Dynamic structural econometric modeling of the ethanol industry

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Abstract

This chapter reviews some of the papers my co-authors and I have written developing and estimating dynamic structural econometric models of dynamic games in the ethanol industry. These structural econometric models model the dynamic and strategic decisions made by ethanol firms and enable us to analyze the effects of government policy. Analyses that ignore the dynamic implications of government 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 Thome and Lin Lawell (2015), we estimate a model of the investment timing game in corn ethanol plants in the United States. In Yi and Lin Lawell (2016a,b), we estimate a model of the investment timing game in ethanol plants worldwide that allows for the choice among different feedstocks. In Yi, Lin Lawell and Thome (2016), we estimate a structural econometric model of ethanol firms' investment, production, entry, and exit decisions in order to analyze the effects of government subsidies and the Renewable Fuel Standard on the U.S. fuel ethanol industry. The results of our research will help determine which policies and factors can promote fuel-ethanol industry development.

1 Introduction

Recently the support of biofuel production has been a politically sensitive topic. Politicians have pushed for support for fuel ethanol production as an environmentally friendly alternative to imported oil, as well as a way to boost farm profits and improve rural livelihoods. Several government policies actively promote ethanol production via tax incentives and mandates, and these policies are blamed for rising food prices around the world (Mitchell, 2008). It is important to understand the factors that have motivated the significant local investments in the ethanol industry that have been made since the mid-1990s both in the U.S. and worldwide, and, in particular, the effects of government policy.

Fuel ethanol has been in use in the United States since the time of the Model T Ford (the original flex-fuel vehicle), and while the United States passed Brazil in ethanol production in 2005, today ethanol is mostly relegated to status as a gasoline additive. The first US ethanol boom began as a result of the oil embargoes in 1973 and 1979. The desire for more energy self-sufficiency, the resulting legislation (in the form of federal income tax credits and blender's credits that continue today), and the phase out of leaded gasoline led to the construction of 153 new plants by 1985 (DOE, 2008). These plants were tiny by today's standards, with an average capacity of 8 million gallons per year, and by 1991 only 35 were still operational due to poor business judgment and bad engineering (DOE, 2008; Urbanchuck, 2006).

The second US ethanol boom began in the mid-1990s and hit full-stride by the early 2000s. Several factors contributed to this most recent boom. The Clean Air Act of 1990 mandated use of oxygenates in gasoline, of which ethanol is one, and the subsequent phase out and ban of MTBE as additive beginning in the late 1990s further increased demand for ethanol. Additionally the Renewable Fuel Standard of the Energy Policy Act of 2005 mandated ethanol production floors beginning in 2007, which rise to 36 billion gallons per year in 2033. Over this time period, the number of ethanol plants rose from 35 plants in 1991, to 50 in 1999, to 192 in September of 2010 for a total capacity of 13 billion gallons per year.

In addition to the policy and demand-side contributors to the recent ethanol boom, this new industry growth has been accompanied by changes in technology. Most significantly, the average capacity of plants in our focus region was 62 million gallons per year in 2008 up from 8 million gallons per year in 1985. In the mid-1990s the industry began designing more efficient plants, which use natural gas instead of coal as fuel (DOE, 2008).

In our analysis of the US ethanol industry, we focus on the second US ethanol boom. Most ethanol plants use corn as a feedstock, and thus are located in the Midwestern United States, where the majority of the corn in the US is grown. Since biofuels have been touted as a way to enhance profits in rural areas, where grain prices have remained stagnant over time, it is important to determine what factors affect decisions about when and where to invest in building new ethanol plants. In Thome and Lin Lawell (2015), we model this decision using both reduced-form and structural models. In Yi, Lin Lawell and Thome (2016), we estimate a structural econometric model of ethanol firms' investment, production, entry, and exit decisions in order to analyze the effects of government subsidies and the Renewable Fuel Standard on the U.S. fuel ethanol industry.

Even when excluding the U.S., which was the country with the largest fuel-ethanol production in 2009, the fuel-ethanol industry has been growing rapidly in the rest of the world (ROW). Ethanol-producing countries in the ROW include Brazil, Canada, China, and Thailand, as well as countries in Europe. There are approximately 200 fuel-ethanol plants in the ROW, which is a little more than in the U.S., and over 80% of them were built after 2005. In Yi and Lin Lawell (2016a,b), we estimate a model of the investment timing game in ethanol plants worldwide that allows for the choice among different feedstocks.

