Demand for Ethanol in the Face of Blend Wall: Is it a Complement or a Substitute for Conventional Transportation Fuel in the United States?

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United States spends more than one quarter of its energy on transportation. Historically, crude oil has been the primary source for generating this energy. Though ethanol has been proposed to substitute conventional transportation fuel since the 1970s, the expansion of ethanol industry slowed down after 2010 when the ethanol blended reached around 10% of the total gasoline, the so-called “blend-wall effect”. This study focused on estimating the demand for ethanol in the United States and analyzed the effect of blend-wall on this demand and its relationship to conventional fuels. The almost ideal demand model (AIDS) is adopted to analyze the US expenditure on transportation fuels including petroleum, natural gas and biomass energy. Both monthly and annual data are collected and the presence of unit roots at different frequencies (monthly, quarterly, annually) is identified and used to help improve the structural model. Preliminary results showed that, though ethanol was proposed as a substitute for gasoline, the substitution effect faded away as the ethanol share in the blend increased, and turning ethanol to be a complement under the state-of-the-art technology.

Keywords: Demand for ethanol, blend wall, almost ideal demand system, transportation fuel

JEL Classification: Q41,Q42

1. Introduction

With the widespread attention on the security of energy supply and global warming due to greenhouse gas emission, an array of public policies implemented to promote the expansion of bio-ethanol as an alternative and renewable energy source for fossil fuels over the past decade. Compared to 2000, fuel ethanol production has increased nearly eight times in 2014. The Medium-Term Renewable Energy Market Report (MTRMR) of the International Energy Agency (IEA) predicts that ethanol is expected to remain the dominant biofuel in 2018, and U.S. is expected to remain the world's largest bio-ethanol producer in terms of absolute volume which will increase to 979,000 barrels per day by 2018.

The initial increase of ethanol production in mid-1970s was driven by 1973's oil crisis and U.S. has supported the development and use of ethanol since the late 1970s in two ways: by imposing quantity-based constraints on biofuels productions and by offering biofuel producers a package of financial, primarily tax-related incentives (although some of the incentives have expired). In 2005, Energy Policy Act established the Renewable Fuel Standard (RFS) which requires producing and blending of several different classes of biofuels, eventually requiring 36 billion gallons per year of biofuels be blended with petroleum fuels in 2022 (Table 1). And under the U.S. Clean Air Act, the maximum percentage of ethanol permitted for use in U.S. conventional non-flex-fueled vehicles is 10% (E10). This cap, which is popular termed the "blend wall", has also concentrated the expansion of ethanol production.

The growing demand for ethanol requires the usage of a large amount of corn, soybeans, or other crops to produce fuel ethanol. The need for corn to produce much larger quantities of ethanol has inflated prices from the generally stable price of $2/bushel to more than $4 by early 2007. As feed grains such as corn become more expensive, the cost of producing livestock is higher. Additionally, since land use changes to satisfy the rising demand of corn, the high price of other agricultural products will be accelerated. Consequently, the great demand for corn derived from ethanol demand is clearly having an effect on the U.S. economy.

The recent surge in the demand for fuel ethanol, coupled with above mentioned legislative mandates and proposals for the use of ethanol, has already begun to have an impact on the U.S. gasoline and agricultural markets. In order to be better understanding the likely impacts of these mandates and regulations, this paper will study the fuel ethanol market from the perspective of ethanol demand.

Furthermore the proportion of ethanol consumption in total gasoline consumption (ES) increased stably but started to fluctuate after reaching 10%, which might be due to the "blend wall". We focus on the possible relationship between ethanol and gasoline in this ethanol demand analysis using elasticity with respect to the change of ethanol share in gasoline.

2. Literature Review

The relationship between ethanol demand the gasoline has been studies previously and most of the studies use elasticity to test whether there is a substitution/complementary effect. Soren (2012) showed that ethanol was a gasoline substitute and estimated demand for ethanol (E85) as a gasoline (E10) substitute in a household preference framework. He found that a $0.10/gallon increase in ethanol price relative to gasoline could lead to a 12–16% decline in the quantity of ethanol demanded, which meant the demand for ethanol (E85) as a gasoline(E10) substitute was sensitive to relative fuel prices. They used monthly data from a large number of fueling stations in Minnesota for ethanol (E85) prices and gasoline (E10) prices as well as sales volumes for both E85 and E10 from October 1997 to November 2006. Their findings implied that some households were willing to pay a sizeable premium for ethanol, which meant that increasing blend limit was not the most efficient ways to encourage ethanol use.

