What Factors Affect the Decision to Invest in a Fuel Ethanol Plant?: A Structural Model of the Ethanol Investment Timing Game[1]

Fujin Yi and C.-Y. Cynthia Lin Lawell

Abstract

The decision to invest in building an ethanol plant that uses a particular feedstock is a dynamic decision that may be affected by economic factors and government policies. Owing to competition effects and agglomeration effects, a potential investor's investment decision may also depend on the investment decisions of other investors. This paper analyzes how economic factors, strategic factors, and government policies affect the decision to invest in building new ethanol plants in Europe. We distinguish among investments in ethanol plants of different feedstocks. Our empirical methodology is to estimate a structural econometric model of the dynamic ethanol investment timing game. According to our results, 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.

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[1] Yi: Nanjing Agricultural University; fujinyi@njau.edu.cn. Lin Lawell: Cornell University; clinlawell@cornell.edu. We thank Neha Bazaj, David Fletes, Robert Gormley, and Ida (Yunbai) Li for excellent research assistance. We received helpful comments from Aureo de Paula, Rosa Matzkin, Stephen Ryan, and Chris Timmins; and from seminar and conference participants at the Stanford Berkeley Industrial Organization Conference, the Berkeley Bioeconomy Conference, Duke University, and Rice University. We received funding from the University of California at Davis Sustainable Transportation Energy Pathways program; from a University of California at Davis Hellman Fellowship; and from the National Center for Sustainable Transportation, which is supported by the U.S. Department of Transportation through the University Transportation Centers program. All errors are our own.

1. Introduction

The development and use of ethanol has been the subject of international attention and support. The motivating factors for this attention and support include high oil prices, security concerns from relying on foreign energy sources, support for economic growth in the agricultural community, the desire to use surplus grains, environmental goals related to criteria pollutants, and climate change emissions (Si et al., 2018).

The ethanol industry has been growing rapidly around the world, not only in the U.S. and Brazil, the top two ethanol producing countries, but also in countries in Europe and Asia as well. Of the ethanol plants located in countries other than the U.S. and Brazil, over 80% were built after 2005 and more than 40% are located in Europe (RFA, 2009). Ethanol is produced from a variety of feedstocks worldwide, including wheat, sugar beet, rice, sugarcane, and corn. In some countries, including Canada, France and Germany, multiple feedstocks are used.

Several countries have implemented policies to actively promote ethanol production, and these policies are blamed for rising food prices (Mitchell, 2008). In particular, because the feedstocks used for the production of ethanol, specifically first generation ethanol, can also be used for food, there is a concern that ethanol policies might affect the relationship between food and fuel markets, and, in particular, have potential adverse effects on the price of basic food prices for the world's poor (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; de Gorter et al., 2013). It is therefore important to understand the factors that affect the decision to invest in building an ethanol plant that uses a particular feedstock, and, in particular, the effects of government policy on this decision.

Previous empirical studies have shown that government policies have a positive effect on ethanol production and investment in the U.S. (Lambert et al., 2008; Sarmiento Wilson, and Dahl, 2012; Thome and Lin Lawell, 2018), but less research has been done on the effects of government policies on the ethanol industry in Europe.

This paper examines what factors affect the decision to invest in ethanol plants in Europe, including when the investors start to construct the plants, how they make their location decisions, and what feedstock they choose to use to produce ethanol. In particular, we analyze the effects of economic factors, government policies, and strategic factors on the ethanol plant investment decision.

The decision to invest in building an ethanol plant that uses a particular feedstock 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 profits 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 when they choose the same feedstock or they may compete in the local 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.

High transportation costs are a reason why there may be local competition in both the feedstock input market and the ethanol output market. On the input side, approximately 70% of the cost of producing ethanol is the feedstock cost, of which the transportation costs for bulky grains or sugar beets constitute a significant share (Whittington, 2006). As a consequence, the distance from a plant to the feedstock production area is extremely important, and local competition for feedstock matters. On the output side, ethanol transportation is harder and more expensive than gasoline transportation due to the fact that ethanol can easily absorb water during the transportation process, and thus is normally transported using tank trucks for dehydrated ethanol. The higher transportation cost makes it costly for ethanol to be sold far away. Owing to high transportation costs for both inputs and outputs, the competition effect may be a source of strategic interaction between nearby plants.

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 an 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 payoffs 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 and Pindyck, 1994).

In this paper, we develop and estimate a structural econometric model of the ethanol investment timing game that incorporates both the strategic and dynamic aspects of the ethanol investment decision, and apply the model to data on ethanol plants from 20 European countries.

Our structural model has several advantages over a reduced-form discrete response model of investment. First, our structural model explicitly models the dynamic investment decision, including the continuation value to waiting. Because the profits from investing in building a new ethanol plant depend on market conditions such as feedstock prices 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). In contrast, a reduced-form discrete response model of the investment decision only estimates the per-period probability of investment.

A second advantage of our structural model is that with the structural model we are able to estimate the effect of each state variable on the expected payoff from investing in an ethanol plant that uses a particular feedstock. A potential investor invests if the payoff from investment exceeds the continuation value from waiting. The parameters in a reduced-form model of the probability of investment would represent parameters in the relative difference between the payoff from investment and the continuation value from waiting, and therefore are not the structural parameters of interest, since there is a structural relationship between the continuation value from waiting and the payoff from investment. In particular, the continuation value from waiting is the expected value of the value function next period, where the value function is the maximum of the payoff from investment and continuation value from waiting. As a consequence, the parameters in reduced-form models are confounded by continuation values. In contrast, with a structural model we are able to estimate parameters in the payoff from investing in the ethanol plant, since we are able to structurally model how the continuation value from waiting relates to the payoff from investing.

A third advantage of our structural model is that with the structural model we are able to analyze the strategic interaction between investors and estimate the net effect of other investors' decisions on a potential investor's payoff from investing in an ethanol plant of a particular feedstock. Since we identify the effects of state variables of the payoffs from investment, and since other investors' investment decisions affect future values of these state variables, we are able to identify the effects of other investors' investment decisions on a potential investor's decision and payoffs.

According to our results, competition between plants dominates the agglomeration effect 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 support policies play an important role in the development of the ethanol industry in Europe. Ethanol investment decisions in Europe are affected more by government policies and strategic interactions than by economic factors. Our results have important implications for renewable fuel policy.

The balance of our paper proceeds as follows. We provide background information on ethanol production and policy in Europe in Section 2. We review the previous literature in Section 3. Section 4 presents our model of the ethanol investment timing game. We describe the econometric estimation in Section 5 and the data in Section 6. Section 7 presents the results. We conclude in Section 8.

2. Ethanol Production and Policy in Europe

The ethanol industry has been growing rapidly in Europe. Of the ethanol plants located in countries other than the U.S. and Brazil, more than 40% are located in Europe (RFA, 2009). Ethanol is produced from a variety of feedstocks worldwide, including wheat, sugar beet, rice, sugarcane, and corn. In some countries, including Canada, France and Germany, multiple feedstocks are used.

By 2007, 20 countries in Europe produced ethanol and most of their ethanol plants were built after 2000. As seen in Figure 1, both ethanol production and ethanol consumption in Europe have been increasing at least since 2001.

The feedstocks used for ethanol production in Europe vary by country. A few countries, including the Czech Republic, the Netherlands and Spain, use wheat. Several countries use corn, including Hungary. Some countries use several feedstocks: for instance, France and Germany use both wheat and sugar beet as their main feedstocks. In contrast, the primary feedstock used in the U.S. is corn (Thome and Lin Lawell, 2018).

The development of the European ethanol industry has been guided by two European Union (EU) Directives: the Renewable Energy Directive (RED) of 2003/30/EC, which sets 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, which is mandatory and therefore legally binding.

Individual EU countries have implemented their own ethanol policies as well. Table 1 lists the ethanol policies implemented in each country in Europe by 2007 and the dates they were implemented. The main policies include financial support policies; blending mandates; and research and development (R&D) support policies. Financial support policies include tax credits and direct funding support from the local government. Blending mandates are mandates that gasoline should contain a certain percentage of ethanol. R&D support policies provide support for research and development. Most of the policies were implemented after 2003.

From the perspective of potential investors in the ethanol industry, the evolution of financial support policies, blending mandates, and research and development (R&D) support policies over time was uncertain at the beginning of the study period, due to the democratic nature of lawmaking and uncertainty about the evolution of the ethanol industry, energy prices, and feedstock prices. Although the basic strategy of supporting the ethanol industry over time was likely known by potential investors, the exact timing and values of any of the support policies could not have been perfectly anticipated. We therefore model future values of these policies as uncertain from the point of view of the potential investors in any given year of our period of study in our dynamic structural model. In particular, we assume that financial support policies, blending mandates, and research and development (R&D) support policies evolve as a finite state first-order Markov process, and that a potential investor's expectations of future values of these government policies depended on current values of these policies and on current values of other state variables, including energy prices and feedstock prices.

We use empirical probabilities over the entire time period of our data set to estimate a potential investor's expectation of future values of these policies conditional on current values of these policies and on current values of other state variables. We therefore assume potential investors have rational expectations and that the distribution of possible future policies conditional on current policies and current state variables incorporates the possibility of changes in policies due to a variety of factors, including changes in market conditions and changes in technology.