In Europe, 20 countries have fuel ethanol production and most of the fuel ethanol plants were built after 2000. The development of European biofuel is based on two Directives: the Renewable Energy Directive (RED) of 2003/30/EC sets indicative targets of 2% renewable fuels in transport by 2005 and 5.75% by 2010 but is not legally binding; and the RED of 2009/28/EC is made mandatory and therefore legally binding. The main fuel ethanol policies in Europe include a tax credit, a blending mandate and R&D support. Most of the policies were implemented after 2003. Empirical research shows that the effects of policies for the U.S. fuel ethanol production are positive (Lambert et al., 2008; Sarmiento and Wilson, 2007; Thome and Lin Lawell, 2015), however, whether the stimulation effects of the government policies play the same role in Europe is not yet clear, especially for the different varieties of feedstocks. In Yi and Lin Lawell (2016b), we evaluate the effects of government policies on investment in ethanol plants in Europe.

The decision to invest in building an ethanol plant is a dynamic decision that may be affected by economic factors and government policies. For example, commodity markets occasionally exhibit broadly based massive booms and busts; at the core of these cycles is a set of contemporaneous supply and demand surprises that coincide with low inventories and that are magnified by macroeconomic shocks and policy responses (Carter, Rausser and Smith, 2011). Market volatility can induce periods of boom and bust in the ethanol industry, causing episodes of bankruptcy and reduced capital investment (Hochman, Sexton and Zilberman, 2008).

Because the payoff from investing in building a new ethanol plant depend on market conditions such as the feedstock price that vary stochastically over time, a potential entrant that hopes to make a dynamically optimal decision would need to account for the option value to waiting before making this irreversible investment (Dixit and Pindyck, 1994).

A potential investor's investment decision may also depend on the investment decisions of other investors. When the decision of a potential investor is affected by the decisions of other investors, the decision-making problem is no longer a single-agent dynamic optimization problem, but instead becomes a multi-agent investment timing game.

There are two sources of strategic interactions that add a strategic (or non-cooperative) dimension to the potential entrants' investment timing decisions. The first source of strategic interaction is a competition effect: if there is more than one ethanol plant located in the same region, these plants may compete in the local feedstock input supply market or they may compete in the local fuel ethanol output market. The competition effect, whereby nearby plants may compete in local feedstock markets and/or local ethanol markets, deters ethanol plants from entering in regions where there are other ethanol plants already present.

The second source of strategic interaction is an agglomeration effect: if there are several ethanol plants located in the same region, the existing plants may have developed transportation and marketing infrastructure and/or an educated work force that new plants can benefit from (Goetz, 1997; Ellison and Glaeser, 1999; Lambert et al., 2008). The agglomeration effect induces an ethanol plant to locate near other plants, since a fuel ethanol plant benefits from the existence of other plants.

Owing to both competition and agglomeration effects, the dynamic decision-making problem faced by the potential ethanol plants is not merely a single-agent problem, but rather can be viewed as a non-cooperative game in which plants behave strategically and base decisions on other investors' strategies. Since the investment decisions of others affect future values of state variables which affect the future payoff from investing, potential investors must anticipate the investment strategies of others in order to make a dynamically optimal decision. Uncertainty over whether a plant might be constructed and start production nearby is therefore another reason there is an option value to waiting before investing (Dixit Pindyck, 1994).

In addition to the decision to build a fuel ethanol plant, ethanol firms make other decisions as well, including decisions about capacity investment, production, entry, and exit. These decisions are dynamic and strategic as well. Analyses that ignore the dynamic implications of government ethanol 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.

This article reviews some of the papers my co-authors and I have written developing and estimating dynamic structural econometric models of dynamic games in the ethanol industry. These structural econometric models model the dynamic and strategic decisions made by ethanol firms. In Thome and Lin Lawell (2015), we estimate a model of the investment timing game in corn ethanol plants in the United States. This model follows my previous work estimating a structural econometric model of the multi-stage dynamic investment timing game in offshore petroleum production (Lin, 2013). In Yi and Lin Lawell (2016a,b), we estimate a model of the investment timing game in ethanol plants worldwide that allows for the choice among different feedstocks. In Yi, Lin Lawell and Thome (2016), we estimate a structural econometric model of ethanol firms' investment, production, entry, and exit decisions in order to analyze the effects of government subsidies and the Renewable Fuel Standard on the U.S. fuel ethanol industry.

