

Private Sector Innovation in Biofuels in the United States: Induced by Prices or Policies?

Rupa Karmarkar-Deshmukh and Carl E. Pray

Rutgers University

It has been shown in recent years that high energy prices induce investments in energy research. \$100/barrel oil, strategic concerns, concerns about global warming, and pork-barrel politics have also rekindled the enthusiasm of the public and government for policies that encourage research and innovation on biofuels. This article is a first attempt to develop an econometric model to measure how innovations as measured by ethanol-related patents have responded to high oil prices and to government policies. We look at both the demand-side factors, such as federal policies subsidizing ethanol production or mandates for the use of biofuels, and supply-side factors, such as government funding for biofuels research. We find that both oil prices and federal research grants have significant positive effects on innovation. However, the size of the ethanol market has a negative effect, as do federal tax credits, with mandates being insignificant.

Key words: biofuels, ethanol, government policy, innovation, patents.

Introduction

The recent rise in the world crude oil prices has not only affected energy and fuel prices, but its effects have been seen in food and land prices across the world. The economic concerns about the limited supply of fossil fuel in tandem with environmental concerns about global warming and pollution issues have driven the search for alternative fuels that have superior environmental benefits and are economically competitive with fossil fuel.

Whereas solar, hydroelectric, and wind energy can replace coal and oil for producing electricity in the transportation sector, ethanol and biodiesel are the only real alternatives for gasoline and diesel, respectively. Ethanol from corn is an established product, being widely used in the alcohol industry and in the chemical industry as a solvent and as an additive to gasoline. Therefore, corn ethanol has gained much attention from the public and private sector with the result that it has become rapidly absorbed in the automotive industry as a fuel blend.

These factors and the power of the corn lobby have also led politicians to support ethanol production through production subsidies, mandated use of ethanol or biofuels more generally, and financial support for research and pilot production in the public and private sector.

It is now becoming clear, however, that corn as a feedstock has its limits; if all US corn was used to produce ethanol it would only meet 20% of current demand (Brown, 2008) along with the rising demand for feed and food, which is pushing up corn prices. In addition,

the public is becoming aware of the limited environmental benefits of using corn to produce ethanol and the impact of ethanol production on higher food prices, which affects their welfare and the welfare of the poor and hungry in developing countries. In recent years, research on alternative feedstock to corn, such as cellulosic biomass, is getting a lot of attention. The objective of this article is to find out whether government policies can play an important role in inducing private-sector research and innovation in biofuels or whether R&D and innovation are simply driven by economic factors such as the prices of oil and its alternatives. In this article we first identify the primary areas of research in biofuels and analyze the effects of the various factors on the amount and direction of private biofuel R&D. In order to do this, we look at the major players in biofuels production and research, the markets, and their size across the supply chain, and put together a quantitative measure of biofuel research. Then we identify the factors that influence private R&D investments and quantify, when possible, their significance. In doing so, we aim to further our knowledge of the effectiveness of government research investments and policy in inducing research and innovation in biofuels.

Description of Ethanol Production

Bio-ethanol is obtained from the conversion of carbon-based feedstock, as shown in Figure 1. The major steps of the production process include: feedstock production, harvesting and collection, feedstock storage and preparation, pretreatment, ethanol fermentation, and ethanol