3. Literature Review

3.1. Ethanol investment and government policy

One strand of previous literature upon which we build is that on ethanol investment and government policy. Previous papers have analyzed the decision to invest in an ethanol plant using a static framework. Lambert et al. (2008) use a probit regression model along with spatial clustering methods to analyze investment activity of ethanol plants at the county level for the lower U.S. 48 states from 2000 to 2007. They find that five categories of factors determine the location of ethanol plant: infrastructure, product and input markets, fiscal attributes of local communities, and state and federal incentives. However, Lambert et al. (2008) do not model the effect of existing ethanol plants on potential entrants.

Sarmiento, Wilson and Dahl (2012) use a logistic regression to analyze the impacts from the agricultural characteristics of a county, competition, and state-level subsidies. The competition between existing ethanol plants and entrants are expressed by the distance. Their results conclude that existence of a competing ethanol plant reduces the likelihood of making a positive location decision and this impact decreases with distance.

Herath Mudiyanselage, Lin and Yi (2013) analyze the effects of economic factors, strategic factors, and government policy on ethanol investment using discrete response and fixed effects regression models. Results show that the main factor that affects the decision to invest in building an ethanol plant in a particular changwat (province) is the number of ethanol plants already in the changwat. The number of ethanol plants already in the changwat has a significant negative effect on the decision to invest in building an ethanol plant in a particular changwat, which suggests that potential investors are deterred by local competition in input and output markets.

Previous empirical literature using static models, including those mentioned above, miss an important dimension of the investment decision: time. Investors not only choose whether to invest in ethanol plants but also choose when to enter the ethanol industry. Their goal is to maximize the present discounted value of the entire stream of profits. Expectations about exogenous conditions such as factors affecting the input market and government policies affect whether, when and where ethanol plants will be built. A dynamic model is therefore a more realistic model of ethanol investors' behavior and there may be patterns in the data that are simply not captured by a static model. Hence, ignoring the dynamics could potentially generate misleading conclusions about behavior (Dubé al., 2005).

Schmit, Luo and Conrad (2011) consider the influence of policies on the U.S. corn-based ethanol investment decisions using a dynamic model. A potential ethanol investor's decision is determined by revenue and cost, two factors which are evolving over time with other covariates. According to the results, the current ethanol industry expansion was induced by the revenue-enhancing effects of policy and, in the absence of these policies, much of the recent expansionary periods would have not existed. Due to limitations of their model, however, their study does not analyze the strategic interactions between ethanol plants.

Thome and Lin Lawell (2018) use U.S. data to analyze how economic factors, government policy and strategic interactions affect decisions about when and where to invest in building new corn-ethanol plants in the Midwestern United States using both reduced-form discrete response models and a structural model of a dynamic game. Their research indicates that availability of inputs is important in determining expected profits from investment in an ethanol plant and that competition between plants is enough to deter local investment.

We build upon the work of Thome and Lin Lawell (2018) in several ways. First, as the primary feedstock used in the U.S. is corn, Thome and Lin Lawell (2018) do not model the feedstock choice decision, but instead focus on the decision to invest in building new corn-ethanol plants. In contrast, since several different feedstocks are used in Europe, we build on Thome and

Lin Lawell's (2018) work by also modeling feedstock choice, thereby allowing potential investors to choose the type ethanol plant to invest in. Second, the econometric model Thome and Lin Lawell (2018) use requires them to discretize all the continuous state variables so that some important information may have been lost when the variables were binned. In contrast, we use continuous state variables in our econometric model. A third way in which we build upon the work of Thome and Lin Lawell (2018) is that we analyze the ethanol industry in Europe instead of the United States.

While there have been several studies on the effects of government policies on the ethanol industry the U.S. (see e.g., Lambert et al., 2008; Sarmiento, Wilson and Dahl, 2012; Thome and Lin Lawell, 2018), less research has been done on the effects of government policies on the ethanol industry in Europe. Padella, Finco and Tyner (2012) use a general equilibrium model to analyze the combined impacts of the US and EU biofuels programs, considering in particular the socio-economic effects on prices, employment and welfare in the European Union in 2015.

Our paper improves upon the previous literature by developing and estimating a structural econometric model of a dynamic game using panel data from 20 European countries in order to directly estimate the effect of covariates on the investment profit itself. In contrast to previous cross-sectional studies, this paper uses a dynamic framework in which investors choose their ethanol investment strategies in order to maximize the present discounted value of the entire stream of payoffs. Unlike Thome and Lin Lawell (2018), this paper allows investors to choose from multiple feedstocks and does not discretize the continuous variables.

3.2. Structural econometric models of dynamic games

In addition to the previous literature on ethanol investment, another strand of literature upon which we build is the literature on structural econometric models of dynamic games. 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. 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 current values of state variables and the past influences current play only through its effect on these state variables.

Dynamic discrete choice structural models are estimated under the principle of revealed preference using individual's choices (Aguirregabiria and Mira, 2010). Recently, methods have been developed to estimate structural parameters semiparametrically (Pesendorfer and Schmidt-Dengler, 2008; Pakes, Ostrovsky and Berry, 2007; Aguirregabiria and Mira, 2007) and to use simulation estimators (Hotz et al., 1994; Bajari, Benkard and Levin, 2007). Bajari and Hong (2006), Bajari, Benkard and Levin (2007), Srisuma and Linton (2012), and Bajari et al. (2015) innovate upon this literature by proposing methods to estimate parameters in a dynamic game with continuous state variables.

Most of these econometric methods involve a two-step estimation procedure. The common logic is to use a specific equilibrium solution concept to work backward from the observed equilibrium action(s) to statements about unobserved profits (Reiss and Wolak, 2007). Pesendorfer and Schmidt-Dengler (2008) show that a number of recently proposed estimators for dynamic models are two-step asymptotic least squares estimators defined by the set of equilibrium conditions.

Research on dynamic competition has shown that computing an equilibrium for even relatively simple industry models is all but prohibitive (Bajari, Benkard and Levin, 2007). The econometric method employed in this paper is based on the introduction of the Hotz-Miller inversion (Hotz and Miller, 1993), and the estimation of the equilibrium is simplified to two steps without having to analytically solve the equilibrium of a dynamic game, which reduces the high computational burden. In this two-step estimator, the economist first flexibly estimates the agent's policy functions, choice probabilities that are conditional on state variables and the other agents' actions, and the transition probabilities for state variables. Second, structural parameters from the period profit function are estimated.

In some models the first step is estimated using a nonparametric method based on discrete state variables. However, some state variables are naturally continuous, and thus must be discretized into bins in order to use such methods. When using dynamic structural econometric models requiring one to discretize state variables into a finite number of bins, one could increase the number of bins to minimize the loss of information, but at a cost of increasing the dimensionality of the state space. Instead of discretizing continuous variables, Bajari and Hong (2006), Bajari, Benkard and Levin (2007), and Bajari et al. (2015) suggest that policy and value functions can be approximated parametrically using a combination of basis functions in which the nonparametric first step estimation can be implemented using continuous state variables.[2]

[2] Whether or not prices and other state variables are continuous or discrete may be in part a philosophical issue. For example, it may be argued that prices are in cents and thus must be discrete. Similarly, one may argue that observed data are finite and thus discrete by definition. In our paper, a "continuous" variable is one whose support is large enough that it must be discretized into coarser bins before dynamic structural econometric models based on discrete state variables can be used.

Previous papers have applied structural econometric models of dynamic games to analyze offshore petroleum production (Lin, 2013), the cement industry (Ryan, 2012; Fowlie, Reguant and Ryan, 2016), fisheries (Huang and Smith, 2014), dynamic natural monopoly regulation (Lim and Yurukoglu, 2018), the U.S. ethanol industry (Thome and Lin Lawell, 2018), the effects of government subsidies on firm investment (Yi, Lin Lawell and Thome, 2018), the decision to wear and use glasses (Ma, Lin Lawell and Rozelle, 2018), migration decisions (Rojas Valdes, Lin Lawell and Taylor, 2018a; Rojas Valdes, Lin Lawell and Taylor, 2018b), the world petroleum market (Kheiravar, Lin Lawell and Jaffe, 2018), climate change policy (Zakerinia and Lin Lawell, 2018), Chinese shipbuilding (Kalouptsidi, forthcoming), and the global market for solar panels (Gerarden, 2017).

The econometric model we use in this paper is based on one developed by Bajari et al. (2015). This paper is the first to our knowledge to apply the econometric model developed by Bajari et al. (2015) to actual data.

4. A Model of the Ethanol Investment Timing Game

In our model of the ethanol investment timing game, each "market" m has I potential investors i. There are $t = 1, \cdots, \infty$ time periods.

We focus on the decision to invest in building an ethanol plant that uses a particular feedstock. We assume that all the potential investors move simultaneously in each time period t and that each potential investor i chooses strategy a_{imt} from the same choice set $A = \{0,1, \cdots, K\}$. Action $k = 0$ represents the outside option, which is to wait outside of the ethanol market and not produce ethanol, and the remaining actions represent investments in building ethanol plants that use different feedstocks for ethanol production.

Ethanol plants in Europe consist of both first generation and second generation ethanol plants. Second generation ethanol plants produce ethanol using cellulosic biomass such as straw from wheat and barley, and their capacities make up 10% of EU ethanol production. The remaining plants are first generation plants which are using starch- or sugar-based feedstocks such as corn, wheat, and sugar beet. In 2009, 60% of the ethanol produced in the EU was produced from grains, primarily wheat, corn, and barley, and 30% was produced from sugar beet. Our model therefore focuses on ethanol plants that use barley, corn, sugar beet, or wheat as their feedstock.

