An Analysis of the Effects of Government Subsidies and the Renewable Fuels Standard on the Fuel Ethanol Industry: A Structural Econometric Model

Fujin Yi[1], C.-Y. Cynthia Lin[2] and Karen Thome[3]

1. College of Economics and Management
Nanjing Agricultural University
1 Weigang, Nanjing, Jiangsu, 210095, China
Email: fujinyi@njau.edu.cn

2. Department of Agricultural and Resource Economics
University of California, Davis
One Shields Avenue
Davis, CA 95616
Email: cclin@primal.ucdavis.edu

3. Department of Agricultural and Resource Economics
University of California, Davis
One Shields Avenue
Davis, CA 95616
Email: thome@primal.ucdavis.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

An Analysis of the Effects of Government Subsidies and the Renewable Fuels Standard on the Fuel Ethanol Industry: A Structural Econometric Model

Abstract

This paper analyses the effects of the expiration of the volumetric ethanol subsidy and the implementation of the renewable fuels standard (RFS) on the U.S. fuel ethanol industry. Analyses that ignore the dynamic implications of these policies, including their effects on incumbent ethanol firms' investment, production, and exit decisions and on potential entrants' entry behavior, may generate incomplete estimates of the impact of the policies and misleading predictions of the future evolution of the fuel ethanol industry. In this paper, we construct a dynamic model to recover the entire cost structure of the industry including the distributions of fixed entry costs and of exit scrap values. We use the estimated parameters to evaluate 3 different types of subsidy: a volumetric production subsidy, an investment subsidy, and an entry subsidy, each with and without the RFS. Results show that the RFS is a critically important policy to support the sustainability of corn-based fuel ethanol production, and that investment subsidies and entry subsidies are more effective than production subsidies.

Keywords: Fuel ethanol, subsidy, renewable fuels standard, structural model

JEL codes: Q16, Q42, Q48, L21

1 Introduction

The development of fuel ethanol in the U.S. has historically been accompanied by government subsidies and, more recently, by the Renewable Fuels Standard (RFS). According to empirical studies by Schmit et al. (2011) and Lin and Thome (2013), subsidies have contributed the development of fuel ethanol plant investment. The primary ethanol subsidy, the federal volumetric ethanol excise tax credit, was reduced from 51 cents per gallon to 45 cents per gallon in the 2008 Farm Bill and subsequently eliminated on December 31, 2011[1]. Such changes may have affected fuel ethanol plant investment and ethanol production. Indeed, the rate of expansion in ethanol production capacity has decreased from a 4.6% growth rate over the period 2005-2008 to a growth rate of 0.6% per month in 2009 (O.Brien and Woolverton, 2010). In addition to volumetric production subsidies, the fuel ethanol industry has also been supposed by the Renewable Fuels Standard (RFS), which was implemented in 2005, setting a goal of 7.5 million gallons of renewable fuel by 2012, and then extended in 2008, setting a goal of 15 billion gallons of corn-based fuel ethanol and 16 billion gallons of cellulosic biofuels by 2022. Although the industry production capacity for corn-based ethanol reached its targeted volume of 15 billion gallons at the end of 2012, cellulosic fuel ethanol production is still negligible due to both technological and economic issues and many scientists still suggest that commercialization of cellulosic is several years down the road (Celebi et al., 2010; Schnepf and Yacobucci, 2012).

This paper analyses the effects of the volumetric ethanol production subsidy and the implementation of the renewable fuels standard (RFS) on the U.S. fuel ethanol industry. Analyses that ignore the dynamic implications of these policies, including their effects on incumbent ethanol firms' investment, production, and exit decisions and on potential entrants' entry behavior, may generate incomplete estimates of the impact of the policies and misleading predictions of the future evolution of the fuel ethanol industry. In this paper, we construct a dynamic model to recover the entire cost structure of the industry including the distributions of fixed entry costs and of exit scrap values. We use the estimated parameters to evaluate 3 different types of subsidy: a volumetric production subsidy, an investment subsidy, and an entry subsidy, each with and without the RFS.

Many previous studies have estimated the viability of fuel ethanol plants under deterministic or stochastic conditions (Whims, 2002; Gallagher et al., 2006; Eidman, 2007; Ellinger, 2007; Schmit et al., 2009, 2011; Richardson et al., 2007a,b; Gallagher

[1]Fuel ethanol subsidy legislation has a long history up to 1978 and has been modified a couple times (Tyner, 2007). Based on the data analyses range in this study from 1995 to 2009, we choose the most recent point-in-time, in 2008, when the subsidy most dramatically decreased since 1990, due to our research interest although the subsidy level also decreased from 54 cents per gallon to 51 cents per gallon in 2005. Consider the fact that the subsidy decrease in 2005 is really minor comparing with baseline, we assume that such change will not affect fuel ethanol industry and the development trend is retained after 2005 since 1995, and this assumption will help us distinguish the impact of RFS implementation later.

et al., 2007), while others have predicted the economic plant size (Gallagher et al., 2005, 2007). Schmit et al. (2009) point out that previous studies of firm investment and operation of ethanol plants have focused largely on break-even or net present value analysis, return on investment, or similar assessments in a deterministic framework, with sensitivity analyses conducted on important costs, technologies, or prices (Whims, 2002; Gallagher et al., 2006; Eidman, 2007; Ellinger, 2007; Dal-Mas et al., 2011). To evaluate the viability of ethanol plants, price risk and cost risk have been incorporated by some studies to evaluate the profitability of a representative fuel ethanol plant (Richardson et al., 2007a,b; Gallagher et al., 2007; Dal-Mas et al., 2011); in addition, demand uncertainty and competitive effect uncertainty are also assessed by Jouvet et al. (2012). Gallagher et al. (2005, 2007) and Khoshnoud (2012) try to estimate the most profitable plant size under different market conditions. Several recent studies analyze ethanol plant investment option values (Schmit et al., 2009; Gonzalez et al., 2012) based on engineering cost information and various simulations, but these studies do not empirically estimate costs.

There are fewer studies focusing on how government policies impact investment in fuel ethanol plants. Cotti and Skidmore (2010) found subsidies can have a significant effect on a state's production capacity in their survey. Schmit et al. (2009, 2011) used dynamic programming methods to show that without government policies, the recent expansionary periods would have not existed and market conditions in the late-1990s would have led to some plant closure. Lin and Thome (2013) also empirically show that subsidy policies have contributed to fuel ethanol plant investment. These findings emphasize the importance of government support in the development of ethanol industry.

In this paper, we analyze how government subsidies and the renewable fuels standard affect fuel ethanol production, investment, entry, and exit by estimating a structural econometric model of a dynamic game. We use the structural econometric model of a dynamic game developed by Bajari et al. (2007) and applied by Ryan (2012) to evaluate the effects of environmental regulation on the U.S. cement industry. In particular, we assume that each plant optimizes its behavior conditional on the current state variables including other agents' actions and its own private shocks, which results in a Markov perfect equilibrium (MPE). We estimate the structural econometric model in two steps. In the first step, we characterize the policy functions for the plants' decisions regarding entry, capacity expansion and exit, which are functions of state variables. In the second step, we use a simulation-based minimum distance estimator proposed by Bajari et al. (2007) to estimate the distribution of fixed costs and the variable costs for changing ethanol plant capacity, the distribution of scrap values a plant would receive if it exited the market, and the distribution of entry costs and the variable costs for either constructing a new plant or buying a shut-down plant. We build upon the previous literature by estimating the various investment and production costs empirically, and also by allowing for two different types of entry: entry via constructing a new plant and entry via buying a shut-down plant. An additional innovation in our paper is that we allow our estimated cost parameters to depend on production subsidy levels and on the implementation of the RFS. In contrast to our paper, which empirically estimates costs, the cost information used in previous studies of the ethanol industry are mainly from the literature or from engineering experiments (Eidman, 2007; Ellinger, 2007; Schmit et al., 2009, 2011; Gonzalez et al., 2012). Our empirical results are that the production subsidy does not affect either the investment costs or scrap value, but the RFS significantly impacts the fixed cost of plant capacity investment and the scrap value.

We then use our estimated structural model of the fuel ethanol industry to simulate the effects of 3 different types of subsidy: a volumetric production subsidy, an investment subsidy, and an entry subsidy, each with and without the RFS. Results show that the RFS is a critically important policy to support the sustainability of corn-based fuel ethanol production. In addition, we find that investment subsidies and entry subsidies are more effective than production subsidies and that with an investment subsidy or an entry subsidy the government can pay much less than it would under a production subsidy but still reach the goal set by the RFS.

The rest of paper is organized as follows. In Section 2, we describe our theoretical model of ethanol plant decisions. In Section 3, we describe our empirical methods for estimating policy functions and structural parameters including unobserved costs. Section 4 describes our data. In Section 5, we present our empirical results. In Section 6, we construct several counterfactual policy experiments to analyze how the RFS and different types of subsidy affect future market capacity. Section 7 concludes.

2 Theoretical model

The theoretical model is built on the framework of industry dynamics developed by Maskin and Tirole (1988) and Ericson and Pakes (1995), and on the structural econometric model of a dynamic game developed by Bajari et al. (2007). Ryan (2012) applies this model to the evaluate the effects of environmental regulation on the U.S. cement industry.

We model the decisions of two types of agents: incumbent ethanol plants and potential entrants in the ethanol market. Incumbents choose how much to produce, whether to invest in capacity and if so by how much, and whether to exit. Potential entrants choose whether to construct a new plant, to buy a shut-down plant, or not to enter. The strategy of each agent i is assumed to be a function of a set of state variables and private information:

$$a_i = \sigma_i(s, \varepsilon_i), \tag{1}$$

where ε_i is the shock to agent i, which is not observed by either other agents or the econometrician, and where s are publicly observable state variables. State variables include own capacity, competitors' capacity, number of shut-down plants, ethanol price, feedstock price, and fuel ethanol policies.

We assume that fuel ethanol plants compete in quantities in a homogeneous goods market. The demand of fuel ethanol is homogenous over all the states, and each plant faces the national elasticity of demand. Therefore, the nation-wide fuel ethanol demand curve is given by:

$$\ln Q = \alpha_0 + \alpha_1 \ln P, \tag{2}$$

where Q is the aggregate demand for ethanol, P is the market price and α_1 is the price elasticity of demand.

