The Impact of Ethanol Production on the U.S. Gasoline Market

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1. Introduction

Biofuels have become a leading alternative to fossil fuels because in many countries they can be produced domestically, are a partial solution to global climate change, and have the potential to spur rural development. Ethanol production will affect the current gasoline demand and supply relationship but to what magnitude remains to be answered. This is an important question which has had relatively little empirical research done so as to understand the relationship between ethanol production and gasoline supply and demand. However, it is of vital importance to be able to estimate the price changes that result from increased ethanol production.

While the immediate goal of our paper is to address the impact of the introduction of greater quantities of ethanol in the motor gasoline market, we will also estimate U.S. gasoline demand and supply price elasticity. Specifically, we want to explore how ethanol production has affected gasoline price and supply in the United States. Almost 99% of the ethanol produced in the United States is added to gasoline in mixtures of up to 10% ethanol and 90% gasoline (EIA, 2011a). Any car that uses gasoline in the United States can use gasoline with 10% ethanol.

2. Background

In this part of the paper we discuss the situation of the U.S. gasoline and ethanol markets very briefly.

2.1. Ethanol Production

Ethanol is a renewable bio-fuel that can be produced in the United States, which helps reduce U.S. dependence on imported crude oil. Even though ethanol has been produced in the United States for many years, it has not been considered a significant fuel source until recently. Efforts to reduce air pollution, concerns over global warming, the

elimination of Methyl Tertiary Butyl Ether (MTBE) as a fuel oxygenate (due to underground water pollution concerns), the existence of a cheap and abundant source of grain (specifically corn), high oil prices, and energy security concerns are all important factors that have contributed to the stimulation of the U.S. ethanol market in recent years.

Based on the U.S. Clean Air Act, the U.S. federal government mandated that all gasoline sold within the United States be blended with an oxygenate so that fuel would burn more cleanly, thus reducing vehicle tailpipe emissions (namely carbon monoxide emissions). This law created a market for the fuel additive MTBE to be the oxygenation agent, which had been used in the United States for some time. However a few years ago, scientists discovered traces of MTBE leaking into ground water, posing a potential threat to public health. Since MTBE is highly soluble in water, it can pollute underground and surface water supplies, rendering MTBE decontamination efforts as very expensive.

Because of MTBE-related health concerns, many states have banned using MTBE as a fuel oxygenate. Banning MTBE has forced gasoline producers and distributors to use other alternatives such as ethanol. The federally mandated requirement for a fuel oxygenate created a new market for ethanol to be used as a substitute for MTBE. It must be noted that the demand for ethanol as a gasoline oxygenate is not its sole source of demand. Ethanol can also be blended with gasoline in different quantities to reduce the consumption of gasoline, in addition to the positive benefit of a reduction in air pollution. The increasing number of Alternative Fuel Vehicles (AFV) on America's highways is another potential factor that drives the increased demand for ethanol.

Ethanol can be used as fuel for automobiles, either as the main fuel (E85) in a special engine or as an additive to gasoline for petroleum engines. In fact, ethanol can be blended up to 10% by volume with gasoline for use in any current vehicle without

requiring any subsequent mechanical changes be made to those cars. However, gasoline blends containing more than 10% ethanol do require engine modifications to prevent engine damage. E85, which contains 15% gasoline and 85% ethanol, can only be used in so called flexible-fuel vehicles that have special engine modifications that allow the usage of E85. Since selling E85 requires additional equipment to store and dispense it in gas stations, it is not available in all areas of the United States. E85 is mainly sold in the Midwest.

U.S. ethanol production increased from 175 million gallons in 1980 to 13,230 million gallons in 2010 (RFA, 2011a). The rate of increase in ethanol production has been especially high after 2000. Ethanol's production capacity increased from 1,702 million gallons per year in 1999 to 13,508 million gallons per year in 2010 (RFA, 2011a). The United States is the world's largest ethanol producer. Governmental policies related to ethanol, such as tax credits, import tariffs, loan programs, subsidies, and especially the 2005 and 2007 Energy Acts, have increased the number of ethanol plants from 54 in January of 2000 to 204 in January of 2011 (RFA, 2011a). Banning the use of MTBE in gasoline (which was implemented in 1999) and adopting ethanol as an MTBE substitute, along with a boost in gasoline prices, have also served to stimulate the demand for ethanol, helping to increase the number of ethanol plants. In January 2011, more than half of the fifty U.S. states (29 states) had ethanol plants (RFA, 2011a).

