THE IMPACT OF FUEL ETHANOL ON MOTOR GASOLINE MARKET: MODELING THROUGH A SYSTEM OF STRUCTURAL EQUATIONS

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

THE IMPACT OF FUEL ETHANOL ON MOTOR GASOLINE MARKET:

MODELING THROUGH A SYSTEM OF STRUCTURAL EQUATIONS

presented by WANG Xiaoyang,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Wyatt Thompson

Professor William Meyers

Professor Douglas Miller

DEDICATION

To my beloved parents.

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Abstract

This paper studies the impact of fuel ethanol on motor gasoline market, especially how the gasoline price will be affected if fuel ethanol takes a big share of motor fuel consumption. A system of structural equations is estimated over historical data to simulate the motor gasoline market. The proportion of fuel and additive use ethanol is calculated in the historical period. Ethanol supply is treated as a substitute to motor gasoline in the future and set to increase exogenously as mandated in scenarios. Projections for period 2008 to 2022 are made. Modeling results suggest a rise in future gasoline consumption and price. Ethanol use will partially offset gasoline price increase, though not much.

INTRODUCTION

The recent years have seen a tremendous increase in ethanol use in the motor fuel market. The 2005 Energy Policy Act mandated that 4 billion gallons of renewable fuel must be added to the gasoline supply in 2006. This amount rises to 4.7 billion gallons for 2007 and 7.5 billion in 2012. And the policy changed to increase further the use of ethanol. In 2007, the actual use of ethanol in the motor fuel market was 6.48 billion gallons, 38% more than mandated use.[1] The Energy Independence and Security Act (EISA) of 2007 includes a new Renewable Fuel Standard (RFS) that requires 8 billion gallons of renewable fuels to be blended into the country's fuel supply in 2008, and up to 36 billion gallons in 2022.

Though now the share of ethanol in the motor fuel market is still very small compared to the approximate 140 billion gallons annual gasoline consumption, a rapid expansion of the ethanol production capacity is expected. And ethanol may become an important fuel in the near future. Two factors will contribute to the ethanol production boost. One is supportive policy that creates mandates and economic stimulus. The other is the high oil price that gives incentive for adopting alternative fuels. Under these positive conditions, ethanol industry volume was expected to reach 31.5 billion gallons per year by 2015, which would be 20% of projected US fuel consumption of that year (Elobeid et al, 2006). A more conservative projection is that ethanol production reaches 18 billion gallons in 2017 (FAPRI, 2008B).

[1] Energy Efficiency and Renewable Energy news, U.S. Department of Energy (2007), http://www.eere.energy.gov/news/news_detail.cfm/news_id=11633.

Currently, the role of ethanol in motor fuel market is subordinate to gasoline due to its small share. But if ethanol use increases from less than 5% now to more than 20% in 2015 and beyond, ethanol will become a more important fuel type in the motor fuel market. Then it will affect the current gasoline demand and supply relationship. How large will this effect be? It is a question worth studying but very limited work has been done in this area. Another reason to do this research is the huge impact that gasoline price has on the agricultural market. And ethanol may integrate energy and agricultural market closely in the future (Tyner and Taheripour, 2007; De Gorter and Just, 2008; Collins, 2008). Thus, gasoline price will affect commodity prices more than ever. It is important to estimate how gasoline price changes given the supply shock from ethanol use.

The rest of this paper is organized as follows. First is a summary of ethanol development, key policy factors, and also a description of the motor fuel gasoline market. Then, in the section on method, the literature relevant to ethanol and gasoline markets is reviewed. The main model of this paper and data description will be developed after the literature review. The modeling procedure and results are briefly reported and discussed thereafter. The conclusion is last.

CHAPTER I. BACKGROUND OF FUEL ETHANOL AND MOTOR GASOLINE MARKET

Fuel-ethanol Development

The general information about fuel ethanol can be found in many agencies and organizations, such as Energy Efficiency and Renewable Energy in U.S. Department of Energy, American Coalition for Ethanol and Renewable Fuel Association. Ethanol is a clean-burning, high-octane motor fuel that is produced from renewable sources.[2] At its most basic, ethanol is grain alcohol, produced from crops such as corn. The biggest use of fuel ethanol in the United States before 2008 was as an additive in gasoline. Motor fuel comprised of 100% ethanol is not generally used as a motor fuel, but instead, a percentage of ethanol is now being used to combine with unleaded gasoline to fuel vehicles. Any amount of ethanol can be combined with gasoline, but the most common blend is E10 - 10% ethanol and 90% unleaded gasoline. E10 is approved for use in any make or model of vehicle sold in the U.S. About 46% of America's gasoline contained some ethanol, most as this E10 blend.[3] E85 is another common alternative fuel for use in flexible fuel vehicles (FFVs) which contains up to 85% ethanol and at least 15% gasoline. There are currently more than 6 million FFVs on America's roads today, and automakers are rolling out more each year. When E85 is not available, these FFVs can operate on straight gasoline or any ethanol blend up to 85%. Other ethanol-gasoline blends between E10 and E85, like E20 and E40, are still under experiment to see whether standard

[2] Energy Efficiency and Renewable Energy (2007), U.S. Department of Energy, www.eere.energy.gov.
[3] American Coalition for Ethanol (2008), http://new.ethanol.org/index.php?id=34&parentid=8.

automobiles can accommodate them. Now, none of them has been introduced to the market and they will not be considered here.

According to Lescaroux and Rech (2008), about 55% of the corn used for ethanol is processed by “dry” milling plants, which is a grinding process. The other 45% is processed by a chemical extraction process called “wet” milling plants. Ethanol is produced largely in the Midwest corn belt, with almost 90% of the national output occurring in five major corn-producing states: Illinois, Iowa, Nebraska, Minnesota and Indiana. When ethanol is used in other regions, shipping costs tend to be high, since ethanol-blended gasoline cannot travel through petroleum pipelines, and must be transported by truck, rail, or barge.

Ethanol Marketing

According to the Renewable Fuel Association (2008), most ethanol is sold under long-term contracts. These contracts are private agreements between ethanol producers or marketers and petroleum companies. Roughly 90 to 95% of ethanol is sold under these long-term contracts (6 to 12 months). Many of these contracts are ‘fixed price’. In other words, the price a petroleum company pays for the ethanol does not change, regardless of changes in the spot (wholesale) market price. Some of these contracts may be ‘pegged’ to a gasoline benchmark. In this case, when wholesale gasoline prices move up or down, the price a petroleum company pays for ethanol moves accordingly. The remaining small amount of ethanol is sold on the 'spot' market. Prices fluctuate daily according to market conditions.[4]

Economically, the role of ethanol in the gasoline market can be divided into two parts. One use, which was traditionally the dominant one, is as an additive to fuel gasoline, within the mandated oxygenate content level, ethanol is a complement to gasoline consumption. Ethanol had been competing with another common additive methyl tertiary butyl ether (MTBE). As the content of ethanol in motor fuels exceeds required level by government, it is then viewed as a substitute to gasoline. Here the two uses will be discussed separately.

1. As a fuel gasoline additive

According to Zhang et al (2007), the passage of the 1990 Clean Air Act Amendments opened the gate for use of ethanol. The amendments first established the Oxygenated Fuels Program which requires a minimum oxygen content of 2.7% by weight in winter fuels for non-attainment regions, which are defined as regions that do not meet carbon monoxide air quality standards. Second, it mandated reformulated gasoline with 2% oxygenates by weight to be used in cities with the worst smog pollution to reduce harmful emissions of ozone. Many regions adopted higher regulations to increase this minimum federal requirement of oxygenate content to 3 - 3.5% by weight. As a result, two fuel additives, ethanol and MTBE, became the primary choices in all non-attainment regions throughout the U.S. MTBE is refined by reacting methanol, generally obtained

4 Renewable Fuel Association, http://www.ethanolrfa.org/industry/statistics/.

from natural gas, with isobutylene. The substitutability between ethanol and MTBE, taking a 2.7% oxygenate fuel requirement as an example, is that the standard can be met by either a 7.7% ethanol blend or a 15% MTBE blend.

MTBE was cheaper than ethanol (Zhang et al, 2007). The Environmental Protection Agency (2008) reports that the market share of ethanol had been merely half of MTBE until the ban of MTBE use in several states from 2002. MTBE was found to contaminate ground and surface waters and many states began to ban its use. By 2005 a total of 16 states had banned MTBE with other states either phasing out MTBE within two years or considering similar bans. California and New York, which together accounted for 40% of U.S. MTBE consumption, banned the chemical starting January 1, 2004, and as of September 2005, twenty-five states had signed legislation banning MTBE (EPA as reproduced in Biofuels Journal, 2005). So MTBE had actually been eliminated from the additive market by 2008, leaving ethanol as the only qualified player at least at recent prices.