For each ethanol plant i, the cost of output is assumed to be the following quadratic function of output:

$$c_i(q_i; \delta_1, \delta_2) = \delta_1 q_i + \delta_2 q_i^2, \tag{3}$$

where δ_1 and δ_2 are variable cost coefficients and q_i is the output of plant i.

Firms can change their capacities by x_i, and we assume the cost associated with capacity change is given by:

$$\Gamma(x_i;\gamma) = 1(x_i > 0)(\gamma_{1i} + \gamma_2 x_i + \gamma_3 x_i^2). \tag{4}$$

Our capacity adjustment cost function is different from the power function used in Gallagher et al. (2005, 2007) but the implicit assumption is the same: the construction cost of an ethanol plant is U-shaped. Since we do not observe divestment in our data set, the capacity change is only for capacity expansion.[2] The capacity adjustment cost function shows that investment in capacity will have fixed cost γ_{1i} and quadratic variable cost with parameters γ_2 and γ_3. The individual-specific fixed cost γ_{1i} captures the necessary setup costs such as the costs of obtaining permits and constructing support facilities, which accrue regardless of the size of the capacity.

An ethanol plant i also faces a fixed cost $\Phi_i(a)$ unrelated to production given by:

$$\Phi_i(a_i;k,d) = \begin{cases} k_{1i} & \text{if the new entrant constructs a plant} \\ k_{2i} & \text{if the new entrant bought a plant from a previous owner} \\ -d_i & \text{if the firm exit the market} \end{cases},$$

where a_i represents the entry and exit decisions, and k_{1i} and k_{2i} are the sunk costs of entry. k_{1i} is the sunk cost of constructing a new fuel ethanol plant. Instead of constructing a new plant, another way to enter the market is to buy an existing ethanol plant that has shut down; the purchasing of existing plants was more common after 2008. Therefore, k_{2i} is the sunk cost of buying a shut-down plant. These sunk costs are private information and drawn from the distributions F_{k_1} and F_{k_2}, with means μ_{k1} and μ_{k2} and standard deviations σ_{k1} and σ_{k2}, respectively. If a plant exits the market, it can receive a scrap value d_i, for example from selling off the land or facility, which is private information and drawn from distribtution F_d with mean μ_d and standard deviation σ_d.

Since the U.S. government subsidizes fuel ethanol plants based on the volume of their production, the production subsidy a fuel ethanol plant receives is:

$$r_i(q_i;\varphi) = \varphi q_i, \tag{5}$$

[2]It is therefore rational for fuel ethanol producers to stop running part of capacity rather than divesting to contract plant capacities

where φ is the subsidy level per unit of fuel ethanol.

The profit function from production for an incumbent is thus given by:

$$\bar{\pi}_i(s;\alpha,\delta_1,\delta_2,\varphi) = Pq_i - \delta_1 q_i - \delta_2 q_i^2 + \varphi q_i. \tag{6}$$

The per-period payoff function is therefore as follows:

$$\pi_i(s,a,x;\alpha,\delta,\varphi,\gamma,k,d) = \pi_i(s,a;\theta) = \bar{\pi}_i(s;\alpha,\delta,\varphi) - \Gamma(x_i;\gamma) - \Phi_i(a_i;k,d). \tag{7}$$

Hence, the value function for an incumbent, who chooses how much to produce, whether to invest in capacity and if so by how much, and whether to exit, can be represented by:

$$\begin{aligned}
&V_i(s;\sigma(s),\theta,\varepsilon_i) = \bar{\pi}_i(s;\theta) + \\
&\max\Big\{\max_{x_i>0}\big[-\gamma_{1i} - \gamma_2 x_i - \gamma_3 x_i^2 + \beta \textstyle\int E_{\varepsilon_i'} V_i(s';\sigma(s'),\theta,\varepsilon_i')dp(s';s,a_i,\sigma_{-i}(s))\big]\ , \\
&\beta \textstyle\int E_{\varepsilon_i'} V_i(s';\sigma(s'),\theta,\varepsilon_i')dp(s';s,a_i,\sigma_{-i}(s)),\ d_i\Big\}
\end{aligned}$$

where the continuation value $\int E_{\varepsilon_i'} V_i(s';\sigma(s'),\theta,\varepsilon_i')dp(s';s,\sigma(s))$ is the expected value of the value function next period conditional on the state variables and strategies in the current period, s' is the vector of next period's state variables, $p(s';s,a_i,\sigma_{-i}(s))$ is the conditional probability of state variable s' given the current state s, player i's action a_i (including any capacity changes x_i) and the strategies $\sigma_{-i}(s)$ of all other players.

Similarly, the value function for a potential entrant, who can either stay out of the ethanol market, build a new plant or buy a shut-down plant from a previous owner, is:

$$\begin{aligned}
&V_i(s;\sigma(s),\theta,\varepsilon_i) = \max\Big\{\varepsilon_{0i}, \\
&\max_{y_i>0}\left[-k_{1i} - \gamma_{1i} - \gamma_2 y_i - \gamma_3 y_i^2 + \varepsilon_{1i} + \beta \textstyle\int E_{\varepsilon_i} V_i(s';\sigma(s',\theta,\varepsilon_i))dp(s';s,a_i,\sigma_{-i}(s))\right]\ , \\
&\max_{\substack{y_i>0,\\ y_i\in\boldsymbol{Y}}}\left[-k_{2i} - \gamma_4 y_i - \gamma_5 y_i^2 + \varepsilon_{2i} + \beta \textstyle\int E_{\varepsilon_i} V_i(s';\sigma(s',\theta,\varepsilon_i))dp(s';s,a_i,\sigma_{-i}(s))\right]\Big\}
\end{aligned}$$

where y_i is the capacity for plant i; γ_4 and γ_5 are transaction cost parameters for an entrant buying an shut-down plant; $\boldsymbol{Y}$ is the set of shut-down plants' sizes in the market; and $\varepsilon_{0i}, \varepsilon_{1i}$ and ε_{2i} are idiosyncratic preference shocks that we assume are independently distributed with an extreme value distribution. If an entrant decides to buy an existing shut-down plant, its plant size choice is limited to set $\boldsymbol{Y}$. We assume, as does Ryan (2012), that potential entrants are short-lived and that if they do not enter this period they disappear and their payoff is zero forever so that they never enter in future. This assumption is for computational convenience; otherwise, we would have to solve an optimal waiting problem for the potential entrants. In addition, once an ethanol plant is constructed, we assume the capacity is used at a fixed rate, and therefore that plants do not suspend operations. Option value issues are carefully discussed by Schmit et al. (2009); Gonzalez et al. (2012). However, due to the fact that fuel ethanol industry development is driven by the government and that demand is usually more than supply, it is not rational for a manager to reduce ethanol output. Therefore, we believe this assumption is reasonable in the near future.

We assume that each plant optimizes its behavior conditional on the current state variables including other agents' actions and its own private shocks, which results in a Markov perfect equilibrium (MPE). The optimal strategy $\sigma_i^*(s)$ for each player i should therefore satisfy the following condition for all state variables s and alternative strategies $\tilde{\sigma}_i(s)$:

$$V_i(s; \sigma_i^*(s), \sigma_{-i}, \theta, \varepsilon_i) \geq V_i(s; \tilde{\sigma}_i(s), \sigma_{-i}, \theta, \varepsilon_i).$$

3 Empirical estimation

We estimate the structural econometric model in two steps. In the first step, we characterize the equilibrium policy functions for the plants' decisions regarding entry, capacity expansion and exit as functions of state variables by using reduced-form regressions correlating actions to states. We also estimate parameters in the per-period production profit function and the transition density for the state variables. In the second step, we use a simulation-based minimum distance estimator proposed by Bajari et al. (2007) to estimate the distribution of fixed costs and the variable costs for changing ethanol plant capacity, the distribution of scrap values a plant would receive if it exited the market, and the distribution of entry costs and the variable costs for either constructing a new plant or buying a shut-down plant.

3.1 Step 1: Product market profits, policy functions and transition density

3.1.1 Fuel ethanol demand

We estimate fuel ethanol demand at time t as follows:

$$\ln Q_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2' X_t + \varepsilon_t \tag{8}$$

where α_1 is the elasticity of demand and X is a vector of covariates that influence demand. To address the endogeneity of price in the demand function, we use supply shifters such as natural gas prices, electricity prices and wage rates as instruments. Since the Renewable Fuel Standard (RFS1) was first established in 2005 and updated in 2008 as RFS2, and since the production subsidy decreased at the same time in 2008, to identify the different policy effects after 2008 we will assume that RFS1 and RFS2 have the same effects through the whole estimation. Therefore, the vector X will include dummy variables to represent such policy changes.

3.1.2 Cost function

All the fuel ethanol plants are assumed to be competing in a homogeneous goods Cournot game. $P(Q)$ is the demand function estimated above . The first-order condition from each plant's profit-maximization problem is given by:

$$\begin{aligned}\frac{\partial P(Q)}{\partial Q} q_i + P(Q) - \delta_1 \left[1 + 1(\text{if after 2005})\alpha_{11} + 1(\text{if after 2008})\alpha_{12}\right] \\ -2\delta_2 \left[1 + 1(\text{if after 2005})\alpha_{21} + 1(\text{if after 2008})\alpha_{22}\right] q_i \\ +\varphi_1(\text{if before 2008}) + \varphi_2(\text{if after 2008}) \quad = \quad 0,\end{aligned}$$

where $\alpha = [\alpha_{11}\ \ \alpha_{12}; \alpha_{21}\ \ \alpha_{22}]$ are the parameters for interactions between the policy variables and the cost parameters. In particular, we consider 3 policy regimes. In the period before 2005, when both the post-2005 and the post-2008 dummies are 0, there is no RFS and there is a \$0.51 per gallon production subsidy. In the period between 2005 and 2008, when the post-2005 dummy is 1 but the post-2008 dummy is 0, the RFS was in place and there is a \$0.51 per gallon production subsidy. In the period after 2008, when both the post-2005 and post-2008 dummies are 1, the RFS was in place and there is a $0.45 per gallon production subsidy. We interact the poliy dummy variables with each of cost parameters to capture any changes in the production cost parameters due to the RFS implementation and the production subsidy level reduction, respectively. $\boldsymbol{\varphi} = [\varphi_1 \ \varphi_2]$ is the observed volumetric subsidy levels before and after 2008, respectively. We derive the predicted quantity of output $\hat{q}_i$ from rearranging the above first-order condition to get:

$$\hat{q}_i = \frac{P(Q) - \delta_1[1 + 1(\text{if after 2005})\alpha_{11} + 1(\text{if after 2008})\alpha_{12}] + \varphi_1(\text{if before 2008}) + \varphi_2(\text{if after 2008})}{2\delta_2[1 + 1(\text{if after 2005})\alpha_{21} + 1(\text{if after 2008})\alpha_{22}] - \frac{\partial P(Q)}{\partial Q}}.$$

We estimate the parameters $\delta_1, \delta_2, \alpha_{11}, \alpha_{12}, \alpha_{21}$ and α_{22} by finding the values of the parameters that minimize the sum of squared difference between observed quantity and predicted ouput, which can be represented by $\sum_{i,t}(q_{it} - \hat{q}_{it})^2$.