In order to estimate fuel ethanol demand, corn price and ethanol price were both important factors to be considered. Luchansky and Monks (2009) examined the ethanol own price elasticity. On the supply side, their results showed that the ethanol supply price response was inelastic, indicating the shifts in demand 'translate primarily into changes in ethanol prices rather than ethanol production, at least in the short run'. Besides, due to the unprecedented increase in ethanol production in recent years, ethanol production was not found to be consistently significantly related to corn prices. In the past, corn as a major input, its price strongly affected the ethanol production. Now, given the current ethanol mandate, ethanol production heavily influenced the prices of corn. Recent studies showed that about 40% of the corn in US is used for ethanol production. On the demand side, the estimation of own price elasticity was high, suggesting that ethanol prices had a very strong effect on the quantity demanded.

The effect of blend wall on ethanol and gasoline consumption was inducing more and more concerns in many studies. Zhang et al. (2010) proposed a theoretical model and showed that under a wide range of elasticity, a positive shift in the blend wall would actually increase the consumption of petroleum gasoline. Qiu, Colson and Wetzstein (2014) investigated this theoretical model proposed by Zhang et al. (2014) empirically using Monte Carlo simulations. Their result was consistent with the theoretical model: while intention of the waiver that allowed an increase in the fuel-ethanol blend limit (the blend wall) was to stimulate ethanol demand, it would, in fact, increased petroleum gasoline demand.

3. Data

This analysis employed national monthly data from January 1994 to December 2013. In addition to monthly ethanol consumption and price data, other variables were examined for inclusion in demand model including crude oil prices, corn prices, gasoline prices, and income. The data used in this study were found from an assortment of government and national organization. Ethanol consumption data was from U.S. Energy Information Administration (EIA). Ethanol price data was accessed from Nebraska Energy Office website, corn price data was from United States Department of Agriculture (USDA), and crude oil price and gasoline price data were all from U.S. Energy Information Administration (EIA). All the price data described ahead were converted to real terms based on the seasonally adjusted CPI (1982=100). Summary statistics of data used is in table 2.

4. Theoretical Model

The baseline model is a double-log demand function of the ethanol demand as a function of ethanol price and gasoline price, which is given as follows:

$$\ln Q_{ethanol} = \beta_0 + \beta_1 \cdot \ln P_{ethanol} + \beta_2 \cdot \ln P_{gas} + \beta_3 \cdot \ln P_{corn} + \beta_4 \cdot \ln P_{oil} + \beta_5 \cdot \ln Inc + u \quad (1)$$

where the coefficient of $\ln P_{gas}$, β_2, is the cross price elasticity of ethanol on gasoline price.

As discussed in the previous section, gasoline and ethanol might not constantly be compliments or substitutes to each other and we suspect the relationship is affected by the blend wall effect. To examine this effect, we model β_2 as a function of the ethanol share as in equation (2).

$$\beta_2 = f(ES) \quad (2)$$

where is the ES (as in Fig. 2) is the percent of ethanol in the total gasoline consumed as in equation (3).

$$\text{ES} = \frac{\text{Ethanol Consumption}}{\text{Gasoline Consumption}} \quad (3)$$

Ethanol mandate is the minimum yearly ethanol production and blend wall is the upper limit of the percentage of ethanol that can be blended in to gasoline, so we thing ES is constrained by both ethanol mandate and blend wall. Assuming that the cross price elasticity between ethanol and gasoline is affected by the blend wall, it is assumed that β_2 changes when ES increases and approaches the 10% blend wall.

At the beginning, ethanol production is promoted as a substitute for conventional gasoline for varies considerations such as greenhouse gas emission and energy independence. During that time we expect that ES is small and $\beta_1 > 0$. As time going, the demand for ethanol relative to gasoline (ES) increases due to ethanol mandate and people's awareness of environmental issue. When ES reaches 10%, which is the blend wall as of 2013 (the end of the data period covered in this paper), additional gasoline cannot be blended into the gasoline product, thus no additional ethanol production is demanded unless there is increase in the demand for the total gasoline. As a result, we expected that $\beta_1 < 0$.

By plugging equation (3) in to equation (1), we get the demand function (4).

$$\ln Q_{ethanol} = \beta_0 + f(ES) \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_4 \cdot \ln P_{oil} + \beta_5 \cdot \ln Inc + u \quad (4)$$

We propose three functional forms for $f(ES)$

$$\text{Constant: } \beta_2 = f(ES) = c \quad (5)$$

$$\text{Linear: } \beta_2 = f(ES) = \alpha \cdot ES + \varepsilon \quad (6)$$

$$\text{Nonlinear: } \beta_2 = f(ES) = \alpha \cdot \ln ES + \varepsilon \quad (7)$$

where α is the coefficient telling us the relationship between cross price elasticity β_2 and the Ethanol Share and ε is the error term.