2. As an alternative fuel

Demand for ethanol as a competing source of motor fuel mainly comes from E10, and also some from demand for E85. In 2005, 3.9 billion gallons of ethanol were produced in the U.S., and net imports were 0.13 billion gallons, so a total of 4 billion gallons ethanol were supplied. But only about 40 million gallons were used as E85, 1% of overall ethanol demand from 240 thousand FFVs.[5] This quantity is very small but growing fast. For 2005, the Energy Information Agency (EIA) estimates that the number of E-85 vehicles that are capable of operating on E85 and gasoline is about 5 million. Many of these FFVs are sold and used as traditional gasoline-powered vehicles. EIA estimates the amount of FFVs that are believed to be used as FFVs were 120 thousand in 2002.[6] Those are primarily fleet-operated vehicles. And this number doubled in 3 years to 240 thousand in 2005. So about only 5% of FFVs were actually using E85, even though the number of FFVs on road was much bigger.

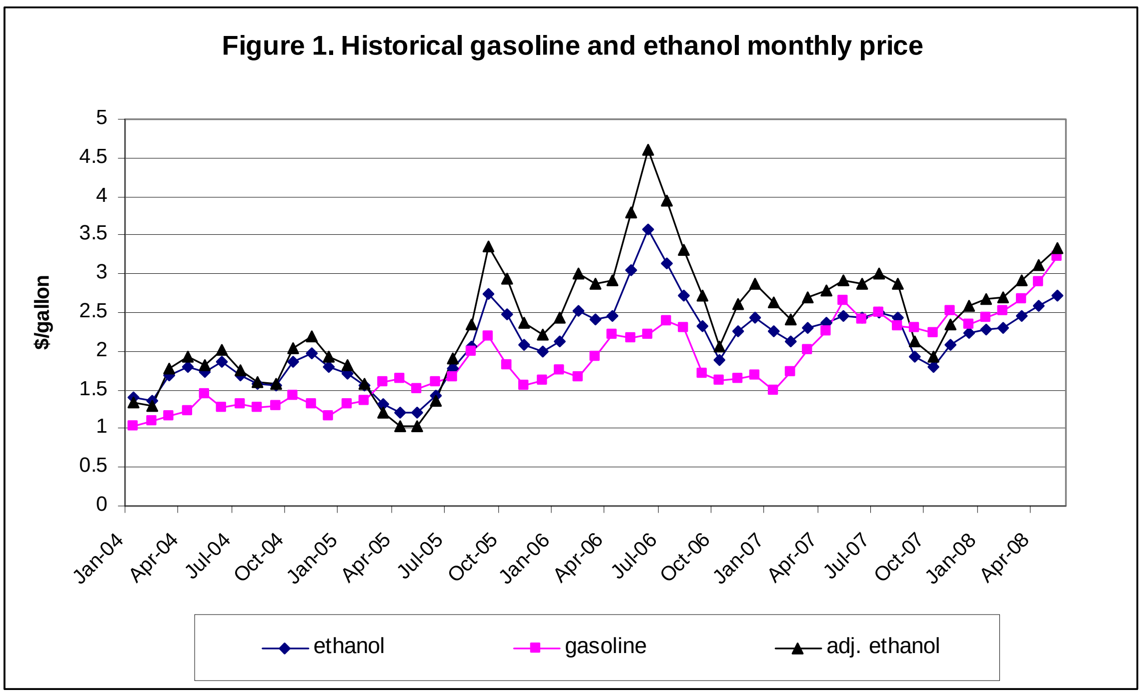
Based on this estimation, we can safely say the market potential for E85 is far from being saturated. A big concern about expanding the use of E85 used to be the compatibility of vehicles with E85. But the market can actually absorb 20 times of the E85 use in 2005, which would be 800 million gallons of ethanol. As the distribution of FFVs spread in recent years, a bigger market potential is expected for E85. And this paper will assume ethanol extension not be limited by small stock of FFVs.

Currently, ethanol does not have much competitiveness with respect to gasoline due to its higher price based on its energy content. In April 2008, national average ethanol rack price was about $2.75/gallon.[7] Meanwhile, the average U.S. gasoline retail price was $3.50 per gallon.[8] Since ethanol's energy content is about two thirds of gasoline, the ethanol price was still twenty cents higher than gasoline on an energy basis. But as

[5] Calculated from the EIA (2007).
[6] Calculated from the EIA (2007).
[7] DTN ethanol center, http://www.dtnethanolcenter.com/index.cfm?show=10&mid=32.
[8] DTN ethanol center, http://www.dtnethanolcenter.com/index.cfm?show=10&mid=32.

gasoline price moves upward, ethanol is gradually gaining a competitive margin. Meyer and Meyers (2008) traced the demand curve of 10% ethanol blend and 85% ethanol blend. The results showed when energy content adjusted price of ethanol blended gasoline fell to same as gasoline price or lower, the demand would be price responsive and elastic in the long run. The historical ethanol and gasoline prices are shown in Figure 1. The adjusted ethanol price is calculated as the ethanol price minus the $0.51/gallon tax credit and then times its energy content ratio compared to gasoline.

Figure 1 Historical Gasoline and Ethanol Monthly Price



Source: Nebraska Energy Office.

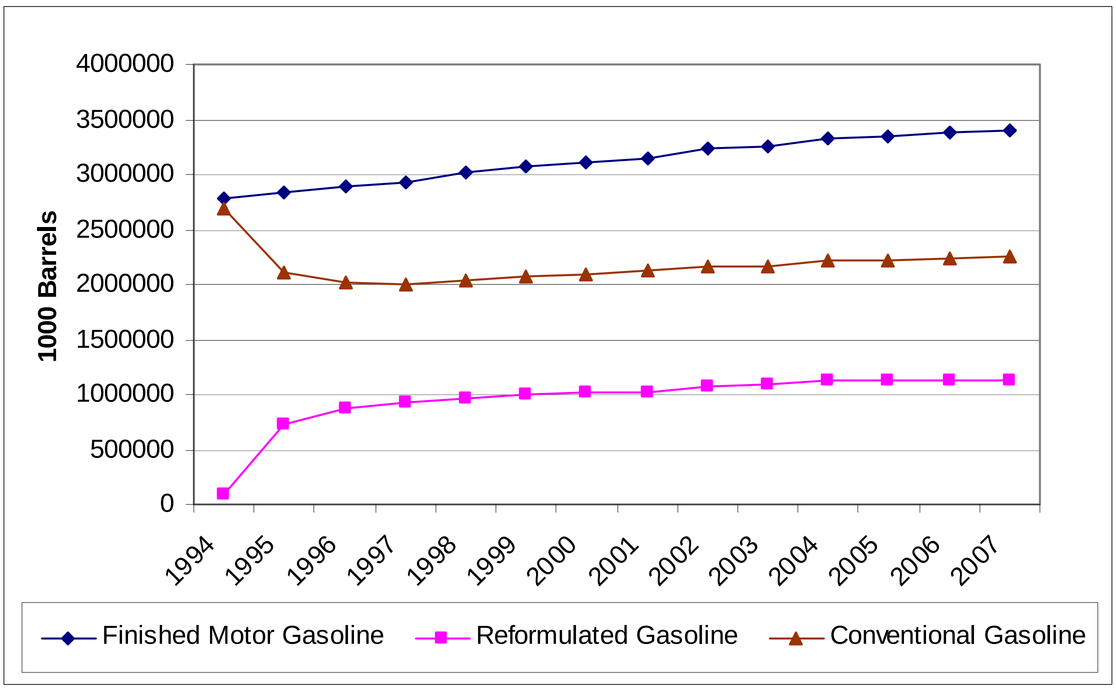
Gasoline Market

Contrary to the limited research on the ethanol market, the motor fuel gasoline market has been studied very frequently. From Energy Information Administration statistics, U.S. crude oil production has been decreasing since 1980s. In 2007, 1.86 billion barrels of crude oil were produced compared to the 3.1 billion barrels production in 1980. And importation has increased from about 2 billion barrels in 1980 to 3.6 billion barrels in 2007. For each barrel of crude oil, about 20 gallons gasoline can be produced. In the United States, about 2/3 of all oil use is for transportation. Gasoline, in turn, accounts for about 2/3 of the total oil used for transportation in the United States. Thus, gasoline represents 45% in all US transportation oil consumption.