An investor's time-t investment timing decision depends on the state of the market $\Omega_{mt} = (x_{mt}, g_{mt}, n_{mt}, c_m, y_t)$ for market m at time t, which can be separated into economic factors x_{mt}, government policies g_{mt}, strategic factors n_{mt}, country fixed effects c_m, and year effects y_t. These state variables affect the payoffs from investing in ethanol plants of each particular feedstock.

The economic state variables x_{mt} include economic factors that affect the payoffs from investing in building an ethanol plant. On the revenue side, we include ethanol price; gasoline price; and proximity to cattle and hogs. Gasoline price could have either a positive or negative effect on the payoffs from investment depending on whether ethanol is viewed as an energy substitute for gasoline or as an additive to gasoline, respectively. We use proximity to cattle and hogs is a proxy for the sales price of distillers' grains (DDGS, or distillers' dried grains with solubles), which is a co-product of ethanol production used for animal feed.

The economic state variables x_{mt} also include economic factors that affect the costs of ethanol production. Approximately 70% of the cost of producing ethanol is the feedstock cost, of which the transportation costs for bulky grains or sugar beets constitute a significant share (Whittington, 2006). As the availability and cost of feedstocks are important factors affecting production costs, we include feedstock prices and feedstock availability. We also include natural gas price, as natural gas is an important energy source in ethanol plants.

The policy state variables g_{mt} include government policies that may affect the payoffs from investing in building an ethanol plant. In particular, we include dummy variables for the financial support policies, blending mandates, and R&D support policies described in Table 1.

The strategic state variables n_{mt} include strategic variables that track, for each feedstock, the number of existing plants in the market that use that particular feedstock.

The state variables Ω_{mt} also include country fixed effects c_m to control for unobserved industry policies and market conditions that can affect the investment decisions of potential investors. In one of our specifications we also include year effects y_t to control for unobserved common shocks.

We assume that the market-level state variables Ω_{mt} are common knowledge to all players in the market and are observable to the econometrician. The state variables summarize the direct effect of the past on the current environment, and the past only influences current decisions insofar as it affects current values of the state variables. All state variables except the strategic variables n_{mt} are assumed to evolve according to a first-order Markov process $\bar{g}(\Omega'|\Omega, a_i, a_{-i})$, where Ω' are the values of the state variables next period, and where state variables and actions this period affect the distribution of state variables next period.

We use empirical probabilities over the entire time period of our data set to estimate a potential investor's expectation of future values of all state variables except the strategic variables n_{mt}, conditional on current values of these policies and on current values of other state variables. We therefore assume potential investors have rational expectations and that the distribution of possible future state variables conditional on current state variables incorporates the possibility of changes in state variables due to a variety of factors, including changes in market conditions, changes in policy, and changes in technology. The strategic variables n_{mt} evolve deterministically as a function of the strategic variables and the actions of all players this period.

Other investors impact a potential investor's payoffs from investing through their effect on the strategic variables n_{mt} , which depend on others' decisions. These strategic state variables track, for each feedstock, the number of existing plants in the market that use that particular feedstock. The number of existing plants in the market that use each feedstock at time $t+1$ depends on the number of existing plants that use each feedstock at time t as well as the investment decisions made by potential investors at time t. A potential investor's expectation about the strategies of other investors therefore impacts his expectation of future values of these strategic state variables n_{mt} .

Owing to competition effects and agglomeration effects, the presence of other ethanol plants may affect the payoffs from investing in an ethanol plant. As a consequence, a potential investor's investment decision depends on its conjecture about competitors' behavior. The effects of the strategic variables n_{mt} on the payoffs from investment measure the net effects of the competition and agglomeration effects.

In addition to the publicly observed state variables Ω_{mt}, the expected profit from investing an ethanol plant depends on shocks that are private information to the ethanol plant but not observed by either other plants or by the econometrician. Let $\epsilon_{imt} = (\epsilon_{imt}(0), \cdots, \epsilon_{imt}(K))$ denote a vector of $i.i.d$ shocks to potential plant i's payoffs to investing at time t, one for each of the possible actions a_{imt}. We assume the error terms are distributed type I extreme value.

The payoff from investing in time t in an ethanol plant that uses a particular feedstock a_{imt} depends on the state variables and random preference shocks, and has the additively separable representation:

$$u(a_{imt}, \Omega_{mt}, , \epsilon_{imt}) = u_0(a_{imt}, \Omega_{mt}) + \epsilon_{imt}(a_{imt}), \tag{1}$$

where the stochastic component is the privately observed shock ϵ_{imt} and the deterministic component $u_0(a_{imt}, \Omega_{mt})$ is linear in the publicly observable state variables when an investment is made ($a_i > 0$):[3]

$$u_0(a_{imt}, \Omega_{mt}) = \Omega'_{mt}\gamma_a \qquad \text{if } a_i > 0, \tag{2}$$

where γ_a denotes the vector of coefficients in the payoff function for investing in an ethanol plant that uses feedstock a, and are the parameters that we estimate.

We assume that this payoff represents the expected present discounted value of the entire stream of profits (revenue minus costs) from operating and producing ethanol from this plant over the plant's lifetime. The payoff to investing in building an ethanol plant of a particular feedstock is independent of time except through the state variables Ω_{mt} and the shock ϵ_{imt}.

The sources of economic structure in our structural econometric model of the ethanol investment timing game are dynamic programming and game theory. Since our focus is on the decision to invest in building an ethanol plant, we do not model the subsequent annual ethanol production decisions explicitly, and therefore use a reduced-form specification for the payoff to investing in building an ethanol plant of a particular feedstock. We account for the important factors in a potential investor's ethanol plant investment decisions by including in the investment payoff function economic factors x_{mt} that affect revenue and/or costs, government policies g_{mt}, strategic factors n_{mt}, country fixed effects c_m, and year effects y_t. We also include shocks to the investment payoff function that may reflect shocks to ethanol production, revenue, and/or costs.

Although we use a reduced-form specification of the payoff from investing in time t in an ethanol plant that uses a particular feedstock a_{imt}, this payoff from investment is embedded in a structural model of a dynamic game where the structure arises from dynamic programming and game theory. Our structural model therefore has several advantages over a reduced-form discrete response model of investment. First, our structural model explicitly models the dynamic

[3] Linearity is also assumed and studied in detail in the dynamic game model of Sanches, Silva and Srisuma (2016).

investment decision, including the continuation value to waiting. Second, with the structural model we are able to estimate the effect of each state variable on the expected payoff from investing in an ethanol plant that uses a particular feedstock. Third, with the structural model we are able to analyze the strategic interaction between investors and estimate the net effect of other investors' decisions on a potential investor's payoff from investing in an ethanol plant of a particular feedstock. Since we identify the effects of state variables of the payoffs from investment, and since other investors' investment decisions affect future values of these state variables, we are able to identify the effects of other investors' investment decisions on a potential investor's decision and payoffs.

We normalize the deterministic payoff from the outside option of not investing ($a_i = 0$) to be zero:

$$u_0(a_{imt} = 0, \Omega_{mt}) = 0. \tag{3}$$

The coefficients γ_a are the coefficients on the state variables in the payoff for investing in an ethanol plant that uses feedstock a. We expect that ethanol price, local feedstock availability, and government policies supporting ethanol would have positive effects on the ethanol plant investment payoff. Natural gas is an important bio-refinery energy source, so we expect natural gas price to have a negative effect on the payoff. Similarly, we expect feedstock price to have negative impacts on the payoff. Gasoline price could have either a positive or negative effect on the payoffs from investment depending on whether ethanol is viewed as an energy substitute for gasoline or as an additive to gasoline, respectively.

The coefficients on the strategic state variables measure the net effects of the agglomeration and competition effects on the payoff for investing in an ethanol plant that uses feedstock a, and therefore indicate whether ethanol plants interact strategically on net. The strategic state variables track, for each feedstock, the number of existing plants in the market that use that particular feedstock. Positive coefficients on the strategic state variables would indicate that the agglomeration and competition effects were positive on net, and therefore that the agglomeration effect is dominant. Negative values would indicate that the effects were negative on net, and therefore the competition effect is dominant. By estimating the effect of the strategic state variables n_{mt} on the payoffs from investing in ethanol plants that use particular feedstocks, we can identify the net effects of other investor's decisions on a potential investor's payoffs.