2.2. Ethanol and Gasoline

In any major world economy, energy plays a significant role in economic growth. With the United States importing more than 60 percent of its oil, any weakness in the energy supply chain could pose a potential threat to its economy. Although the United States only contains 3 percent of the world's known oil reserves, it accounts for more than 25

percent of the world's oil consumption (Natural Resources Defense Council and Climate Solutions, 2006).

In 2010, the United States imported more than 60 percent (4.3 billion barrels) of its petroleum consumption, which includes crude oil and refined petroleum products (EIA, 2011b). On a daily basis, the United States consumed 19.1 million barrels of petroleum products in 2010 while only producing 5.5 million barrels (EIA, 2011a). At $100 per barrel, the United States pays more than $496 billion annually to other countries in petroleum products purchases. The United States spends approximately $35 billion dollars per year in defense expenditures in order to protect the flow of oil from the Middle East (Launder, 2001). Producing ethanol domestically is one way to change this situation and reduce the need for these defense expenditures and increase energy security.

The United States consumed 137.86 billion gallons of finished motor gasoline, including ethanol and other gasoline components, in 2010 (EIA, 2011b). As stated previously, the United States produced 13.2 billion gallons of ethanol in 2010. This means that the U.S. gasoline consumption in 2010 was 9 billion gallons lower compared to when there was no ethanol production.

Even though mandatory ethanol consumption laws and increased gasoline prices both increase the demand for ethanol, the means by which these two factors manifest themselves on ethanol production are different. Federal mandates make ethanol a complementary product for gasoline, which gasoline blenders (oil refineries) are required to use if they want to supply gasoline. This means that fuel producers blend ethanol with gasoline only to the required level, provided the gasoline price is lower than or equal to the subtotal of the ethanol production and blending costs. Therefore, in this case, federal mandates force refineries to use ethanol, resulting in ethanol being a complementary

good for gasoline. On the other hand, when gasoline prices are significantly higher than ethanol production and blending costs, it encourages oil refineries to blend more ethanol in gasoline in order to take advantage of price differences between ethanol and gasoline. Subsequently, this allows producers to increase net profits. In this case, when gasoline price is higher than ethanol costs, ethanol is a substitute for gasoline so that the quantity of ethanol blended with gasoline is greater than the required level. We show these relationships between ethanol and gasoline in figure 1.

Based on the discussion above, an increase in ethanol prices does not have significant negative impacts on the amount of ethanol demanded up to the federally mandated level, but after that, an increase in ethanol prices reduces the demanded amount of ethanol. Thus we can summarize our discussion as follows:

- *If ethanol price + blending costs >= gasoline price ➔ mandatory law will be in force ➔ ethanol is a complementary good for gasoline*

- *If ethanol price + blending costs < gasoline price ➔ refineries use ethanol in gasoline to make profit ➔ ethanol is a substitutionary good for gasoline*
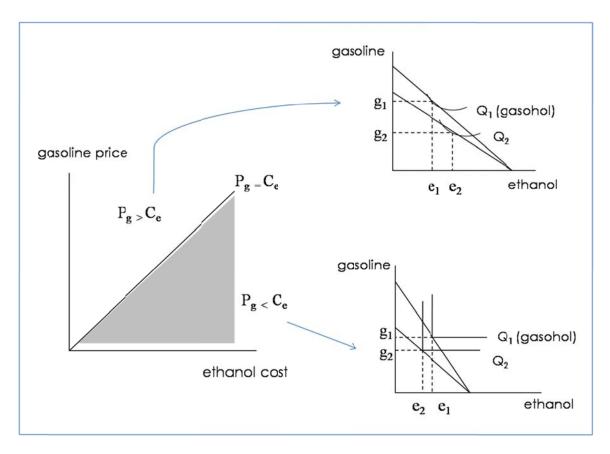
Figure 1. Relationship between ethanol and gasoline

3. Literature review

Ethanol supply is treated as a substitute to motor gasoline and also as an additive to fuel gasoline at the same time. While the motor fuel gasoline market and biofuel industry have been studied very frequently, limited research has been done on the impact of ethanol production on the gasoline market. Most of the studies on the gasoline market have discussed gasoline market supply and demand elasticities.