Government regulations in recent years have created a variety of gasoline grades to meet different regional environmental records. As mentioned earlier in the discussion about gasoline additives, the 'reformulated gasoline', designed to control ground-level ozone, is largely a phenomenon of the Northeast and some large cities elsewhere in the country. In addition, California requires a special version of reformulated gasoline. Reformulated gasoline accounts for about 30 percent of nationwide gasoline consumption. 'Oxygenated' gasoline is required during the cold months in areas where carbon monoxide levels are high. But even during the October - March gasoline season, this special gasoline for these areas accounts for less than 10 percent of the nationwide total.

So, now motor fuel gasoline is mainly divided into two large categories: the conventional gasoline and reformulated gasoline (RFG). In 2007, RFG supply was 1.13 billion gallons, and conventional gasoline was 2.26 billion gallons, twice as much as RFG. In EIA statistics, the two sum up as the Finished Motor Gasoline Product Supply. These two gasoline demands will be the research target in this paper. Figure 2 shows the constitution of U.S. motor gasoline produced each year.

Figure 2 Constitution of U.S. Motor Gasoline Production



Source: EIA, as described in the text.

For competitive motor fuels, E10 fuel is widely available in many states, but E85 has limited availability, at stations clustered mostly in the mid-western states. E10 has 3.3 percent less energy content per gallon than conventional gasoline. E85 has 24.7 percent less energy per gallon than conventional gasoline. So that 1.03 gallons of E10 or 1.33

gallons of E85 are needed for a vehicle to cover the same distance than it would with a gallon of conventional gasoline. Although the difference is not expected to have a significant effect on purchases of E10, EIA (2007A) assumes that motorists whose vehicles are able to run on E85 or conventional gasoline will compare the two fuels on the basis of price per unit of energy. There may also be some institutions using E85 from supporting public interest. But this assumption will be kept in this paper.

Relevant Policy Evolution

There are many policies supporting the use of ethanol. Both economic incentives and use mandate have been created for the ethanol industry. The U.S. ethanol fuel industry has experienced preferential treatment from federal and state governments ever since the Energy Tax Act of 1978, when the 10% ethanol tax was exempted for ethanol and gasoline blend (gasohol). Combined with a 54¢ per gallon ethanol import tariff, this exemption was designed to provide incentives for the establishment and development of a U.S. ethanol industry. The American Jobs Creation Act of 2004 (JOBS Bill), which was signed into law in October of 2004, created the Volumetric Ethanol Excise Tax Credit (VEETC), assigning fuel ethanol blended into gasoline a 51 cents/gallon tax credit. The Energy Policy Act 2005 extended it to end of 2008. The Farm Bill 2008 reduced the 51¢ per-gallon incentive to 45¢ per gallon for calendar year 2009 and thereafter. But the reduction will be delayed if a threshold of 7.5 billion gallons per year of ethanol produced in or imported into the United States (including cellulosic ethanol) is not met. As noted by Harris (2008), the farm bill also included a new, temporary cellulosic biofuels production tax credit for up to $1.01 per gallon to help get these fuels to commercial viability. The credit is available through December 31, 2012. The bill extended the tariff on imported ethanol for two years through December 31, 2010 (Harris, 2008).

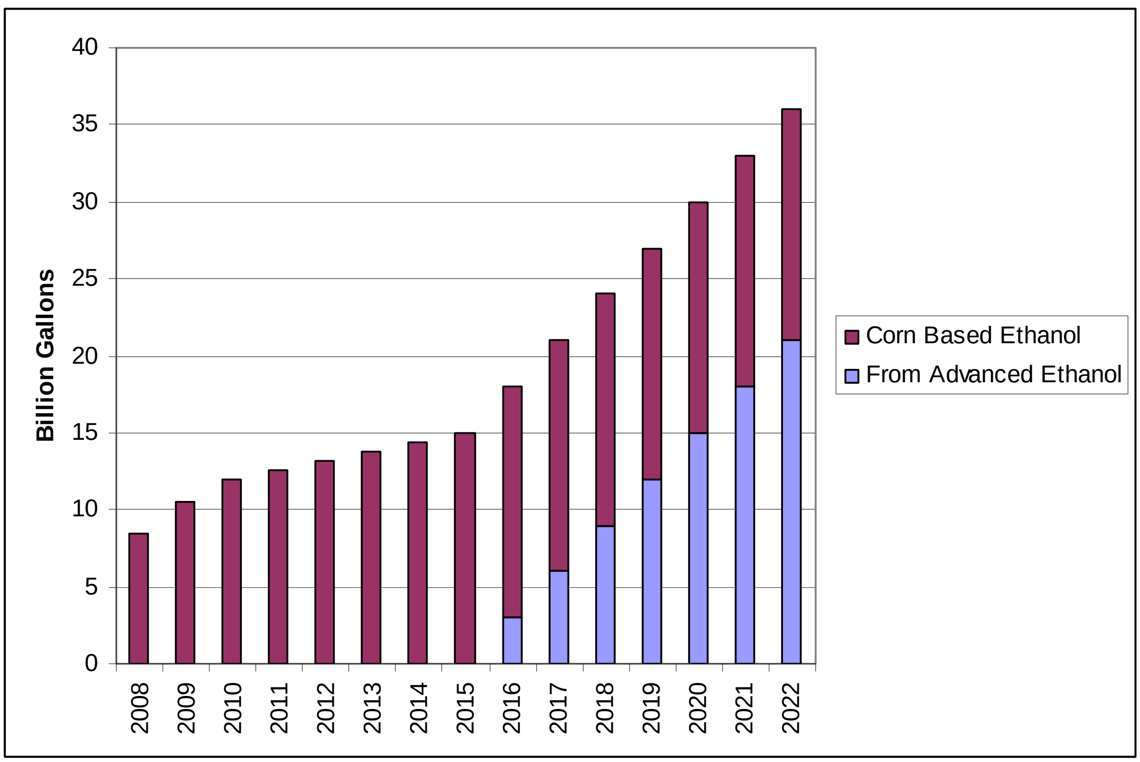
Besides the economic incentives stated above, a mandate has also been placed on bio-fuel use. Clean Air Act Amendments of 1990 established Oxygenated Fuels Program and Reformulated Gasoline (RFG) Program, which created demand for additive MTBE and ethanol. The ban and phase out of MTBE use in early 2000s left ethanol as the only additive in the market. But the Energy Policy Act of 2005 eliminated the federal RFG requirement. However, Energy Policy Act of 2005 also set up the Renewable Fuel Standard (RFS), which established a minimum mandate amount for bio-fuels use each year, mainly ethanol. Starting at 4 billion gallons in 2006, bio-fuel use should increase each year by 700 million gallons, and finally reach the level of 7.5 billion gallons in 2012. After 2012, renewable fuel production must grow at least the same rate as gasoline production. In 2007, the EISA of 2007 modified the Renewable Fuels Standard. In 2008, the minimum renewable fuel use starts at 9.0 billion gallons, and the mandated use should rise to 36 billion gallons by 2022. And of the 36 billion gallons in 2022, 21 billion gallons is required to be obtained from cellulosic based ethanol and other advanced biofuels. But the major content still consists of ethanol, and little is bio-diesel and other bio-mass, whose mandate is 0.5 billion gallons in 2009 and 1 billion gallons in 2012. Only up to 15 billion gallons of ethanol based on corn starch can count towards the mandate, though more production is not limited. The exact annual mandate level is listed in Table 1 and Figure 3.

Table 1 Proposed H.R.6 Expansion of Renewable Fuels Standard

	Biofuel mandate	Portion from advanced biofuel (not corn based)	cap on corn based ethanol
	billion gallons	billion gallons	billion gallons
2008	8.5		8.5
2009	10.5		10.5
2010	12		12
2011	12.6		12.6
2012	13.2		13.2
2013	13.8		13.8
2014	14.4		14.4
2015	15		15
2016	18	3	15
2017	21	6	15
2018	24	9	15
2019	27	12	15
2020	30	15	15
2021	33	18	15
2022	36	21	15

Source: http://assets.opencrs.com/rpts/RL34265_20071203.pdf.

Figure 3 Biofuel Mandate in EISA 2007



Source: http://assets.opencrs.com/rpts/RL34265_20071203.pdf.

Distribution of ethanol to blenders is recorded by a credit trading system, as described in Texas State Energy Conservation Office: “under the RFS, refiners can receive credits for renewable fuels blended above the baseline. This gives gasoline suppliers the flexibility to use less renewable fuel than required by the RFS and still meet the standard by purchasing credits from suppliers who choose to use more renewable fuel than required.”[9]

CHAPTER II. METHOD

There have been several papers discussing ethanol and gasoline market relationship from different perspectives. First, literature is reviewed and then the model is described.