3.1.3 Investment policy function

We use a Tobit model to describe an ethanol plant's decision to invest in capacity. Due to the presence of fixed costs of capacity adjustment in the model, Ryan (2012) uses an (S, s) rule to model lumpy investment behavior as suggested by Arrow et al. (1951) and Attanasio (2000). However, an (S,s) policy depends on a critically strict assumption that the observed level of capacity before investment or divestment is equal to either the lower or upper bound of the (S, s) band; in addition, no direct observations for the band can be used for the plants without capacity changes. Instead of using an (S, s) rule, we assume that a latent capacity investment variable s^*_{it} exists for every ethanol plant at specific state variables that determines if a plant will invest; investment x_i will only occur if the latent variable s^*_{it} is positive. The latent investment variable is assumed to be a linear function of regressors X_{it} with additive error u_{it} that is normally distributed and homoskedastic. Thus,

$$s^*_{it} = X'_{it}\xi + u_{it}, \tag{9}$$

where ξ is the estimated parameters and X_{it} is a vector of state variables including own capacity, rivals' capacity and ethanol production policies. The Tobit model is shown as follows:

$$x_{it} = \begin{cases} 0 & \text{if } s^*_{it} \leq 0 \\ s^*_{it} & \text{if } 0 < s^*_{it} \leq \bar{s} \\ \bar{s} & \text{if } s^*_{it} > \bar{s} \end{cases}, \tag{10}$$

where $\bar{s}$ is a maximum investment level in capacity. Consistent with the data, investment in capacity is censored both from left and from right. Also consistent with the data, we observe no divestment. The Tobit model enables us to estimate the probability $p_i(s)$ of investment, which is the incumbent's investment policy function.

3.1.4 Entry and exit policy functions

The equilibrium strategy for each potential entrant is to choose from its three possible actions — construct a new plant, buy a shut-down plant, or not to enter — with probabilities $p_c(s)$, and $p_b(s)$ and $p_o(s)$, respectively. We estimate these choice probabilities as functions of state variables using a multinomial logit. For an incumbent, the exit policy probability $p_e(s)$ is estimated as a function of state variables using a logit model.

3.1.5 State transitions

In addition to estimating the optimal policy functions, we also estimate the state transition probabilities as a function of the current state variables and of the firms' strategies in investment, entry and exit. As an assumption, the changes of state variables through entry, investment and exit take one period to occur and cannot be changed in the same period. The first part of the assumption is normally assumed in discrete time models, and the second part is to reduce the computational complexity of solving the model's equilibrium if uncertainty over time is added into the model.

3.2 Recovering the structural parameters

In a Markov perfect equilibrium, each incumbent plant follows optimal strategies for output, investment and exit, and each potential entrant follows optimal strategies for constructing a new plant, buying a shut-down plant or doing nothing, all as functions of state variables. After estimating the policy functions in the first step, we then estimate the structural parameters in the second step by imposing optimality on the recovered policy functions. In particular, from the definition of a Markov perfect equilibrium, we impose that the optimal strategy $\sigma_i^*(s)$ for each player i should satisfy the following condition for all state variables s and alternative strategies $\tilde{\sigma}_i(s)$:

$$V_i(s; \sigma_i^*(s), \sigma_{-i}, \theta, \varepsilon_i) \geq V_i(s; \tilde{\sigma}_i(s), \sigma_{-i}, \theta, \varepsilon_i),$$

where θ are the structural parameters to be estimated. The structural parameters we estimate include the distribution of fixed costs and the variable costs for changing ethanol plant capacity, the distribution of scrap values a plant would receive if it exited the market, and the distribution of entry costs and the variable costs for either constructing a new plant or buying a shut-down plant.

Following Bajari et al. (2007), we assume the per-period payoff function is linear in the unknown parameters θ so that:

$$\pi_i(a, s, \varepsilon_i; \theta) = \Psi_i(a, s, \varepsilon_i) \cdot \theta,$$

where $\Psi_i(a, s, \varepsilon_i)$ is an M-dimensional vector of "basis functions" $\psi_i^1(a, s, \varepsilon_i), \psi_i^2(a, s, \varepsilon_i), \ldots,$ $\psi_i^M(a, s, \varepsilon_i)$, where, to simplify the calculation, we assume that π_i is linear in (a, s, ε_i), then the ψ_i^j are the elements of (a, s, ε) . Thereafter the value function can be written as:

$$V_i(s; \sigma, \theta) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \Psi_i(\sigma(s_t, \varepsilon_t), s_t, \varepsilon_{it})\right] \cdot \theta = W_i(s; \sigma) \cdot \theta.$$

With a linear per-period payoff function, $W_i = [W_i^1 \ \cdots \ W_i^M]$ does not depend on unknown parameter θ.

3.2.1 Parameters for incumbents

Given the strategy profile $\boldsymbol{\sigma}$, we can define an incumbent's value function as:

$$\begin{aligned} V_i(s; \sigma(s), \theta) &= W_i^1(s; \sigma) - W_i^2(s; \sigma) \cdot \gamma_{1i} - W_i^3(s; \sigma) \cdot \gamma_2 - W_i^4(s; \sigma) \cdot \gamma_3 + W_i^5(s; \sigma) \cdot d_i \\ &= \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \bar{\pi}_i(s_t)\right] - \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t p_i(s_t)\right] \cdot \gamma_{1i} - \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t p_i(s_t) x_{it}\right] \cdot \gamma_2 \\ &\quad - \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t p_i(s_t) x_{it}^2\right] \cdot \gamma_3 + \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t p_e(s_t)\right] \cdot d_i, \end{aligned}$$

where the expected values are taken over the various strategy choices $\sigma(s)$ of the other firms.

However, we cannot directly estimate the unconditional distribution characteristic parameters for γ_{1i} and d_i in the above equation. The reason is that the draw of each shock is conditional on having chosen that action. To account for the truncated conditional distribution of the two parameters, Ryan (2012) suggests using flexible linear b-spline functions of the strategy probabilities to estimate conditional expectations of the random draws. The main argument is that all the strategy probabilities capture the relevant information faced by a plant at a specific state, then the conditional mean of fixed cost or scrap value is also a function of those probabilities. The intuition behind this method is straightforward: if other alternatives become more attractive, which would be reflected in a higher choice probability for those alternatives, the draw of the investment or scrap value should represent such preference.

Before we show how to estimate γ_{1i} and d_i, we need an assumption to simplify our estimation.

Assumption 1 *There exits a set of state variables s such that $p_i(s) \approx 0$ for all $p_e(s) \in (0,1)$, vise versa.*

where $p_i(s)$ and $p_e(s)$ are the probabilities of investment in capacity and exit, respectively. Then we construct linear b-spline functions to estimate the conditional means of γ_{1i} and d_i:

$$E[\gamma_{1i}|V_i^+(s) - \gamma_{1i} > V_i^0,\ V_i^+(s) - \gamma_{1i} > d_i] = \theta_{\gamma_1} \cdot bs(p_i(s)) \tag{11}$$

$$E[d_i|d_i > V_i^0,\ d_i > V_i^+(s) - \gamma_{1i}] = \theta_d \cdot bs(p_e(s)). \tag{12}$$

$V_i^+(s)$ is the value after optimal investing capacity, and $V_i^0(s)$ is the value using current capacity. Assumption 1 allows us to invert the probability of investment (exit) onto the distribution of fixed investment costs (scrap value) , without having to worry about the exit (investment) cost. By incorporating the above two equations, (11) and (12), into the following (14), we can simultaneously estimate the unknown parameters $\theta_{\gamma 1}$ and θ_d and thereafter compute the conditional mean and variance for γ_{1i} and d_i.

Let us define $W_i(s;\sigma) = \left[W_i^1(s;\sigma)\ W_i^2(s;\sigma)\ \ldots\ W_i^5(s;\sigma)\right]$. Following Bajari et al. (2007), we calculate $W_i(s;\sigma)$ via forward simulation. Based on the definition of Markov perfect equilibrium, the optimal strategy $\sigma_i^*(s)$ for each incumbent i should satisfy the following condition for all state variables s and alternative strategies $\tilde{\sigma}_i(s)$:

$$W_i(s; \sigma_i^*, \sigma_{-i}) \cdot [1 \quad \theta]' \geq W_i(s; \tilde{\sigma}_i, \sigma_{-i}) \cdot [1 \quad \theta]'. \tag{13}$$

To estimate the unknown parameters above, we can construct a criterion condition:

$$g(\tilde{\sigma}; \theta) = [W_i(s; \sigma_i^*, \sigma_{-i}) - W_i(s; \tilde{\sigma}_i, \sigma_{-i})] \cdot [1 \quad \theta]'. \tag{14}$$

Then we search for incumbent parameters $\theta = (\theta_{\gamma 1}, \theta_d, \gamma_2, \gamma_3)$ such that profitable deviations from the optimal actions are minimized:

$$\min_{\theta_I} Q_n(\theta) = \frac{1}{n_c} \sum_{j=1}^{n_c} (\min\{g(\tilde{\sigma}_{i,j}; \theta), 0\})^2, \tag{15}$$

where n_c is the number of random draws. In practice, we add a noise term to the optimal policy function. For example, to perturb the exit policy function of incumbent we draw errors to the exit function from the standard normal distribution n_c times. Then, the random action drawn from the above procedure is used in both per-period profit function and the state transition probabilities, and the corresponding state variables are estimated. Such steps will be repeated until each firm reaches a terminal state with known payoff such as exit the market, or repeated T periods[3] such that β^T becomes insignificantly small relative to the simulation error generated by averaging over only a finite number of paths (Bajari et al., 2007).

The objective function (15) is a non-smooth function with numerous local optima, which makes it difficult to use an extremum estimator. To handle this, we use the Laplace Type Estimator (LTE) proposed by Chernozhukov and Hong (2003) to search θ in equation (15).