Using these three functional forms, we have can develop our baseline model into the following three models

Model 1:

$$\ln Q_{ethanol} = \beta_0 + c \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_4 \cdot \ln P_{oil} + \beta_5 \cdot \ln Inc + u \tag{8}$$

Model 2:

$$\ln Q_{ethanol} = \beta_0 + \alpha \cdot ES \cdot \ln P_{gas} + \varepsilon \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_4 \cdot \ln P_{oil} + \beta_5 \cdot \ln Inc + u \tag{9}$$

Model 3:

$$\ln Q_{ethanol} = \beta_0 + \alpha \cdot lnES \cdot \ln P_{gas} + \varepsilon \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_4 \cdot \ln P_{oil} + \beta_5 \cdot \ln Inc + u \tag{10}$$

Based on Model 3, we remove price of oil due to its high correlation with gasoline price and get Model 4.

Model 4:

$$\ln Q_{ethanol} = \beta_0 + \alpha \cdot lnES \cdot \ln P_{gas} + \varepsilon \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_5 \cdot \ln Inc + u \tag{11}$$

And we add ES to Model 4 to get Model 5.

Model 5:

$$\ln Q_{ethanol} = \beta_0 + \alpha \cdot lnES \cdot \ln P_{gas} + \varepsilon \cdot \ln P_{gas} + \beta_1 \cdot \ln P_{ethanol} + \beta_3 \cdot \ln P_{corn} + \beta_5 \cdot \ln Inc + ES + u \tag{12}$$

5. Empirical Result and Discussion

In this section, we estimated five models specified in the previous section. Table 3a summarized the attributes of the five models and Table 3b reports the estimation result for each model.

Model 1 is the simple autocorrelation model assuming the cross price elasticity of ethanol demand on price of gasoline remains constant. From Table 3b, we can see that the only significant term is the lagged variable. Own price elasticity is negative and insignificant. Cross price elasticity for corn, oil, gasoline as well as the income elasticity are not significant either. In summary, model 1 has poor explanation power on the ethanol demand. One potential reason can be the constant cross price elasticity assumption.

Model 2-5 are all models with non-constant cross price elasticity.

For own price elasticity, Model 2, 3, 4 and 5 all report negative result which makes sense, but the coefficient is not significant in Model 2 and Model 5. Cross price elasticity for corn and the income elasticity are also positive and significant.

The cross price elasticity for gasoline price can be recovered from the estimated parameters for $\ln P_{gas}$ and $\ln P_{gas}$ ·ES. The projected estimates are in Fig. 4. Though the estimations across four models vary due to the difference in attributed considered and assumption on the model structure of $f(ES)$, Model 2-4 show very similar results. We can see that at the beginning part of our data period when the ethanol share is small, the cross price elasticity for gasoline price is positive, indicating a substitution effect of ethanol for gasoline. As the ethanol share increasing, the substitution effect fade away and when the ethanol share reaches the 10% blend wall, ethanol became a complement rather than substitutes of gasoline. According to Model 2-4, the turning point for ethanol share is around 3.8%-4.5%.

Based on AIC criterion, we decide that Model 5 is the best fitted one. Since Model 5 is a AR (1) model which only considers one lag, we decide to compare AR (1) model (the original Model 5) with AR(2) model (Model 5.2) and AR(2) model with corrected unit root. (footnote: P value for Dickey-Fuller Test of unit root problem in ethanol demand is 0.3857, which is a little over the critical value and indicates potential unit root problem, but since it is considered as a marginal number, here we only use the model with corrected unit root (Model 5.3) as an alternative and compare it with Model 5 and Model 5.1.

The estimation result for Model 5.2 and Model 5.3 are shown in Table 4 together with the estimation result for Model 5. From Table 4, we can see that based on AIC criterion and the number of significant variables, the best fitted model is Model 5.2, though the parameter estimations are very close with those in Model 5. Model 5.3 doesn't give us desirable fit: only first lag, price of gas and the interaction term of ethanol share and price of gas are significant.

Figure 5 shows the projected cross price elasticity of ethanol on gasoline price with different ARIMA assumptions. We can see that the turning point from substitution effect to complementary effect is different for Model 5.3 while are very similar for Model 5 and Model 5.2. The turning point of Model 5.3 is smaller: when ES is a little less than 2.5%. While the turning points of Model 5 and Model 5.2 are around 4%, close to Model 2-4.

6. Conclusions and Future Study

Under the state-of-the-art technology, the upper bound for the market demand of ethanol in the transportation sector is 10% of the total energy consumed, which is the blend wall status quo faced by the US ethanol industry. One major challenge, as indicated by our study, is that ethanol becomes compliment good instead of substitute for the conventional gasoline. The current demand for ethanol is not likely to increase unless there is an increase in the demand of the total transportation fuel sector. As a result, alternatives to break the blend wall such as the drop-in technology or new-generation infrastructure investment are needed to stimulate the further development of the ethanol industry.