Manzan and Zerom provide an extended application of the Partially Linear Additive Model (PLAM) to the analysis of gasoline demand using a panel of U.S. households. Their results show that the price elasticity of gasoline demand ranges between −0.2, at low prices, and −0.5, at high prices (Manzan and Zerom, 2007). Hughes et al. compare

the price and income elasticities of gasoline demand in two different periods of similarly high prices from 1975 to 1980 and 2001 to 2006. They found that the short-run price elasticities varied significantly and ranged from -0.034 to -0.077 during 2001 to 2006, as opposed to -0.21 to -0.34 for 1975 to 1980 (Hughes et al., 2006). The estimated short-run income elasticities ranged from 0.21 to 0.75, and when estimated with the same models were almost the same for the two periods.

Du and Hayes used pooled regional time-series data from January 1995 to March 2008 in order to examine the impact of ethanol production on gasoline prices. They show that ethanol production has had a negative effect on gasoline prices (Du and Hayes, 2009). They suggest wholesale gasoline prices could be $0.29 to $0.40 higher per gallon if there was no ethanol production. They also show that both ethanol production and gasoline imports have negative impacts on refineries' profit margins, which indicates the significant substitution effect of ethanol on gasoline.

A study by National Renewable Energy Laboratory (NREL) shows that having 6.4% ethanol in a gasoline/ethanol mixture reduced gasoline prices as much as $0.17 per gallon in 2008 (NREL, 2008). This study predicts that having 10% ethanol would result in having lower gasoline prices between $0.19 and $0.50, depending on gasoline and corn prices.

Du and Hayes revised their paper in 2011 by adding data for 2009 and 2010. In their new study, they show that ethanol production has had a negative effect on gasoline prices to the extent that, on average for the period of 2000 to 2010, wholesale gasoline prices could be $0.25 higher per gallon if it were not for ethanol production (Du and Hayes, 2011). Based on this study, high ethanol production at the end of the period (2010)

8

has had a greater impact on gasoline prices and has brought $0.89/gallon reduction in U.S. gasoline prices on average and between $0.58 to $1.37 gallon reductions in different regions.

4. Data and Methods

A system of structural equations is estimated over historical data to simulate the U.S. motor gasoline market. This model has five behavioral equations and one identity to close the market. The behavioral equations comprised of U.S. gasoline demand, supply, production, imports, and price equations. We have used quarterly data from 1982 to 2010 to estimate the model. Gasoline data, including gasoline consumption, production, supply, imports, stocks, and prices, were collected from the U.S. Energy Information Administration's (EIA) website. Ethanol production data is collected from the Renewable Fuels Association's (RFA) website. Socio-economic data, including GDP and population, are collected from the U.S. Department of Commerce's website, and consumer price index (CPI) is acquired from the U.S. Department of Labor's website. By using CPI, gasoline prices were converted into real prices. Because of simultaneous estimations of supply and demand, we have used 2sls regression method to estimate this structural equations system.

U.S. finished-motor-gasoline consumption has increased from 107.8 billion gallons in 1979 to 137.86 billion gallons in 2010. Per capita gasoline consumption was 445 gallons per year or 1.2 gallons per day in 2010 (EIA, 2011b). Notice that finished-motor-gasoline includes all ethanol blended gasoline (e.g. E10, E85). Like any other commodity, gasoline demand is a function of gasoline price, income, and population. Also, gasoline tax and the price of ethanol, as a related commodity, can influence demand for motor gasoline. The suggested equation for motor gasoline is as follows:

(1) $Q^D = f(P^G, GDP, Pop, P^E, Tax)$

In this equation, Q^D, P^G, GDP, Pop, P^E, and Tax are used for the U.S. quantity of motor gasoline demanded (consumption), real gasoline price, Gross Domestic Product, population, ethanol price, and gasoline tax, respectively. We expect gasoline price and tax to have a negative impact and the other variables to have a positive impact on gasoline demand.