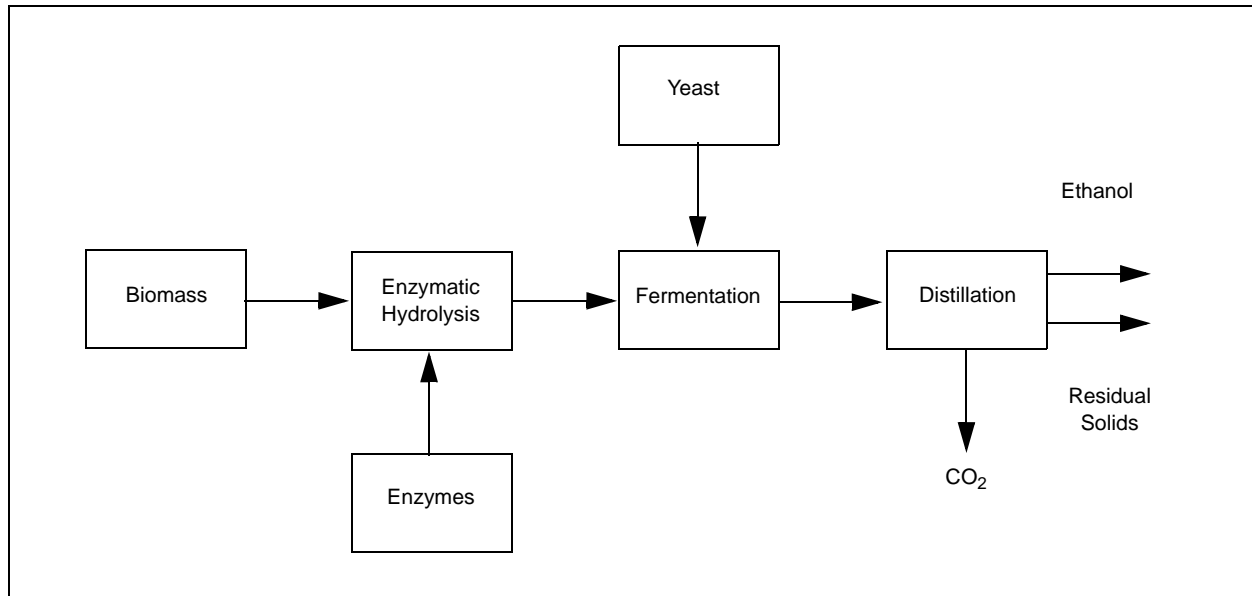


Figure 1. Ethanol production process.

Source: RFA (2007).

recovery. The biomass feedstock, such as corn, wheat, or barley, is first milled and cleaned in the preparation stage. In the case of cellulosic biomass, there is an additional stage of enzymatic hydrolysis in which the pre-treated biomass is digested by enzymes to release sugars. Enzymes are an important input into the bioethanol conversion process, as the complex carbohydrates in the biomass need to be broken down into simpler sugars, which can be then fermented to produce ethanol as a by-product (Sheehan & Himmel, 1999). A critical difference between feedstock conversion technologies is the kind of enzyme used to treat the biomass since using the right enzymes based on the feedstock is crucial to obtaining energy-efficient ethanol at the end of the process. These sugars are then fermented by yeast to yield ethanol and carbon dioxide. Ethanol is recovered in the distillation process, and the fermentation residue is processed further for use as animal feed or to recover useful chemicals. The carbon dioxide co-product is commonly captured and marketed to the food processing industry for use in carbonated beverages or the production of dry ice (Alternative Fuels and Advanced Vehicles Data Center [AFDC], DOE, n.d.).

Description of Industry and Policies

The first set of players contributing to biofuel research are the agricultural input companies studying biofuel crops, such as biotech firms and seed companies that are finding new crops or new varieties of existing crops

with optimum energy content. In the past decade, a number of small biotech firms have been doing research on new crops, new varieties of biofuel crops that would have higher ligno-cellulosic content and less undesirable traits for optimum energy content. For example, Ceres Inc. is looking at higher-yield switchgrass varieties, whereas Edenspace Corporation is developing commercial corn hybrids for low-cost conversion to ethanol (Biomass Research and Development Initiative [BRDI], DOE, 2007). Major seed/biotech companies such as Monsanto, Pioneer, and Syngenta, seeing the potential profitability of the biofuel crop market, have shifted R&D resources to screen their elite corn lines and developed hybrids that can produce more ethanol per acre, as well as varieties of the new energy crops.

