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Abstract

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Keywords

market competition, social welfare, E10, E85, courot game theory, sustainability, modeling, sustainable development, global warming, renewable energy, environmentally friendly energy sources, alternative fuels, ethanol, oligopoly model, market share, price premium, willingness to pay, societal wellbeing, govenrment policies, market equilibrium, industry size, market performance, tax credits

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Comments

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Market Competition and Social Welfare Analysis for E10 and E85 with a Game Theory Model

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Key words: Ethanol, E10, E85, Flexible-fuel Vehicles, Cournot game theory model, Market share, Social welfare, Tax credits, Mandates

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1. Introduction

With the rising gasoline price and the increasing concerns on the global warming, there is an impressing need for a cleaner and renewable transportation fuel to supplement and replace the fossil fuel. Ethanol is a renewable fuel produced from agricultural feedstock and it can reduce the greenhouse gas emission level, which is a good substitute to conventional fossil fuels. Ethanol has two main advantages over gasoline. The first is to reduce greenhouse gas emissions. Previous studies showed that the direct greenhouse gas emission of ethanol from corn is 69.4gCO_2e/MJ, which is about 28% less compared to 95.86gCO_2e/MJ of gasoline (Air Resources Board, 2011). Another advantage of ethanol over gasoline is that it provides the possibility of localized production of fuel in agricultural areas. For example, if Iowa can produce as much biofuel to meet the fuel demands at a reasonable cost, there is no need to transport fuels from other states or abroad.

Ethanol is mainly used as a gasoline additive and currently most of the ethanol is blended to be E10 (10% of ethanol and 90% of gasoline) or E85 (85% of ethanol and 15% of gasoline). E10 and E85 are two competing products on the transportation fuel market. Most of the U.S. cars are able to run on E10. In 2010, two thirds of the nation's gas supply is blended with up to 10% of ethanol (Galbraith, 2008). E85 is produced for flexible-fuel vehicles (FFV) which in North America are optimized to run on a maximum blend of 85% ethanol with 15% gasoline. Though FFVs are still a minority on U.S. road, its number is increasing rapidly in the past years. Currently, the total FFVs sold in U.S. market is nearly 10 million (Motavalli, 2012).

The average gasoline price fluctuates frequently and the range is fairly large. In 2011, it went as high as $3.95/gallon in May and fell back to $3.2/gallon in December. The fluctuation of E85 price is very similar to that of gasoline since E85 price is highly related and influenced by the price of gasoline. In May, it went up to $3.3/gallon and in December, it fell down to $2.98/gallon. The price gap between gasoline and ethanol remain in the range of $0.25/gallon to $0.75/gallon (E85Prices.com, 2012). Although the retail price of E85 is much lower than that of gasoline, it is not as significant as it appears, because the energy content of E85 is also much lower than that of E10. The energy content of E10 is 33.18 MJ/L and for E85, it's only 25.65 MJ/L (Thomas, 2000), which means, the price for every unit of energy in the two fuels may not have a big difference and that's why they are competing on the market.

U.S. government has played an important role in renewable energy. Renewable Fuel Standard (RFS) was implemented in 2007 to support the production and consumption of renewable fuels. RFS

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mandates the volume of renewable fuel blended into transportation fuel increased from 9 billion gallons in 2008 to 36 billion gallons by 2022 (U.S. Environmental Protection Agency, 2011). Specific mandates were created for various types of biofuels, such as advanced biofuels, cellulosic biofuels, and biomass-based diesel. EPA divides the mandate among the obligated parties, including fossil fuel producers and importers, according to the annual volume of gasoline and diesel produced or imported by the obligated parties. For example, EISA set a total mandate of 13.95 billion gallons of total renewable fuel to be blended in gasoline in 2011, and EPA calculated the final percentage standard for renewable fuel at 8.01 percent. Thereby, the renewable volume obligation for each obligated party is calculated by multiplying this percentage standard with the annual volume of gasoline and diesel produced or imported (McPhail, Westcott, and Lutman, 2011).

Renewable Identification Number (RIN) is a tool created by EPA to administer the compliance of the mandate. A RIN is a 38-digit number generated when one gallon of renewable fuel is produced, and it will remain with the renewable fuel through the distribution system, until the renewable fuel is blended into the fossil fuels. The RIN contains the information of the year of production, company ID, facility ID, batch number, the renewable fuel category, start of RIN block, and end of RIN block, etc. Thus, every RIN is unique and traceable. Each year, the obligated parties have to fulfill the required blending quota and submit the amount of RINs to EPA for record. If an obligated party has not acquired enough RINs in a calendar year, it can purchase RINs from the RINs market. On the other hand, if the obligated party has acquired more than enough RINs, it can sell the extra RINs to the market. While the RINs transaction is managed by EPA, the RIN prices are determined by the market. There are various factors impacting the price of RINs, including the core value of RINs, transaction cost and speculative components. In this study, the price of ethanol RIN is estimated from the historical RIN price and is assumed to be stable for a specific year.

To study the competition between E10 and E85, an oligopoly Cournot model is formulated to study the market equilibrium and the impacts of the government policies. Three market indices are derived from the equilibrium, including the market share of E85, the E85 price premium, and the total social welfare. The first two market indices are good indicators of E85’s performance on the market. The third market index the social welfare can provide insights for the government and policy makers to measure the societal well-being.

Numerical examples are presented to validate the model formulation and derive managerial insights for relative decision makers. The results of the examples show that the elimination of tax

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credit and the mandate could lead to the decrease of both the market share of E85 and the total social welfare. If the blenders industry sizes down, it could be beneficial for both the market performance of E85 and the well-being of the entire society. The increase of the proportion of FFVs on the road will lead to the increase of the market share of E85, but the effect is not significant until the proportion of FFVs goes higher than 90%.

The rest of the paper is organized as following: section 2 discusses the research background and the relevant literature for this study. The Cournot game theory model that studies the competition between E85 and E10 and the corresponding analysis is introduced in section 3. In section 4, the author presented several numerical examples to explore the effects of policy and situation changes to the market equilibrium. Section 5 concludes the paper and points out some future research directions.

2. Research Background

The literature on the competition between E10 and E85 is limited. E85 is a relatively new transportation fuel and it takes time to be accepted by the public. In addition, E85 is not as widely used as E10 since only FFVs can run on E85. As more consumers become environmental conscious and more FFVs on the road, it becomes of interest of study how the market responds to the changes.

There are some earlier studies that helped shape the research ideas on the market structure and the competition between E10 and E85. Anderson (2011) estimated the demand for ethanol as a gasoline substitute. The household preference for ethanol (E85) as a gasoline (E10) substitute was estimated by developing a model linking the shape of the ethanol demand curve to the underlying distribution among the households of the willingness to pay for ethanol. The instrumental variables techniques were used and data were acquired from many retail fueling stations. The main result is that a \$0.01/gallon increase in ethanol's price relative to gasoline leads to a 12-16% decrease in the ethanol consumption. This implies that the preferences for ethanol are heterogeneous and that a substantial fraction of households are willing to pay a premium for the fuel. Tatum, Skinner and Jackson (2010) investigated the economic sustainability of E85. The author used an empirical model and conducted an econometric analysis of the E85 market using demand and supply analysis. The main result is that any rise in the gasoline prices will be matched by a corresponding rise in the price of E85. Thus, the authors draw the conclusion that given the current market (which includes significant government subsidy) the prospect that E85 will ever be price competitive with gasoline is indeed dim. Greene (2008) studied on the market environment for promoting the consumption of ethanol fuel and claimed that flexible-fuel vehicles and E85 stations are needed to achieve ethanol

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goals. A model of consumers' decisions to purchase E85 versus gasoline based on prices, availability, and refueling frequency is derived, and preliminary results for 2010, 2017 and 2030 consistent with the president's 2007 biofuels program goals are presented. The analysis results show that to meet a 2017 goal of 26 billion gallons of E85 market sale, on the order of 30% to 80% of all fuel stations in the U.S. may need to offer E85 and that 125 to 200 million flexible-fuel vehicles will need to be on the road.