Equation 2 estimates U.S. motor gasoline production. Most gasoline used in motor vehicles in the United States is produced domestically. Motor gasoline is one of the main products obtained from refining crude oil. Each barrel of crude oil yields around 19.2 gallons of motor gasoline along with other petrochemical products. In 2010, the United States produced 1,998.14 million barrels of crude oil from its oil fields and imported 3,362.86 million barrels of crude oil from other countries (EIA, 2011b). As these numbers show, only about 37% of the crude oil used by U.S. refineries is produced in the United States. Using domestic and imported crude oil, U.S. refineries produced 138.87 billion gallons of finished-motor-gasoline in 2010 (EIA, 2011b). U.S. gasoline production, without adding ethanol, was around 125.64 billion gallons in 2010. U.S. gasoline production, with and without ethanol, has followed an increasing trend from 1980 to 2010. As figure 2 illustrates, after 2002, motor gasoline production with ethanol has had a steeper increasing trend than motor gasoline production without. This indicates that a partial share of gasoline production has been replaced with that of ethanol.
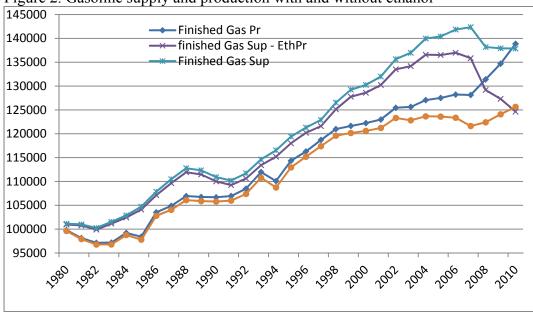
Figure 2. Gasoline supply and production with and without ethanol

Crude oil is the main input for producing motor gasoline. An increase in crude oil should have a negative impact on gasoline production. Gasoline price, U.S. gasoline production capacity, and technology improvement are expected to have positive impacts on gasoline production. In this study, the amount of gasoline production for previous quarters is used as the gasoline production capacity. Equation (2) shows the suggested equation for gasoline production.

(2) $Pr = f(P^G, P^C, Cap, T)$

In this equation, Pr, P^G, P^C, Cap, and T are used for gasoline production, gasoline price, crude oil price, and gasoline production technology improvement.

Finished gasoline import is illustrated in equation (3). Since the United States does not have enough refineries to produce sufficient motor gasoline, in addition to imported crude oil, this country has to import several million gallons of finished gasoline each year. After 2005, gasoline imports declined sharply and fell from 9,239 million

11

gallons in 2005 to 2,058 million gallons in 2010 (EIA, 2011b). Substitution of imported

gasoline with ethanol is one of the possible causes for this sharp reduction in gasoline

imports. In fact, most of the ethanol produced has been substituted for imported gasoline

so that gasoline imports show a sharp downward trend from circa 2005. As figure 3

shows, if we add the amount of produced ethanol to gasoline imports, the new variable's

trend after 2005 is the same as the trend which gasoline imports alone could have been

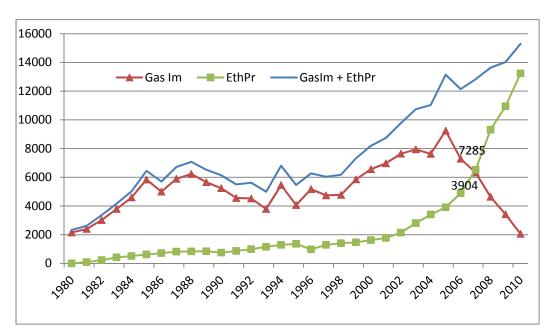without ethanol production.

Figure 3. U.S. gasoline imports and ethanol production
Source: EIA and RFA

Gasoline price, GDP, and exchange rate are the most important elements which

can have influence on gasoline imports. It is expected that an increase in GDP raises

gasoline imports and an increase in both the gasoline price and exchange rate reduces

gasoline imports. Equation (3) illustrates the gasoline import equation.