Our structural econometric models enable us to model ethanol firms' strategic and dynamic investment, production, entry, and exit decisions. These decisions are dynamic because they are involve irreversible investments, because their payoffs are uncertain, and because ethanol firms have leeway over the timing of these investment decisions. Because the profits from these decisions depend on market conditions such as the ethanol and feedstock prices that vary stochastically over time, an individual firm operating in isolation that hopes to make dynamically optimal decisions would need to account for the option value to waiting before making these irreversible investments (Dixit and Pindyck, 1994).

The decisions of ethanol firms are not only dynamic but strategic as well. Ethanol producers consider not only future market conditions but also their competitors' investment, production, entry and exit activities when making their current decisions. Since the production decisions of other firms affect the ethanol price, and therefore affect a firm's current payoff from production, and since the investment, production, entry, and exit decisions of other firms affect future values of state variables which affect a firm's future payoff from producing and investing, ethanol firms must anticipate the strategies of other firms in order to make a dynamically optimal decision. Uncertainty over the strategies of other firms is therefore another reason there is an option value to waiting before investing (Dixit and Pindyck, 1994).

The methodology we use is to develop and estimate a structural econometric model of the dynamic game among ethanol firms. As explained by Reiss and Wolak (2007), a structural econometric model is one that combines economic theory with a statistical model, enabling us to estimate structural parameters. Incorporating firm dynamics into structural econometric models enhances our understanding of behavior and also enables us to estimate structural parameters which have a transparent interpretation within the theoretical model that frames the empirical investigation (Aguirregabiria and Mira, 2010).

Dynamic discrete choice structural models are useful tools in the analysis of economic and social phenomena whenever strategic interactions are an important aspect of individual behavior. In the ethanol market, because a firm's costs and market demand hinge on the structure of market, a firm's decision depends on its conjecture about competitors' behavior. This type of model assumes agents are forward looking and maximize the expected discounted value of the entire stream of payoffs. Agents are assumed to make decisions based only on historic information directly related to current payoffs, and history only influences current decisions insofar as it impacts a state variable that summarize the direct influence of the past on current payoffs.

There are several advantages to using a dynamic structural model to analyze the investment, production, entry, and exit decisions of ethanol firms. First, unlike reduced-form models, a structural approach explicitly models the dynamics of these decisions. Second, our dynamic games model models the strategic nature of ethanol firms' decisions.

A third advantage of the structural model is that with the structural model we are able to estimate the effect of each state variable on the expected payoffs from investment, production, entry, and exit decisions, and are therefore able to estimate parameters that have direct economic interpretations. Our dynamic model accounts for the continuation value, which is the expected value of the value function next period. With the structural model we are able to estimate parameters in the payoffs from ethanol firms' decisions, since we are able to structurally model how the continuation values relate to the payoffs from these decisions.

A fourth advantage of our structural model is that we can use the parameter estimates from our structural model to simulate various counterfactual scenarios. We use our estimates to simulate the ethanol industry under counterfactual scenarios for government policy in order to evaluate the effects of government policy.

The results of our research will help determine which policies and factors can promote fuel-ethanol industry development.

2 Literature Review

The research reviewed in this chapter builds on previous research my co-authors and I have pursued on designing and analyzing policies for renewable fuels (Lin, 2012; Lin, 2013b); on the implications of an E10 ethanol-blend policy (Lin et al., 2009); on the design and economics of low carbon fuel standards (Lade and Lin Lawell, 2015); on the economics of Californias low carbon fuel standard (Lade and Lin, 2013); on containing the costs of Californias low carbon fuel standard (Lade and Lin, 2013; Lin, 2013a; Lade and Lin, 2014); on the design of renewable fuel policies and cost containment mechanisms (Lade and Lin Lawell, 2015); on ex post costs and the compliance credit market under the Renewable Fuel Standard (Lade, Lin and Smith, 2015); on the effects of policy shocks that reduced the expected Renewable Fuel Standard mandates (Lade, Lin Lawell and Smith, 2016); on the factors that affect ethanol investment decisions in Thailand (Herath Mudiyanselage, Lin and Yi, 2013); and on the effects of China's biofuel policies on agricultural and ethanol markets (Si et al., 2016).