LTE is defined similarly as a Bayesian estimator, but it uses a general statistical criterion function instead of the parametric likelihood function. The Markov chain Monte Carlo (MCMC) approach for LTE are usually used, and the estimates are the mean values of a Markov chain sequence of draws from the quasi-posterior distribution of θ, generated by the tailored Metropolis Hastings Algorithm (Zubairy, 2011). The

[3] We set T = 70.

first advantage of LTE is that it is a global optimization method. When the number of the Monte Carlo draws approaches to infinity, the mean and standard-deviation of the posterior distribution of θ corresponds to its asymptotic distribution counterpart (Houde, 2008). Then the estimation results are the mean values and standard deviation of the 5000 Markov chain draws and the first 1000 draws in the burn-in stage are discarded.

To empirically compute the posterior distribution of θ, we use Metropolis Hastings algorithm as follows:

1. Start with $j = 0$. Choose θ^0 and compute $Q_n(\theta^0)$
2. For each j from $j = 0$ to $j = 5000$,
   i. Draw θ^+ from the distribution $q(\theta^+|\theta^j)$ and compute $Q_n(\theta^+)$
   ii. Update θ^{j+1} using

$$\begin{aligned} \theta^{j+1} &= \begin{cases} \theta^+ \text{ with probability } \rho(\theta^j, \theta^+) \\ \theta^j \text{ with probability } 1 - \rho(\theta^j, \theta^+) \end{cases} \\ \text{where, } \rho(x, y) &= \min\left\{ \frac{e^{Q_n(y)}\pi(y)q(x|y)}{e^{Q_n(x)}\pi(x)q(y|x)}, 1 \right\}. \end{aligned}$$

Following Chernozhukov and Hong (2003), we let the distribution $q(x|y)$ be a symmetric mean-0 Gaussian distribution $f(x - y)$, which we choose to be $N(0, \sigma^2)$, where the variance σ^2 is updated with the varinace of $(x - y)$ every 100 draws. We also assume uninformative priors: $\pi(x) = 1$.

3.2.2 Parameters for potential entrants

Let $\boldsymbol{a} = (0,\ 1,\ 2)$ be a subset of strategy profile $\boldsymbol{\sigma}$ for an entrant, in which $a = 0$ represents not entering the market, $a = 1$ represents entering the biofuel market by constructing a new plant, and $a = 2$ represents buying an existing shut-down plant. If we assume the preference shocks ε_{0i}, ε_{1i} and ε_{2i} in the value function are distributed extreme value, the equilibrium probabilities and choice specific value functions are related through the following equation for the probability of each choice:

$$Pr(a_i = k|s) = \frac{\exp(V_i(a_i = k, s))}{\sum_{l=0}^{2} \exp(V_i(a_i = l, s))}. \tag{16}$$

It is possible to compute the choice-specific values using forward simulation which should include parameters that need to be estimated. The choice specific value function V_i are defined as:

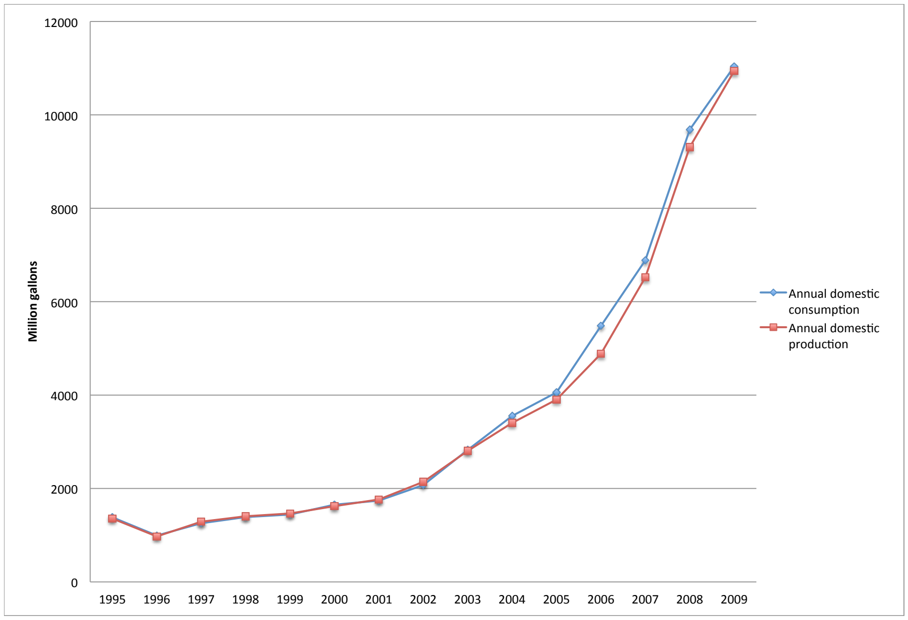
$$
\begin{aligned}
V_i(a_i = 0, s; \theta) &= 0 \\
V_i(a_i = 1, s; \theta) &= -k_{1i} - \gamma_{1i} - \gamma_2 y_{it} - \gamma_3 y_{it}^2 + \beta E\left[V^c(s'; a_i = 2, s)\right] \\
V_i(a_i = 2, s; \theta) &= -k_{2i} - \gamma_4 y_{it} - \gamma_5 y_{it}^2 + \beta E\left[V^b(s'; a_i = 3, s)\right]
\end{aligned}
\tag{17}
$$

The conditional distribution of γ_{1i} and the parameters γ_2 and γ_3 were estimated from the incumbent's problem. The continuation values $E\left[V^c(s'; a_i = 2, s)\right]$ and $E\left[V^b(s'; a_i = 3, s)\right]$ can be computed through forward simulation. The individual sunk costs k_{1i}, k_{2i} are drawn from private information. Using an argument similar to the one regarding the fixed cost of investing capacity and scrap values for incumbents, we can use a linear b-spline function of the entry probabilities to estimate the conditional means of k_{1i} and k_{2i}:

$$
\begin{aligned}
&E[k_{1i}|V_i(a_i = 1, s; \theta) > V_i(a_i = 0, s; \theta),\ V_i(a_i = 1, s; \theta) > V_i(a_i = 2, s; \theta)] \\
&\quad = \theta_{k_1} \cdot bs(p_c(s), p_b(s)) \\
&E[k_{2i}|V_i(a_i = 2, s; \theta)) > V_i(a_i = 0, s; \theta),\ V_i(a_i = 2, s; \theta) > V_i(a_i = 1, s; \theta)] \\
&\quad = \theta_{k2} \cdot bs(p_c(s), p_b(s)).
\end{aligned}
$$

where $V^c(s)$ and $V^b(s)$ are the values from constructing a new plant and buying a shut-down plant which also include optimal size of plant decision, respectively, and where $p_c(s)$ and $p_b(s)$ are the probabilities of constructing a new plant and buying an existing plant, respectively.

The entry policy function on the left hand side of equation (16) were estimated previously in the first stage using a reduced-form mulitnomial logit regression. To estimate the potential entrant parameters $\theta = (\theta_{k_1}, \theta_{k_2}, \gamma_4, \gamma_5)$, we draw n_s random states of the fuel ethanol industry and search for the parameters θ which best match the logit probabilities to the logit share equation by minimizing the sum of the squared



Data source: EIA state energy data system

Figure 1: U.S. total fuel ethanol production and consumption

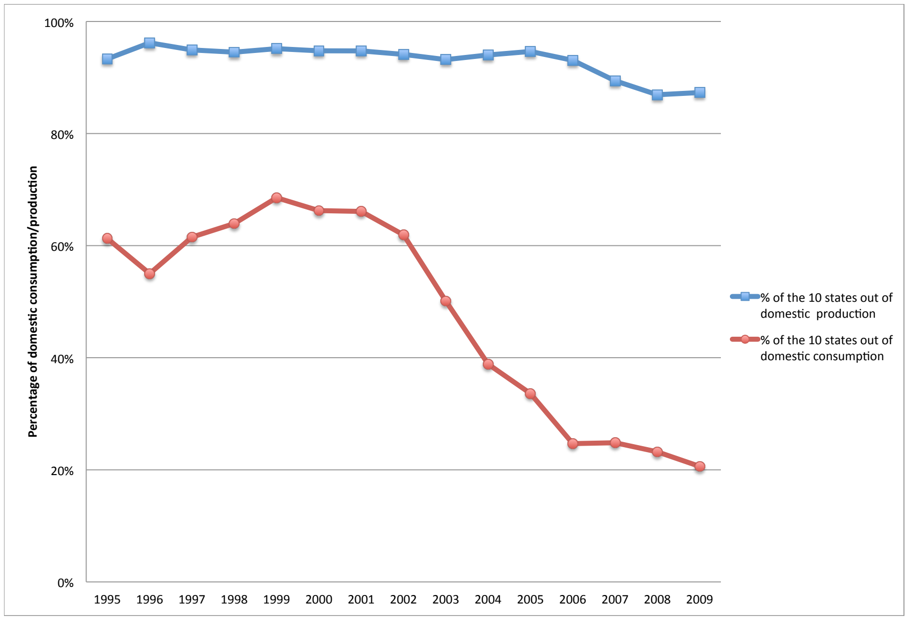
differences:

$$\min_{\theta} \frac{1}{n_s} \sum_{j=1}^{n_s} \sum_{a_i=0}^{2} \left\{ Pr(a_i|s_j) - \frac{\exp(V_i(a_i, s_j; \theta))}{\sum_{l=0}^{2} \exp(V_i(a_i = l, s_j; \theta))} \right\}^2 . \tag{18}$$

4 Data sources

As seen in Figure 1, US fuel ethanol production has the same trend as US fuel ethanol consumption. On average, as presented in Figure 2, over 90% of fuel ethanol is produced in 10 Midwestern states: Iowa, Illinois, Indiana, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. According to the Renewable Fuels Association (RFA), there were 164 fuel ethanol plants, located in these 10 Midwest states in 2010, making up roughly 80% of the total number of fuel ethanol plants in the U.S. Beacuse the majority of ethanol is produced in these 10 Midwest states, we focus our analysis of ethanol entry, exit, production, and investment decisions on these states.