Literature Review

FAPRI Missouri has conducted a series of research (from 2005 to 2008) on the relationships among ethanol, commodity and gasoline markets. Meyer and Meyers (2008) studied the volatility brought into commodity market from bio-fuel production using stochastic modeling analysis. FAPRI-MU report #01-08 (2008) analyzed the bio-fuel provisions in EISA of 2007. They found lower petroleum prices were associated with lower biofuel prices and production levels, when mandate was not binding. When petroleum prices were sufficiently high, corn-based ethanol production would be likely to

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[9] See http://www.seco.cpa.state.tx.us/re_ethanol_incentives.htm.

exceed the levels specified in EISA. A 15 billion gallons biofuel use mandate to 2015 was also analyzed (FAPRI-MU, 2007). Results showed domestic use of ethanol and biodiesel might slightly exceed the mandate on average. The mandate was most likely to be exceeded if high petroleum prices increase market demand for biofuels. The mandate was usually binding when petroleum prices are low. But the petroleum market was not endogenized into the model. There are also studies focusing on the impact on commodity markets from bio-fuels production and policies (Kruse et al, 2007).

Tyner and Taheripour (2007) studied the market integration of corn and energy markets. In their paper, they assumed ethanol as a substitute to gasoline without any additive use. A strong future linkage between crude oil price and corn price was found in their research. Another assumption they made was ethanol had been priced at an energy equivalent basis to gasoline. The model elasticities were taken from existing research. The model was closed by the corn market clearing condition and a zero profit condition for ethanol producers. Their paper calibrated the corn and gasoline market model using 2006 data and gasoline supply shock simulations were made based on it.

Du and Hayes (2008) analyzed the impact of ethanol production on gasoline prices and refinery profits. The method they used was regression analysis of pooled regional time-series data and panel data estimation. Ethanol price was regressed on ethanol production and other relevant variables. They found ethanol had caused retail gasoline prices to be $0.29 to $0.40 per gallon lower than without ethanol production. And ethanol production has significantly reduced the profit margin of the oil refinery industry. But they did not give an exact explanation of how the effect was transmitted.

Tokgoz and Elobeid (2007) studied the scenario of a 20% gasoline price increase in terms of the impact on ethanol market. In their paper, ethanol was mainly assumed as a complement to gasoline, which now is a little dated. They acknowledged ethanol and gasoline are substitutes, but assumed it was in a negligible amount. They used a non-spatial multi-market world model to link ethanol's production and consumption. The linkage between ethanol and energy markets was achieved by modeling demand for transportation fuels, like U.S. motor fuel consumption. Fuel-ethanol demand was a derived demand from the cost function for refiners blending gasoline with additives, including ethanol. The demand structure consisted of equations for composite gasoline consumption including unleaded gasoline and gasoline blended with ethanol, and the share of ethanol in gasoline consumption. The model also included major policy parameters like the 51¢-per-gallon volumetric ethanol excise tax credit that blenders receive for blending ethanol with gasoline, the mandated requirement of ethanol blend in certain states, and the RFS of the Energy Policy Act of 2005. In the U.S. demand model, consumer response to a decrease in the price of the composite gasoline was set as positive to capture the dominant complementary relation between gasoline and ethanol. And they also argue that the proportion of FFVs in vehicle fleets was the key to determine the direction of ethanol consumption response. In the long run, when there are more FFVs, the ethanol consumption might behave as a substitute to gasoline.

Vedenov, Duffield, and Wetzstein (2006) studied when consumers will switch from traditional gasoline to ethanol blended fuels. They calculated the threshold price to switch from gasoline to alternative E10 and E85 using a real options approach. Because historically ethanol had a much smaller price volatility than gasoline, consumers are more willing to switch to ethanol despite its lower energy content.

The most comprehensive systematic model in petroleum and energy market is the petroleum market model (PMM) maintained by the EIA. The PMM models (Brown, 2007) petroleum refining activities, the marketing of petroleum products to consumption regions, the production of natural gas liquids in gas processing plants, domestic methanol and ethanol production, and gas-to-liquids and coal-to-liquids production. The PMM projects petroleum product prices and sources of supply for meeting petroleum product demand. The sources of supply include domestic and imported crude oil; other inputs including alcohols, biodiesel, and ethers; domestic natural gas plant liquids production; petroleum product imports; unfinished oil imports. PMM also estimates domestic refinery capacity expansion and fuel consumption. Product prices are estimated at the Census Division level and much of the refining activity information is at the Petroleum Administration for Defense District (PADD) level. The essential outputs of this model are product prices, a petroleum supply and demand balance, demands for refinery fuel use, and capacity expansion. PMM inputs include petroleum product demands, domestic crude oil production levels, and information on the costs and available quantities of imports of crude oil and petroleum products. In addition, the costs of refinery inputs such as natural gas and electricity are needed, as well as the costs and available quantities of blending components such as ethanol and methyl tertiary butyl ether (MTBE). Yield coefficients for crude oil distillation and other processing units, processing unit capacities, investment costs for capacity additions, capacities and costs for pipeline and other transportation modes, and product specifications are other essential model inputs.

There have been many papers discussing gasoline market supply and demand elasticities. In Dahl and Sterner's 1991 survey, they found a significant degree of consensus with respect to short and long run own-price and income elasticities. The short-run and long run own-price elasticities were -0.26 and -0.86 on average, respectively. The long-run income demand elasticity was greater than one, whereas the short-run income elasticity was less than one. Dahl (2007) also found gasoline demand elasticity became more inelastic. The price elasticity in 1975 to 1980 was -0.3, and in 2001 to 2006 was –0.04. Basso and Oum (2007) found the most popular approach, dynamic reduced-form demand models with time-series data, had dominated the core elasticity values obtained. The model specification was $D_{g,t} = f(P_{g,t}, D_{gc,t-1}, Income_t)$. The range of elasticities in recent studies is summarized in Table 2.

Table 2 Demand Elasticity Range

	Price elasticity	Income elasticity
short run	-0.2 to -0.3	0.3 to 0.5
long run	-0.6 to -0.8	0.9 to 1.3

Source: summary of various published sources, as listed in the text.

Crude oil supply has been found very inelastic, and sometimes even with negative short run supply elasticity. Askari and Krichene (2008) estimated a short-run world crude oil and natural gas model, the world short run crude oil supply price elasticity is 0.02 for time period 1984 to 2006, and demand price elasticity is -0.02. Krichene (2002) estimated a world crude oil and natural gas supply and demand function. In the time period from 1973 to 1999, the short supply price elasticity was -0.07, and demand price elasticity was -0.02, estimated using the 2SLS method, and 0.01 and -0.02, estimated using an error correction model. The long run supply elasticity was 0.1 and demand elasticity was -0.005. For United States crude oil supply elasticity, Dahl and Duggan (1996) surveyed many literatures and found it ranged from -1.39 to -0.05 in general, and only one paper reported a short supply elasticity, namely 0.09, as well as a long run elasticity of 0.58, in the period from 1966 to 1987.