(3) $Im = f(P^G, GDP, ExRt)$

In this equation, *Im*, *PG*, *GDP*, and *ExRt* are used for gasoline imports, gasoline price, Gross domestic production, and U.S. exchange rate.

The fourth model's equation estimates total gasoline supply. As figure 2 shows, U.S. finished gasoline supply, including ethanol, increased from 101.13 billion gallons in 1980 to 137.86 billion gallons in 2010. Total supply of gasoline without ethanol was about 124.63 billion gallons in 2010. Total supply of gasoline without ethanol has an increasing trend until 2006, but after that, starts to decrease. Gasoline supply with ethanol has an increasing trend until 2007, then after that, has a downward trend. However, the decrease in gasoline supply with ethanol is less than the decrease in gasoline supply without ethanol. This shows a part of reduction in gasoline supply is resulted from substituting gasoline with ethanol.

In this model, ethanol supply is a function of gasoline and crude oil prices and technology improvement. Gasoline price has a positive impact on gasoline supply, while an increase in crude oil prices decreases gasoline supply. The suggested equation for total gasoline supply is shown in equation (4). As before, P^G and P^C are used for gasoline and crude oil prices, respectively.

(4) $Q^S = f(P^G, P^C, T)$

The last behavioral equation of the model estimates the impact of gasoline consumption, gasoline supply, and ethanol production on gasoline prices. In this equation, instead of the total supply variable, its fragments, including gasoline production, imports, and beginning stock, are used. Equation (5) illustrates the suggested equation for gasoline price. This equation shows how gasoline price has been affected by ethanol production.

(5) $P^G = f(Q^D, Pr, Im, BigSt, P^C, EthPr)$

In this equation, P^G, Q^D, *Pr*, *Im*, and P^C are as stated before and *BigSt* and *EthPr* are used to represent gasoline beginning stock and ethanol production, respectively.

5. Estimation Results

Our simultaneous equation system is estimated using the Statistical Analysis System (SAS). Table (1) shows the estimation results for our model. As expected, the results show that gasoline price and gasoline tax have a negative impact on the demand for gasoline, while escalation of GDP raises gasoline demand. Dummy variable *Du1* shows that the demand for gasoline is relatively lower in the first quarter of each year. Based on our data, the demand price elasticity of gasoline for the average amount and price of gasoline is –0.06, which is very low.

Estimated results from the gasoline production equation illustrate that crude oil prices have a negative impact and gasoline price and production capacity have a positive impact on U.S. gasoline production. The price elasticity of gasoline, for average *q* and *p*, is also very small and around 0.03.

Based on estimation results, gasoline price and exchange rate have a negative impact and per capita GDP and ethanol price have a positive impact on U.S. gasoline imports. Therefore, a decrease in ethanol price, an increase in gasoline price, and/or a depreciation of the U.S. Dollar decreases gasoline imports. On average, gasoline import in the second quarter is relatively lower and in the fourth quarter is relatively higher than in the first and third quarters.

Estimated results from the gasoline supply equation indicate that the total U.S. gasoline supply is a direct function of gasoline price, technology improvement, and indirect function of crude oil price.

14

The gasoline price equation shows the impact of gasoline supply and demand and ethanol production on gasoline price. Based on estimated results from this equation, higher gasoline production and beginning stock decrease gasoline prices. An increase in gasoline demand and crude oil prices increases gasoline prices. As these results show, ethanol production has a negative impact on U.S. gasoline prices. An interesting point in this equation is that the absolute magnitude of impact on gasoline prices from gasoline demand, gasoline production, gasoline beginning stock , and ethanol production is almost the same and between 0.00006 to 0.00007. This means that on average, for every one billion gallons of increase in gasoline production or gasoline beginning stocks, U.S. gasoline prices decrease by $0.07 cents. On the other hand, for every billion gallons of increase in gasoline demand, gasoline prices rise as much as $0.06 cents. Also, every billion gallons of increase in ethanol production decreases gasoline price as much as $0.06 cents. Adding ethanol to gasoline has the same impact on gasoline as a positive shock to gasoline supply. So, adding ethanol to gasoline should reduce gasoline prices.