Several defects need to be addressed in the future study. First of all, the ethanol production and demand are heavily influenced by government policies such as the mandates. Policy indicators are needed to complete the model in the future study. Besides, endogeneity issue might exist in the current model without considering the market equilibrium effect of both ethanol supply and demand.

Finally, the current estimation indicates that the turning point from a substitute into a complement is around 4%, which is less than the 10% blend wall as expected. One potential reason is the spatial variation. The market penetration for ethanol varies significantly in different states of US due to policy and other factors. State level data can be used to test this spatial variation in future studies.

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Appendix

Table 1 Renewable Fuel Volume Requirements in Billion Gallons

Year	Total Renewable Fuel	Cap on Corn Ethanol
2006	4.00	4.00
2007	4.70	4.70
2008	9.00	9.00
2009	11.10	10.50
2010	12.95	12.00
2011	13.95	12.60
2012	15.20	13.20
2013	16.55	13.80
2014	18.15	14.40
2015	20.50	15.00
2016	22.25	15.00
2017	24.00	15.00
2018	26.00	15.00
2019	28.00	15.00
2020	30.00	15.00
2021	33.00	15.00
2022	36.00	15.00

Table 2 Summary statistics for U.S. ethanol demand (Jan. 1994 to Dec. 2013)

Var.	Unit	Min	Max	Range	Median	Mean	Std. Dev
P_{oil}	$/barrel	4.20	28.31	24.11	10.47	12.32	5.05
P_{corn}	$/bushel	0.45	1.80	1.35	0.80	0.88	0.28
P_{gas}	$/gallon	0.35	0.87	0.51	0.52	0.55	0.11
$P_{ethanol}$	$/gallon	0.29	0.88	0.58	0.46	0.47	0.09
$Q_{ethanol}$	1000 barrel	1.21	27.98	26.77	6.68	10.77	9.31
$Income$	$1000	19.45	41.26	21.81	29.91	29.97	6.33

Table 3 Summary of Models and Outputs

a. Model description

	Attributes included	Assumption on β_2
Model 1	Income, Price of oil, corn, gas and ethanol	Constant β_2
Model 2	Income, Price of oil, corn, gas and ethanol	Linear $\beta_2 = \alpha \cdot ES + \varepsilon$
Model 3	Income, Price of oil, corn, gas and ethanol	Non-linear $\beta_2 = \alpha \cdot \ln ES + \varepsilon$
Model 4	Income, Price of corn, gas and ethanol	Non-linear $\beta_2 = \alpha \cdot \ln ES + \varepsilon$
Model 5	Income, Price of corn, gas and ethanol, ES	Non-linear $\beta_2 = \alpha \cdot \ln ES + \varepsilon$

b. Model output

	Model 1		Model 2		Model 3		Model 4		Model 5	
AR1	0.9916	***	0.6876	***	0.635	***	0.6207	***	0.5071	***
intercept	1.5436		-36.8094	***	-29.9928	***	-30.5111	***	-22.2014	***
$\ln P_{oil}$	0.063		0.2411	*	0.1329					
$\ln P_{corn}$	-0.1007		0.1638	*	0.3642	***	0.365	***	0.0459	
$\ln P_{gas}$	-0.2816		1.093	***	-3.1718	***	-3.1343	***	-2.075	***
$\ln P_{ethanol}$	-0.0267		-0.1199		-0.183	*	-0.1803	*	-0.0087	
$\ln Inc$	0.7611		4.6828	***	4.0187	***	4.1171	***	3.2083	***
$\ln P_{gas}$ ·ES			-23.9895	***						
$\ln P_{gas} \cdot \ln ES$					-0.977	***	-1.0126	***	-0.6632	***
ES									9.2166	***
Likelihood	147.25		141.35		149.89		149.4		168.12	
AIC	-278.5		-264.69		-281.77		-282.79		-318.24	