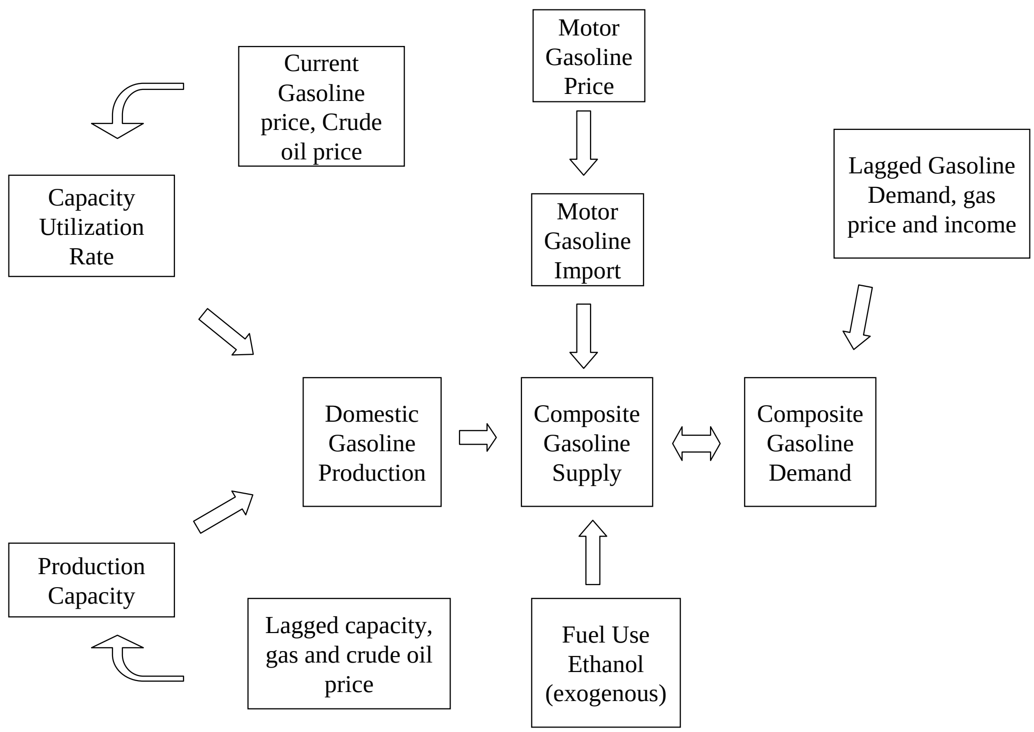
A more general study and reasons for such phenomenon was done by Ramcharran (2002). He studied crude oil production responses to price changes in OPEC and non-OPEC countries. He found the world crude oil supply was not a competitive market. The OPEC countries showed negative and significant price elasticities of supply. This result indicated OPEC countries might have set some target revenue. For most of the non-OPEC members, the estimate results supported the competitive model. And OPEC's loss of market share may tend to make this market more competitive.

Model Specification and Data

When ethanol is introduced into the motor gasoline market as an alternative fuel, the effect it will produce is like a positive supply shock, added to the original gasoline supply. The gasoline production will be less and gasoline price should fall. But for the lower fuel price, overall fuel consumption might increase. Gasoline production derived demand on crude oil will shift backward, and crude oil price also drops.

This paper builds a structural-equations model to simulate motor gasoline market's supply and demand. Market-clearing condition solves for equilibrium gasoline price. With historical data, both demand and supply equations will be estimated. Figure 4 is a brief flow chart of the model structure. Here is a detailed specification of the supply and demand equations.

Figure 4 Flow Chart of Model Structure



Supply Equations

Motor gasoline supply consists of three parts: the finished motor gasoline, which is a combination of conventional and reformulated gasoline in EIA's database, the finished motor gasoline import, and voluntary ethanol use, mainly as the ethanol component in E10 and E85. The voluntary ethanol use will increase in the future as mandate expands.

The finished motor gasoline supply will bear the major impact when fuel ethanol use rises. The domestic gasoline production is co-determined by that year's refinery capacity level times capacity utilization rate. So we have to model the true capacity and utilization rate separately. In EIA database definitions and explanatory notes page, the capacity utilization rate is defined as 'the utilization of the atmospheric crude oil distillation units. The rate is calculated by dividing the gross input to these units by the operable calendar day refining capacity of the units.'[10] This input-based definition is not directly relevant to our question of how much gasoline can be produced each year. But from the utilization rate, we can calculate the possible maximum gasoline production of that year by dividing gasoline production by utilization rate. So

$$Capacity_{g,t} = Q_{g,t} / Utilization_t \qquad (3)$$

is the output-based capacity variable in the model. $Q_{g,t}$ is the domestic motor gasoline supply of year t.

The net capacity change is modeled as an investment function of last year gasoline price and crude oil price. Refiners will choose to change capacity of this period based on last period gasoline and crude oil prices. The capacity function is specified as

$$Capacity_{g,t} - Capacity_{g,t-1} = f(P_{g,t-1}, P_{cr,t-1}, \varepsilon) \qquad (1)$$

However, capacity utilization rate reflects refiners' current period margin, and is a function of gasoline and current year price of crude oil. The utilization rate is modeled in the logit form to avoid boundary problems,

$$\ln\left(\frac{Utilization_t}{1 - Utilization_t}\right) = f(P_{g,t}, P_{cr,t}, \varepsilon) \qquad (2).$$

To better represent the refinery sector of gasoline market, the crude oil price is also endogenized as function of the sum of gasoline production and import,

[10] See http://tonto.eia.doe.gov/dnav/pet/TblDefs/pet_pnp_unc_tbldef2.asp.

$$P_{cr,t} = f((S_{g,t} + S_{imp,t}), \varepsilon) \quad (4).$$

This specification is not very sufficient to represent the effect of U.S. crude oil consumption on world crude oil price. To compare the estimated parameter with other research, a synthetic parameter is also calculated to make projections for 2008 to 2022 period. The synthetic elasticity of crude oil excess supply to U.S. is calculated by world crude oil supply elasticity times the multiple of world crude oil supply over U.S. crude oil consumption, minus the product of demand elasticity from rest of the world and multiple of rest of the world crude oil demand over U.S. crude oil demand,

$$\varepsilon_{ES,US} = \varepsilon_{S,W} \, S/ES_{US} - \varepsilon_{D,ROW} \, D_{ROW}/ES_{US} \quad (5).$$

Each year about 5% of US finished motor gasoline is imported. This part of supply is very price sensitive. So gasoline import is specified as a function of domestic gasoline price,

$$S_{gimp,t} = f(P_{g,t}, \varepsilon) \,. \quad (6)$$

The leftover source of fuel considered here is ethanol use excluding mandate use, namely the voluntary ethanol use. This part of ethanol is not added to gasoline as an additive but as a substitute fuel, like E85. Its existence has been negligibly small compared to the 140 billion gallons annual gasoline consumption. The quantity of voluntary ethanol use is also very tricky. There are no data on how much ethanol is used voluntarily, so this volume is calculated based on other information. The calculation will be discussed in the data section. Since 2008, Clean Air Act’s additive regulation expired and ethanol will be mainly used as fuel, and mandate quantity will replace the voluntary use ethanol for projections. The voluntary ethanol use is treated as exogenous.

Demand Equation

All three sources of supply are converted into one composite gasoline quantity, which is here considered as one demand equation:

$$D_{gc,t} = f(P_{g,t}, D_{gc,t-1}, Income_t, \varepsilon) \qquad (7).$$

The underlying assumption here is consumers will choose ethanol at its energy content ratio compared with gasoline. The other assumption to permit this simplification is that there are enough FFVs in market to consume the E85. As discussed previously, this is a reasonable assumption. If all ethanol were primarily used as E10, then it would be 14 billion gallons a year, far more than current mandate level. And as manufactures roll out more FFVs, E85 can be consumed by market.

This simplified specification of demand captures the main motor fuel consumption trend instead of estimating separate demands for gasoline and ethanol. This is a better way not only for data availability of short period fuel-use ethanol, but also because motor fuel has been very steady in history. Thus, one main equation will be the best choice to represent motor gasoline consumption behavior.

Market Clearing Conditions

Market is cleared when total supply equals demand at

$$D_{gc,t} = S_{finished\_gasoline} + S_{gas\_import} + S_{ethanol} * (ethanol\_energy\_content) \qquad (8).$$

In this model, composite gasoline demand, gasoline import and domestic gasoline production are estimated over historical data. Historical voluntary ethanol is calculated and treated as exogenous. Future ethanol supply quantity is set by mandate level or, alternatively, held constant. Other exogenous variables are the macroeconomic data: real GDP and GDP deflator. Gasoline price, gasoline production capacity, import, crude oil price and capacity utilization rate are endogenous in the model.

Ethanol Expansion Scenarios

The fuel ethanol use scenario in this model is based on EISA 2007's mandated bio-fuel use, assuming all mandate bio-fuels are ethanol. According to the latest 2007 Renewable Fuel Standard, 9 billion gallons of renewable fuels, mostly ethanol, are required in 2008. And this mandate will increase steadily to 15.2 billion gallons in 2012 and to 36 billion gallons in 2022.[11] Based on Renewable Fuel Association's latest data, the current ethanol production capacity is 8.8 billion gallons per year, and capacity under construction is 4.8 billion gallons, only a little more than current mandate level.[12] Thus, it is safe to use the mandate amount as ethanol supply scenario. Ethanol supply is exogenous, so changes are readily incorporated. The comparative scenario is based on the assumption that ethanol quantity will remain at the 2008 level.

[11] See http://www.seco.cpa.state.tx.us/re_ethanol_incentives.htm.
[12] See http://www.ethanolrfa.org/industry/locations/.

Data Description

Data used in modeling procedure are mainly obtained from two sources: EIA for gasoline industry data and BEA for macro data. Descriptive statistics of the data used are listed in Table 3.