As mentioned before, the United States produced more than 13 billion gallons of ethanol in 2010. Based on estimation results for impact of ethanol production on gasoline price, this amount of ethanol can lower the gasoline price as much as $0.78 cents per gallon. This result is very close to that of the Du and Hayes study, which claims 2010 gasoline prices could be lowered by $0.89 cents per gallon because of ethanol production. This low price means around $107 billion in annual savings for U.S. drivers as a whole.

As figures (2) and (3) show, produced ethanol is mostly replaced for gasoline imports and has decreased gasoline prices through reducing demand for gasoline.

As expected, results show that the variables of gasoline price and tax have a negative impact and income (GDP) has a positive impact on gasoline consumption.

Crude oil prices and ethanol production have negative effects and gasoline price has a positive effect on U.S. gasoline supply. U.S. Gasoline prices have been affected by ethanol and gasoline production negatively and by gasoline consumption and crude oil price positively.

6. Conclusion

This study quantifies the impact of increasing ethanol production on gasoline prices employing quarterly time-series data from the first quarter of 1982 through the fourth quarter of 2010. The system of structural equations, containing five behavioral and one identity equation, is estimated using the Statistical Analysis System (SAS). Estimation results show that own price elasticity of gasoline demand and supply are very low, amounted to 0.06 and 0.03, respectively. We find that the growth in ethanol production kept gasoline prices lower than would otherwise have been the case. Based on our results, each additional billion gallons of ethanol reduces gasoline prices as much as $0.06 per gallon. Considering U.S. ethanol production in 2010, which was more than 13 billion gallons, ethanol production could result in having lower gasoline prices of up to $0.78 per gallon. Estimation results illustrate that the impact of gasoline import and gasoline production on gasoline prices are the same and they are only one cent more than the impact of ethanol on gasoline. Each additional billion gallons of gasoline imports or production decreases gasoline price by $0.07.

Table 1. Estimated Behavioral Equations Used in the Econometric Model

Equation	Estimated Coefficients (*t*-values)	R^2	DW
Gasoline Demand	Q^D = 22286.43 – 1993.11 P^G + 1.27 GDP – 112.51 GT – 1838.57 Du1 $(28.34)^{***}$ $(6.28)^{***}$ $(60.09)^{***}$ $(3.82)^{***}$ $(18.28)^{***}$	0.98	1.87
Gasoline Production	Pr = 3232.55 + 1872.13 P^G - 59.74 P^C + 0.89 Pr1 – 2486.72 Du1+ 1201.29 DuR $(3.44)^{***}$ $(7.26)^{*}$ $(2.32)^{**}$ $(30.05)^{***}$ $(13.13)^{***}$ $(3.23)^{***}$	0.92	2.28
Gasoline Import	Im = -393.21 – 1183.21 P^G + 51.15 GDPP + 0.72 Im1 – 579.91 ExRt + 821.32 P^E + 268.80 Du2 – 101.23 Du4 (0.73) $(2.73)^{***}$ $(3.02)^{***}$ $(10.05)^{***}$ $(2.57)^{***}$ $(2.21)^{**}$ $(5.24)^{***}$ $(1.99)^{**}$	0.76	1.84
Gasoline Supply	Q^S = 8598.76 + 970.20 P^G – 37.84 P^C + 0.59 GS1 + 34.46 T + 2561.78 Du2 + 1919.81 Du3 + 1057.15 Du4 $(4.69)^{***}$ $(1.88)^{*}$ $(2.96)^{***}$ $(8.04)^{***}$ $(5.30)^{***}$ $(16.11)^{***}$ $(15.81)^{***}$ $(8.05)^{***}$	0.98	2.02
Gasoline Price	P^G = 1.26 + 0.00006 Q^D + 0.025 P^C – 0.00007 Pr – 0.00007 BigSt – 0.00006 EthPr $(5.61)^{***}$ $(2.83)^{***}$ $(28.44)^{***}$ $(3.03)^{***}$ $(4.60)^{***}$ $(2.37)^{**}$	0.96	1.81

- Parentheses show *t*-statistic values

- *** 1% significance; ** 5% significance;* 10% significance level.

- Variables definition can be found in Appendix.

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