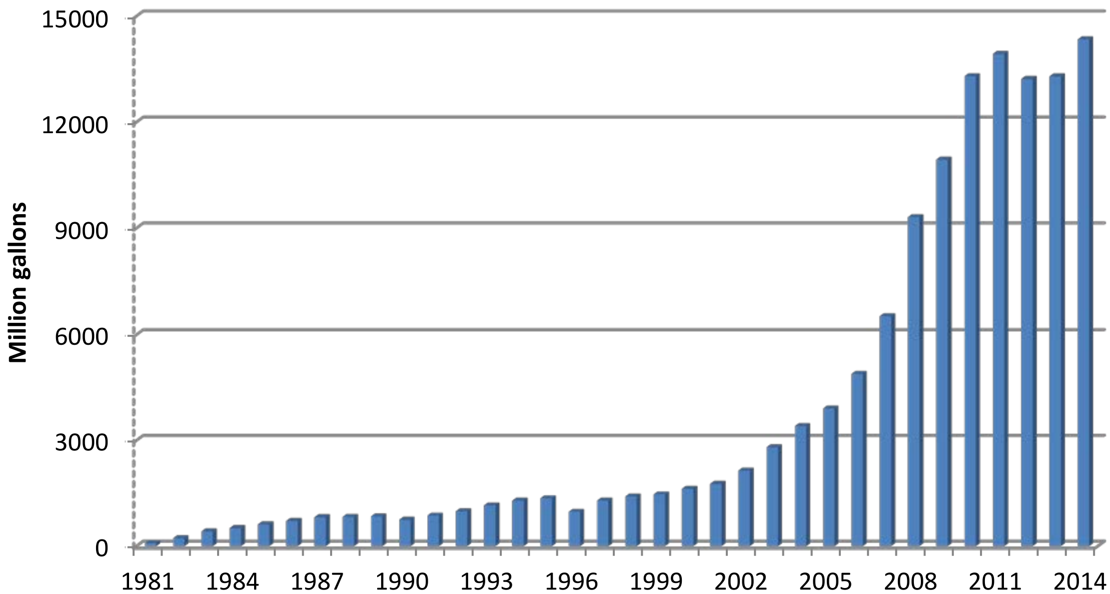
Note: * indicates significance at 0.10 level.

** indicates significance at 0.05 level.

*** indicates significance at 0.01 level.

Table 4 Summary of Models and Outputs with Different ARIMA Assumptions

	Model 5		Model 5.2		Model 5.3	
ar1	0.5071	***	0.4171	***	-0.4608	***
ar2			0.2332	***	-0.1036	
intercept	-22.201	***	-22.6214	***		
$\ln P_{corn}$	0.0459		-0.0095		-0.1401	
$\ln P_{gas}$	-2.075	***	-1.7122	***	-1.049	***
$\ln P_{ethanol}$	-0.0087		0.0241		0.0647	
$\ln Inc$	3.2083	***	3.2428	***	0.71	
$\ln P_{gas} \cdot \ln ES$	-0.6632	***	-0.5509	***	-0.28	***
ES	9.2166	***	10.7617	***	2.4821	
Likelihood	168.12		173.77		172.26	
AIC	-318.24		-327.54		-326.51	
ARIMA	(1,0,0)		(2,0,0)		(2,1,0)	



Source: U.S. Energy Information Administration.