In the following sections, to reduce the notational complexity we drop the market and time subscripts. Let $\sigma_i(a_i|\Omega)$ denote the probability that potential investor i chooses action a_i given state variables Ω. We assume that potential investors optimize their behavior conditional only on the current state variables and their private shocks, which results in a Markov perfect equilibrium. In a Markov perfect equilibrium, the potential investor's strategy and corresponding conditional choice probabilities $\sigma_i(a_i|\Omega)$ solve the following dynamic optimization problem:

$$W(\Omega, \epsilon_i; \sigma_{-i}) =$$
$$\max_{a_i} \begin{Bmatrix} u_0(a_i = 0, \Omega) + \epsilon_i(a_i = 0) + \beta E[W(\Omega', \epsilon_i'; \sigma_{-i})|a_i = 0, \Omega] \text{ if } a_i = 0, \\ u_0(a_i, \Omega) + \epsilon_i(a_i) \text{ if } a_i > 0 \end{Bmatrix}, \tag{4}$$

where $W(\Omega, \epsilon_i; \sigma_{-i})$ is investor i's value function given state Ω and private information ϵ_i , and conditional on the strategies σ_{-i} of the other investors. If the investor chooses to invest in an ethanol plant ($a_i > 0$), then the investor receives the payoff $u_0(a_i, \Omega) + \epsilon_i(a_i)$ from investing in an ethanol plant that uses feedstock a_i. If the investor chooses not to invest this period ($a_i = 0$), he receives the payoff $u_0(a_i = 0, \Omega) + \epsilon_i(a_i = 0)$ plus the discount factor β times the continuation value $E[W(\Omega', \epsilon_i'; \sigma_{-i})|a_i = 0, \Omega]$ to waiting instead of investing this period. The continuation value to waiting instead of investing this period is the expected value of the value function this period conditional on the state variables this period and on not investing this period:

$$E[W(\Omega', \epsilon_i'; \sigma_{-i})|a_i = 0, \Omega] =$$

$$\int \sum_{a_{-i}} W(\Omega', \epsilon_i'; \sigma_{-i})\ \bar{g}(\Omega'|\Omega, a_i = 0, a_{-i})\sigma_{-i}(a_{-i}|\Omega) f(\epsilon_i') d\epsilon_i' d\Omega' \quad . \tag{5}$$

We define the choice-specific value function $V(a_i, s)$ as:

$$V(a_i, \Omega) = \begin{Bmatrix} u_0(a_i = 0, \Omega) + \beta E[W(\Omega', \epsilon_i'; \sigma_{-i})|a_i = 0, \Omega] \text{ if } a_i = 0, \\ u_0(a_i, \Omega) \text{ if } a_i > 0 \end{Bmatrix}, \tag{6}$$

which is interpreted as the returns excluding $\epsilon_i(a_i)$ when the investor chooses action a_i this period and then reverts to the solution of the dynamic programming problem in all future periods. Then, we can define the *ex ante* value function as:

$$V(\Omega) = \int W(\Omega, \epsilon_i; \sigma_{-i}) f(\epsilon_i) d\epsilon_i. \tag{7}$$

The *ex ante* value function is the expected value of the value function $W(.)$ where the expectation is taken over the shocks ϵ_i. We can then rewrite the choice-specific value function as a function of the *ex ante* value function as follows:

$$V(a_i, \Omega) = \begin{Bmatrix} u_0(a_i = 0, \Omega) + \beta E[V(\Omega')|a_i = 0, \Omega] \text{ if } a_i = 0, \\ u_0(a_i, \Omega) \text{ if } a_i > 0 \end{Bmatrix}. \tag{8}$$

Finally, using the assumption that the shocks ϵ_i are distributed type I extreme value, we can derive the equilibrium probabilities using the choice-specific value function as follows:

$$\sigma_i(a_i|\Omega) = \frac{exp(V(a_i, \Omega))}{\sum_{a_i'} exp(V(a_i', \Omega))}. \tag{9}$$

5. Econometric Estimation

In the econometric estimation, we first estimate the policy functions, transition densities, and choice-specific value functions; and then estimate the parameters in the payoff functions. Bajari et al. (2015) show that given the knowledge of policy function $\sigma_i(a_i|\Omega)$ from the observed actions, one can uniquely recover the deterministic component $u_0(a_i, \Omega)$ of the payoffs after making an assumption that agents have correct beliefs about their environment and the behavior of other agents. We thus first estimate the policy functions $\hat{\boldsymbol{\sigma}}(\boldsymbol{a}|\Omega)$ for the agents, the transition densities $g(\Omega'|\Omega,\ a_i = 0,\ a_{-i})$ for the state variables, and the choice-specific value functions $\hat{V}(a_i, \Omega)$; and then estimate the parameters $\hat{\gamma}$ in the deterministic payoff function $u_0(a_i, \Omega)$.

In the first step, we estimate the policy functions (or choice probabilities) and the transition densities. We estimate the choice probabilities $\hat{\sigma}_i(a_i|\Omega)$ flexibly using a sieve logit, where the sieve logit estimator is simply the standard multinomial logit where the covariates are selected basis functions, and a sieve of polynomial spaces are selected. Let $\{q_l(\Omega),\ l = 1, 2, \cdots\}$ denote a sequence of known basis functions that can approximate a real valued measurable function of state variables Ω arbitrarily for a sufficiently large value of the basis function dimension. Although the sieve could be formed using splines, Fourier series, or orthogonal polynomials (Bajari and Hong, 2006), we set a simplest form of the sieve: a space of polynomials. Owing to state space considerations since we have many state variables, we set the degree of the sieve dimension to $l = 4$.

For the continuous state variables Ω, we choose a parametric method to estimate the transition densities $g(\Omega'|\Omega,\ a_i = 0,\ a_{-i})$ because we have little prior knowledge on the form of the state transitions. We define $g(\Omega'|\Omega,\ a_i = 0,\ a_{-i})$ as a density function and then let $g(\Omega'|\Omega,\ a_i = 0, a_{-i}; \alpha)$ be a flexible parametric density with parameter α. We assume the all state variables Ω except government policies and the strategic factors satisfy a multivariate normal distribution and use a seemingly unrelated regression to estimate $\hat{\alpha}$, thus enabling us to obtain $\hat{g}(\Omega'|\Omega, a_i = 0, a_{-i})$.

For the strategic state variables n_{mt}, the number of existing plants in the market that use each feedstock at time $t + 1$ is a known deterministic function of the number of existing plants that use each feedstock at time t as well as the investment decisions made by potential investors at time t. Thus, the transition density $g(\Omega'|\Omega,\ a_i = 0,\ a_{-i})$ for the strategic state variables n_{mt}

is a known deterministic function that does not need to be estimated.

Because we estimate our model using data that is pooled across all markets, we assume that the data are generated by a single Markov perfect equilibrium profile $\boldsymbol{\sigma}$ (Bajari, Benkard and Levin, 2007), and therefore that the same equilibrium is played in each market. By assuming that the data generating process follows the players' optimal behavior in the game, we can estimate the choice probabilities in the first step without having to solve for the equilibria of the game, enabling us to avoid a high computational burden.

In the present model, the existence of multiple equilibria is a prevalent feature in most empirical games where best response functions are nonlinear in other players' actions. We can either use estimators that explicitly accommodate multiplicity, which is analytically difficult, or assume uniqueness. When observed games are drawn from a population that is culturally or geographically close, sharing similar norms and conventions, as perhaps can be argued holds for Europe, one would expect that it is adequate to assume that the same equilibrium is played across games (de Paula, 2013).

Bresnahan and Reiss (1990, 1991) consider a specification where, conditional on the state variables, a firm's action depends on the number of firms that are operating in the market, not on the identity of these firms. Their assumption is that all the firms are symmetric conditional on the state variables and that they produce a homogeneous good. Therefore, we will follow this method and use only the number of other plants choosing certain feedstocks, rather than the identity of the plants choosing certain feedstocks, to represent the strategic interactions.

If a long panel is available, it may be sometimes possible to estimate the policy functions separately for each market (Bajari, Benkard and Levin, 2007). However, due to the scarcity of long panel data, we instead assume that the pooled data have a unique equilibrium.[4]

In the second step of the econometric estimation, we estimate the choice-specific value function $\hat{V}(0, \Omega)$ for $a_i = 0$ and then use this estimate to estimate the choice-specific value functions $\hat{V}(a_i, \Omega)$ for all actions a_i by applying the Hotz-Miller inversion:

$$\hat{V}(a_i, \Omega) - \hat{V}(0, \Omega) = \log\big(\hat{\sigma}_i(a_i|\Omega)\big) - \log\big(\hat{\sigma}_i(0|\Omega)\big), \tag{10}$$

and using the choice probabilities $\hat{\sigma}_i(a_i|\Omega)$ that were estimated in the first step. $\hat{V}(0, \Omega)$ is assumed to have the following linear series approximation:

$$\hat{V}(0, \Omega) = q_l(\Omega)' \, \hat{\theta}_{il} \ , \tag{11}$$

and is estimated using the empirical analog estimation method based on series expansion suggested by Bajari et al. (2015).