Our structural model of the effects of ethanol price, corn price, gasoline price, and ethanol policy on the ethanol industry relates to the work of de Gorter, Drabik and Just (2015), who combine theory and empirical evidence on how biofuel policies create a link between crop (food grains and oilseeds) and biofuel (ethanol and biodiesel) prices; and on the previous literature on the relationship between food and fuel markets (Runge and Senauer, 2007; Rajagopal et al., 2007; Wright, 2014; Poudel et al., 2012; Abbott, Hurt and Tyner, 2008, 2009, 2011; de Gorter, Drabik and Just, 2013; Zilberman et al., 2012). De Gorter et al. (2013) analyze the impact of OECD biofuels policies on grain and oilseed prices in developing countries.

The dynamic structural model we will develop will build upon the dynamic structural models my co-authors and I have developed to analyze wind turbine owners' decisions about scrapping or replacing their turbines and the effects of government policies on these decisions (Cook and Lin Lawell, 2015); investment decisions in offshore petroleum production (Lin, 2009; Lin, 2013c); long-term and short-term decision-making for disease control (Carroll, Carter, Goodhue, and Lin Lawell, 2016b); and externalities between spinach seed companies and farmers (Carroll, Carter, Goodhue, and Lin Lawell, 2016a).

The structural econometric models of dynamic games we use build on a model developed by Pakes, Ostrovsky and Berry (2007), which has been applied to the multi-stage investment timing game in offshore petroleum production (Lin, 2013c), and to the decision to wear and use glasses (Ma, Lin Lawell and Rozelle, 2015); a model developed by Bajari et al. (2015); as well as on a model developed by Bajari, Benkard and Levin (2007), which has been applied to the cement industry

(Ryan, 2012; Fowlie, Reguant and Ryan, 2016).

3 Theoretical Model

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, 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:

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

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}, which is private information and drawn from the distribution F_{γ_1} with mean μ_{γ_1} and standard deviation σ_{γ_1}, 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. 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_{k_1} and μ_{k_2} and standard deviations σ_{k_1} and σ_{k_2}, 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 the distribution F_d with mean μ_d and standard deviation σ_d.

The production subsidy a fuel ethanol plant receives is:

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

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. Incumbents receive the profits $\bar{\pi}_i(s;\theta)$ from production this period and then, depending on their action, additionally incur the costs of capacity investment if they invest, additionally receive the continuation value if they stay in the market (regardless of whether they invest), and additionally receive the scrap value from exiting if they exit.

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. The value function for a potential entrant is therefore the maximum of: (1) the payoff from staying out of the market, which is the idiosyncratic preference shock ε_{0i}; (2) the payoff from building a new plant, which includes the fixed cost of entry k_{1i}, the costs of capacity investment, the idiosyncratic preference shock ε_{1i}, and the continuation value; and (3) the payoff from buidling a shut-down plant, which includes the fixed cost of entry k_{2i}, the transactions costs, the idiosyncratic preference shock ε_{2i}, and the continuation value. If an entrant decides to buy an existing shut-down plant, its plant size choice is limited to set $\boldsymbol{Y}$.

We assume that each plant optimizes its behavior conditional on the current state variables, other agents' strategies 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 $\tilde{\sigma}_i(s)$:

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

4 Econometric Methodology

In Thome and Lin Lawell (2015), we estimate a model of the investment timing game in corn ethanol plants in the United States. This model follows my previous work estimating a structural econometric model of the multi-stage dynamic investment timing game in offshore petroleum production (Lin, 2013c), which is based on an econometric model developed by Pakes, Ostrovsky and Berry (2007). In Lin (2013c), I build on the work of Pakes, Ostrovsky and Berry (2007) on discrete games of entry and exit by examining sequential investments with a finite horizon. The econometric estimation technique takes place in two steps. In the first step, the continuation value is estimated nonparametrically and used to form the model's estimate of the investment probabilities. In the second step, the investment probabilities predicted by the model are matched with the empirical investment probabilities in the data using generalized method of moments.