Figure 1 Fuel Ethanol Production

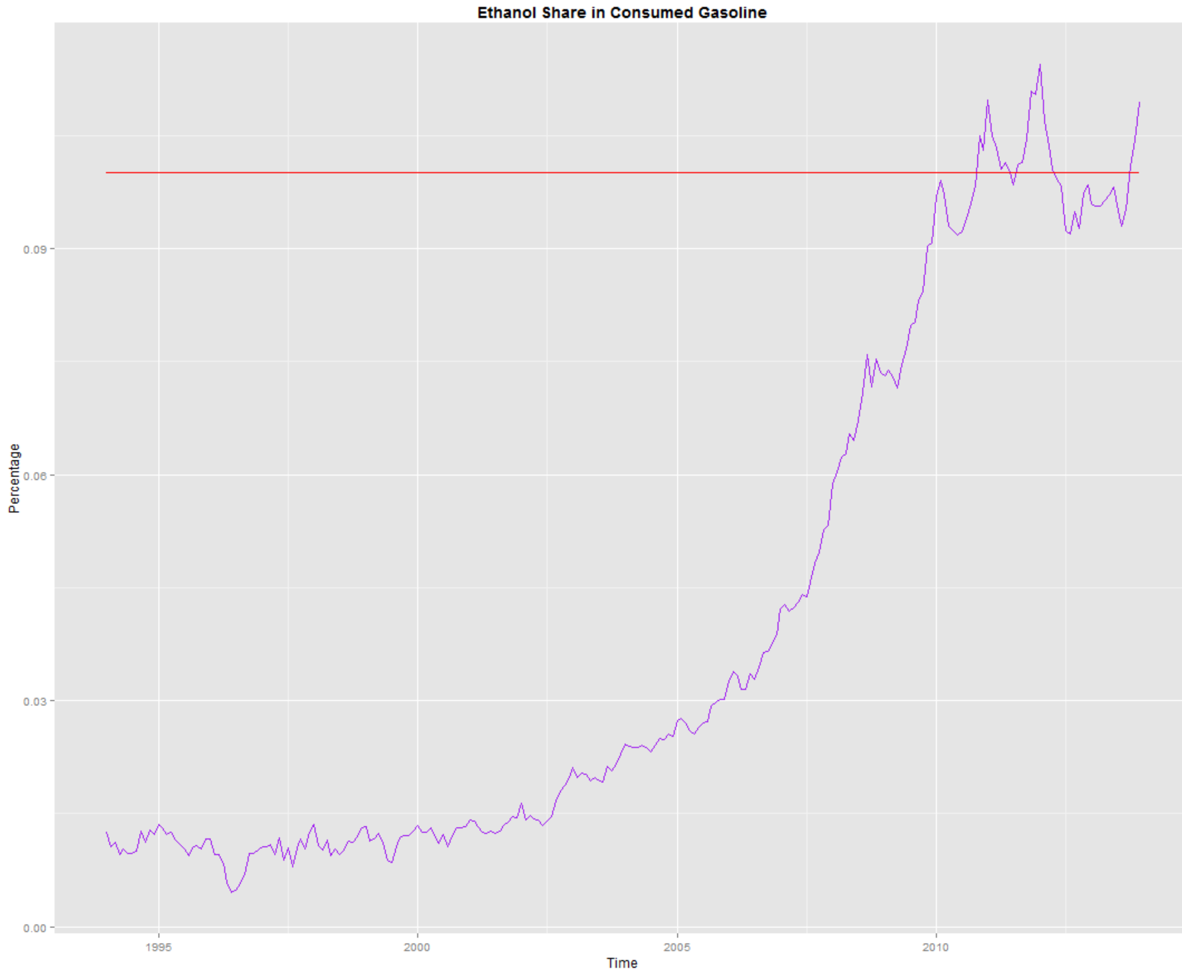


Figure 2 The ethanol share (ES) from Jan. 1994 to Dec. 2013

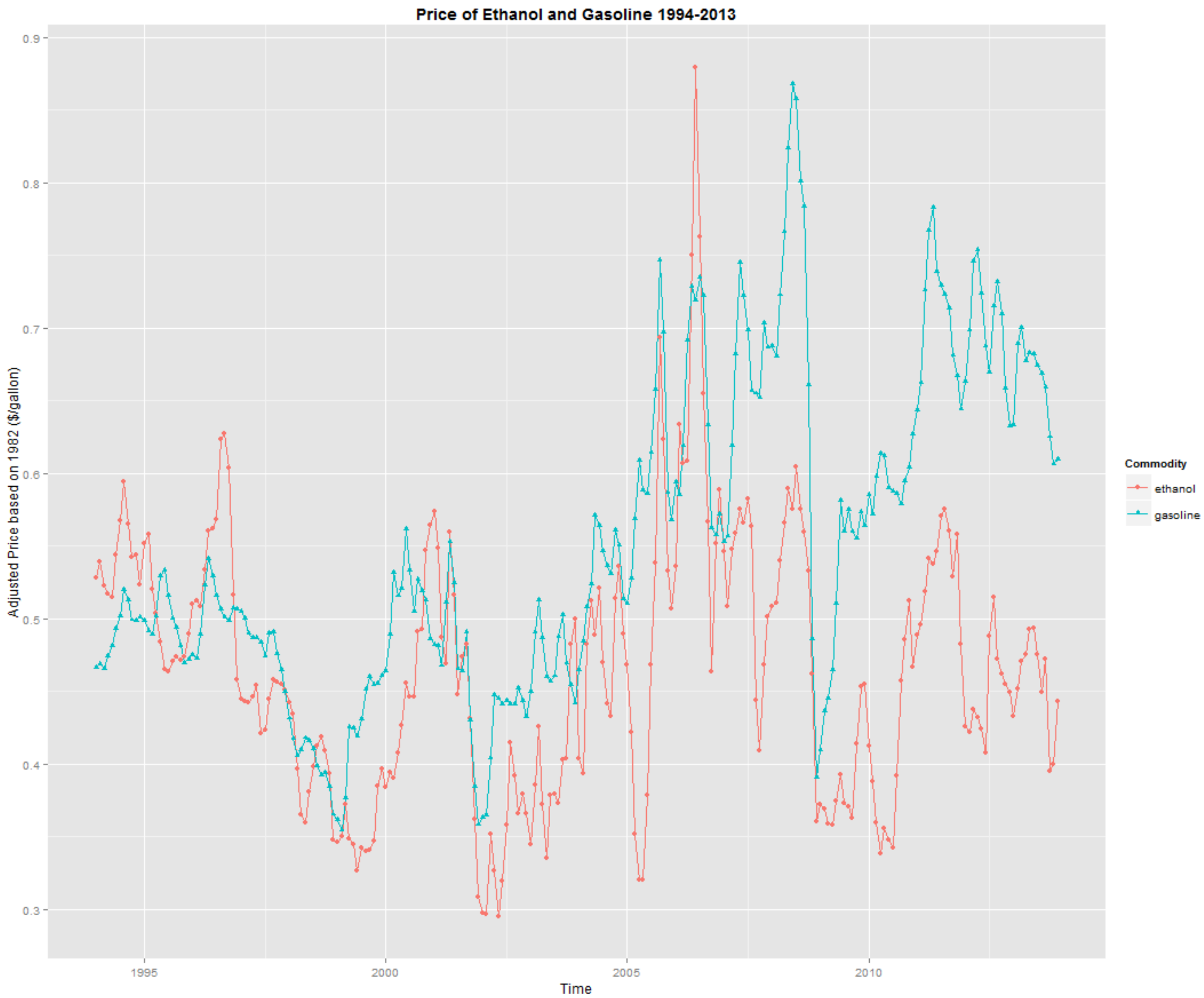


Figure 3 Ethanol and gasoline adjusted price from Jan. 1994 to Dec. 2013 (based on 1982)