In the third step of the econometric estimation, we estimate $\hat{u}_0(a_i, \Omega)$, the static choice-specific deterministic payoff function given that the action is a_i and the state is Ω. Solving equation (8) for the deterministic payoff $u_0(a_i, \Omega)$ and then using the estimates of the choice-specific value function $\hat{V}(a_i, \Omega)$, we can estimate $\hat{u}_0(a_i, \Omega)$ using the following equation:

$$\hat{u}_0(a_i, \Omega) = \begin{Bmatrix} \hat{V}(a_i, \Omega) - \beta E[V(\Omega')|a_i = 0, \Omega] \text{ if } a_i = 0, \\ \hat{V}(a_i, \Omega) \ \text{ if } a_i > 0 \end{Bmatrix}, \tag{12}$$

where, owing to the extreme value distributional assumptions for the shocks ϵ_i, the continuation value can be written as:

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[4] Otsu, Pesendorfer and Takahashi (2016) propose statistical tests for finite state Markov games to examine whether data from distinct markets can be pooled. Unfortunately, their test is not applicable to our context for two reasons. First, their test is for finite state variables, while some of our state variables are continuous. Second, their test performs well for moderate values of the number of markets (e.g., 20 or 40), while our study involves a large number of markets (168) and a small number of time periods (7). As seen in their Monte Carlo results when multiple equilibria are possible with non-zero probability in Tables 3 and 4, their test does not perform well in their simulations in which the number of markets is closest to that in our study (i.e., 80 or 160) and the number of time periods is closest to that in our study (i.e., 5 or 10).

$$E[V(\Omega')|a_i = 0, \Omega] =$$

$$\int \left(\log \sum_{k=0}^{K} \exp\left(\hat{V}(k, \Omega')\right)\right) \hat{g}(\Omega'|\Omega, a_i = 0, a_{-i}) \hat{\sigma}_{-i}(a_{-i}|\Omega) d\Omega' , \qquad (13)$$

To calculate the continuation value we use numerical integration, in which we randomly draw Ω' multiple times from the transition density $\hat{g}(\Omega'|\Omega, a_i = 0, a_{-i})$ estimated in the first step, where a_{-i} is drawn from the choice probabilities $\hat{\sigma}_{-i}(a_{-i}|\Omega)$ also estimated in the first step, and then take the mean value of $\log \sum_{k=0}^{K} \exp(\hat{V}(k, \Omega'))$ over all the draws. For the structural estimation, we set the discount factor β to 0.9.

In the fourth step of the econometric estimation, we estimate the parameters $\hat{\gamma}$ of the deterministic component $\hat{u}_0(a_i, \Omega)$ of the payoff from investing in an ethanol plant for each feedstock a_i. A nonparametric method for $\hat{u}_0(a_i, \Omega)$ is more flexible, but is not practical for our intermediate-sized sample because nonparametric estimators may be poorly estimated due to the sensitivity of the bandwidth or choice of the kernel without a sufficiently large sample. Therefore, our strategy is to choose appropriate parameters $\hat{\gamma}$ to minimize the distance between the choice-specific payoff functions $\hat{u}_0(a_i, \Omega)$ estimated in the third step and the parametric form of the deterministic payoff function $u_0(a_{imt}, \Omega_{mt})$ given in equation (2). To this end, our semiparametric approach solves the following minimization problem:

$$\hat{\gamma}_a = \operatorname{argmin}_{\gamma_a} \sum_{m=1}^{M} \sum_{t=1}^{T} \left(\hat{u}_0(a_{imt}, \Omega_{mt}) - (x'_{mt}\gamma_{ax} + n'_{mt}\gamma_{an})\right)^2 \qquad (14)$$

where, as defined in equation (2), the deterministic component $u_0(a_{imt}, \Omega_{mt})$ of the payoff to investing in an ethanol plant that uses feedstock a_{imt} is a linear function of the state variables. As common in semiparametric estimation, $\hat{\gamma}$ converges to the true value at a rate proportational to the square root of the sample size and has a normal asymptotic distribution (Bajari et al., 2015).

Standard errors are formed by a nonparametric bootstrap. Markets are randomly drawn from the data set with replacement to generate 100 independent panels of size equal to the actual sample size. The structural econometric model is run on each of the new panels. The standard error is then formed by taking the standard deviation of the estimates from each of the random samples.

6. Data

We apply our model of the ethanol investment timing game to the European ethanol industry. Of the 27 members of the European Union (EU), we focus on the 20 countries for which ethanol price was available. As seen in Table 2, there were 75 ethanol plants running in these 20 European countries in 2007. Six plants were built before 2001 and the earliest one was built in 1979. We choose 2001 to 2007 as our period of study to coincide with the second ethanol boom in the US, during which ethanol plant technology was different from that of the first ethanol boom preceding it (Thome and Lin Lawell, 2018) and because country-level ethanol price data was not available for the 20 countries before 2001.

Figure 2 presents the number of ethanol plants that use barley, corn, sugar beet, and wheat, respectively, in the years from 2001 to 2007. Except for barley-based ethanol plants, the number of plants is increasing in time for each feedstock. The total number of ethanol plants has increased rapidly since 2005, especially for wheat-based ethanol plants. In 2007, 2 ethanol plants used barley as feedstock, 12 plants used corn, 13 plants used sugar beet and the remaining 42 ethanol plants used wheat as feedstock. We therefore model the choice set of a potential investor in each year t as having five options including the outside option of not investing: $a_{it} \in \{\text{outside option}, \text{barley}, \text{corn}, \text{sugar beet}, \text{wheat}\}$.

We collect information on the feedstock used for all ethanol plants in the 20 European countries from 2001 to 2007 from either the plants' own websites or from existing survey information. Rye is also an alternative feedstock used in Europe ethanol production (GAIN, 2010), however, it constitutes an extremely small proportion of ethanol production in Europe and is usually used in conjunction with another primary feedstock such as wheat or barley. Therefore, to simplify the discrete choice model, we focus on the decision to choose a single primary feedstock out of the choice set of barley, corn, sugar beet, or wheat.

In the semiparametric estimation, the 20 EU countries are divided into 168 "markets" based on the Nomenclature of Territorial Units for Statistics (NUTS). We choose to use the NUTS delineation for markets for several reasons. First, the NUTS delineation yields markets with geographical areas commensurate with the extent of local competition. Owing to high transportation costs, the geographical extent of local competition in both the feedstock input market and the ethanol output market is unlikely to be larger than the size of markets defined at the NUTS level. Second, even at the NUTS level, we never observe more than 3 ethanol plants in any market. If we were to define markets to be smaller than the NUTS delineation, we would have few if any markets with more than one ethanol plant. Since we are interested in analyzing the possibility of strategic interaction, we want to define the markets to be large enough for us to observe multiple ethanol plants in some markets. Third, defining markets based on the NUTS delineation makes the area of each market as similar as possible across the different countries. Fourth, the NUTS level was the finest geographical resolution for which any of our variables was available for all 20 EU countries.

Table 2 describes the ethanol markets by country. The average area of each market over all the countries is 23,064 km^2. Since we never observe more than 3 ethanol plants in any market in our data set, we assume that the maximum number of potential investors in each market is 3.

We chose our state variables based on considerations of state space and data availability. By using an estimation approach that does not need a preliminary estimation of the continuation values of the players (Bajari et al., 2015), our estimation does not rely on the discreteness of state space, so we can keep the continuous state variable continuous as they are.

For the ethanol price, since regional ethanol prices are not available, we use country-level ethanol prices. In particular, we use ethanol import prices for net ethanol importing countries and the ethanol export prices for net ethanol exporting countries. All the prices are from Global Information, Inc. Since we do not have local variation in ethanol prices, local competition in the ethanol output market is captured by the strategic state variables n_{mt} that track, for each feedstock, the number of existing plants in the market that use that particular feedstock.

For the natural gas price, since historical natural gas prices are not available for each NUTS region, we use country-level natural gas prices. We use several different sources for the natural gas prices: OECD (Austria, Germany, Italy, Netherlands), Energy Information Administration (EIA) (Czech Republic, Finland, France, Hungary, Ireland, Poland, Slovakia, Spain, UK), EUROSTAT (Belgium, Bulgaria, Denmark, Sweden), and the Mundi Index (Latvia, Lithuania, Romania). Since we do not have local variation in natural gas prices, local competition in the natural gas input market is captured by the strategic state variables n_{mt} that measure the net strategic interaction.

For gasoline price, we use country-level gasoline prices from the EIA. Since we do not have local variation in gasoline prices, local competition in the gasoline input and output markets is again captured by the strategic state variables n_{mt} that measure the net strategic interaction.

As a measure of local feedstock availability, we use market-level feedstock intensities, which we calculate by dividing the market-level output for each feedstock by the geographical area of the respective market. For market-level feedstock output, we use market-level feedstock production data from the European Commission's data base. Since the markets vary in their geographical area, we use feedstock intensity to capture the area-independent production by each market.

We calculate market-level feedstock prices using the market-level outputs for all the feedstocks and their corresponding yearly total values from the European Commission's data base. Production values for corn are not available for several markets, including some in the UK; for these markets, we use FAO national prices to represent local prices. As a robustness check, we run a specification of our model where we use national feedstock prices for all markets. The European Commission's database shows that none of the markets in Finland produce corn, so we use FAO import prices of corn to represent the corn feedstock prices in all markets in Finland.

As a measure of proximity to cattle and hogs, we use local livestock densities, which we calculate by dividing the market-level numbers of cattle and hogs from the European Commission's data base by the geographic areas of the respective markets.

There are 3 different types of ethanol support policies in Europe: financial support, blending mandate and R&D support. Financial support policies include tax credits and direct funding support from the local government. Blending mandates are mandates that gasoline should contain a certain percentage of ethanol. R&D support policies provide support for research and development (R&D). For each policy, we include a dummy variable that equals 1 if the policy is in place in a particular market m in year t and 0 otherwise. Data for these policies are from European Renewable Energy Council's Renewable Energy Policy Review (2009). Table 1 lists the ethanol policies implemented in each country in Europe by 2007 and the dates they were implemented.

In our dynamic structural econometric model, we assume that the ethanol support policies evolve as a first-order Markov process. From the perspective of potential ethanol plant investors, the evolution of these policies over time was uncertain at the beginning of the study period, due to the democratic nature of lawmaking and uncertainty about the evolution of the European ethanol industry. Although the basic strategy of providing government support for ethanol was likely known by potential investors, the exact timing of the ethanol support policies could not have been perfectly anticipated. We therefore model future implementation and timing of these policies as uncertain from the point of view of potential investors in any given year of our period of study. We use empirical probabilities to estimate a potential investors' expectation of the implementation and timing of these policies conditional on current values of these policies and on current values of other state variables.

