known to produce lower greenhouse gas emissions than corn-based ethanol production techniques (California Air Resources Board 2011), has empowered government agencies to affect consumer behavior with price changes.

The 3SLS results for the supply equation are presented in the following figure:

| Dependant Variable = ln(MBPD of Gasoline Production) | Estimate  | Std. Error | t value | Pr(>|t|) |
|-----------------------------------------------------|-----------|------------|---------|---------|
| (Intercept)                                         | 3.047728  | 0.9412123  | 3.23809 | 0.0015145|
| ln(price)                                           | 0.2323871 | 0.0800907  | 2.90155 | 0.0043374|
| ln(price of crude)                                  | -1.1907867| 0.162039   | -7.34877| 1.72E-11|
| ln(variable refining costs)                         | 1.2313393 | 0.1324346  | 9.29771 | 4.44E-16|
The supply equation exogenous variables were log price of gasoline, the log price of Brent crude, and the log of total variable refining costs. The price elasticity of supply is positive and significant at the 1 percent level. Feedstock costs represent the largest portion of gasoline production costs. While the crude slate of Brazilian refineries is considerably complex, with several dozen of different crude grades from numerous local and international fields, Brent crude prices are a reasonable barometer for refinery feedstock costs outside of the United States. As Brazil continues to develop more of its local oil fields, (Brazil is now the 12th largest producer of crude oil globally), estimating supply curves will require a closer look at Brazilian crude prices. The crude price elasticity for gasoline supply was -1.19 and significant. These results indicate that Brazilian refiners are relatively sensitive to variations in crude prices with respect to output decisions.

8. Regulatory Implications

Reducing greenhouse gas emissions from transportation fuels has become a priority of the United States Environmental Protection Agency (EPA). In the United States, the Energy Independence Security Act (2007) advanced the Renewable Fuel Standard (RFS) initiative, with the goal of reducing greenhouse gas emissions by mandating ethanol blending into gasoline. The law mandates annual increases to the required blending levels of ethanol and gasoline, with maximum blending at close to 25 percent of gasoline consumption. If fully implemented, RFS will require U.S. consumers to increase their ethanol consumption via blending in their gasoline. One probable outcome of this regulation will be higher gasoline costs, with more seasonal variation as increasing the ethanol in the gasoline blend becomes more expensive at higher blending levels, and ethanol prices can have high variances in the short run due to unpredictable corn prices.

This study has shown that higher gasoline prices with a mechanism for fuel substitution (flex-fuel vehicles) will have a measurably larger effect on gasoline consumption than markets without flex fuel vehicles. While the RFS laws require incremental ethanol consumption, it does not offer incentives for consumers to use flex-fuel vehicles. A major problem with the RFS law is the “blending wall,” a barrier that prevents higher than 10 percent blends of ethanol-gasoline without significant investment in infrastructure. Part of the infrastructure investment needed to break the “blending wall” is a wider availability of E-85 (85% ethanol) blends for flex fuel vehicles. The results of this study indicate the infrastructure investments will “set the table” for consumers to optimize their fuel consumption based on the relative prices of ethanol and gasoline. Without proper infrastructure, Du & Carriquiry and Coyle et al. have shown that consumers have inelastic responses to gasoline price changes. Currently the U.S. falls behind Brazil in flex-fuel vehicles, with only 504,297 flex-fuel vehicles on the road in 2009 (Brazil had over 23 million in 2013). This research shows that, from the case-study of Brazil, wide-spread adoption of flex-fuel technology will have an immediate impact on consumer responses to gasoline price changes, which opens the door for more effective greenhouse gas reducing policies.
Minnesota leads the United States in E-85 availability and consumption with 343 gas stations offering E-85 in 2012, and 14,691,585 gallons sold. Minnesota consumed 2,579,261,120 gallons of gasoline (E-10 blend) in 2012. Despite widespread availability of E-85 in Minnesota (13 percent of gas stations in Minnesota sell E-85), only 0.5 percent of gasoline-ethanol fuel was the E-85 blend. Minnesota's leading E-85 position is partially due to the defunct 38 cent per gallon federal tax subsidy on ethanol, and Minnesota's proximity to ethanol producers. Clearly, the tax credit, substantially lowering the price of E-85, did not have a material effect on consumer's fuel choice because the price elasticity of demand is relatively low. A subsidy combined with appropriate incentives for flex-fuel vehicle purchases would be a more effective approach to curbing gasoline consumption (and greenhouse gas emissions) by increasing the price elasticity of gasoline.

The United States is the world’s largest producer and consumer of ethanol, but does not have a viable infrastructure for ethanol as a possible replacement for gasoline. Higher blends of ethanol are not widely available in the United States, and when they are they are not priced to provide a significant alternative to gasoline. U.S. ethanol production is also more carbon intensive than the sugarcane production techniques available to Brazil. Therefore ethanol’s capacity to limit greenhouse gas emissions in the United States is severely limited.

While ethanol will not likely become a substitute for gasoline in the U.S., the results of this study suggest that a short-run substitute transportation fuel will enhance regulatory power in curbing greenhouse gases by affecting consumer response to gasoline price variations. Electric-hybrid vehicles are growing in popularity and their production is encouraged by increasing Corporate Average Fuel Economy (CAFE) standards. As the market for these vehicles grows, consumers in the United States are likely to have similar fuel substitution options as consumers in Brazil.

9. Conclusions

Brazil’s mature ethanol market and the adoption of flex-fuel technology have changed consumer behavior dramatically. With a competitive substitute in the short-run, consumers are able to arbitrage between gasoline and ethanol. These results have interesting implications on fuel-tax policy and emission regulations in Brazil. Consumers will be more likely to switch fuels and reduce gasoline consumption in response to an increase in gasoline taxes. For the United States, the world’s largest consumer of ethanol, national and regional policies aimed at expanding the biofuels market are likely to affect consumer behavior in a similar way as Brazilian policies (assuming the market is able to grow enough to provide a consistent substitute for gasoline).

Works Cited