There is a relatively richer literature on the ethanol industry and governmental policy analysis. Gorter and Just (2009) studied on the economics of a blend mandate for biofuels. They built two separate models to analyze the economics of a biofuel mandate and the economics of combined mandate and tax credit. They found that if tax credits are implemented along with the mandates, tax credits subsidize gasoline consumption instead of the biofuels industry. This contradicts the goal of energy policy since it increases oil dependency and social costs. The authors provided policy implications for various scenarios and showed that a mandate by itself is a better choice. Babcock (2010) also pointed out that the biofuel industry does not need all of the mandates, tax credits and tariffs in one of the CARD policy briefs. The result in his study shows that the biofuel producers will receive little or no additional benefit from tax credits while import tariffs will continue to provide U.S. corn ethanol producers a cost advantage over imported ethanol.

The goal of this study is to address the scarcity of the literature on competition in the transportation fuel market. We aim to study the market competition between E10 and E85 and initiate more future research along this topic. Our study contributes to the literature in the following two ways: First, a quantitative model is built to analyze the competition between E10 and E85. The parameters in the model can be adjusted according to specific situations of interest. This modeling framework provides the flexibility of incorporating more complicated demand functions. This provides a good base for future studies along this topic. Second, three market indices are defined and derived: market share of E85, E85 price premium, and social welfare. With these indices, the market performances of E10 and E85 can be better evaluated and compared. The policy makers can also obtain insights from the scenario analysis on how the government policies affect the market equilibrium of E10 and E85.

3. Model Formulation

In this study, an oligopoly game theory model is formulated to study the competition between E10 and E85 in the transportation fuels market. Suppose there are s fuel blenders in the industry and they

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produce both E10 and E85. The competition among the fuel blenders is assumed to be Cournot, in which each fuel blender simultaneously and independently determines the supply quantities of E10 and E85 to maximize its own profit.

Notations:

q_k^G, q_k^E : the supply quantities of E10 (Gasohol) and E85 by blender k ;

Q^G : the total supply of E10 in the market, where $Q^G = \sum_{i=1}^{s} q_i^G$;

Q_{-k}^G : the total supply of E10 in the market excluding the supply from blender k , where $Q_{-k}^G = Q^G - q_k^G$;

Q^E : the total supply of E85 in the market, where $Q^E = \sum_{i=1}^{s} q_i^E$;

Q_{-k}^E : the total supply of E85 in the market excluding the supply from the blender k , where $Q_{-k}^E = Q^E - q_k^E$;

c^G, c^E : unit production cost of E10 and E85, respectively;

ρ^G, ρ^E : retail unit prices of E10 and E85, respectively;

λ^G, λ^E : emission cost of E10 and E85, respectively;

p^G, p^E : unit prices (that consumers consider when they make consumption choices, including their consideration of the effect of fuels on the environment) of E10 and E85, respectively;

p_r : unit price of RINs in the RINs market;

M_k : ethanol purchasing mandate for blender k ;

s : the total number of blenders in the market;

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3.1 Demand Functions

We assume the inverse demand functions of E10 and E85 to be:

$$\begin{bmatrix} p^G \\ p^E \end{bmatrix} = \begin{bmatrix} a \\ a \end{bmatrix} - b \begin{bmatrix} 1 & \theta^E \\ \theta^G & 1 \end{bmatrix} \begin{bmatrix} Q^G \\ Q^E \end{bmatrix}.$$

Here, it is important to note that E10 was abbreviated as G since it's also called Gasohol. Similarly, we abbreviate E85 as E when we use then as superscripts and subscripts. The prices p in the demand functions are unit prices that consumers consider in their purchasing process which consists of two components, the retail prices ρ and the emission costs λ.

The corresponding demand functions are:

$$\begin{bmatrix} Q^G \\ Q^E \end{bmatrix} = \frac{a}{b(1-\theta^G\theta^E)} \begin{bmatrix} 1-\theta^E \\ 1-\theta^G \end{bmatrix} - \frac{1}{b(1-\theta^G\theta^E)} \begin{bmatrix} 1 & -\theta^E \\ -\theta^G & 1 \end{bmatrix} \begin{bmatrix} p^G \\ p^E \end{bmatrix},$$

Here, $\theta^G, \theta^E \in (0,1)$ are the substitutability parameters, indicating how substitutable one product to another. Generally, a negative value of the substitutability parameter indicates the complementarity of the two products which is not the case for E10 and E85, since they are two competing products in the transportation fuel markets. If θ^G (θ^E) equals 0, it means E10 (E85) cannot substitute E85 (E10) at all and they do not affect each other in the market, which is obviously not true for the two products. If θ^G (θ^E) equals exactly 1, it means E10 (E85) is a complete substitute to E85 (E10) and this is also not true for E85. Since FFV is still a small part of all vehicles, E85 can only substitute a limited part of E10, which made θ^E very small. The estimated values will be discussed in the numerical example part.

3.2 Market Indices

We derive the following three market indices to measure the performance of the two types of fuels in the market. The first two market indices (market share and price premium) are easy to measure and are good indicators of E85's performance on the market. Generally, a higher market share and a lower price premium indicate a greater acceptance. The third market index is the total social welfare which can provide insights for the government and policy makers who aim to maximize the wellbeing of the entire society.

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3.2.1 Market share of E85

The market share of E85 is defined as the percentage of products in the market:

$$\beta^E = \frac{Q^E}{Q^E + Q^G}.$$

3.2.2 Total and upfront green price premium

From the inverse demand functions, we can derive the total green price premium:

$$\Delta p = \alpha p^E - p^G = \alpha\left[a - b\left(\theta^G Q^G + Q^E\right)\right] - \left[a - b\left(Q^G + \theta^E Q^E\right)\right],$$

where $\alpha = \frac{127.56}{95.38}$ is a coefficient to transform the price of E85 to a unit price for a gasoline-equivalent gallon. Here, 95.38 and 127.56 (in MJ/gallon unit) are the energy contents of E85 and E10 respectively. We propose to adjust the prices to an energy equivalent basis. Thus, the adjusted price for E85 is 127.56/95.38 times the retail price of E85.

Intuitively, a higher price premium will cause more demand of E10 and a low price premium will cause more demand of E85. It should be noted that consumers' choices will involve more than the price premium.

Similarly, the upfront green price premium can be derived from total green price premium incorporating the gas emission costs of the two fuels:

$$\Delta \rho = \alpha\rho^E - \rho^G = \alpha\left[a - b\left(\theta^G Q^G + Q^E\right)\right] - \left[a - b\left(Q^G + \theta^E Q^E\right)\right] - \alpha\lambda^E + \lambda^G.$$

3.2.3 Social welfare

Government policies could impact all stakeholders along the biofuel supply chain, including farmers, the gasoline and ethanol industry and the fuel market. Typically, the goal of the government is to maximize the well-being of the entire society, which we define as social welfare. Thereby, the government wants to implement policies that can maximize the social welfare.