Table 3 presents summary statistics for the state variables. In addition to our state variables, we also include country fixed effects to control for unobserved industry policies and market conditions that can affect the investment decisions of potential investors. In one of our specifications we also include year effects to control for unobserved common shocks.

7. Results

We run three different specifications of our econometric model. The parameters estimated are the coefficients γ_a in the payoff function for investing in an ethanol plant that uses feedstock a for each of the four feedstocks (barley, corn, sugar beet, and wheat). The coefficients on the number of existing plants using the same feedstock and the number of existing plants using a different feedstock measure the net effect of the strategic interactions. The coefficients the economic and policy state variables measure the effects of economic factors and government policy, respectively, on the payoffs to investing in an ethanol plant that uses feedstock a. We include country fixed effects in all our specifications.

Table 4 reports the results from the base case model. According to the results, for each of the feedstocks, both the number of existing plants using the same feedstock and the number of existing plants using a different feedstock have a significant negative effect on the payoffs to investing in an ethanol plant that uses that feedstock. For barley, corn and sugar beet, the effect of existing plants using the same feedstock is larger in magnitude than the effect of existing plants using a different feedstock; for wheat, the effects of both types of existing plants are similar in magnitude. Our results on the strategic interaction therefore show that the competition effect dominates the agglomeration effect, yielding a net negative strategic effect. Competition between plants deters local investments and has a large negative effect on the payoffs from investment.

According to the results from the base case model, ethanol price does not have significant effect on the ethanol plant's profit although it has the expected positive sign. As an input, natural gas price has a significant negative effect on the payoffs to investing in a barley-based ethanol plant, but does not have a significant effect on the payoffs to investing in ethanol plants using any other feedstock. Gasoline price has a significant positive effect on the payoffs from investing in barley-, corn- and wheat-based ethanol plants, and this suggests that the positive effect of gasoline price on payoffs due to the complementary nature of gasoline and ethanol when blended in fuel outweighs the negative effect of gasoline price on payoffs due to its use as an input.

As expected, feedstock prices have negative effects on the payoff to investing in an ethanol plant using the respective feedstock. Barley prices, sugar beet prices, and wheat prices have significant negative effects on the payoffs to investing in ethanol plants using barley, sugar beet and wheat, respectively, as the feedstock. For all feedstocks, feedstock availability, as measured by feedstock intensity, has a positive effect on the payoffs to investing in ethanol plants, but the only significant effect is the positive effect of local corn intensity on the payoffs to investing in an ethanol plant using corn as a feedstock. Thus, while local feedstock price has a significant effect on payoffs to investing in ethanol plants using barley, sugar beet and wheat, local feedstock intensity has a significant effect on the payoff to investing in an ethanol plant that uses corn as a feedstock.

There are interesting results governing the relationships between ethanol plants and livestock. Proximity to cattle, as measured by cattle density, has a significant positive effect on the payoffs to investing in an ethanol plant that uses either barley or corn as the feedstock, since the co-products from ethanol production can be used to feed cattle. In contrast, proximity to hogs, as measured by hog density, has a significant negative effect on the payoffs to investing in an ethanol plant that uses either barley or corn as the feedstock, which suggests that hog production competes with barley-based and corn-based ethanol plants in the feedstock markets and this negative competition effect dominates the positive effect that co-products from ethanol production can feed hogs.

As expected, all three ethanol support policies (financial support, blending mandate, and R&D support) have positive effects on the payoffs from investing in ethanol plants for all feedstocks. All the positive effects are significant except the effect of financial support on payoffs to investing in sugar beet-based ethanol plants and the effect of R&D support on payoffs to investing in wheat-based plants.

The magnitudes of the effects of strategic interactions and of the government support policies are comparable to each other and quite large in comparison to the magnitudes of the effects of the economic variables. For barley, an increase in the number of existing ethanol plants using barley by one has roughly the same magnitude of an effect on the payoffs to investing in a barley-based ethanol plant as the implementation of a blending mandate (though the former is a negative effect while the latter is a positive effect), and the magnitude of each effect is slightly greater than the magnitude of the effect of an increase in the number of existing ethanol plants using a feedstock other than barley, more than twice as large as the magnitude of the effect from a change in the gasoline price of $0.12/liter (which is roughly 10% of its mean value), and more than 11 times as large as the magnitude of the effect from a change in local barley price of $1.69/ton (which is roughly 10% of its mean value). Other economic variables, such as the ethanol price and the natural gas price, have no significant effect on the payoffs to investing in an ethanol plant that uses barley.

For corn, an increase in the number of existing ethanol plants using corn by one has roughly the same magnitude of an effect on the payoffs to investing in a corn-based ethanol plant as the implementation of a financial support policy (though the former is a negative effect while the latter is a positive effect), and the magnitude of each effect is more than ten times the effect of an increase by one in the number of existing ethanol plants that use a feedstock other than corn and orders of magnitude larger than the effect of a change in local corn intensity. Other economic variables, such as the ethanol price, gasoline price and the natural gas price, have no significant effect on the payoffs to investing in an ethanol plant that uses corn.

For sugar beet, an increase in the number of existing ethanol plants using sugar beet by one has more than 1.5 times the effects on the payoffs to investing in a sugar beet-based ethanol plant as the implementation of an R&D support policy (though the former is a negative effect while the latter is a positive effect), and the magnitude of the effect is about 2.5 times the magnitude of the effect of an increase by one in the number of existing ethanol plants that use a feedstock other than sugar beet, about 100 times magnitude of the effect of a change in the natural gas price of $0.69/MBtu (which is roughly 10% of its mean value), more than 40 times the magnitude of the effect of a change in the gasoline price of $0.12/liter (which is roughly 10% of its mean value), more than 3 times the magnitude of the effect of a change in the sugar beet price of $4.82/ton (which is roughly 10% of its mean value). The ethanol price has no significant effect on the payoffs to investing in an ethanol plant that uses sugar beet.

For wheat, an increase in the number of existing ethanol plants using wheat by one has roughly the same magnitude of an effect on the payoffs to investing in a wheat-based ethanol plant as the implementation of either a financial support policy, the implementation of a blending mandate, or an increase in the number of existing plants using a feedstock other than wheat, and the magnitude of each effect is orders of magnitude larger than the magnitude of the effect from a change in the gasoline price of $0.12/liter (which is roughly 10% of its mean value) and orders of magnitude larger than the magnitude of the effect from a change in local wheat price of $17.32/ton (which is roughly 10% of its mean value). Other economic variables, such as the ethanol price and the natural gas price, have no significant effect on the payoffs to investing in an ethanol plant that uses wheat.

The second specification adds year effects to the base case model, and the results are in Table 5. The year effects control for any unobserved common shocks. For the most part, the qualitative results and the signs and relative magnitudes of the significant coefficients are robust to the addition of year effects.

The third specification uses national feedstock prices instead of local feedstock prices. We did not have data for local feedstock prices for all four feedstocks for the UK, Finland, Denmark, Czech Republic, and Spain; for these countries we used national prices for regions without a local price. The third specification is a robustness check in which we use only national feedstock prices for all the markets. The results are shown in Table 6. For the most part, the qualitative results and the signs and relative magnitudes of the significant coefficients on the strategic, policy and economic variables are robust. The main difference is that while the number of existing plants using corn had a more negative effect on the payoffs to investing in an ethanol plant that uses corn than did the number of existing plants using a feedstock other than corn in the first two specifications, the reverse is true when national feedstock prices are used instead of local feedstock prices. A second difference is that while the ethanol price did not have a significant effect on the payoffs to investing in an ethanol plant of any feedstock in either of the first two specifications, in the third specification ethanol price has a significant positive effect on the payoffs to investing in an ethanol plant that uses sugar beet.

8. Conclusion

The decision to invest in building an ethanol plant that uses a particular feedstock is a dynamic decision that may be affected by economic factors and government policies. Owing to competition effects and agglomeration effects, a potential investor's investment decision may also depend on the investment decisions of other investors. This paper analyzes how economic factors, strategic factors, and government policies affect the decision to invest in building new ethanol plants in Europe. We distinguish among investments in ethanol plants of different feedstocks.

Our empirical methodology is to estimate a structural econometric model of the dynamic ethanol investment timing game. We build upon the previous literature on ethanol investment by developing and estimating a model that incorporates the dynamic and strategic aspects of the investment decision, that allows for a choice among multiple feedstocks, and that does not require continuous variables to be discretized. The econometric model we use in this paper is based on one developed by Bajari et al. (2015). This paper is the first to our knowledge to apply the econometric model developed by Bajari et al. (2015) to actual data.

According to our results, competition between plants dominates the agglomeration effect 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 support policies play an important role in the development of the ethanol industry in Europe. Ethanol investment decisions in Europe are affected more by government policies and strategic interactions than by economic factors such as ethanol prices, natural gas prices, and feedstock prices: the effects of government policies and strategic interactions on the payoffs to ethanol plant investment are more statistically significant than the effects of these economic factors.