In Yi and Lin Lawell (2016a,b), we estimate a model of the investment timing game in ethanol plants worldwide that allows for the choice among different feedstocks. We use a structural model developed by Bajari et al. (2015). We construct a dynamic discrete choice model for a potential fuel ethanol plant in which the investor maximizes its present discounted value of its entire stream of payoffs, and in which the decisions of other plants in the same local market affect an investor's decision. The innovative features of our model are the consideration of interactions between fuel ethanol plants and the dynamic decision making framework. The effects of economic, policy and strategic variables on per-period profit are estimated via a semiparametric approach.

Our research in Yi and Lin Lawell (2016a,b) differs from previous studies of the investment and location of ethanol plants because it models the decision as a dynamic one rather than a static one, because it allows for the choice among multiple feedstocks rather than just one feedstock such as corn, because its strategic framework allows the estimation of strategic interactions among plants, and because it uses international data rather than data from the U.S.

In Yi, Lin Lawell and Thome (2016), 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 developed by Bajari, Benkard, and Levin (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 investment and exit, which are functions of state variables. In the second step, we use a simulation-based minimum distance estimator proposed by Bajari, Benkard, and Levin (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.

In Yi, Lin Lawell and Thome (2016), 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 Renewable Fuel Standard. 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, Luo and Tauer, 2009; Schmit, Luo and Conrad, 2011; Gonzalez, Karali and Wetzstein, 2012).

5 Results

The results of our structural model in Thome and Lin Lawell (2015) show that in the US, the intensity of corn production; government policies, particularly the MTBE ban and the 2007 Renewable Fuel Standard (RFS2); and private information shocks all have significant effects on ethanol investment payoffs and decisions. We use the estimated structural parameters to simulate counterfactual policy scenarios to disentangle the impacts of state and national policies on the timing and location of investment in the industry. We find that, of the policies analyzed, the MTBE ban and the RFS2 led to most of the investment during this time period.

Our results in Yi and Lin Lawell (2016b) show that in Europe, competition between plants deters local investments and has a large negative effect on the payoffs from investment. We also find that government policies have a large positive effect on payoffs from investment. Ethanol investment decisions in Europe are affected more by government policies and strategic interactions than by economic factors.

Our results in Yi and Lin Lawell (2016a) show that in Canada, competition between plants is enough to deter local investments, the availability of feedstock is important in determining plant location, and the effects of policy support for wheat-based plants are significant.

Our empirical results in Yi, Lin Lawell and Thome (2016) show that the production subsidy does not affect either investment costs or scrap values, but the Renewable Fuel Standard significantly impacts the distributions of both the fixed cost of plant capacity investment and the scrap value a plant would receive if it exited the market. 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 Renewable Fuel Standard. Results show that the Renewable Fuel Standard is a critically important policy for supporting 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 Renewable Fuel Standard.

6 Conclusions

This chapter reviews some of the papers my co-authors and I have written developing and estimating dynamic structural econometric models of dynamic games in the ethanol industry. These structural econometric models model the dynamic and strategic decisions made by ethanol firms and enable us to analyze the effects of government policy. Analyses that ignore the dynamic implications of government 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.

According to our results, we find in Thome and Lin Lawell (2015) that, in the United States, the intensity of corn production; government policies, particularly the MTBE ban and the 2007 Renewable Fuel Standard (RFS2); and private information shocks all have significant effects on ethanol investment payoffs and decisions. For Europe, we find in Yi and Lin Lawell (2016b) that competition between plants deters local investments and ethanol support policies encourage investments. For Canada, we find in Yi and Lin Lawell (2016a) that competition between plants is enough to deter local investments, the availability of feedstock is important in determining plant location, and the effects of policy support for wheat-based plants are significant.

Our results in Yi, Lin Lawell and Thome (2016) show that the Renewable Fuel Standard is a critically important policy for supporting 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 Renewable Fuel Standard.

Our results have important implications for the design of government policies for ethanol. In particular, the results of our research will help determine which policies and factors can promote fuel-ethanol industry development.

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