The gasoline quantity data used in domestic supply is the 'Finished Motor Gasoline' category in EIA petroleum database. 'Finished Motor Gasoline' is the sum of reformulated gasoline and conventional gasoline supplied. For reformulated gasoline, the additive ethanol and MTBE volume are included in final data. They are not isolated because they are part of the finished gasoline component. Gasoline price is the retail level motor gasoline price. The price is in real terms, which has been calculated by EIA, chained in 2000 dollars by GDP deflator. The crude oil price used in this paper is 'Refiner's Acquisition Cost of Crude Oil', composite of imported and domestic crude oil. For gasoline suppliers, consider blenders and refiners as one agent, whose marketing margin is decided by retail gasoline price and crude oil price. Capacity utilization rate is the operable utilization rate. Refinery capacity is calculated by gasoline production divided by capacity utilization rate. 'Finished Motor Gasoline import' data are from total net imports of all countries, of the same goods as are included in domestic 'Finished Motor Gasoline'.

Table 3 Data descriptive statistics

	Real GDP	*Gasoline Production*	*Real Gasoline Price*	*Real Crude Oil Price*	*Gasoline Net Import*	*Ethanol*	*Capacity Utilization*	*Refinery Capacity*
Unit	Billion Dollars	Billion Gallons	$/Gallon	$/Gallon	Billion Gallons	Billion Gallons	%	Billion Gallons
Mean	8593.18	123	1.51	0.63	4.45	0.78	87.97	140
Standard Error	361.55	2.58	0.07	0.06	0.27	0.07	1.39	2.22
Median	8328.34	121	1.38	0.54	4.38	0.72	90.7	141
Standard Deviation	1733.92	12.37	0.33	0.27	1.31	0.32	6.66	10.63
Range	5513.55	37.7	1.28	1.04	4.97	1.48	18	35.67
Minimum	6052.87	105	1.16	0.31	2.19	0.41	77.6	125
Maximum	11566.42	142	2.44	1.35	7.16	1.89	95.6	161
Sum	197643.1	2830	34.84	14.56	102	18.03	2023.4	3220
Count	23	23	23	23	23	23	23	23

The macro data are downloaded from Bureau of Economic Analysis. The data include population, real GDP which is chained in year 2000 dollar value, and a GDP deflator. Projections of macro data are obtained from Global Insight 2007.

The voluntary ethanol use is very tricky. There has been no definite data on what percentage of ethanol is used as an additive, and how much is used as fuel. The additive use also varies sharply due to policy changes in recent years, such as the ban on MTBE. So here the voluntary ethanol use must be inferred from other information sources.

Previous to the Clean Air Act, no RFG was required in market. Thus, although there had been MTBE and ethanol added into gasoline prior to RFG, it was on voluntary basis, and blenders have to consider the energy content loss. Only after the Clean Air Act passage did the ethanol and MTBE additive use become compulsory. So if the additive use ethanol can be inferred, the rest of the ethanol use could be ascribed into voluntary use.

EPA (2008) reports the percentages of summer RFG oxygenated by ethanol and MTBE, which sum up to 100%. The data range from 1996 to 2005 and the share of ethanol increased from 11% to 53%. Assuming the share remains the same throughout the year, the quantity of RFG using ethanol can be calculated. And taking a step further, multiply the ethanol oxygenated RFG quantity by the minimum 7.7% additive ethanol volume ratio. This product is the additive use ethanol. Voluntary ethanol use is then the annual ethanol production minus additive ethanol use, and times its 66.7% energy content ratio compared to gasoline. Since in EIA’s database, RFG was reported from 1994, so we assume ethanol's additive market share in 1994 and 1995 were the same as 1996. And by 2006, most states had banned MTBE use, so ethanol's share is set to be 100%. Detailed calculations are shown in Table 4.

The annual data period of regression is 1985 to 2007 because the earliest utilization rate data provided by EIA are from 1985 and gasoline price data end in 2007. EIA data on ethanol production start from 1992, but there has been recorded ethanol use before that year. So ethanol production from 1985 to 1991 are from the Renewable Fuel Association, with all ethanol assumed to be voluntary fuel use.[13]

CHAPTER III. MODELING RESULTS

The system of structural equations is estimated using the Statistical Analysis System (SAS). Some potential statistical problems are discussed at first. Then elasticities estimated from the equations will be reported and then compare them with previous research. Next is how predicted values fit historical data. Finally is projection for future ethanol mandate scenario.

[13] See http://www.ethanolrfa.org/industry/statistics/.

Table 4 Calculated Voluntary Ethanol Use

Year	Ethanol Production, 1000 barrels	RFG Production, 1000 Barrels	% of RFG using ethanol	volume of RFG using ethanol	ethanol use volume	voluntary ethanol use, 1000 barrels	Voluntary ethanol, 1000 gasoline equivalent gallons
column	A	B	C	D=B*C	E=D*0.077	F=A-E	G=F*42*0.67
1994	30477	86485	0.11	9513.35	732.53	29744.5	832845
1995	32242	735319	0.11	80885.1	6228.2	26013.9	728388
1996	23177	874631	0.11	96209.4	7408.1	15768.9	441529
1997	30703	931662	0.1	93166.2	7173.8	23529.2	658818
1998	33048	969295	0.11	106623	8209.9	24838.1	695466
1999	35005	1008099	0.12	120972	9314.8	25690.2	719325
2000	38854	1010860	0.12	121303	9340.3	29513.7	826382
2001	41973	1022181	0.15	153327	11806	30166.8	844671
2002	50937	1067870	0.18	192217	14801	36136.3	1011817
2003	66732	1093245	0.37	404501	31147	35585.5	996393
2004	81009	1123142	0.54	606497	46700	34308.8	960645
2005	92961	1133003	0.53	600492	46238	46723.2	1308248
2006	116294	1132518	1	1132518	87204	29090.1	814523
2007	154416	1129654	1	1129654	86983.4	67432.6	1888114

- In blue tile are made up numbers

Source: raw data of columns A and B are from EIA and calculations of other columns are defined in the text.

Estimation Method and Possible Problems

The whole model consists of 7 equations and identities. They are listed as follows. Equations (11) and (15) are identities and the rest are equations with parameters to be estimated.

$$Capacity_{g,t} - Capacity_{g,t-1} = f(P_{g,t-1}, P_{cr,t-1}, \varepsilon) \quad (9)$$

$$\ln\left(\frac{Utilization_t}{1 - Utilization_t}\right) = f(P_{g,t}, P_{cr,t}, \varepsilon) \quad (10)$$

$$Capacity_{g,t} = Q_{g,t} / Utilization_t \quad (11)$$

$$P_{cr,t} = f((S_{g,t} + S_{imp,t}), \varepsilon) \quad (12)$$

$$S_{gimp,t} = f(P_{g,t}, \varepsilon) \quad (13)$$

$$D_{gc,t} = f(P_{g,t}, D_{gc,t-1}, Income_t, \varepsilon) \quad (14)$$

$$D_{gc,t} = S_{finished\_gasoline} + S_{gas\_import} + S_{ethanol} * (ethanol\_energy\_content) \quad (15)$$

The 7 equations and identities are estimated together in SAS through 'proc model' procedure. Because these variables comprise a system of equations and contains both non-linear and linear equations, the SAS proc model procedure can estimate the parameters at first, and save the parameters. Then the model can be used to simulate and make forecast for future time period. The estimations method used is Ordinary Least Square (OLS).

There also might be several technical problems with the system of structural equations. First is endogeneity. Endogeneity may happen when the independent variable is correlated with the error term in a regression model. In such case, the OLS estimator is biased and instrument variables should be used. The equations mostly likely to have such problem are (9), (10), and (13) because of the few variables involved. But with respect to the instrumental variable approach, the two-stage-least-square method cannot be supported by the limited number of data. And in a competitive market, prices were purely decided by demand and supply, so we can assume the price variables are not correlated with other factors.

The multicolinearity also comes up in the model. In equation (9), the correlation between real gasoline price and real crude oil price reaches 98%. So parameter significance level for the two variables will be affected. But in order to keep the economic meaning of the parameters, the original specification is kept.

Serial correlation is also identified in several equations by Durbin-Watson statistics. So the significance level might be actually lower for some variables than the t-statistic indicates. Another possible problem is omitted variables, which is related to serial correlation problems. There might not be enough lag terms included in some equations, such as the capacity investment function, and gasoline import function. Given the simplicity of model specification, many factors affecting dependent variables cannot be represented. This is another source of estimator bias.