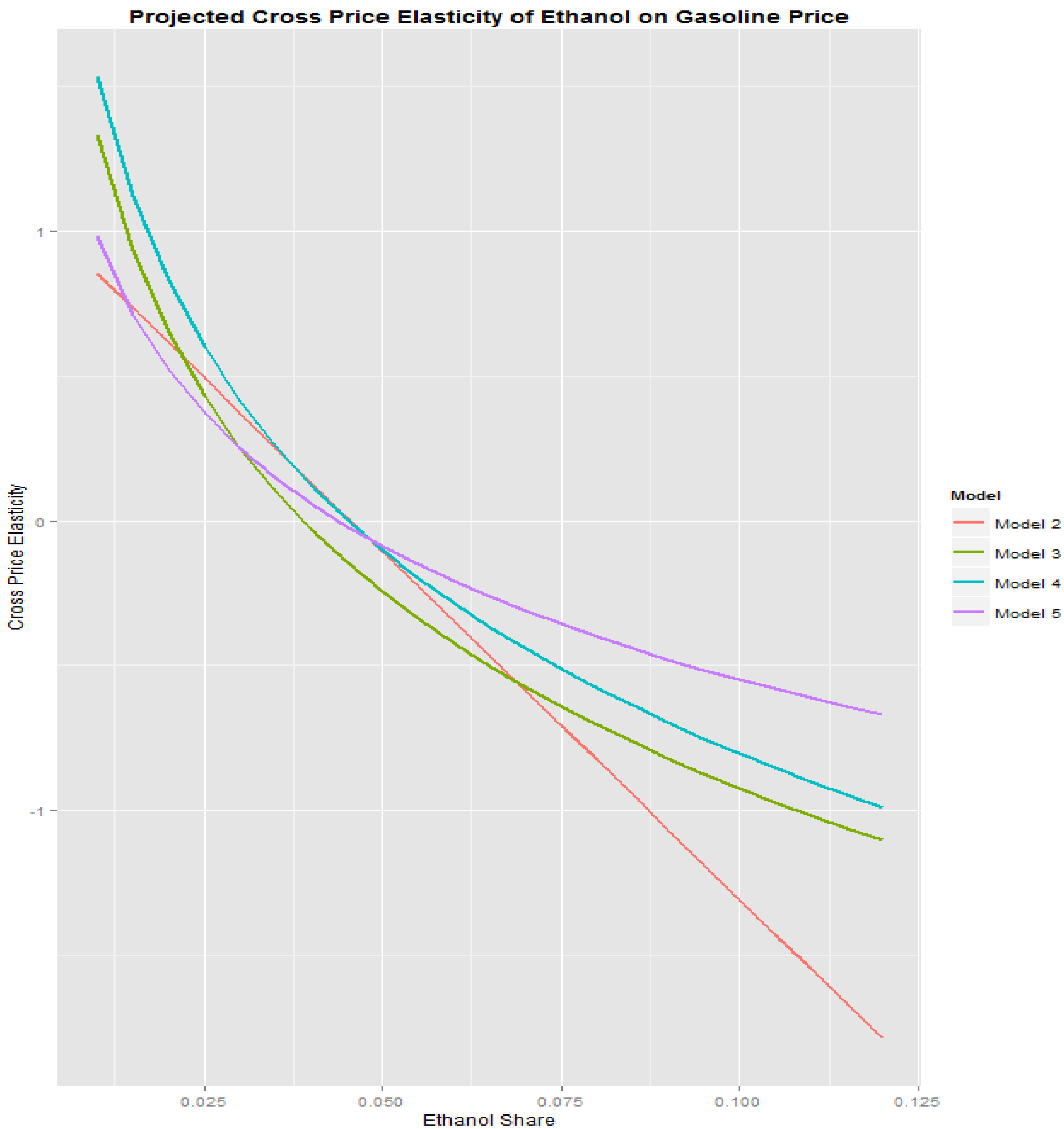


Figure 4 Projected cross price elasticity of ethanol on gasoline price