However, because these 10 midwestern states only constitute around 35% of U.S. fuel ethanol consumption, we estimate a national demand function for ethanol. For our demand estimation, we use national consumption quantity and consumption ex-



Data source: EIA state energy data system

Figure 2: 10 Midwest states fuel ethanol production and consumption

penditure data from the U.S. Energy Information Administration (EIA). As most of fuel ethanol is produced in the 10 Midwest states, we use the following supply shifters as instruments for price in the demand curve estimation: average natural gas price over the 10 states, total number of plants in the 10 states, and lagged average corn price over the 10 states. The natural gas price data are from EIA. Corn prices are available annually from the National Agricultural Statistics Service of the USDA (NASS) at the state level. For covariates in the estimation of the demand curve, we use gasoline prices from the EIA and population from the Population Division of U.S. Census Bureau. All prices and income are adjusted to 2000 constant dollars.

We create an unique panel dataset of information on ethanol plants in the 10 Midwest states from 1995 to 2009, which includes plant start-up date, nameplate capacity, and the size of any expansions. The original list of fuel ethanol plants are from the Renewable Fuels Association (RFA) and Ethanol Producer magazine; these lists do not match perfectly. We rectify inconsistencies between the two lists as well as collect additional information on plant owners by searching through plant websites, newspaper articles. Summary statistics are presented in Table 1.

The RFA only reports real production quantities for each plant in the recent years,

Table 1: Summary Statistics

Variable	Mean	Minimum	Maximum	Standard deviation
Nation-level demand data				
Consumption (billion gallon)	2.2602	0.0831	11.0366	2.7335
Ethanol price ($/gallon)	1.1160	0.7782	1.7774	0.2859
Population (million)	265.5156	229.4657	307.0066	24.4643
Renewable fuels standard*	0.1724	0	1	0.3844
Gasoline price ($/gallon)	1.4868	1.0189	2.3641	0.3830
State-level data				
Plants in state	3.2310	0	37	5.7018
Natural gas price ($/million Btu)	5.5494	2.5120	9.9024	1.5960
Corn price ($/bushel)	2.9560	1.5783	5.8783	0.9442
Plant-level data				
Capacity (million gallon)	58.3555	5	290	51.7771
Capacity investment (million gallons)	0.95	0	60	5.9724

Notes: All the prices are at 2000 $, and all the variables are from 1981 to 2009. * represents binary variable.

not for all the observed years. As seen in Table 2, the industrial rate of operation over the years 1998-2010 is around 88.8%. We therefore assume that each plant produces at 88.8% of its capacity. We believe that it is reasonable to assume that all the plants are running at fixed industrial rates of capacity.

5 Empirical results

5.1 Estimation of demand

We use national data on prices and quantities over the period 1995-2009 to estimate the U.S. fuel ethanol demand equation (2). In addition to ethanol price, we include gasoline prices and a time trend in the demand function as demand shifters. To address the endogeneity of ethanol price, we use the following supply shifters as instruments for price: average natural gas price over the 10 Midwest states, total number of plants in the 10 Midwest states, and lagged average corn price over the 10 Midwest states. We use supply shifters from the 10 Midwest states since most of the fuel ethanol produced

Table 2: Fuel ethanol plant capacity, production and operation rate

Year	Capacity (10^6 gallon)	Production (10^6 gallon)	Rate of operation (%)
1998	1701.7	1400	82.27
1999	1748.7	1470	84.06
2000	1921.9	1630	84.81
2001	2347.3	1770	75.41
2002	2706.8	2130	78.69
2003	3100.8	2810	90.62
2004	3643.7	3410	93.59
2005	4336.4	3905	90.05
2006	5493.4	4855	88.38
2007	7888.4	6485	82.21
2008	10569.4	9235	87.37
2009	11877.4	10600	89.25
2010	13507.9	13230	97.94
Average	5449.5	4841	88.83

Data Sources: Renewable Fuel Association.

in the U.S. is produced in these states. The results are shown in Table 3.

The first specification includes a time trend and log gasoline price as covariates. The estimated price elasticity of fuel ethanol demand is -17.85. Specifications II, III, and IV control for the effects of the RFS and log population, which turn out not to be significant.

Overall, the demand elasticities estimated across the 4 specifications are high, most likely due to two characteristics of the fuel ethanol market. First, ethanol is almost a perfect substitute for gasoline. Table 3 shows the elasticity of ethanol demand with respect to gasoline price is high. The Clear Air Act Amendments of 1990 mandated the use of oxygenates in gasoline, of which ethanol is one and MTBE is another, and MTBE was subsequently phased out and banned beginning in the late 1990s, which means that it may be necessary to add a small quantity of ethanol into gasoline as a complement. However, most current U.S. engines can run on at most 10% ethanol. Therefore, the demand for fuel ethanol can be easily satisfied by consuming gasoline instead, which yields a high elasticity of demand for ethanol. Another reason for the high demand elasticity is based on the fuel ethanol policy, typically the blending rate. In the U.S., federal or state governments emphasize that gasoline should be blended

Table 3: Fuel ethanol demand estimates

	I	II	III	IV
Log price	-17.84579***	-19.69749***	-14.81915**	-16.81843**
	(4.326533)	(5.492871)	(5.287619)	(5.672375)
Log population			-4.271966	-6.684307
			(5.564752)	(5.79972)
RFS		-0.156656		-0.2175548
		(0.1957942)		(0.1930713)
Log gasoline price	18.06763***	20.07311***	15.11246**	17.33061**
	(4.193857)	(5.500254)	(5.146878)	(5.631973)
Time trend	0.1374992***	0.141983***	0.1867705**	0.2211521**
	(0.0132363)	(0.0142681)	(0.0660214)	(.0704688)
Constant	-258.6429***	-268.1434***	-273.2905***	-295.7264***
	(26.59923)	(29.06775)	(32.86186)	(37.03617)

Notes: Dependent variable is log quantity. Instruments are average natural gas prices and lagged prices over the 10 states and total number of plants in the 10 states. Significance codes: * 5% level, ** 1% level, *** 0.1% level.

with a required rate of ethanol, however, that is just the minimum requirement. Once the actual blending rate is higher than the governments' requirements, fuel ethanol demand should be sensitive to the price because gasoline can perfectly substitute for it.

We will choose specification I to use throughout the rest of our analysis. Although the other specifications take into account more potential explanatory variables, these variables are not statistically significant. We believe that the demand elasticity of -17.85 is an acceptable value across the 4 estimations[4]. Ryan (2012) argues that, in this stage of estimation, a lower elasticity in the demand curve results in firms facing unreasonably large investment costs in order to rationalize their behavior. In other words, firms would be leaving very large amounts of money on the table. Fortunately, our estimates of demand elasticities are high even for the relative conservative one we choose to use.

We also test whether the instruments used in the demand estimation are both cor-

[4]Anderson (2011) estimates that the elasticity is between negative 3.2-3.8 using Minnesota data only for the flexible fuel vehicle (FFV) ethanol consumption. He treats E85 as pure fuel ethanol and E10 as pure gasoline, hence, that would make the estimation unclear. On the other hand, considering the fact that the total consumption of E85 for FFV until 2011 is less than 0.02% of E10 used by conventional gasoline vehicles (EIA, 2011), we believe our estimation covers the main consumption behavior of fuel ethanol rather than just for the FFV fuel demand.

related with endogenous fuel ethanol price and uncorrelated with the error term. For specification I[5], the first-stage F-statistic for the instruments is 14.67, which is significant at 5% level and greater than 10, the "rule of thumb" critical value. In the Sargan-Hansen overidentification test, the p-values of over identification are greater than 10%, which means that we cannot reject the joint null hypothesis that our instruments are uncorrelated with the error term and that the instrument variables are correctly excluded from the estimated equation.

5.2 Production costs

After estimating the demand curve for fuel ethanol, we recover the production cost parameters by matching predicted quantities as close as possible to their actual outputs. As described above, we assume that the production cost is quadratic with parametesr δ_1 and δ_2 to be estimated. In addition, two policy shifters: RFS and the decrease of volumetric subsidy in 2005 and 2008, respectively, have been incorporated to capture the policy effects to the cost parameters. Totally, we have six parameters have to be recovered and the results are shown in Table 4.

Consider the fact that we do not have full observations of fuel ethanol plants' production from 1995 to 2009, the first specification assumes all the plants produce ethanol as much as they can up to their capacities. Specification II is based on the real outputs for each plant from 2007 to 2009. The third scenario assumes that all the plants produce a specific rate of their capacities according to annual industrial utilization rate. All the three specification estimates show that the linear term of cost function is not significantly different from zero and the only significant parameter is the quadratic term. It represents that the marginal cost of producing fuel ethanol follows a curve through the origin. Regarding the policy shifters' effects, the estimation results suggest that they do not have significant effects on the cost function.

The three different output assumptions show similar estimates, and we decide to use the results from specification I for later estimations. Given two facts that the estimation using the available recent three year observations shows similar results and the US demand of fuel ethanol is always greater than production which should drive those

[5] The other specifications F-value of regression of the instruments on fuel ethanol price are marginally less than 10.

Table 4: Production cost estimates

	I	II	III
$\hat{\delta}_1$	-0.2549	0.6792	0.3534
	(0.4126)	(0.3999)	(0.2021)
$\hat{\delta}_2$	0.0149***	0.0101*	0.0113***
	(0.0038)	(0.0051)	(0.0024)
$\hat{\alpha}_{11}$	2.7634	0.5790	-1.9452
	(2.1137)	(4.8012)	(121.4237)
$\hat{\alpha}_{12}$	2.1638	2.2686	20.8086
	(3.1064)	(30.5001)	(121.5258)
$\hat{\alpha}_{21}$	-0.0251	-0.3732	0.8761
	(0.3067)	(0.4549)	(51.0382)
$\hat{\alpha}_{22}$	1.2851	2.5801	-6.1835
	(0.9357)	(12.4313)	(52.0883)

Significance codes: * 5% level, ** 1% level, *** 0.1% level. The estimation is constructed using "lsqnonlin" in Matlab

plants producing fuel ethanol as much as possible, we believe that the first specification results are plausible. Referring the information from Table 1, we can calculate the yearly gross revenue of a firm with average capacity is around 91 and 65 million dollars with and without federal government subsidy. Accordingly, the profit margins are around 44.32% and 21.78%, respectively. As a typical 50-million-gallon plant in Georgia, its production cost is $ 0.77/gallon from Gonzalez et al. (2012), which is close to our result, $ 0.75/gallon[6].