The welfare is defined as the summation of the consumers' surplus and the producers' surplus, which is the difference between what the consumers willing to pay and what the producers willing to supply a good for. In another word, it's what the consumers willing to pay minus the total production cost of the good.

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To define social welfare for the transportation fuel market, we construct two non-decreasing functions $f_G(t)$ and $f_E(t)$ to represent the process of price discrimination, though which the producers can maximally exploit consumers' willingness to pay. The two functions are continuously differentiable in (0, 1) and that $f_G(0)=0,\ f_G(1)=Q^G$, and $f_E(0)=0,\ f_E(1)=Q^E$. Then consumers' willingness to pay can be expressed as:

$$\begin{aligned}\Upsilon &= \int_0^1 \left\{a-b\left[f_G(t)+\theta^E f_E(t)\right]\right\} df_G(t)+\int_0^1 \left\{a-b\left[f_E(t)+\theta^G f_G(t)\right]\right\} df_E(t)\\ &= a\left(Q^G+Q^E\right)-\frac{b}{2}\left[\left(Q^G\right)^2+\left(Q^E\right)^2\right]-b\theta^E\int_0^1 f_E(t)df_G(t)-b\theta^G\int_0^1 f_G(t)df_E(t)\\ &= a\left(Q^G+Q^E\right)-\frac{b}{2}\left[\left(Q^G\right)^2+\left(Q^E\right)^2\right]-b\theta^E Q^G Q^E+b\left(\theta^E-\theta^G\right)\int_0^1 f_G(t)df_E(t)\end{aligned}$$

By the definition of $f_G(t)$, we have

$$\int_0^1 f_G(t)df_E(t)\geq\int_0^1 0\,df_E(t)=0, \text{ and}$$

$$\int_0^1 f_G(t)df_E(t)\leq\int_0^1 Q^G df_E(t)=Q^G Q^E.$$

Since we want to maximize Υ, it becomes

$$\Upsilon = a\left(Q^G+Q^E\right)-\frac{b}{2}\left[\left(Q^G\right)^2+\left(Q^E\right)^2\right]-b\min\left\{\theta^G,\theta^E\right\}Q^G Q^E.$$

Subtracting total cost from Υ, we get the social welfare function:

$$\Psi := \left(a-\lambda^G-c^G\right)Q^G+\left(a-\lambda^E-c^E\right)Q^E-\frac{b}{2}\left[\left(Q^G\right)^2+\left(Q^E\right)^2\right]-b\min\left\{\theta^G,\theta^E\right\}Q^G Q^E$$

Here, we assume $a-\lambda^G-c^G>0$ and $a-\lambda^E-c^E>0$ so that a positive social welfare is achievable.

3.3 Analysis of the Model

In this model, we assume there are s symmetric blenders in the market which produce both E10 and E85 and their products are homogeneous. Their profits come from the sales of E10 and E85. The Cournot competition model is used to analyze their competition, in which a single firm has to decide its supply quantities of E10 and E85 to maximize its profit.

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Given the total supply quantities of E10 and E85 by other blenders:

$$Q_{-k}^{G} = Q^{G} - q_k^{G} \text{ and } Q_{-k}^{E} = Q^{E} - q_k^{E},$$

the profit function of blender k is,

$$\begin{aligned}
&\pi_k\left(q_k^G, q_k^E; Q_{-k}^G, Q_{-k}^E\right) \\
&= \left(\rho^G - c^G\right)q_k^G + \left(\rho^E - c^E\right)q_k^E \\
&= \left[\left(p^G - \lambda^G\right) - c^G\right]q_k^G + \left[\left(p^E - \lambda^E\right) - c^E\right]q_k^E \\
&= \left[a - c^G - \lambda^G - b\left(Q^G + \theta^E Q^E\right)\right]q_k^G + \left[a - c^E - \lambda^E - b\left(Q^E + \theta^G Q^G\right)\right]q_k^E \\
&= \left[a - c^G - \lambda^G - b\left(Q_{-k}^G + \theta^E Q_{-k}^E\right)\right]q_k^G + \left[a - c^E - \lambda^E - b\left(Q_{-k}^E + \theta^G Q_{-k}^G\right)\right]q_k^E \\
&-b\left(q_k^G\right)^2 - b\left(q_k^E\right)^2 - b\left(\theta^G + \theta^E\right)q_k^G q_k^E + \left(0.1q_k^G + 0.85q_k^E - M_k\right)p_r
\end{aligned},$$

and its best response is:

$$\begin{bmatrix}\left(q_k^G\right)^* \\ \left(q_k^E\right)^*\end{bmatrix} = \frac{\begin{bmatrix} 2 & -\left(\theta^G + \theta^E\right) \\ -\left(\theta^G + \theta^E\right) & 2\end{bmatrix}\begin{bmatrix} a - c^G - \lambda^G - b\left(Q_{-k}^G + \theta^E Q_{-k}^E\right) + 0.1p_r \\ a - c^E - \lambda^E - b\left(Q_{-k}^E + \theta^G Q_{-k}^G\right) + 0.85p_r\end{bmatrix}}{b\left[4 - \left(\theta^G + \theta^E\right)^2\right]}.$$

Here, the last term in the profit function represents the profit from the RINs market. $0.1q_k^G + 0.85q_k^E$ is the number of gallons of ethanol that the blender blends into gasoline and it is also the number of RINs the blender could obtain. M_k is the mandated volume. The difference (if positive) between the obtained RINs number and the mandated volume is the excess RINs number, which the blender could sell in the RINs market. Conversely, if the difference is negative, then the blenders need to purchase RINs from the market. Here we assume that the market is large enough so they can always sell the RINs out or purchase RINs in on the market.

Proposition 1 Supply quantities under Nash equilibrium with s symmetric firms are

$$\left(q_k^G\right)^* = \frac{(s+1)\left(a - c^G - \lambda^G + 0.1p_r\right) - \left(s\theta^E + \theta^G\right)\left(a - c^E - \lambda^E + 0.85p_r\right)}{b\left[(s+1)^2 - \left(s\theta^G + \theta^E\right)\left(s\theta^E + \theta^G\right)\right]}, \forall k = 1, 2, ..., s,$$

$$\left(q_k^E\right)^* = \frac{(s+1)\left(a-c^E-\lambda^E+0.85p_r\right)-\left(s\theta^G+\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)}{b\left[(s+1)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]}, \forall k=1,2,...,s.$$

Proposition 2 Under Nash equilibrium, market share of E85 fuel is

$$\beta^E = \frac{(s+1)\left(a-c^E-\lambda^E+0.85p_r\right)-\left(s\theta^G+\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)}{\left(s+1-s\theta^G-\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)+\left(s+1-s\theta^E-\theta^G\right)\left(a-c^E-\lambda^E+0.85p_r\right)},$$