Estimated Elasticities

The estimated elasticities for the five equations are represented in Table 5. The price elasticity of demand is –0.052 in short run, which is lower in absolute value than other research, from –0.2 to –0.3 in short run. But as Dahl (2007) found, gasoline price elasticity in 2001 to 2006 was –0.04, more inelastic than previous years. So it is possible that the elasticity is lower in absolute value when using recent years data. For the long run elasticity it is –0.47, much closer though still more inelastic than the –0.6 to –0.8 range. And the inelastic character is consistent with other research. The income elasticity is positive at 0.11 in short run and 1 for the long run, which falls into the range of 0.9 to 1.3. The regression results also indicate a large lagged dependent effect.

Import supply elasticity of gasoline price is positive at 0.52, which is inelastic. The net capacity increase is very elastic on both lagged gasoline price and lagged crude oil price, and more elastic on output price. Utilization rate is positive on gasoline price, and elastic at 1.42, while it is negatively inelastic on crude oil price, which is –0.75.

The crude oil price flexibility on gasoline import and production is 2.8, implying a relatively low price elasticity of 0.36. In such case, a big price adjustment in the crude oil market is expected when ethanol reduces derived demand from gasoline production. Due to concerns in specification of the crude oil price equation, a synthetic crude oil supply elasticity on price is calculated to reflect price effect brought about by changes in U.S. import demand. According to International Energy Agency (IEA) data, in 2005, crude oil supply in U.S. was 788 million tons, and world supply was 3665.5 million tons. Krichene (2002) estimated a long run world supply elasticity of 0.1 and demand elasticity at -0.005. Use -0.005 to represent rest of the world demand elasticity using formula 5, above, the excess supply elasticity of crude oil to U.S. is about 0.48, and price flexibility is about 2.1, lower than the estimated value. For comparison, a projection based on this synthetic elasticity is also made.

Table 5 Estimated Elasticities

Dependent Variable	Gasoline price	Crude oil price	Gasoline price lag	Crude oil price lag	Gas demand lag	Real GDP	Gas production + gas import
Import	0.52						
Net capacity increase			26.85	-12.47			
Demand	-0.052				0.89	0.11	
Crude oil price							2.8*
Utilization rate	1.42	-0.75					

* price flexibility

Table 6 Coefficients and Significance

	gasoline price	crude oil price	gasoline price lag	crude oil price lag	gas demand lag	real GDP	gas production and import	R square	D-W
import	1.5 (1.91^{**})							0.15	0.76
net capacity increase			21.5 -1.28	-24.5 (-1.20)				0.08	1.36
demand	-4.4 (-2.62^{***})				0.89 (5.86^{**})	0.0016 (1.53^{*})		0.99	1.45
crude oil price							0.0141 (4.0^{***})	0.44	0.42
utilization	7.78 (3.92^{***})	-9.91 (-3.95^{***})						0.45	0.99

***, ** and * represent significance level at 5%, 10% and 15%.

Fit of Historical Data

The 5 equations for motor gasoline import, net production capacity increase, gasoline composite demand, crude oil price, and capacity utilization rate are estimated as a group of equations. Table 6 lists the coefficients of the variables for each equation. All parameter signs are as expected. The t-statistics are in parentheses. The superscripts indicate significance level from 5% to 15%. Of all independent variables, only lagged gasoline price and lagged crude oil price for net gasoline capacity increase fail to be significant on 15% level, while others all are significant. This is due to the highly colinearity between the two variables. One possible problematic coefficient is the large lag dependent gasoline composite demand, which is 0.89. The reason for such a high estimator might suggest a very slow change in gasoline consumption patterns.

The R-squared values range from 0.08 to nearly 1. Net capacity investment each year is the poorest equation by this measure of fit, possibly because the investment decision includes numerous factors that are hard to capture. Gasoline import also fits historical data poorly. Crude oil price and utilization rate have similar R-squared values close to 0.5. The demand data is nearly fully explained by explanatory variables. Positive auto-correlation is exhibited in all equations. D-W values range from 0.76 to 1.36. And for the demand equation is 1.45, but not valid due to the lag dependent variable included. So the actual t-statistics values may not be as high as reported.

Future Scenario and Projection

Based on the estimated motor gasoline demand-supply system, a future projection can be calculated given exogenous variables. The scenario to be studied here is the fuel ethanol expansion as the mandate of the in EISA of 2007 requires. In EISA 2007, renewable bio-fuels are mandated to increase from 9 billion gallons in 2008 to 36 billion gallons in 2022. For renewable fuels, both ethanol and bio-diesel are applicable. But bio-diesel may only be a small proportion, which is 0.5 billion gallons in 2009 and 1 billion in 2012. So here the scenario will assume all bio-fuel consists of ethanol only. The future ethanol supplied to market is the mandate level listed in Table 1, and adjusted by the energy content ratio. The base scenario is compared to an alternative in which ethanol supply remains at the 2008 level of 8.5 billion gallons.

First is the results based on estimated parameters. Table 7 summarizes the comparison of two different scenarios at year 2009 and 2022. Under both scenarios, real gasoline price is projected to rise. But if ethanol use expands as mandated, real gasoline price will be $0.27 less than if not. And impact of more ethanol on the gasoline price will increase as the supply of ethanol takes bigger share of gasoline consumption. Despite the rise of the gasoline price, composite gasoline consumption will increase too. This result mainly comes from the increase of real GDP and ethanol plays a small role. If ethanol supply remains at the 2008 level, motor fuel consumption will still increase by 32 billion gallons from 2009 to 2022. The expansion of ethanol will only cause 3% more motor fuel use in 2022 compared to no ethanol expansion.

Table 7 Scenario Comparision, by estimated parameters

	Ethanol Expands As RFS		Ethanol Use Same as 2008	
	2009	2022	2009	2022
Real Gasoline Price ($/gallon)	2.36	2.69	2.39	2.96
Real Crude Oil Price ($/gallon)	1.32	1.61	1.34	1.8
Gasoline Production (billion gallons)	141	160	142	173
Gasoline Production Capacity (billion gallons)	167	199	167	206
Capacity Utilization Rate	84.22	80.48	84.91	83.95
Gasoline Import (billion gallons)	4.2	4.7	4.2	5.1
Composite Gasoline Consumption (billion gallons)	152	189	152	184

Table 8 Scenario Comparision, by synthetic parameters

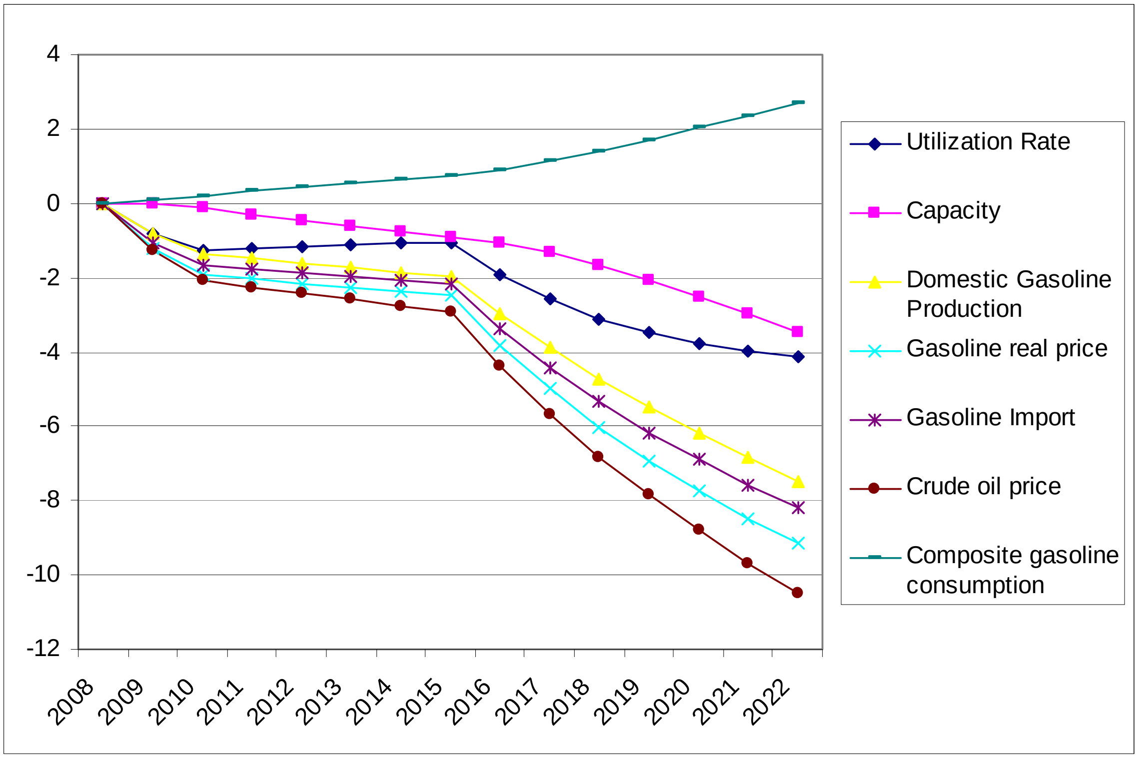
	Ethanol Expands As RFS		Ethanol Use Same as 2008	
	2009	2022	2009	2022
Real Gasoline Price ($/gallon)	2.37	2.62	2.39	2.85
Real Crude Oil Price ($/gallon)	1.33	1.55	1.34	1.7
Gasoline Production (billion gallons)	141	162	142	176
Gasoline Production Capacity (billion gallons)	167	199	167	206
Capacity Utilization Rate	84.16	81.25	84.87	85.17
Gasoline Import (billion gallons)	4.2	4.6	4.2	4.9
Composite Gasoline Consumption (billion gallons)	152	190	152	186