5.3 Investment policy estimation

In Table 5, we report the estimates from the Tobit model. In the sample, we can first consider the dependent variable of capacity change has been censored at two points: first, at left-hand side, instead of decreasing capacity, we only observe zero change of capacity due to the relative high fixed cost to completely shut down part of plant. On the other side, we do not observe capacity changes over 60 million gallons. The reason

[6]Schmit et al. (2009)'s estimation of operating cost is around 0.05 US $/gallon which does not count feedstock expenditure.

Table 5: Probability of changing capacity using Tobit

	I	II	III	IV
Capacity	-0.8486**	-0.8935**	-0.8765**	-0.8545**
	(0.3219)	(0.3361)	(0.3316)	(0.3244)
Rivals' capacity	-0.0244**	-0.0295**	-0.0236*	-0.0202
	(0.0090)	(0.0108)	(0.0093)	(0.0121)
Lag ethanol price	173.9980**	119.7424	140.9785	157.9971*
	(66.3847)	(70.3478)	(78.2443)	(71.9162)
Year		8.1522		
		(4.6079)		
Renewable fuels standard			17.93665	
			(24.0476)	
Subsidy decrease				-16.1027
				(33.0000)
Constant	-202.8695***	-16455.64	-175.9130**	-197.0280**
	(56.43481)	(9201.0100)	(64.5007)	(56.5464)
Prob > χ^2	0.0000	0.0000	0.0000	0.0000

Significance codes: * 5% level, ** 1% level, *** 0.1% level.

for the right-hand side truncated might be that for a manager, it is not the best way to expand the current capacity more than 60 million gallons due to quick increase of the expansion cost, otherwise they could directly build another independent plant and costs less. Therefore, we set two censoring limits, 0 and 60 million gallons. The results are shown in Table 5.

In the first three specifications of Table 5, the coefficients of own capacity and sum of competitors' capacity are quite robust when other regressors are added into the estimations including lag ethanol price, time trend and RFS. Both of them have negative effects to expand plant size. It makes a lot sense that the large competitors' capacities will dampen the manager's production goal and a large size plant has less incentives to expand capacity because of rapid increase of costs. In the meantime, our estimation is consistent with the results from Ryan (2012). In addition, the main policies we focus on, RFS and subsidy decrease, do not have significant impacts to investment decisions although they have expected signs.

It is also valuable to mention another possible way to model the investment decision of changing capacity is using a Heckman two-stage estimation. One might expect that the expansion size of fuel ethanol plant might correlated with own capacity and other

Table 6: Exit policy estimation results

Specification	I	II	III	V
Capacity	-0.0090825	-0.0141491*	-0.0142611*	-0.0140681*
	(0.0054071)	(0.0062384)	(0.0063588)	(0.0065337)
National sum of rivals' capacity	0.0004353***	0.000399**	0.000452**	
	(0.0001315)	(0.0001348)	(0.0001484)	
State-wide sum of rivals' capacity				0.0015073*
				(0.000611)
Subsidy decrease from 2008			-0.6774594	-0.3306446
			(0.494315)	(0.4999631)
State MTBE ban			0.9846518	1.521525
			(0.8356177)	(0.8428378)
Renewable fuels standard	-2.15661*	-2.010861*	-2.396794*	-1.030044
	(0.9928082)	(1.019211)	(1.003194)	(0.6129466)
Constant	-4.053357***	-4.098581***	-4.986667***	-4.47805***
	(0.4927511)	(0.7406122)	(0.9913086)	(0.985674)
Regional fixed effects	No	Yes	Yes	Yes
Log likelihood	-140.07545	-128.4404	-125.97898	-128.39306
Prob > χ^2	0.0001	0.0000	0.0000	0.0002

Significance codes: * 5% level, ** 1% level, *** 0.1% level.

rivals' capacities, but the investment decision may have self-selection problem due to the variability of manager's ability. However, we find that the self-selection problem is not statistically significant (results not shown).

5.4 Entry and exit policy estimation

Table 6 and 7 present the estimates of exit and entry policy function. Once a plant owner has made an exit decision, during the exit procedure, we assume that the owner cannot contact the potential entrants and therefore, the owner cannot sell the plant directly to potential entrants. In other words, the exit plant owner only can get the scrap value from the shut-down plant, and if a potential entrant decides to buy a shut-down plant, the only sign for the availability of this choice is through the number of shut-down plants in the market. The main reason why we need this assumption is that we cannot identify the exit behavior with or without selling the plant to a potential entrant. Even though we can identify such behavior differences, how and when the potential exit plant and potential entrant make the deal will be out of our model framework. This assumption also simplifies our later estimation.

Table 7: Entry policy estimation results

Specification	I	II	III	V
Construct a new plant				
State-wide incumbent plant number		0.0254514	0.0363316*	0.0338762
		(0.0148227)	(0.0162078)	(0.0251319)
Renewable fuels standard	1.77717***	1.609265***	0.9944703***	1.09671**
	(0.186272)	(0.2125712)	(0.2727677)	(0.3248798)
Number of shut-down plants	0.5828927**	0.4796479*	-0.2105033	-0.2664445
	(0.1996755)	(0.2103128)	(0.2393303)	(0.2525602)
Dummy for shut-down plant	0.1107411	0.0875036	0.4284061	0.4189562
	(0.3441228)	(0.3452659)	(0.3765642)	(0.4134661)
Subsidy level			40.4227***	46.05438***
			(6.961446)	(7.827656)
State MTBE ban			0.300788	0.323839
			(0.2774698)	(0.2843542)
Constant	-3.02***	-3.126682***	-21.42989***	-24.26068***
	(0.1308809)	(0.1461258)	(3.546983)	(3.599343)
Buy existing shut-down plant				
State-wide incumbent number		-0.0366157	-0.0278613	0.0714663
		(0.0395297)	(0.0404154)	(0.0896447)
Renewable fuels standard	0.6049246	0.8265209	-0.2372723	0.04716
	(0.5835563)	(0.6147496)	(0.8435561)	(0.9740585)
Number of shut-down plants	1.02407***	1.153358***	0.5450337	0.1281007
	(0.2503383)	(0.2959426)	(0.3459121)	(0.429403)
Dummy for shut-down plant	1.901455**	1.98196**	1.890419*	2.692221**
	(0.6915496)	(0.6951695)	(0.7750777)	(1.00824)
Subsidy level			41.83855 *	41.64608*
			(16.88723)	(20.69253)
State MTBE ban			1.186518	0.4485962
			(0.92613)	(1.130628)
Constant	-5.904527***	-5.773988***	-25.03617**	-25.51162**
	(0.5171988)	(0.5347957)	(7.628549)	(9.559419)
Regional fixed effects	No	No	No	Yes
Log likelihood	-522.588	-520.23631	-498.90148	-483.62965
Prob > χ^2	0.0000	0.0000	0.0000	0.0000

Significance codes: * 5% level, ** 1% level, *** 0.1% level.

In the estimation of exit policy, specifications I and II in Table 6 consider the effects from own capacity and national-wide competitors' capacity with or without taking account the regional fixed effects. Own capacity has a negative effect on the exit probability, which means that the larger size of a plant, the more costly it is to shut it down. We also notice that competitors' capacity increases the probability of exit. In these two specifications, we also include RFS and it has an expected significant negative effect on the exit probability. Since this study pays more attention to the subsidy decrease from 2008, we add this policy change in specification III. It turns out that we do not have evidence to show that the decrease in the production subsidy will affect the exit probability. The reason might be that the decrease of subsidy is only 12% of original subsidy level and such small change of subsidy has not been captured in our dataset, i.e., we only have two-year observations after 2008. One might also expect that the competition from the same state dominates further plants in other states, hence, specification IV shows the evidence of this speculation. In specifications III and IV, we also control state MTBE ban although they do not show that the ban affects the exit decision. Overall, the sign and magnitude of estimated coefficients across the four different specifications are close. The log likelihood values of specification III is marginally better than the others, so we decide to use specification III in the following analysis.

In the entry policy estimation from Table 7 we first test the effects of the number of fuel ethanol plants that shut down and of the RFS since 2005 on entry. Results show that the RFS has a significantly positive effect on entry, most likely because it provides an expectation that both demand and production will increase. The number of shut-down plants may increase the possibility of entering the fuel ethanol industry either through constructing a new plant or buying a plant. The latter one is easy to understand because the potential entrant has more options to buy an appropriate plant. The benefit from more exit plants that would drive less competition in the feedstock market could also interpret the positive sign in the estimation of constructing a new plant. In addition, Lin and Yi (2012) argue there might be positive agglomeration effects and negative competition effects between potential entrants and incumbent plants and they suggest using the number of incumbent plants to capture the net effect. If its sign is positive, it means agglomeration dominates the competition effect, and *vice versa.*

Specification III shows that agglomeration effect is the dominant one for the choice of constructing a new plant.

Specification III incorporates the subsidy policy change since 2008 and MTBE ban for each state. Especially, the decrease in the subsidy in 2008 significantly decreases the probability of entry no matter through constructing a new plant or buying a shut-down plant. However, the MTBE ban does not significantly affect either entry decision. In specification IV, we include state dummy variables and we will use these results for the remainder of the analysis. We conclude from specification IV that the policy change such as RFS and subsidy affect the probability of entry through constructing a new plant. At the same time, the availability of shut-down plants and relevant policies significantly affect the probability of entry through buying an existing shut-down plant.

5.5 Structural parameters

In the structural estimation, we set the discount factor β to 0.9. The estimation results are shown in Table 8. We report results for 3 scenarios: the first one is without RFS but with a $0.51 per gallon production subsidy, and this scenario is the period before 2005. The second scenario is between 2005 and 2008 because the RFS was implemented in 2005 but the subsidy has not been decreased, and the third scenario is after 2008 with less subsidy per unit of ethanol. Over all the 3 scenarios, we find that variable costs (γ_2, γ_3, γ_4 and γ_5) for capacity investment or for purchasing an existing plant are all significantly different from zero. For the entrants who construct a new plant, the variable cost in the scenarios with RFS is higher than the variable cost in the scenario without RFS, which is understandable because the RFS reduces the uncertainty of the ethanol market demand and therefore attract more potential entrants, causing entities related to ethanol construction would charge more due to the increased competition. However, we do not see the difference in either γ_2 or γ_3 for the scenario with the $0.51 production subsidy and the one with $0.45 production subsidy because the subsidy level in the estimation of investment policy (see Table 5) is not significant. On the other hand, the variable costs parameters γ_4 and γ_5 over all the three scenarios are close, and the relevant policies seems not affect them significantly. Our interpretation is that purchasing a plant is a one-time transaction; when a new entrant buys a plant, all the connections to upstream producers are kept and the variable cost related to the capacity will not be affected by the policies. In addition, the shut-down plant usually stays at a disadvantage in the negotiation of the price. The policy changes only affect the fixed cost of buying a plant (k_2) because the RFS will increase the number of competitors who want to buy plants. That is why we find that the entry cost of buying a plant is significant, while the other two scenarios, i.e., without RFS or subsidy decreased, do not statistically have entry costs.