Proposition 3 Under Nash equilibrium, the total ethanol fuel price premium is

$$\Delta p = (\alpha-1)a + \frac{s\left[s+1-\alpha\theta^G+\alpha\theta^E-s\theta^G\theta^E-\left(\theta^E\right)^2\right]\left(a-c^G-\lambda^G+0.1p_r\right)}{(s+1)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)}$$
$$-\frac{s\left[\alpha s+\alpha-\theta^E+\theta^G-\alpha s\theta^G\theta^E-\alpha\left(\theta^G\right)^2\right]\left(a-c^E-\lambda^E+0.85p_r\right)}{(s+1)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)}$$

, and

$$\Delta \rho = (\alpha-1)a + \frac{s\left[s+1-\alpha\theta^G+\alpha\theta^E-s\theta^G\theta^E-\left(\theta^E\right)^2\right]\left(a-c^G-\lambda^G+0.1p_r\right)}{(s+1)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)}$$
$$-\frac{s\left[\alpha s+\alpha-\theta^E+\theta^G-\alpha s\theta^G\theta^E-\alpha\left(\theta^G\right)^2\right]\left(a-c^E-\lambda^E+0.85p_r\right)}{(s+1)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)}-\alpha\lambda^E+\lambda^G,$$

Proposition 4 Under Nash equilibrium, the social welfare is

$$\Psi = \frac{s\left(a-c^G-\lambda^G\right)\left[\left(s+1\right)\left(a-c^G-\lambda^G+0.1p_r\right)-\left(s\theta^E+\theta^G\right)\left(a-c^E-\lambda^E+0.85p_r\right)\right]}{b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]}$$
$$+\frac{s\left(a-c^E-\lambda^E\right)\left[\left(s+1\right)\left(a-c^E-\lambda^E+0.85p_r\right)-\left(s\theta^G+\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)\right]}{b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]}$$
$$-\frac{s^2\left[\left(s+1\right)\left(a-c^G-\lambda^G+0.1p_r\right)-\left(s\theta^E+\theta^G\right)\left(a-c^E-\lambda^E+0.85p_r\right)\right]^2}{2b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]^2}$$
$$-\frac{s^2\left[\left(s+1\right)\left(a-c^E-\lambda^E+0.85p_r\right)-\left(s\theta^G+\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)\right]^2}{2b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]^2}$$
$$+\frac{\min\left\{\theta^G,\theta^E\right\}s^2\left(s+1\right)\left(s\theta^G+\theta^E\right)\left(a-c^G-\lambda^G+0.1p_r\right)^2}{b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]^2}$$
$$+\frac{\min\left\{\theta^G,\theta^E\right\}s^2\left(s+1\right)\left(s\theta^E+\theta^G\right)\left(a-c^E-\lambda^E+0.85p_r\right)^2}{b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]^2}$$
$$-\frac{\min\left\{\theta^G,\theta^E\right\}s^2\left[\left(s+1\right)^2+\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]\left(a-c^G-\lambda^G+0.1p_r\right)\left(a-c^E-\lambda^E+0.85p_r\right)}{b\left[\left(s+1\right)^2-\left(s\theta^G+\theta^E\right)\left(s\theta^E+\theta^G\right)\right]^2}.$$

4. Numerical Examples

In this section, numerical examples are presented to study the market equilibrium for E10 and E85, and analyze the sensitivity of the market equilibrium with respect to the production cost, the proportion of FFVs on road, the number of firms in the market and various government policies. Real world data are utilized supplemented with reasonable assumptions. This case study focuses on the national level around year 2011.

4.1 Assumptions on the parameters

We assume that there are two types of transportation fuels in the market, E10 and E85, and there are two types of consumers: one that drives regular cars and the other that drives FFVs. The regular cars can only use E10 while FFVs can run on both E10 and E85. FFVs currently only counts for a small proportion of all the light-duty vehicles registered in USA. As mentioned, up to 2011, there are 10 million of FFVs sold, which represents about 4% of the U.S. total vehicles on the road.

Since the regular cars can only run on E10, we say $\theta_R^G = 1$ and $\theta_R^E = 0$. The FFVs group can run on either E10 or E85, so E10 and E85 are perfect substitutes to each other for this group, which means $\theta_F^E = \theta_F^G = 1$. Then we can use the two separated substitutability parameters to calculate the weighted substitutability parameter for the entire market, and we have $\theta^G = 96\%\theta_R^G + 4\%\theta_F^G = 1$, and $\theta^E = 96\%\theta_R^E + 4\%\theta_F^E = 0.04$.

The reduction of greenhouse gas emission could have some economic benefit thanks to the emission cost. Social cost of carbon (SCC) is used to measure the negative effect on climate change and global warming. SCC is the marginal cost of emitting one ton of carbon dioxide to the atmosphere. The measurement of this cost is partially based on the cost to offset the negative consequences of the pollution. Peer-reviewed estimates of the SCC for 2005 had an average value of \$43/tC with a standard deviation of \$83/tC (Yohe, et al., 2007), or after transformation, average \$12/tCO2 with a standard deviation of \$23/tCO2. As mentioned, the carbon density of gasoline is 96gCO_2e/MJ and for corn ethanol, it is 69gCO_2e/MJ. Therefore, the carbon density of E10 is 93.3gCO_2e/MJ, and the carbon density of E85 is 73.05gCO_2e/MJ. Also, we have the energy content of E10 and E85 to be 33.18MJ/L and 25.65 MJ/L, respectively. Having this information, we can calculate the social carbon cost for per gallon of the fuels. Here is the social carbon cost for E10: $\$12/t\text{CO}_2 \times * \left(93.3\text{gCO}_2\text{e}/\text{MJ}/10^6\right) \times \left(33.18\text{MJ}/\text{L} * 3.79\text{L}/\text{gallon}\right) = \$0.14/\text{gallon}$, and for E85: $\$12/\text{tCO}_2 \times \left(70.05\text{gCO}_2\text{e}/\text{MJ}/10^6\right) \times \left(25.65\text{MJ}/\text{L} * 3.79\text{L}/\text{gallon}\right) = \$0.08/\text{gallon}$. Thus we have $\lambda^G = 0.14$ and $\lambda^E = 0.08$.

Tax credit was an important policy to promote the production and consumption of biofuels. Although the tax credit of 45¢/gallon of ethanol expired at the end of 2011, it would be of interest to policy makers to compare the scenarios with and without the tax credit. We will include the tax credit in the baseline scenario.

We estimate RIN price from the historical price data. In recent years, the conventional ethanol RIN price averaged at a very low level. In 2010, the conventional ethanol RIN price stays below 1 cent per gallon and in 2011, the price stays around 3 cents (McPhail, Westcott, and Lutman, 2011). We assume the RINs price to be 3 cent/gallon during a short period. Therefore, p_r =\$0.03/gallon.

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We need to determine the values of a and b in the demand function. Since b is related to the price elasticity of demand, it can be estimated based on existing literature on gasoline price elasticity. Based on Hughes, Knitte and Sperling (2008), the short-run price elasticity of gasoline in U.S. ranges from -0.034 to -0.077 between 2001 and 2006. It is assumed that the elasticity in the model is about -0.05. We know that $E_d = \frac{p}{Q} \cdot \frac{dQ}{dp} = -\frac{1}{b} \cdot \frac{p}{Q}$, and the average price of gasoline in 2010 was \$2.78/gallon and the total consumption of gasoline during the year was about 138,496million gallons (American Fuels, 2011). Therefore, the parameter of b is estimated to be around 4e-10. From the demand function, the parameter a can be viewed as the price when the demand is zero which is not easy to estimate. From the simplified inverse demand function $p = a - b \cdot Q$, we can see that parameter a can be estimated with historical price and production quantity data. Therefore, $a = p + b \cdot Q = 2.58 + 4e - 10 \times 1.38496e11 \approx 58$.