Production of ethanol (called biorefineries) in the United States is mostly done in the private sector by major agribusinesses or chemical companies that already have key agricultural or manufacturing infrastructure in place. Archer Daniels Midland, POET energy, and VeraSun Energy are the three major US producers, with a combined production of 30% of total ethanol production (Renewable Fuels Association [RFA], 2007). There are also companies that are either wholly or partially owned by farmers or cooperatives, such as Glacier Lakes Energy, SD, and Absolute Energy, IA, which produce about 100 million gallons a year each. In Louisiana, Verenum is planning a 1.4 million gallon demonstration plant from bagasse—the fiber that is left after all the juice is extracted from sugarcane (Krupp &

Table 1. Research across the ethanol supply chain.

	Ag inputs	Ethanol inputs	Ethanol producers	Distributors/blenders	Auto & tractor firms
Type of research	Plant breeding genomics, crop management	Enzyme research, processing and conversion	Engineering improved production, technology	Fuel blend technology, improving distribution	Develop engines that can run on biofuels
Firms doing research	Biotech, lumber companies, e.g., Mendel, Pioneer Hybrid, Syngenta	Biotech, e.g., Novozymes, Ceres, Genencor	Manufacturing companies, e.g., Abengoa, ADM, Cargill	Oil companies, e.g., Chevron, Texaco, Shell	e.g., John Deer, Daimler, Ford, General Motors, Volkswagen
DOE* grants to private companies, 2002-2006	\$10.7 million	\$25.2 million	\$93.4 million		
USDA* grants to private companies, 2002-2006	\$6.9 million	\$13.6 million	\$14.7 million		
Number of ethanol-related patents	4 0.1%**	400 89.8%**	9 2%**	36 8%**	

*Source: Biomass R&D Initiative, DOE (2008)

**Percentage of total patents searched on USPTO

Horn, 2008). Commercialization of cellulosic ethanol from wheat straw has been successfully demonstrated by Iogen Inc. with a plant that has a 10-million-gallons-per-year capacity, the first of its kind in Canada. The annual production of ethanol in the United States has increased dramatically, with a net 41% increase in number of ethanol plants from 2000 to 2005 (RFA, 2007).

The next set of players in the bioethanol market is the enzyme and biotech companies doing research in different enzyme technologies. Among the top enzyme companies, Genencor and Novozymes hold 60% of the number of patents on enzymes in biofuels (Clark, Patel, Jensen, & Bennett, 2008). Diversa, an enzyme company that became part of Verenum in 2007, has identified millions of microbial genomes from which enzymes can be tailored for any feedstock.

Petroleum companies such as Royal Dutch/Shell, Conoco-Phillips, and BP are doing research on the effects of different ethanol blends on engine performance, whereas car manufacturers such as Ford and Chevrolet and tractor manufacturers such as John Deere have shifted their research and engineering budgets to develop modified engines to accommodate the properties of the new fuel blend. Flexible Fuel Vehicles (FFV) have engines that can operate with either ethanol-blended gasoline or 100% ethanol.

Table 1 provides some indicators of research across the ethanol supply chain. The first and second rows contain types of research and major companies as described above. Since few companies report how much R&D they do on biofuels, the only publicly available indicators of private research are patents or government fund-

ing of private R&D and joint public-private research, as shown in the third and fourth rows of Table 1. The Department of Energy (DOE) has supported research in biomass-to-biofuels processing and conversion technologies for many years. DOE and the US Department of Agriculture (USDA) formed the Joint Biomass R&D Initiative (BRDI) in 2000 to provide financial incentives to public and private institutions. The BRDI, under which each agency takes individual responsibility for projects, mainly focuses on 'plant science research' and 'biorefinery demonstration and deployment' type of projects in addition to feasibility studies on next generation technologies such as synfuels. As can be seen from the table, the total funds granted by the DOE from 2002-2006 was about \$130 million, of which 71% went to biofuel producers. USDA contributed \$30 million over the same period, with 41% to ethanol-producing companies. In many cases, private firms have to match a portion of the amount of the grant. For example, in 2007, BRDI solicitations required firms to match 20% of the grant money for research projects and up to 50% for demonstration projects.