Our results that financial support policies and R&D support policies have a positive effect on ethanol investment are consistent with the results of Bloom, Griffith and Van Reenen (2002), who find that fiscal incentives have a positive effect on R&D investment in the manufacturing sector in OECD countries. Our result that blending mandates have a positive effect on ethanol investment is consistent with Lade, Lin Lawell and Smith (forthcoming), who argue that binding mandates provide an incentive to invest in technologies to meet the future objectives of the policy.

Our results are of interest to academics, policy-makers, and industry practitioners alike who are interested in the effects of economic factors, strategic interactions, and government policy on investment decisions not only in the ethanol industry in particular, but also in any other industry that may have been affected by government policy or in which strategic interactions may be important.

In future work, we hope to further analyze the effects of the government policies on the ethanol investment decision, including the channels through which the government policies affect payoffs; and the particular characteristics, levels, and combinations of the policies that are most effective, cost-effective, and efficient.

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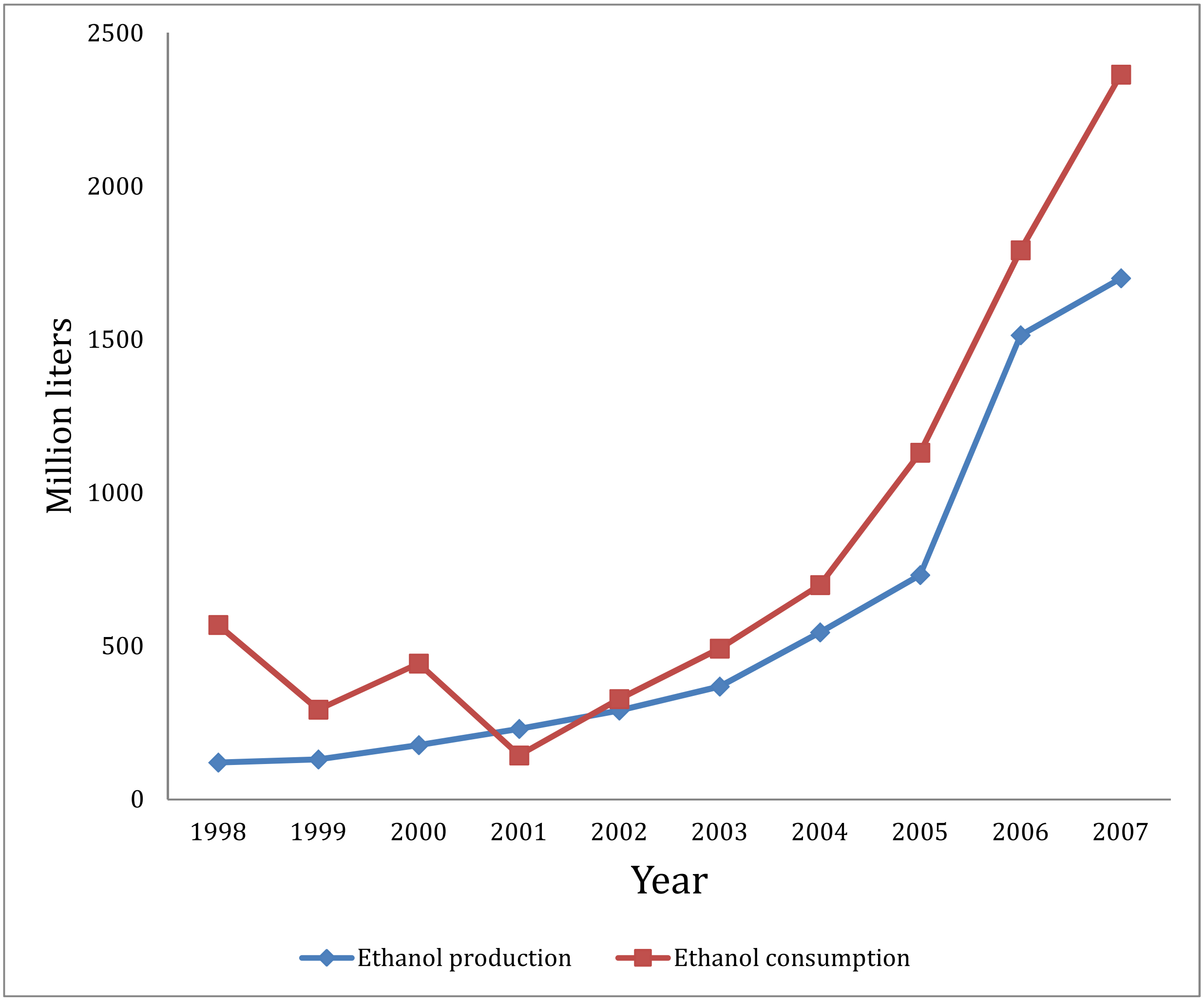
Figure 1. Ethanol production and consumption in Europe



Sources: Ethanol consumption data is from the United Nations Statistics Division. Ethanol production data is from the European Union of Ethanol Producers.

Table 1. Implementation dates for ethanol support policies implemented by 2007

Country	Financial Support	Blending Mandate	R&D Support
Austria	2007	2005	-
Belgium	2006	2005	-
Bulgaria	2005	-	-
Czech Republic	2006	-	-
Denmark	2005	2005	-
Finland	-	-	-
France	2006	2005	2005
Germany	1999	-	-
Hungary	2007	2007	-
Ireland	2005	2007	-
Italy	-	-	-
Latvia	-	2005	-
Lithuania	-	-	-
Netherlands	2006	2007	2006
Poland	2004	-	-
Romania	-	2007	-
Slovakia	2004	2006	-
Spain	2003	2007	2003
Sweden	2006	-	-
UK	-	2006	-

Source: Renewable Energy Council's Renewable Energy Policy Review (2009).

Figure 2. Number of ethanol plants by feedstock

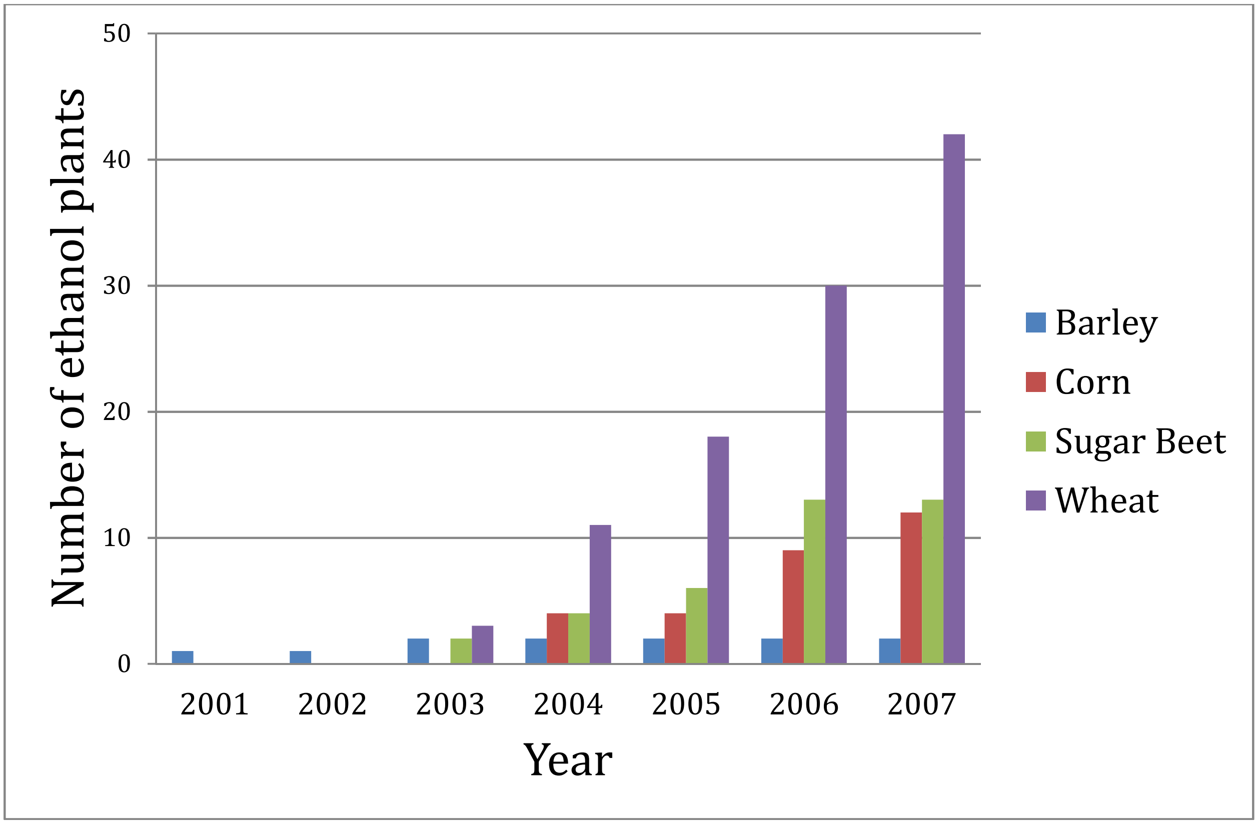


Table 2. Ethanol markets by country

Country	Number of markets	Number of ethanol plants in 2001-2007	Average area for each market (km^2)
Austria	8	1	10,441
Belgium	2	3	15,279
Bulgaria	6	3	18,475
Czech Republic	7	7	11,269
Denmark	5	0	8,602
Finland	5	3	58,433
France	21	13	25,506
Germany	13	9(1)	27,469
Hungary	7	5	13,293
Ireland	2	1(1)	34,899
Italy	20	4(2)	15,067
Latvia	1	1	64,589
Lithuania	1	2	65,200
Netherlands	4	3	9,335
Poland	16	6	19,538
Romania	7	1	33,814
Slovakia	4	2	14,780
Spain	17	7(1)	29,743
Sweden	8	2(1)	45,659
UK	14	2	16,505
Total	**168**	**75(6)**	**23,064**

Notes: Number of ethanol plants built before 2001 in parentheses.