There is no public available data on the production costs of E10 and E85. EIA provides the base for the retail price of gasoline including the cost of crude oil, refining cost and profit, distribution cost, and marketing cost and profit. In this study, we will use similar framework to estimate the production cost of E10 and E85. In 2010, the average retail price of gasoline was \$2.78/gallon and the components for this price are: 68% for crude oil, 14% for federal and state taxes, 7% for refining cost and profit, and 10% for marketing and distribution (U.S. Energy Information Administration, 2011). The 2010 average crude oil price was \$1.70/gallon (InflationData.com, 2012), thus the estimated cost for gasoline is $(\$1.70/\text{gallon})/0.68 \times 0.95 = \$2.375/\text{gallon}$. In Nov 2010, the rack price for ethanol was \$2.47/gallon (Nebraska Energy Office, 2012). When the blenders buy one gallon of ethanol at the rack price, they can get a tax credit of 45¢/gallon back, so the actual ethanol rack price is \$2.02/gallon. With the production costs of gasoline and ethanol, we can calculate the production cost of E10 and E85 with the weighted sum method. Therefore, the estimated cost of E10 should be $c^G = 0.1 \times 2.02 + 0.9 \times 2.375 = \$2.34/\text{gallon}$ and similarly, the cost for E85 should be $c^E = 0.15 \times 2.375 + 0.85 \times 2.02 = \$2.07/\text{gallon}$.

The last parameter that will be used in the model is the number of blenders. As of April 2011, the number of blenders in the U.S. is 141 (Figer, 2011), and thus we have $s = 141$.

All the parameters that will be used are summarized in Table 1.

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Table 1. Model parameters

	s	λ^G	λ^E	c^G	c^E	θ^G	θ^E	a	b	p_r
Value	141	0.14	0.08	2.34	2.07	1	0.04	58	4e-10	0.03

4.2 Baseline scenario

The Nash Equilibrium of the baseline scenario is shown in Table 2. As we can see from Table 2, the estimated total market supply of E10 is 137,741.38 million gallons, compared to the actual consumption of 138,496million gallons in 2010. The estimated retail price for E10 and E85 are \$2.733/gallon and \$2.066/gallon, compared to the actual average retail prices of \$2.78/gallon for E10 and \$2.4/gallon for E85 (E85Prices.com, 2012). These similarities indicate that the model captures the key characteristics of the real market and the estimated result matches the reality well. Under the baseline scenario, the green price premium is negative while the upfront (retail) green price premium is positive. This means if we simply look at the retail price of the two fuels, E85 has a price premium over E10 because of its lower energy content. However, when we consider the emission cost, the green product (E85) has a negative price premium which means it is even “cheaper” than E10. If the consumers are aware of the environmental advantage of E85 over E10, then they have a better chance to choose E85. This demonstrates the importance of public education on the green products’ environmental benefits and green product producers’ marketing strategies.

Table 2. Market Equilibrium in baseline scenario

	E10	E85
Production Quantity of a Single Company (Gallon)	9.769e8	1.344e7
Total Market Supply (Gallon)	1.377e11	1.895e9
Product Price (Demand Price) (\$/gal)	2.873	2.146
Upfront Price (Retail Price) (\$/gal)	2.733	2.066
Market Share	98.6%	1.4%
Green Price Premium (\$/gal)	-3.759e-3	
Upfront Green Price Premium (\$/gal)	2.925e-2	
Total Social Welfare (\$)	3.954e12	

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With the baseline scenario in place, in the next few sections, various alternative scenarios are investigated to study the impacts of policies, such as tax credit and RINs market, the number of refiners, and the proportion of FFVs on roads, to the market competition between E10 and E85 based on the market indices defined (the market share of E85, the green price premiums, and the social welfare).

4.3 Alternative scenario 1: How does the elimination of tax credit affect the market equilibrium?

There are studies (Gorter and Just, 2009 and Babcock, 2010) stating that the biofuel industry does not need both the mandate and tax credit to promote the consumption of ethanol and some commented that tax credit only benefit the blenders rather than the biofuel industry thus it should be eliminated. At the end of 2011, the 45¢/gallon ethanol tax credit expired and now ethanol has to compete with the conventional fuels without the assistance from the government. In alternative scenario 1, we investigate the impacts of eliminating the tax credit on the market equilibrium between E10 and E85. This increases the cost for producing E85 and the production cost becomes $c^E = 0.15 \times 2.375 + 0.85 \times 2.47 = \$2.46 / \text{gallon}$. The result of the Nash equilibrium for alternative scenario 1 is summarized in Table 3.

Table 3. Market equilibrium for alternative case 1 with tax credit eliminated

	E10	E85
Production Quantity of a Single Company (Gallon)	9.772e8	6.238e6
Total Market Supply (Gallon)	1.378e11	8.800e8
Product Price (Demand Price) ($/gal)	2.870	2.533
Upfront Price (Retail Price) ($/gal)	2.730	2.473
Market Share	99.4%	0.6%
Green Price Premium ($/gal)	5.167e-1	
Upfront Green Price Premium ($/gal)	5.497e-1	
Total Social Welfare ($)	3.900e12	

As we can see from Table 3, after the elimination of the ethanol tax credit, the production quantity of E10 increases slightly and the price decreases slightly as well. Meanwhile, the production quantity of E85 has a big decrease and the estimated retail price increases from $2.066/gallon to

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$2.473/gallon, which yields a higher positive green price premium. The market share of E85 also drops from 1.4% to 0.6%. These two indices indicate that E85 is less competitive in this case, which seems to contradict the literature that the ethanol industry should not be affected a lot by the elimination of the tax credit. Here are some explanations: first, the amount of ethanol going into E85 is just a small fraction of the total ethanol production, so the decrease of E85 production does not has big effect on ethanol industry. Second, in this scenario we assume that the mandate is fulfilled by the blenders. However, in the real market, the mandate may not necessarily be met and blenders may need to produce more E85. Third, in our model we do not include the transaction between the ethanol producers and the blenders, which provides a future research direction.

4.4 Alternative scenario 2: How does the elimination of the blend mandate affect the market equilibrium?

In this scenario, we want to study whether the conjecture that the ethanol mandate is not binding is correct or not. Thereby, in alternative scenario 2, we eliminate the mandate for blenders. The profit or loss from the RINs market is removed in this scenario. If the result shows that the elimination of the mandate has a significant impact on the market performance, it means the mandate is binding, otherwise, the mandate may not be binding. The equilibrium result for alternative scenario 2 is summarized in Table 4.

Table 4. Market equilibrium for alternative case 2 with mandate eliminated

	E10	E85
Production Quantity of a Single Company (Gallon)	9.769e8	1.302e7
Total Market Supply (Gallon)	1.377e11	1.836e9
Product Price (Demand Price) ($/gal)	2.876	2.171
Upfront Price (Retail Price) ($/gal)	2.736	2.091
Market Share	98.7%	1.3%
Green Price Premium ($/gal)	2.730e-2	
Upfront Green Price Premium ($/gal)	6.031e-2	
Total Social Welfare ($)	3.951e12	

From Table 4 we can see that the production quantity of E10 almost remains the same and the change in the price of E10 is also very small. The production quantity of E85 decreases by 3% and

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the price increases by 1%. Besides, the market share of E85 decreases from 1.4% to 1.3%. The social welfare has a 0.07% decrease. These changes are not significant. Therefore, we can draw the conclusion that the elimination of mandate from the baseline scenario does not have a big impact on the market performance of E85, which means the mandate in the base scenario may not be binding.