Next we look at the patenting activity by private firms, which is presented in the last column of Table 1, and we find that most of the biofuel related patents (about 90%) are in enzyme research, followed by patents on the effects of higher ratios of ethanol on engine performance. We find that most of the patenting was done by private companies who receive little federal funding and who rely mostly on in-house research investments.

Model

To analyze the relationship between prices, government policies, research, and innovation, we begin by considering that a firm decides to innovate with the goal of making profits and/or to gain a competitive edge over other firms. Innovation in the form of new products can increase profits if it is in response to new market opportunities. Processing innovations can increase profits by reducing the firm’s costs of production. Increases in input prices or changes in the relative prices of inputs pushes the firm to attempt to reduce costs of production by substituting for the more expensive inputs. This often requires research and the development of new process technology. In this context, the relative increase in the energy prices (specifically, price of crude oil) is creating a market demand for alternative fuels, which is driving R&D in alternative fuel technologies such as ethanol. At first, corn was a relatively inexpensive partial substitute for oil, but in recent years the rise in corn prices and the externalities associated with corn ethanol, along with continued high oil prices appear to have led to the exploration of different kinds of alternative feedstock, such as cellulosic biomass, municipal wastes, and wood wastes.

To sort out the relative importance of market prices, government policies, and government-financed research, we have used the ‘induced innovation hypothesis,’ which was first introduced by Sir John Hicks in 1932. He argued that a change in relative prices of factors of production sets the stage for invention, which is directed to economizing the use of the factor that has become relatively expensive (Hicks, 1932). Hayami and Ruttan (1985) suggested a more general theory of induced innovation in which changes in both product demand and relative factor prices determine the rate and direction of technical change. They also incorporate the innovation possibility curve to reflect the state of science and technology at this point in time and the cost of innovation.

Popp (2002) applies induced innovation theory to understanding the relationship between electricity prices and innovation in energy production. Popp considered patents in 11 energy-saving technologies in the United States—such as solar, wind, and biomass—as a measure of innovation. He found that patenting activity increases in response to an increase in energy prices, with the most effect occurring within the first few years and then fading over time due to diminishing returns to R&D. He also found that government-sponsored R&D had little effect on private energy patenting.

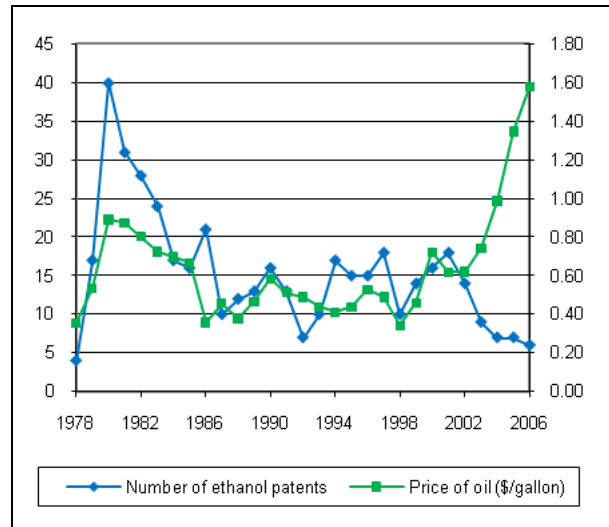


Figure 2. Focal relationship—Ethanol patents and oil prices from 1978-2006.

In the case of biofuels, the only publicly available time series or cross section data available is patent data. Patents must meet the criteria of being novel, commercially viable, and unobvious to someone skilled in the art (Huffman & Evenson, 2006), so they are a measure of the potentially useful technology that firms have created. We begin by finding the number of ethanol-related patents from the US Patent Office (USPTO) based on the patent classification sub-classes for each year, which are provided in the Appendix. We counted the patents in the application year of successful patents, i.e., patents that have been granted. Our dependent variable in the equations below is the number of biofuel patents, which represents innovation in the ethanol-related technology. Figure 2 shows the time-series data on biofuel patents as well as oil prices between the years 1978 and 2006.