Table 3. Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Ethanol price ($/ton)	168	833.627	454.689	460.000	4180.000
Natural gas price ($/MMBtu)	168	6.912	2.681	2.686	15.365
Gasoline price ($/liter)	168	1.213	0.323	0.522	1.999
Barley price ($/ton)	168	169.044	61.641	56.918	390.071
Corn price ($/ton)	168	207.450	142.337	56.293	1081.871
Sugar beet price ($/ton)	168	48.159	21.373	16.240	247.230
Wheat price ($/ton)	168	173.155	65.336	51.011	397.202
Barley intensity (000ton/km^2)	168	0.015	0.017	0	0.093
Corn intensity (000ton/km^2)	168	0.016	0.029	0	0.184
Sugar beet intensity (000ton/km^2)	168	0.040	0.072	0	0.639
Wheat intensity (000ton/km^2)	168	0.039	0.042	0	0.244
Cattle density (head/km^2)	168	0.029	0.106	0.000	3.522
Hog density (head/km^2)	168	0.054	0.123	0.000	1.068
Financial support (dummy)	168	0.043	0.204	0	1
Blending mandate (dummy)	168	0.155	0.362	0	1
R&D support (dummy)	168	0.133	0.339	0	1

Table 4: Results of base case model

	Coefficients in the payoffs from investing in an ethanol plant of feedstock:			
	Barley	Corn	Sugar beet	Wheat
Number of existing plants using the same feedstock	-149.876 ***	-179.170 ***	-500.116 ***	-1935.29 ***
	(1.027)	(0.243)	(5.662)	(0.558)
Number of existing plants using a different feedstock	-138.494 ***	-14.924 *	-203.814 ***	-1935.57 ***
	(14.614)	(6.758)	(27.445)	(0.536)
Ethanol price ($/ton)	0.524	0.044	2.105	0.444
	(17.967)	(0.470)	(4.168)	(0.254)
Natural gas price ($/MBtu)	-36.617	-0.294	-7.138 *	0.040
	(25.346)	(0.722)	(2.942)	(0.198)
Gasoline price ($/liter)	540.263 *	3.860	90.245 *	6.472 *
	(256.554)	(12.002)	(39.903)	(2.687)
Local feedstock price ($/ton)	-7.857 *	-12.289	-31.193 *	-0.262 **
	(3.660)	(4.277)	(12.200)	(0.089)
Local feedstock intensity (000 ton/km^2)	24.298	1.693 *	0.752	0.138
	(45.270)	(0.782)	(1.587)	(0.093)
Cattle density (head/ km^2)	610.557 *	125.478 *	-62.088	-4.573
	(253.294)	(49.002)	(59/961)	(4.2723)
Hog density (head/ km^2)	-262.823 *	-15.274 *	32.319	-0.120
	(114.629)	(6.702)	(42.337)	(0.885)
Financial support (dummy)	29.791 *	179.977 ***	59.000	1934.952 ***
	(11.972)	(0.243)	(43.533)	(0.570)
Blending mandate (dummy)	142.631 ***	15.430 *	202.077 ***	1935.207 ***
	(7.676)	(6.758)	(19.049)	(0.497)
R&D support (dummy)	87.630 ***	109.431 *	296.156 ***	1.787
	(11.599)	(51.394)	(5.662)	(1.147)
Constant	-30.243	0.067	4.099	-0.942 **
	(19.890)	(1.1795)	(2.995)	(0.416)
Country fixed effects		YES		
Year Effects		NO		

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level. Local feedstock price refers to local barley price, corn price, sugarbeet price, and wheat price for the payoffs to investing in ethanol plants using barley, corn, sugarbeet, and wheat, respectively. Similarly, local feedstock intensity refers to the local intensity of barley, corn, sugarbeet, and wheat, respectively.

Table 5: Results of year effect model

	Coefficients in the payoffs from investing in an ethanol plant of feedstock:			
	Barley	Corn	Sugar beet	Wheat
Number of existing plants using the same feedstock	-128.660 ***	-194.375 ***	-719.827 ***	-1915.86 ***
	(1.029)	(0.226)	(23.431)	(0.606)
Number of existing plants using a different feedstock	-117.313 ***	-29.013 ***	-660.805 ***	-1916.21 ***
	(13.433)	(6.749)	(111.652)	(0.573)
Ethanol price ($/ton)	0.390	0.089	0.695	0.537
	(18.209)	(0.465)	(4.546)	(0.288)
Natural gas price ($/MMBtu)	-36.669	-0.332	-7.108 *	0.063
	(25.871)	(0.647)	(2.892)	(0.197)
Gasoline price ($/liter)	541.078 *	5.430	92.641 *	5.746
	(261.831)	(13.152)	(40.382)	(2.942)
Local feedstock price ($/ton)	-7.841	-11.661 **	-30.166 *	-0.197
	(4.461)	(4.222)	(11.779)	(0.114)
Local feedstock intensity (000 ton/km^2)	24.018	1.640 *	0.688	0.159
	(39.201)	(0.772)	(1.437)	(0.104)
Cattle density (head/ km^2)	607.281 *	107.526 *	-60.695	-4.677
	(255.769)	(44.928)	(61.497)	(4.136)
Hog density (head/ km^2)	-253.474 *	-13.291 *	34.097	-0.098
	(110.926)	(6.659)	(42.850)	(0.855)
Financial support (dummy)	29.795 *	195.152 ***	59.011	1915.87 ***
	(10.506)	(0.226)	(179.495)	(0.596)
Blending mandate (dummy)	121.405 ***	29.294 ***	658.764 ***	1915.70 ***
	(7.723)	(6.749)	(78.940)	(0.536)
R&D support (dummy)	87.644 ***	109.431 *	59.319 *	1.881
	(11.589)	(51.328)	(23.431)	(1.320)
Constant	-30.314	-0.047	4.342	-0.960
	(19.907)	(1.1749)	(2.984)	(0.512)
Country fixed effects		YES		
Year Effects		YES		

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level. Local feedstock price refers to local barley price, corn price, sugarbeet price, and wheat price for the payoffs to investing in ethanol plants using barley, corn, sugarbeet, and wheat, respectively. Similarly, local feedstock intensity refers to the local intensity of barley, corn, sugarbeet, and wheat, respectively.

Table 6: Results of national feedstock price model

	Coefficients in the payoffs from investing in an ethanol plant of feedstock:			
	Barley	Corn	Sugar beet	Wheat
Number of existing plants using the same feedstock	-121.195 ***	-26.769 ***	-520.431 ***	-1890.256 ***
	(1.195)	(0.654)	(7.356)	(1.803)
Number of existing plants using a different feedstock	-110.154 ***	-45.182 ***	-248.653 ***	-1890.750 ***
	(11.929)	(7.356)	(34.266)	(1.743)
Ethanol price ($/ton)	-0.989	2.651	7.721 *	0.354
	(7.335)	(-0.407)	(3.616)	(1.935)
Natural gas price ($/MMBtu)	-33.669	-0.587	-11.628 *	-0.148
	(22.715)	(1.941)	(4.917)	(2.092)
Gasoline price ($/liter)	498.674 *	54.360	100.681 *	8.087
	(240.253)	(32.478)	(45.475)	(44.832)
National feedstock price ($/ton)	-6.558	-24.069 *	-42.052 *	-0.240
	(3.933)	(10.580)	(16.917)	(0.397)
Local feedstock intensity (000 ton/km^2)	24.137	0.772	0.988	0.128
	(39.400)	(1.113)	(1.295)	(1.334)
Cattle density (head/ km^2)	599.876 *	150.140	-11.365	-0.526
	(261.768)	(86.306)	(26.494)	(30.368)
Hog density (head/ km^2)	-261.530	-21.876	-92.506	-0.488
	(136.774)	(18.871)	(51.673)	(11.722)
Financial support (dummy)	31.112 ***	26.767 ***	57.732	1891.00 ***
	(8.643)	(0.654)	(55.306)	(1.690)
Blending mandate (dummy)	114.267 ***	44.729 ***	246.252 ***	1890.21 ***
	(7.702)	(5.878)	(23.815)	(1.653)
R&D support (dummy)	88.129 ***	111.437 *	271.965 ***	2.900
	(11.662)	(52.638)	(7.356)	(3.255)
Constant	-31.414	-2.853	11.749 *	-0.989
	(22.324)	(2.582)	(5.425)	(7.335)
Country fixed effects		YES		
Year Effects		NO		

Notes: Standard errors are in parentheses. Significance codes: * 5% level, ** 1% level, *** 0.1% level. National feedstock price refers to national barley price, corn price, sugarbeet price, and wheat price for the payoffs to investing in ethanol plants using barley, corn, sugarbeet, and wheat, respectively. Similarly, local feedstock intensity refers to the local intensity of barley, corn, sugarbeet, and wheat, respectively.