4.5 Alternative scenario 3: How does the change of industry size affect the market equilibrium?

In this case, the number of fuel blender firms decreases and we want to see whether it has a significant impact on the market share of E85 and the total social welfare. This is inspired by the idea that due to the increasing price of crude oil and the developing of the new energies, the competition between fuel blenders will be fiercer and some firms may have to quit the industry. The current number of blenders is 141 in U.S. and we assume that there are 100 competitive blenders left after the narrowing of the industry. The equilibrium result is summarized in Table 5.

Table 5. Market equilibrium for alternative case 3 with number of refiners decreasing to 100

	E10	E85
Production Quantity of a Single Company (Gallon)	1.373e9	2.291e7
Total Market Supply (Gallon)	1.373e11	2.291e9
Product Price (Demand Price) ($/gal)	3.035	2.156
Upfront Price (Retail Price) ($/gal)	2.895	2.076
Market Share	98.4%	1.6%
Green Price Premium ($/gal)	-1.525e-1	
Upfront Green Price Premium ($/gal)	-1.195e-1	
Total Social Welfare ($)	3.975e12	

From Table 5 we can see that the supply quantity of E10 decreases by 0.2% and the decreasing amount is about 400 million gallons while the supply quantity of E85 increases by 20.9% and the growth is about 396 million gallons. The price of E10 increases by $0.162/gallon which is primarily due to the decreasing of the E10 supply. Though the supply quantity of E85 increase a lot, the price of E85 has a small increase from $2.066/gallon to $2.076/gallon, and this is also because of the decreasing supply quantity of E10 since E10 is a complete substitute to E85 in both groups. The market share of E85 increases from 1.4% to 1.6% and the total social welfare increases by $21 billion. This seems to be counter-intuitive. The total social welfare would typically increase with the increase

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of number of companies and decrease with the decrease of number of companies. However, in this scenario, there are two competing products on the market rather than only one product, and the change of number of companies will change the share of the two products which can lead to a different result. This scenario suggests that the narrowing of the blender industry size could be beneficial for both the market performance of E85 and the well-being of the entire society.

4.6 Alternative scenario 4: How does the increase of FFVs affect the market equilibrium?

In this scenario, we are to investigate how the increase of FFVs fraction will affect the market equilibrium between E10 and E85, and the total social welfare. It was pointed out by Greene (2008) that about 125 to 200 million flexible-fuel vehicles may need to be on the road in order to achieve ethanol goals. According to a 2007 DOT study (Bureau of Transportation, 2006), there will be around 254.4 million registered passenger vehicles in the U.S. If 125 to 200 million FFVs are indeed on the road, then the proportion of FFVs will reach up to 50%-80% (assuming that the regular cars are replaced with the FFVs). President Obama said during the 2008 campaign that "sustainably-produced biofuels can create jobs, protect the environment and help end oil addiction-but only if Americans drive cars that will take such fuels" and he promised to work with congress and auto companies to ensure that all new vehicles have FFV capability. If this goal is achieved, in the long run, the proportion of FFVs on road will even go up to a much higher value.

We first assume the proportion of FFVs increase a little from 4% to 10% and thus E85's substitutability parameter θ^E is changed to 0.1. The Nash equilibrium for this case is summarized in Table 6. We can see from Table 6 that with the increase of FFVs proportion, the supply quantity of E10 decreases by about 0.07% while the supply quantity of E85 increases by 3.2%. The price of E10 almost stays the same and the price of E85 increases by $0.023/gallon, which is also very small. The total social welfare decreases by $4 billion (0.10%). Overall, the market performance was not impacted significantly.

Table 6. Market equilibrium for alternative case 4 with FFVs proportion increasing to 10%

	E10	E85
Production Quantity of a Single Company (Gallon)	9.760e8	1.387e7
Total Market Supply (Gallon)	1.376e11	1.955e9
Product Price (Demand Price) ($/gal)	2.873	2.169
Upfront Price (Retail Price) ($/gal)	2.733	2.086

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Market Share	98.6%	1.4%
Green Price Premium ($/gal)	2.794e-2	
Upfront Green Price Premium ($/gal)	6.096e-2	
Total Social Welfare ($)	3.950e12	

Next we assume that in the future, the proportion of FFVs on road will reach 50% and study the performance of E85 on the fuel market. The equilibrium result is summarized in Table 7. We can see from Table 7 that the supply quantity of E10 decreases by 0.9% and the supply quantity of E85 increases by 44.1% when the proportion of FFVs increased to 50%. The total social welfare continues to decrease with the increase of FFVs. The increase of the E85 supply quantity is large but the decrease of the supply quantity of that of E10 is small. Given, that the baseline market share of E85 is small, the market share in this case only increases from 1.4% to 2.0%. The result shows that although the proportion of FFVs is increased significantly, E85 is still not competitive compared to E10 in the fuel market.

Table 7. Market equilibrium for alternative case 4 with FFVs proportion increasing to 50%

	E10	E85
Production Quantity of a Single Company (Gallon)	9.678e8	1.936e7
Total Market Supply (Gallon)	1.365e11	2.730e9
Product Price (Demand Price) ($/gal)	2.872	2.326
Upfront Price (Retail Price) ($/gal)	2.732	2.246
Market Share	98.0%	2.0%
Green Price Premium ($/gal)	2.386e-1	
Upfront Green Price Premium ($/gal)	2.717e-1	
Total Social Welfare ($)	3.928e12	

To further explore how the market share of E85 changes with the proportion of FFVs, we studied the market share with full spectrum of FFVs on road. Figure 1 demonstrates the relationship between the market share of E85 and the proportion of FFV on the road.

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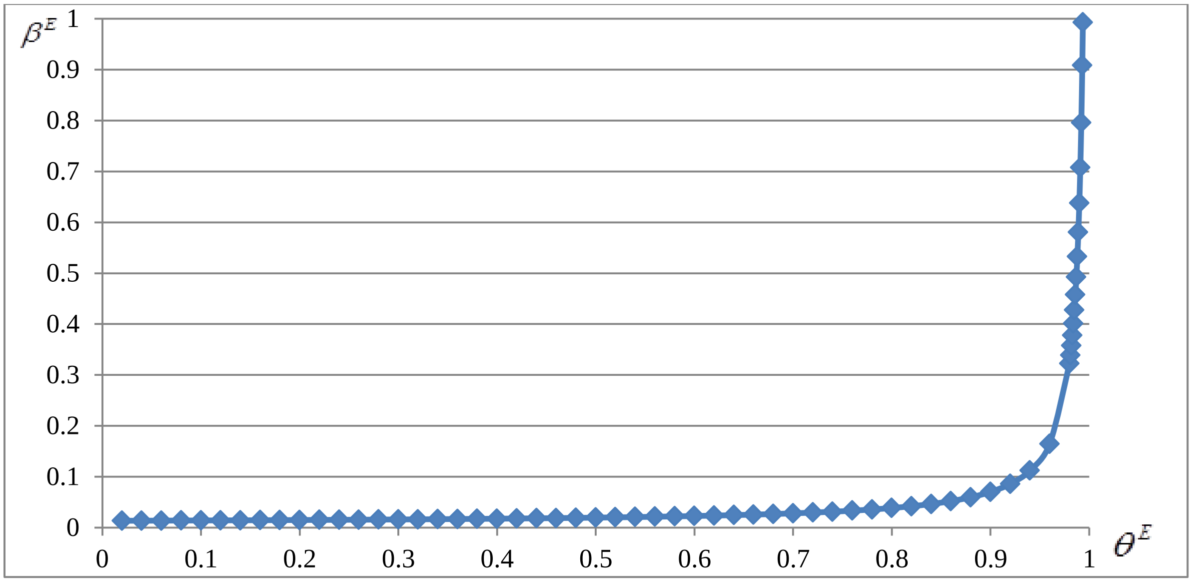