Our estimation framework as shown in Equation 1 is based on the model by Popp (2002):

$$\begin{aligned}
 bio_pat_t = & \exp[\beta_0 + \beta_1 \ln(POil_{t-1}) + \beta_2 \ln(PCorn_{t-1}) \\
 & + \beta_3 \ln(Grants_{t-1}) + \beta_4 \ln(Grants_{t-2}) \\
 & + \beta_5 \ln(Prod_{t-1}) + \beta_5 POL_1 + \beta_6 POL_2 \\
 & + \beta_7 K_t + \beta_8 T + \beta_9 T^2] + \xi_t, \tag{1}
 \end{aligned}$$

where the dependent variable, bio_pat_t , is the count of biofuel-related patents in a particular year t . $POil_{t-1}$ is the lagged price of West Texas crude oil, $PCorn_{t-1}$ is the price of corn, $Grants_{t-1}$ and $Grants_{t-2}$ are the lagged DOE and USDA funding for R&D, and $Prod_{t-1}$ is the

total ethanol production in the past year. K_t represents stock of knowledge in year of application 't' of the patent, POL_1 is the dummy variable for the years when ethanol subsidies were applied, and POL_2 is a dummy for the years when federal mandates applied. The data suggests a constantly changing slope for which a quadratic model may be better suited than a linear time trend model. We use T and T^2 as the linear and quadratic time trend variables, whereas ξ_t is the error term and β_0 to β_8 are respective coefficients.

As seen from Figure 2, the rise in oil prices from 1978-80 spawned an increase in patenting activity that peaked in 1980 and then declined with falling prices. The number of patents seems to follow the price trend with a somewhat lagged effect, which is expected when time needed for innovation is taken into account. From 2003 however, we see that the patent number curve moves in the opposite direction. This could be due to the fact that we use patent data by application dates of successful patents and have not accounted for patents that have not yet been granted. The historic data on price of corn is obtained from the National Agricultural Statistics Service (NASS) of the USDA. Next, we use DOE funds data towards biofuel R&D projects from the DOE 1998 Budget Appropriations Table (US DOE, 1998) and the Kennedy School of Government, Harvard University (Gallagher, 2008). The Prod data is the total US ethanol production in that year (Brown, 2008). Next we create separate dummies POL_1 and POL_2 for regulatory and financial federal policies, respectively. The regulatory policies include mandates, such as the MTBE (methyl tertiary-butyl ether) ban in 2002, and standards, such as the Renewable Fuel Standard (RFS) set by the Energy Policy Act (EPA) of 2005. The financial policies include incentives, such as tax credits like the ethanol producer tax credit of \$0.51/gallon, which has been in effect since 1992. We obtain information on these variables from the International Energy Agency's (IEA) database on Global Renewable Energy Policies and Measures (IEA, 2007).

Popp has measured the existing knowledge stock for future R&D by calculating the probability that the patent granted in a year will be cited by other patents in forthcoming years, thus using the number of citations as an indicator of usefulness of a patent. However, the recent nature of our data set puts limitations on such measures because we see that we do not have a good representation of how useful inventions in 2005 would be, since citations are revealed only when a patent is granted. As a result, we cannot measure the existing stock of knowledge, K , in our model and thus we omit

this variable based on the assumption that each patent that is fuel-ethanol related will be as important as the others.

Results

We use the Poisson Quasi-Maximum Likelihood Estimation (QMLE) for estimating our count data model (Wooldridge, 1997). Stating our model in reduced form,

$$E(\text{bio_pat}_t) = \exp[\beta_0 + \beta_1 \ln(\text{POil}_{t-1}) + \beta_2 \ln(\text{PCorn}_{t-1}) + \beta_3 \ln(\text{Grants}_{t-1}) + \beta_4 \ln(\text{Grants}_{t-2}) + \beta_5 \ln(\text{Prod}_{t-1}) + \beta_6 \text{POL}_1 + \beta_7 \text{POL}_2 + \beta_8 T + \beta_9 T^2] + \xi_t. \quad (2)$$

We use STATA software to estimate the coefficients, which are elasticities for each variable. We tried a number of specifications to study the robustness of our model such as dropping policy dummies in one model and excluding the ethanol production variable in another model. Almost all results seem to suggest that oil price is a significant driver of patenting activity, however in one case, when the ethanol production was dropped, the oil price became insignificant. This could be the result of the limitations of our current data set, which seems to contradict our expectation that higher demand would encourage more R&D activity in the private sector.