Regarding the investment fixed cost γ_{1i}, we find that after the RFS was implemented, the mean of fixed costs dramatically decreased. We could interpret this change as the result of some relevant policies to RFS because federal or state government have their own renewable fuels goal, then, decreasing investment fixed costs is one way for them to stimulate the supply of biofuels. In addition, our estimations have close range as Schmit et al. (2009)'s results, 0.08 US \$/gallon-0.13 US \$/gallon.

On the other hand, the scrap values under the scenario with RFS is relative higher than the case without RFS. The reason is straightforward: RFS increases the expected ethanol price under limited supply of fuel ethanol, then improves the profitability of producing a unit of ethanol. In the meantime, the standard deviation for the scenario with RFS is smaller than the first one, which suggests that the plant owner will have high probability to get a better scrap value after RFS. However, due to the silence of subsidy change to exit decision, we find the subsidy level does not affect the scrap value if RFS is implemented.

We also observe the similar changes between the entry cost through construction and the entry cost of buying a shut-down plant. The benchmark scenario without RFS and \$0.51 per gallon subsidy has insignificant entry cost. If a potential entrant decides to construct a plant after RFS, entry cost is a number drawn from a distribution, which has a mean as million \$3.7, and a variance around million \$0.9. However, when the government decreases the subsidy since 2008 and has no intent to continue such policy, it will lead less competition of entry such as permit, infrastructure, etc., and that drives less sunk cost during entry than the values in the second scenario.

Table 8: Structural parameters

	I		II		III	
	No RFS & $0.51 subsidy		RFS & $0.51 subsidy		RFS & $0.45 subsidy	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
Variable cost of capacity investment						
Capacity (γ_2)	0.526193	0.013137	0.581689	0.005035	0.581689	0.005035
Capacity squared (γ_3)	0.005151	0.000372	0.009958	0.000108	0.009958	0.000108
Variable cost of buying plant						
Capacity (γ_4)	0.527354	0.000406	0.527347	0.000309	0.527746	0.000320
Capacity squared(γ_5)	0.005141	0.000003	0.005141	0.000003	0.005136	0.000003
Fixed cost of capacity investment						
Mean (μ_{γ_1})	0.164171	0.005581	0.065616	0.004771	0.065616	0.004771
Standard deviation (σ_{γ_1})	0.059361	0.003667	0.028731	0.002143	0.028731	0.002143
Scrap value						
Mean (μ_d)	41.366878	4.139625	49.306882	5.106498	49.306882	5.106498
Standard deviation (σ_d)	22.156551	0.485253	14.596099	1.047114	14.596099	1.047114
Entry costs						
Through own construction						
Mean (μ_{k_1})	1.831800	2.170422	3.700916	1.787027	11.298601	11.444329
Standard deviation (σ_{k_1})	0.427599	0.674478	0.885925	0.306962	0.097542	0.199722
Through buying						
Mean (μ_{k_2})	1.967826	2.170259	4.273398	1.786811	11.813752	11.445587
Standard deviation (σ_{k_2})	0.324978	0.676924	0.945295	0.316091	0.224591	0.200016

Note: Units are in millions of dollars (excluding standard deviations).

6 Counterfactual policy experiments

Based on the structural parameters estimated in the last section, we could simulate several counterfactual scenarios based on our policy interests. Our main interest is to examine the sustainability of fuel ethanol production from 2012 onwards given the fact that total ethanol capacity has reached 15 billion gallons yearly, specifically, we are wondering whether the total market capacity of ethanol production in 2022 can reach the level requested by RFS. To reach this, we compute the MPE of the theoretical model using the estimated structural parameters and predict the ethanol production state variables in 2022.

We construct a counterfactual market based on the most recent observations of state variables in 2012 including total market capacity, ethanol price, number of plants on average over all the states who have ethanol plants and average plant size. Over the main fuel ethanol production states in the U.S.,we would ideally wish to simulate all the scenarios for those states. However, due to the heavy computation constraint, we use a representative state, there are 15 incumbent plants and 15 potential entrants with average plant capacity, 73 million gallon per year, which is consistent with the mean capacity in 2012 over all the states that have fuel ethanol plants. The number of incumbent plants are close to a typical state in Midwest, which supplies most of fuel ethanol in the U.S., and we allow 15 potential entrants that is large enough to lessen the impact of our artificial setting.

Table 9 reports the results of simulations under different polices. Scenarios I and II show the results for the situation without RFS when different production subsidy levels are applied, and the rest three columns present the results with RFS. We report not only the total market capacity change from 2012 to 2022, but also social welfare change by using the demand function estimated in the first stage. In addition, total producer profit, consumer surplus and government subsidy are the sums over years from 2012 to 2022 and they are all discounted values. Regarding the predicted price of ethanol, we use price transition estimation including RFS and subsidy as independent variables, and we find that RFS significantly increases the ethanol price because it can directly improve the demand of ethanol. By comparing these scenarios we exploit several important findings: first, the implementation of RFS increases producer profits and consumer surplus. In the the scenarios with RFS, they have around two times of producer profit and consumer surplus of the values in the scenario without RFS if subsidy level is 51 cents per gallon. Comparing with producer surplus, consumer surplus is acceptably low because our estimation of demand elasticity is high. In the meantime, net social welfare taking into account the government subsidy are positive. Second, according to our interest, we find that RFS also affects total market capacity in 2022 referring to 2012. To simplify our simulation, we assume all the potential entrants first decide whether enter the ethanol market or not, and then decide plant capacity. In the case that RFS is applied and the subsidy level is 51 cents per gallon, total market capacity is going to increase by 16.62%, but it will decrease by 5.52% if there is no RFS. Considering the situations with no production subsidy, RFS still can stimulate total market capacity to expand by 4.19%, however, it will dramatically decrease by 16.62% if RFS is not implemented. On the other hand, the total capacity of ethanol supply is decreasing when the subsidy level reduces although RFS mitigates this change. In scenarios III and V, our simulation results are consistent with the most recent fuel ethanol capacity change: market capacity increases quickly when subsidy level is high and the market capacity increases slowly when subsidy level is low. This finding is also consistent with the results by Schmit et al. (2011) and Lin and Thome (2013). As variable cost of ethanol production increases rapidly if the capacity size becomes large, volumetric subsidy is critically important for those large plants. Therefore, the elimination of subsidy drives a few plants exit when ethanol price does not increase much. However, in the long term, we assume ethanol price having increase trend due to RFS mandatory and the expansion of FFV fuel demand. The price increase setting makes small-size plants entry possible, which is consistent with Dal-Mas et al. (2011) result. Therefore, the entry of smaller size plants leads average plant scale smaller than our primitive plant capacity. Without considering the above policy and market conditions, Gallagher et al. (2007) suggests larger plant scale.

Beside the volumetric production subsidy, we also simulate the effects of an investment subsidy and an entry subsidy on the sustainability of fuel ethanol production. We define an investment subsidy to be a subsidy based on capacity that is only paid to a newly constructed plant . We define an entry subsidy as a flat-rate subsidy that is only paid to a newly constructed plant above a threshold size but does not vary by capacity. To avoid extremely small size plant, we set a threshold size, 5 million gallon per year.

In order to make the two investment subsidies comparable with production subsidy, we adjust investment subsidy level to reach 4,000 million US dollars from 2012 to 2022, which is the similar level in the scenario of production subsidy with 51 cents/gallon and no RFS. From the first four scenarios I-IV in Table 10 we can see that total capacity in the representative state will increase by 24% if there is no RFS and increase by 36% if RFS is applied. The changes of total capacity under investment subsidy and entry subsidy are extremely close because the high construction subsidy can cover entry cost easily and lead to high entry probability, therefore, all 15 potential entrants choose to enter through constructing plants. In other words, the assumption of the maximum number of potential entrants has been reached and government can reduce investment subsidy level but still can make total capacity sustainable. Therefore, we report in scenarios V-VIII results from simulations of subsidy levels that have been dramatically reduced. Even though investment subsidy is \$0.10/gallon and entry subsidy is 1 million US dollar for every new entrant, total state capacity will increase more than 14% and 24% without and with RFS by 2022, respectively. Hence, the policy meaning is straightforward that using plant construction subsidy is more effective than using production volumetric subsidy. In addition, the fact that minor subsidy designed to plant construction has significant stimulation impact to capacity expansion shows that potential entrants might face serious liquidity constraint.

In the current situation with RFS but no subsidy as described in Table 9, we can foresee that total production of ethanol is not able to satisfy the demand increase of fuel ethanol by 2022 due to slow-moving cellulosic ethanol technology or FFV market expansion. Although subsidy is still a optional policy, given the fact that both 51 cents per gallon subsidy and RFS only can increases total capacity by 16.62%, around 2.5 billion gallons by 2022, it seems impossible to satisfy the predicted 35 billion gallon fuel ethanol demand increase driven by FFV market. Therefore, we are almost confident that corn-based ethanol is infeasible to provide enough fuel ethanol in the future.