Gasoline production increase will be more affected by ethanol expansion. Without ethanol expansion, gasoline production will increase by 31 billion gallons from 2009 to 2022. The introduction of 36 billion gallons of ethanol will offset 13 billion gallons of gasoline production in 2022. And gasoline production would reach 160 billion gallons rather than 173 billion gallons.

The rise in gasoline price gives incentive to refinery capacity investment, which is fairly sensitive to output price change. Capacity is projected to rise to about 206 billion gallons a year in 2022 without ethanol expansion, and 199 billion if the ethanol mandate applies. But utilization rate falls by 4% or 1% to 2022 depending on the amount of ethanol. The increase in fuel supply over time will lead to crude oil price increases. And crude oil price will be affected by ethanol use too, through demand derived from gasoline output. In 2022, the use of ethanol will reduce crude oil price by $0.19 per gallon relative to the case without mandate.

Gasoline import will increase by 0.5 billion gallons because of rising gasoline price when ethanol mandate applies. If ethanol remains at the 2008 level, the imports will rise by 0.9 billion gallons, still relatively a small proportion to overall motor fuel consumption. By way of comparison, the ethanol production increase will lead to a reduction in imports of 0.4 billion gallons as compared to the case of flat ethanol use. The percent changes in gasoline market caused by the increase in ethanol use as compared to the scenario with flat ethanol use are shown in Figure 5.

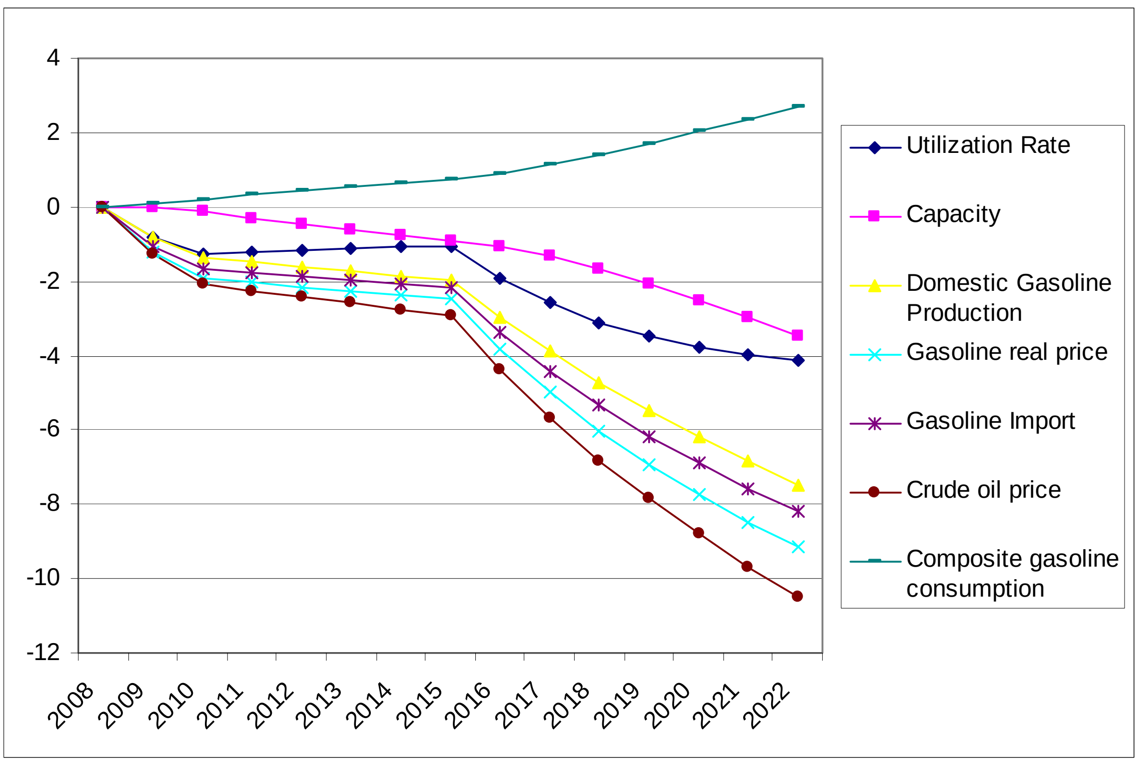
Figure 5 Percent Of Change Caused by Ethanol Expansion, estimated parameters



Source: calculations based on model results.

Table 8 summarized the results obtained by synthetic estimators for crude oil price. The price flexibility synthetically calculated is smaller than estimated, so crude oil price will not rise as much as in the case of the model with estimated parameters. In 2022 and in the case that ethanol use is unchanged, real crude oil price will be $0.1 less than the estimated parameter model, and so the gasoline price is about $.11 less. The implication of flat ethanol use on crude oil price will change. The increase in crude oil price in 2022 with lower ethanol use is 9% with synthetic parameters instead of 11% in the case of estimated parameters. Lower crude oil price in the scenario of expanding ethanol use leads to a slightly higher gasoline production and consumption. The real gasoline price will also not rise as much. The exact percent of changes in gasoline market compared to the base scenario are shown in figure 6. The scale of change is smaller than in the case with estimated parameters. But the change in capacity level is nearly the same as it was observed in the case with estimated parameters. The reason for the very small change in capacity in two cases is the close crude oil and gasoline price coefficients for capacity. When crude oil price changes, gasoline price is affect by it. The effect from crude oil and gasoline prices offset each other and capacity remains quite close in both synthetic and estimator approaches.

Figure 6 Percent of Change Caused by Ethanol Expansion, by synthetic estimator



Source: calculations based on model results.

CONCLUSION

Fuel use of ethanol has been expanding very fast and its share in motor fuel market would increase. As a positive supply shock to motor fuel gasoline market, gasoline price will not rise as much as without ethanol supply. Gasoline production, gasoline import, and crude oil price also rise less than they would without ethanol. Gasoline demand increases as income grows. Even with the inclusion of ethanol use, gasoline price nonetheless will increase in the future as gasoline demand rises. But ethanol use does curb the momentum of gasoline price increase.

Compared with other research on this topic, this paper finds a similar result of fuel ethanol expansion to the study by Du and Hayes (2008). Motor gasoline price will decrease because of increased ethanol use. They found ethanol production reduces gasoline price by $0.29 to $0.4 per gallon. The paper by Du and Hayes was based on time-series estimation over historical data. The present paper makes a forecast based on different ethanol use scenarios in the future. Gasoline price in 2022 is found to be $0.26 or $0.23 per gallon less than ethanol quantity remain at 2008 level. This paper also complements the research of Tokgoz and Elobeid (2007). Tokgoz and Elobeid analyzed the effect of a 20% gasoline price increase. The present paper adds the scenario of ethanol quantity change and its effect. And the substitutive effect of ethanol is discussed in the paper, while Tokgoz and Elobeid assumed complementary be the dominant effect. Finally, the model in the present paper can be added into FAPRI model through ethanol market to link agricultural market to motor gasoline market.

A limit in the model used in the present paper is that gasoline is not completely represented in the equations For example, co-products of gasoline like distillate oils are not included. Some future effort should also be made in endogenizing ethanol supply in gasoline market and agricultural market. Then, agricultural markets and gasoline markets can be linked together for a better simulation. Another problem is crude oil price is not satisfactorily specified, and the refinery capacity investment equation is also not strong. The motor gasoline market could benefit from a more detailed representation.

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