Figure 1. The relationship of market share to E85's substitutability (proportion of FFVs)

As we can see from Figure 1, the curve is very flat when the proportion of FFVs is smaller than 0.9 and becomes very steep when the proportion is around 0.99. What happens at 0.99? If we check the supply quantity's equation derived from the equilibrium, we can find that the supply quantity of E10 will decrease sharply when the proportion of FFVs goes up to around 0.9, and it will become negative when the proportion is larger than 0.99. When E10 equilibrium quantity becomes negative, it means the firms will not produce E10 and the real supply quantity should be zero and we will need to recalculate the equilibrium quantity of the other product. Figure 1 gives us some insight into the effectiveness of increasing the number of FFVs in order to promote the consumption of E85 and increase its market share. If we really want to improve the market competitiveness or E85 in the competition with E10, then we have to make more than 90% of the vehicles on roads to be FFVs, otherwise, the market share is not very sensitive to the change of FFVs proportion.

5. Conclusions

Currently, E10 and E85 are two competing products in the transportation market. E85 contains more renewable energy and reduces more of the greenhouse gas emission. E10 takes the majority of the transportation market. In this study, an oligopoly Cournot model is formulated to study the market equilibrium between E10 and E85. The impacts of the government policies, the industry size and the proportion of FFVs on the road are also investigated.

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It is the author's intention to captures the key characteristics of the two competing products and the market structure with the oligopoly Cournot model. Three market indices are derived from the model equilibrium, including the market share of E85, the E85 price premium, and the total social welfare. The E85 market share is a direct indicator of the consumer acceptance of E85. The E85 price premium is defined as the difference between the price of E85 and the price of E10 in an energy equivalent basis and it indicates the premium consumers willing to pay for E85. The total social welfare is an important concept to measure how the entire society benefits from the products so it provides insights for the government and regulatory agencies.

Numerical examples are presented to validate the model formulation and derive managerial insights for the decision makers, such as biofuel blenders and policy makers. Multiple alternative scenarios have been investigated to study the impacts of various parameters on market equilibrium. The equilibrium results derived from the baseline scenario matches the real market statistics, which validate the model formulation.

The result from alternative scenario 1 in which the tax credit is eliminated shows that the market performance of E85 is degraded with the market share decreasing and the price premium increasing, and the total social welfare decreases. This is due to the significant increase in the E85 production cost with the elimination of ethanol tax credit. This will make E85 less competitive. Alternative scenario 2 demonstrates an interesting finding that the RFS mandate may not be binding, and this may be partly because of the ethanol tax credit. When the tax credit expires, the function of mandates will recover and force blenders to buy ethanol. The market competitions with the RINs market and the mandates are more complicated than what has been modeled in this study. To make the model more realistic, sub-models will be needed to study the interaction. This provides one of the future research directions.

If the blended fuel industry sizes down in the future as in alternative scenario 3, it may become easier for E85 to survive in the competition with E10 with the market share increasing and the price premium decreasing. The total social welfare may also increase. The result from alternative scenario 4 is not very optimistic for E85. It shows that only when the proportion of FFVs is higher than 90% will the market share of E85 increase in a considerable amount with the increase of FFVs proportion. This is hard to achieve in the near future so the prospect of increasing FFVs proportion to help E85 is dim.

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In summary, this study provides some original insights into the competition between E10 and E85. The analysis has derived insights for the decision makers, such as biofuel blenders and policy makers. The RFS mandates may not be binding since the market performance does not change significantly comparing with the case without the RFS mandates. The elimination of tax credit will decrease the total social welfare and it also decreases the market share of E85. While president Obama said he would work with congress and auto companies to ensure that all new vehicles have FFV capability, the policy makers should notice from this study that to promote the consumption of E85, the impact of increasing the number of FFVs may not be significant unless that the proportion of FFVs goes higher than 0.9.

We conclude the paper by pointing out some future research directions: First, more sophisticated and accurate demand functions are needed to represent the demand and price relationship. Second, the blend mandates and the RINs market need deeper analysis and we may need to build a sub model to study the price and quantity relationship for RINs under the mandate. Third, the assumption that all firms are symmetric may be not valid in real market so we may need to differentiate the firms.

Reference

Air Resources Board (2011) 'Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline' [online] http://www.arb.ca.gov/fuels/lcfs/010611lcfs_lutables.pdf

American Fuels (2011) *2010 Gasoline Consumption*. [online] http://americanfuels.blogspot.com/2011/02/2010-gasoline-consumption.html.

Anderson, S. (2011) 'The demand for ethanol as a gasoline substitute', *Journal of Environmental Economics Management,* 08.002.

Babcock, B. (2010) 'Mandates, Tax credits, and Tariffs: Does the U.S. Biofuels Industry Need Them All?' *CARD Policy Brief,* Vols. 10-PB-1.

Bureau of Transportation (2006) *Number of vehicles and vehicle classification.* [online] http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html.

E85Prices.com (2012) 'The National E85 Price Chart', [online] http://e85prices.com

Figer, L. (2011) *RINs and ethanol supply chain: an alternative view.* Unpublished Master's thesis, University of Illinois at Urbana-Champaign, U.S.

Galbraith, K. (2008) 'In Gas-Powered World, Ethanol Stirs Complaints', *The New York Times,* 26 7. [online] http://www.nytimes.com/2008/07/26/business/26ethanol.html?_r=1&pagewanted=all

Gorter, H. and Just, D. (2009) 'The Economics of a Blend Mandate for Biofuels', *American Journal of Agricultural Economics*, Vol. 91, No. 3, pp. 738-750.

Greene, D. (2008) 'Vehicles and E85 Stations Needed to Achieve Ethanol Goals', *Journal of the Transportation Research Board,* Vol. 2058, pp. 172-178.

Hughes, J., Knitte, C. and Sperling, D. (2008) 'Evidence of a shift in the short-run price elasticity of gasoline demand', *The Energy Journal*, Vol. 29, No. 1, pp. 113-134.

InflationData.com (2012), *Historical Crude Oil Prices (Table).* [online] http://inflationdata.com/inflation/inflation_rate/historical_oil_prices_table.asp.