7 Conclusion

This study proposes a dynamic structural model to analyze fuel ethanol managers' production plans (produce, invest capacity or exit) and potential entrants' investment strat-

Table 9: Counterfactual policy experiments — production subsidy

	I No RFS $0.51 subsidy		II No RFS $0 subsidy		III RFS $0.51 subsidy		IV RFS $0.45 subsidy		V RFS $0 subsidy	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Total Producer Profits (million $ in NPV)	4733.11	438.01	734.68	452.74	8446.69	963.86	7671.38	521.63	3771.33	426.51
Total Consumer Surplus (million $ in NPV)	270.77	18.51	215.59	20.08	406.62	30.90	392.52	21.00	381.23	21.96
Total subsidy (million $ in NPV)	3981.03	256.51	0	-	4485.46	319.86	2822.63	182.68	0	-
Total Net social welfare (million $ in NPV)	1022.88	469.67	950.28	445.21	4367.85	739.17	4241.27	439.25	4152.56	439.23
Average Capacity of Plant (million gallon)	42.36	3.11	32.75	3.32	48.48	3.89	46.58	2.56	45.04	2.67
Change of market capacity (2022 v.s. 2012)	-5.52%	0.14	-26.62%	0.14	16.62%	0.14	9.54%	0.11	4.19%	0.11
Average Market Price ($/gallon)	1.15	0.04	1.15	0.04	1.64	0.04	1.64	0.04	1.65	0.04

Table 10: Counterfactual policy experiments — investment subsidy & entry subsidy

	Invest subsidy				Entry subsidy			
	No RFS		RFS		No RFS		RFS	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	I		II		III		IV	
	14 mil. \$/mil. gal.				260 mil. \$/plant			
Total Producer Profits (million \$ in NPV)	839.79	362.90	4762.77	397.57	839.79	362.90	4762.77	397.56
Total Consumer Surplus (million \$ in NPV)	323.54	11.06	452.29	24.27	323.54	11.06	452.29	24.27
Total subsidy (million \$ in NPV)	4043.71	112.80	4198.02	182.62	4003.75	132.29	4165.71	201.32
Total Net social welfare (million \$ in NPV)	-2880.38	376.88	1017.03	449.16	-2840.42	383.84	1049.34	464.35
Average Capacity of Plant (million gallon)	52.01	1.05	54.46	3.16	52.01	1.05	54.46	3.16
Change of market capacity (2022 v.s. 2012)	23.55%	0.04	36.13%	0.15	23.55%	0.04	36.13%	0.15
Average Market Price (\$/gallon)	1.15	0.04	1.15	0.04	1.64	0.04	1.64	0.04
	V		VI		VII		VIII	
	0.1 mil. \$/mil. gal.				1 mil. \$/plant			
Total Producer Profits (million \$ in NPV)	831.43	375.17	4605.26	414.70	778.82	496.55	4512.46	396.60
Total Consumer Surplus (million \$ in NPV)	315.57	12.53	445.54	24.36	309.71	14.18	427.76	23.76
Total subsidy (million \$ in NPV)	28.96	1.42	27.91	1.36	16.08	1.03	15.39	0.78
Total Net social welfare (million \$ in NPV)	1118.04	381.27	5022.89	424.31	1072.44	410.44	4924.83	410.01
Average Capacity of Plant (million gallon)	50.47	1.65	53.68	3.13	49.47	2.16	51.23	3.02
Change of market capacity (2022 v.s. 2012)	17.80%	0.07	34.86%	0.15	14.78%	0.09	24.20%	0.14
Average Market Price (\$/gallon)	1.15	0.04	1.15	0.04	1.64	0.04	1.64	0.04

egy (stay outside of ethanol industry, construct a plant or buy a shut-down plant) by considering interactions among plants, to evaluate sustainability of corn-based ethanol production in the U.S.

In the present study, we have estimated the potential of fuel ethanol production under volumetric subsidy and RFS policies in a dynamic strategic model. We conclude that both policies affect the market capacity by the date requested by RFS. If there is no RFS, even though we have 15 million gallon ethanol production capacity in 2012, such production is not sustainable by 2022. If the government does not subsidize any more from now on but with RFS, total market capacity will increase slightly if fuel ethanol price is increasing. However, consider the possibility of the increase of fuel ethanol demand and the delay of cellulosic ethanol commercialization, our results suggest U.S. government subsidizing corn-based ethanol industry again to mitigate the future shortage of fuel ethanol supply although that volume increase is trivial to the demand increase. In the policy pool, we found that the investment or entry subsidy for the new entrants are more effective than production subsidy.

This study is also the first to implement a dynamic strategic model to empirically estimate various fuel ethanol production and investment costs. It differs from existing literature using financial framework that all cost information is from engineering experiments, production and investment costs are generated endogenously and are allowed to vary smoothly along plant capacity, which is more realistic. In addition, the random draw assumptions for investment and entry fixed costs give more flexibility for the estimation, and the estimations based on real observations are more accurate than engineer's predictions. Since the present study estimates costs in each policy scenario, it offers more views about how renewable fuels mandatory and subsidy policy affect costs through market condition changes.

It is regretful that we do not allow waiting value issues in our model due to the need of simplifying computation. However, we believe that might not be catastrophe given the rapid demand increase of fuel ethanol from EIA predictions because option values of suspending production is not rational for ethanol producers. Even though, we use a strong assumption that ethanol price keeps increasing due to the volatility of feedstock price and extra demand, which might not be true if technology of feedstock production and processing is advancing quickly. All the potential improvements will be addressed in the future work.

References

Anderson, S. (2011). The demand for ethanol as a gasoline substitute. *Journal of Environmental Economics and Management*, page doi:10.1016/j.jeem.2011.08.002.

Arrow, K., Harris, T., and Marschak, J. (1951). Optimal inventory policy. *Econometrica: Journal of the Econometric Society*, pages 250–272.

Attanasio, O. (2000). Consumer durables and inertial behaviour: Estimation and aggregation of (s, s) rules for automobile purchases. *The Review of Economic Studies*, 67(4):667–696.

Bajari, P., Benkard, C., and Levin, J. (2007). Estimating dynamic models of imperfect competition. *Econometrica*, 75(5):1331–1370.

Celebi, M., Evan Cohen, Michael Cragg, D. H., and Shankar, M. (2010). Can the U.S. Congressional Ethanol Mandate be Met? Discussion paper, The Brattle Group, Available at `www.brattle.com/_documents/UploadLibrary/Upload849.pdf`.

Chernozhukov, V. and Hong, H. (2003). An mcmc approach to classical estimation. *Journal of Econometrics*, 115(2):293–346.

Cotti, C. and Skidmore, M. (2010). The impact of state government subsidies and tax credits in an emerging industry: ethanol production 1980-2007. *Southern Economic Journal*, 76(4):1076–1093.

Dal-Mas, M., Giarola, S., Zamboni, A., and Bezzo, F. (2011). Strategic design and investment capacity planning of the ethanol supply chain under price uncertainty. *Biomass and Bioenergy*, 35(5):2059–2071.

EIA (2011). Annual Energy Outlook 2011 with Projections to 2035. U.S. Energy Information Administration Report.

Eidman, V. R. (2007). Ethanol economics of dry mill plants. *Corn-Based Ethanol in Illinois and the US: A Report from the Department of Agricultural and Consumer Economics, University of Illinois*, pages 22–36.

Ellinger, P. N. (2007). Assessing the financial performance and returns of ethanol production: a case study analysis. *Corn-Based Ethanol in Illinois and the US: A Report from the Department of Agricultural and Consumer Economics, University of Illinois*, pages 37–62.

Ericson, R. and Pakes, A. (1995). Markov-perfect industry dynamics: A framework for empirical work. *The Review of Economic Studies*, 62(1):53–82.

Gallagher, P., Schamel, G., Shapouri, H., and Brubaker, H. (2006). The international competitiveness of the us corn-ethanol industry: A comparison with sugar-ethanol processing in brazil. *Agribusiness*, 22(1):109–134.

Gallagher, P., Shapouri, H., and Brubaker, H. (2007). Scale, organization, and profitability of ethanol processing. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 55(1):63–81.

Gallagher, P. W., Brubaker, H., and Shapouri, H. (2005). Plant size: capital cost relationships in the dry mill ethanol industry. *Biomass and Bioenergy*, 28(6):565–571.

Gonzalez, A. O., Karali, B., and Wetzstein, M. E. (2012). A public policy aid for bioenergy investment: Case study of failed plants. *Energy Policy*.

Houde, J. (2008). Spatial differentiation in retail markets for gasoline. *University of Wisconsin, working paper*.

Jouvet, P.-A., Le Cadre, E., and Orset, C. (2012). Irreversible investment, uncertainty, and ambiguity: The case of bioenergy sector. *Energy Economics*, 34(1):45–53.

Khoshnoud, M. (2012). Quantity and capacity expansion decisions for ethanol in nebraska and a medium sized plant. Master thesis, University of Nebraska-Lincoln.

Lin, C.-Y. C. and Thome, K. (2013). Investment in Corn-Ethanol Plants in the Midwestern United States. Working paper, University of California, Davis.

Lin, C.-Y. C. and Yi, F. (2012). What factors affect the decision to invest in a fuel ethanol plant?: A structural model of the investment timing game in Europe. Working paper, University of California, Davis.

Maskin, E. and Tirole, J. (1988). A theory of dynamic oligopoly, I: Overview and quantity competition with large fixed costs. *Econometrica: Journal of the Econometric Society*, pages 549–569.

O.Brien, D. and Woolverton, M. (2010). Trends in U.S. Fuel Ethanol Production Capacity: 2005-2009. Department of Agricultural Economics, Kansas State University. Accessed at `http://www.agmanager.info/energy`.

Richardson, J. W., Herbst, B. K., Outlaw, J. L., Gill, R. C., et al. (2007a). Including risk in economic feasibility analyses: the case of ethanol production in texas. *Journal of Agribusiness*, 25(2):115–132.

Richardson, J. W., Lemmer, W. J., and Outlaw, J. L. (2007b). Bio-ethanol production from wheat in the winter rainfall region of south africa: A quantitative risk analysis. *International Food and Agribusiness Management Review*, 10(2):181–204.

Ryan, S. (2012). The costs of environmental regulation in a concentrated industry. *Econometrica*, 80(3):1019–1061.

Schmit, T., Luo, J., and Conrad, J. (2011). Estimating the influence of us ethanol policy on plant investment decisions: A real options analysis with two stochastic variables. *Energy Economics*, 33(6):1194–1205.

Schmit, T. M., Luo, J., and Tauer, L. W. (2009). Ethanol plant investment using net present value and real options analyses. *Biomass and Bioenergy*, 33(10):1442–1451.

Schnepf, R. and Yacobucci, B. D. (2012). Renewable fuel standard (rfs): Overview and issues. Congressional Research Service Report for Congress.

Tyner, W. E. (2007). U.s. ethanol policy- possibilities for the future. Available at `http://www.intellectualtakeout.org/library/chart-graph/history-ethanol-subsidy-legislation-1978-2005`.

Whims, J. (2002). Corn based ethanol costs and margins. *Agricultural Marketing Resource Center Report, Dept. of Ag. Econ., Kansas State University, May.*

Zubairy, S. (2011). Explaining the Effects of Government Spending Shocks. Bank of Canada, working paper.