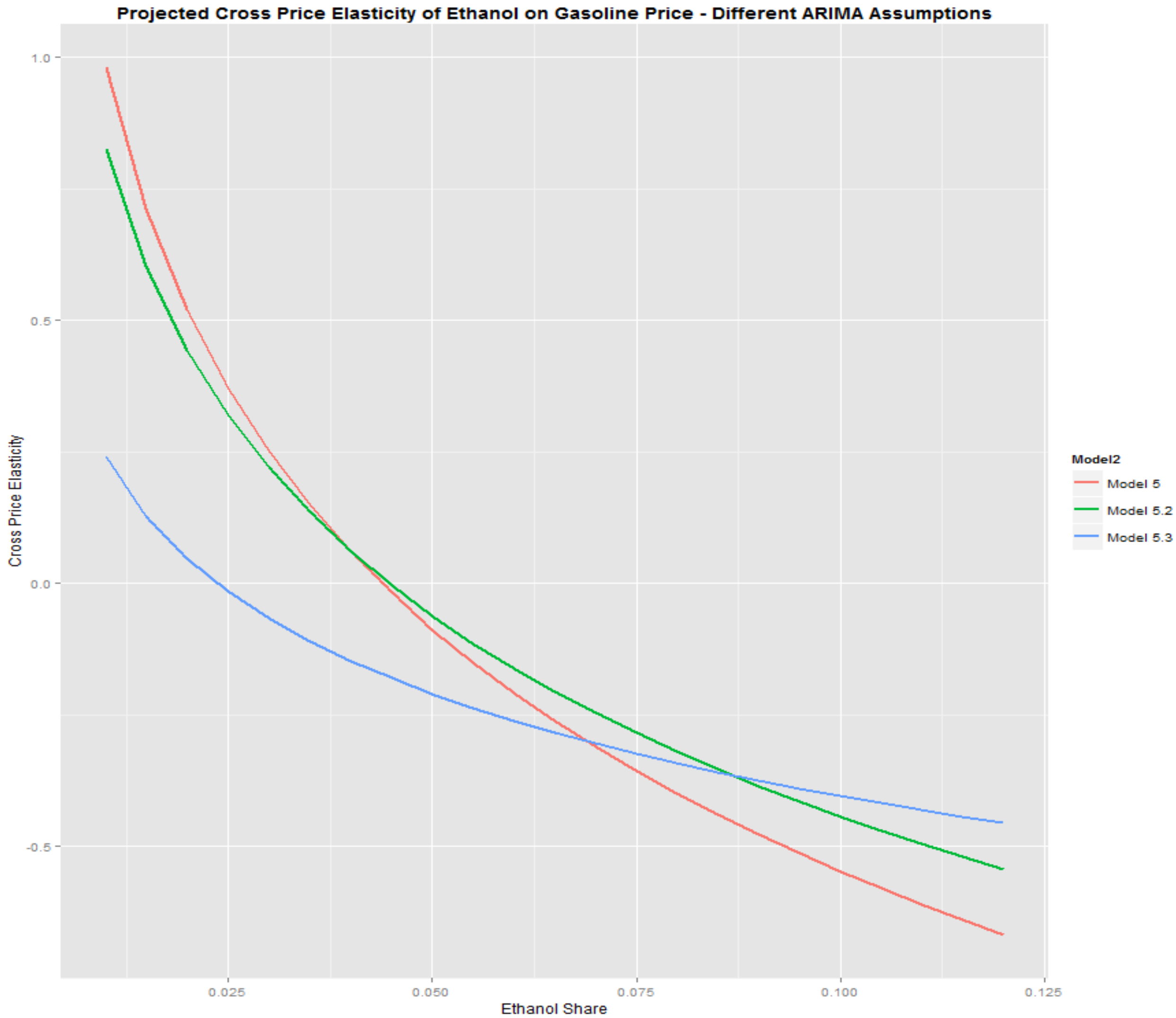


Figure 5 Projected cross price elasticity of ethanol on gasoline price with different ARIMA assumptions