McPhail, L., Westcott, P. and Lutman, H. (2011) 'The Renewable Identification Number System and U.S. Biofuel Mandates' *U.S. Department of Agriculture BIO-03.*

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Motavalli, J. (2012) ‘Flex-Fuel Amendment Makes for Strange Bedfellows’, *The New York Times*, 1 3. [online] http://wheels.blogs.nytimes.com/2012/03/01/flex-fuel-amendment-makes-for-strange-bedfellows/?ref=automobiles

Nebraska Energy Office (2012) *Ethanol and Unleaded Gasoline Average Rack Prices.* [online] http://www.neo.ne.gov/statshtml/66.html.

Thomas, G. (2000) ‘Overview of Storage Development DOE Hydrogen Program’, *Hydrogen Program Review*, [online] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/storage.pdf

Tatum, S., Skinner, S. and Jackson, J. (2010) ‘On the economic sustainability of ethanol E85’, *Energy Economics*, Vol. 32, No. 6, pp. 1263-1267.

U.S. Energy Information Administration (2011) *Gasoline Explained: Factors Affecting Gasoline Prices.* [online] http://www.eia.gov/energyexplained/index.cfm?page=gasoline_factors_affecting_prices.

U.S. Environmental Protection Agency (2011) *Renewable Fuel Standard.*

Yohe, G. et al. (2007) ‘Climate Change 2007: Impacts, Adaptation and Vulnerability’, in Parry, M.L. and Canzia, O.F. (Eds.), *2007: Perspectives on climate change and sustainability*, Cambridge University Press, Cambridge, pp. 811-841.

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Table 1. Model parameters

	s	λ^G	λ^E	c^G	c^E	θ^G	θ^E	a	b	p_r
Value	141	0.14	0.08	2.34	2.07	1	0.04	58	4e-10	0.03

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Table 2. Market Equilibrium in baseline scenario

	E10	E85
Production Quantity of a Single Company (Gallon)	9.769e8	1.344e7
Total Market Supply (Million Gallon)	1.377e11	1.895e9
Product Price (Demand Price) ($/gal)	2.873	2.146
Upfront Price (Retail Price) ($/gal)	2.733	2.066
Market Share	98.6%	1.4%
Green Price Premium ($/gal)	-3.759e-3	
Upfront Green Price Premium ($/gal)	2.925e-2	
Total Social Welfare ($)	3.954e12	

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Table 3. Market equilibrium for alternative case 1 with tax credit eliminated

	E10	E85
Production Quantity of a Single Company (Gallon)	9.772e8	6.238e6
Total Market Supply (Gallon)	1.378e11	8.800e8
Product Price (Demand Price) ($/gal)	2.870	2.533
Upfront Price (Retail Price) ($/gal)	2.730	2.473
Market Share	99.4%	0.6%
Green Price Premium ($/gal)	5.167e-1	
Upfront Green Price Premium ($/gal)	5.497e-1	
Total Social Welfare ($)	3.900e12	

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Table 4. Market equilibrium for alternative case 2 with mandate eliminated

	E10	E85
Production Quantity of a Single Company (Gallon)	9.769e8	1.302e7
Total Market Supply (Gallon)	1.377e11	1.836e9
Product Price (Demand Price) ($/gal)	2.876	2.171
Upfront Price (Retail Price) ($/gal)	2.736	2.091
Market Share	98.7%	1.3%
Green Price Premium ($/gal)	2.730e-2	
Upfront Green Price Premium ($/gal)	6.031e-2	
Total Social Welfare ($)	3.951e12	

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Table 5. Market equilibrium for alternative case 3 with number of refiners decreasing to 100

	E10	E85
Production Quantity of a Single Company (Gallon)	1.373e9	2.291e7
Total Market Supply (Gallon)	1.373e11	2.291e9
Product Price (Demand Price) ($/gal)	3.035	2.156
Upfront Price (Retail Price) ($/gal)	2.895	2.076
Market Share	98.4%	1.6%
Green Price Premium ($/gal)	-1.525e-1	
Upfront Green Price Premium ($/gal)	-1.195e-1	
Total Social Welfare ($)	3.975e12	

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Table 6. Market equilibrium for alternative case 4 with FFVs proportion increasing to 10%

	E10	E85
Production Quantity of a Single Company (Gallon)	9.760e8	1.387e7
Total Market Supply (Gallon)	1.376e11	1.955e9
Product Price (Demand Price) ($/gal)	2.873	2.169
Upfront Price (Retail Price) ($/gal)	2.733	2.086
Market Share	98.6%	1.4%
Green Price Premium ($/gal)	2.794e-2	
Upfront Green Price Premium ($/gal)	6.096e-2	
Total Social Welfare ($)	3.950e12	

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Table 7. Market equilibrium for alternative case 4 with FFVs proportion increasing to 50%

	E10	E85
Production Quantity of a Single Company (Gallon)	9.678e8	1.936e7
Total Market Supply (Gallon)	1.365e11	2.730e9
Product Price (Demand Price) ($/gal)	2.872	2.326
Upfront Price (Retail Price) ($/gal)	2.732	2.246
Market Share	98.0%	2.0%
Green Price Premium ($/gal)	2.386e-1	
Upfront Green Price Premium ($/gal)	2.717e-1	
Total Social Welfare ($)	3.928e12	

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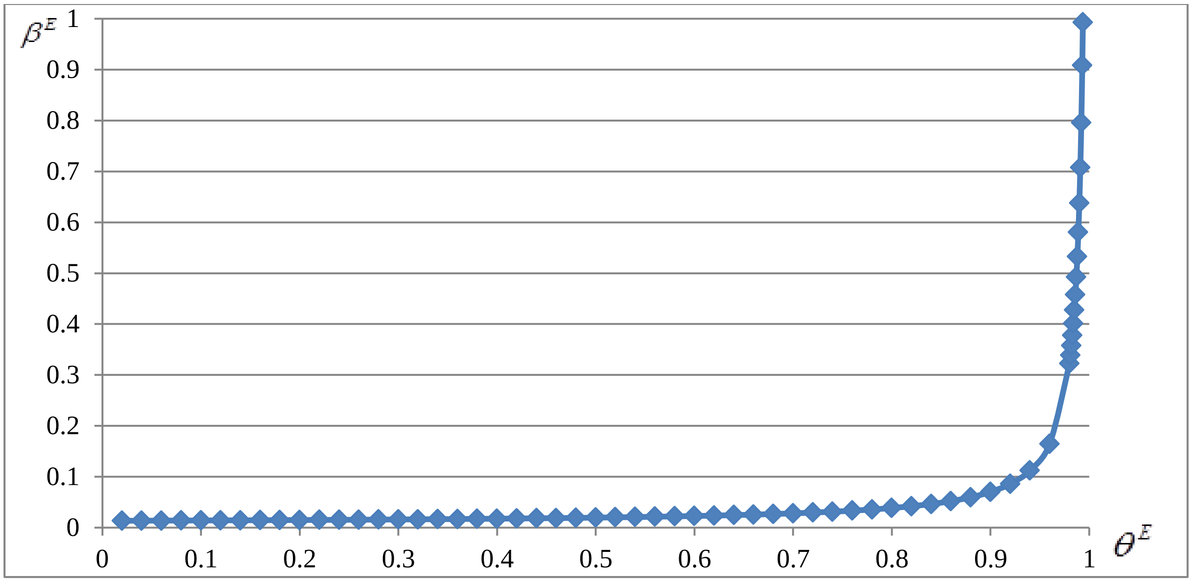

Figure 1. The relationship of market share to E85's substitutability (proportion of FFVs)