We present the regression results of our original model, Model 1 and Model 2, which excludes the ethanol production variable in Table 2 with the z-values in parenthesis. The z-values indicate that in Model 1 all coefficients are significant at the 5% level, except corn price and POL_2 which represents the federal mandate policy. Our test for serial correlation is negative for both models, indicating that there is no correlation between the error terms.

Model 1 indicates that the number of patents responds positively to lagged oil price, POil_{t-1} . This supports our hypothesis that rising oil prices induces patenting by private firms, which is a measure of innovation. Thus, an increase in the price of oil by 1% spawns research activity that results in a 0.36% increase in number of patents in the following year. The price of corn has a positive coefficient, but it does not quite reach statistical significance at the 5% level, which does not strongly support our hypothesis that with changes in corn prices, firms will be motivated to invest R&D dollars in finding alternate feedstock or more efficient production practices. Federal grants for R&D also have a

Table 2. Regression results.

Independent variables	Coefficients [*]	
	Model 1	Model 2
POil _{t-1}	0.36 (1.96)	-0.3 (-1.09)
PCorn _{t-1}	0.3 (1.6)	0.35 (0.98)
Grants _{t-1}	1.2 (7.51)	0.28 (1.57)
Grants _{t-2}	0.28 (2.82)	0.04 (0.35)
Prod _{t-1}	-0.85 (-7.12)	—
POL1 _t	-0.78 (-3.24)	-0.1 (1.75)
POL2 _t	0.1 (0.76)	-0.36 (-0.83)
T	0.3 (4.93)	-0.114 (-1.75)
T2	-0.008 (-5.12)	0.002 (1.08)
R ²	0.38	0.32

^{*}Z value at 95% confidence interval in parentheses

positive influence on patenting as more funds are made available to firms for innovating. Funds in the previous year make a larger contribution than those lagged by two years. For every 1% increase in government funding, patenting activity will increase by 1.2% in the next year and 0.28% in the second year.

The lagged ethanol production variable was expected to be positive because production is supposed to be an indicator of the demand for the final product—ethanol—and greater demand should lead to more research and innovation. The Prod variable is significant; however, it has a negative sign, indicating that increased ethanol production discourages firms from investing in R&D. If annual production rises by 1%, then number of patents in the following year will decrease by almost 0.86%. Part of the problem may be that we have not corrected for the decline in patents at the end of the time period due to the lag between patent application and when the patent was granted—since that is when ethanol production accelerates. An additional factor may be due to the fact that much of the patenting in biofuels is for enzymes to breakdown cellulose rather than corn. It may be that the growth in corn-based ethanol, controlling for prices of oil and corn, discourages companies from investing too much in the search for cellulosic alternatives to corn. This argument is strengthened further by the coefficient on the tax credit

policy dummy (POL_1), which indicates that tax credit policy also has a negative and significant impact on patenting activity. This could also be due to the fact that this credit is mainly given to producers of ethanol from corn and, hence, this variable might lead companies working on cellulosic biofuels to not expect much support for their sources of biomass in the future. The dummy on mandate policy (POL_2) is insignificant and therefore seems to have no effect on research activity by firms.

Next, we drop the ethanol production variable because it is not a great indicator of demand for all biofuels and because we were surprised at the large negative effect in our original model. As seen in Model 2 above, the changes are fairly dramatic—our variable oil price changes sign and becomes insignificant. Most other variables, including the federal grants and tax credit policy dummy, also become insignificant. The corn price, government research, and policy variables continue to have positive signs, but little else remains. The lack of robustness of our results is a matter of considerable concern and suggests more research ahead.

Conclusions and Discussion

In this study, we have attempted to test the role of energy prices in directing technical change in the area of biofuels—specifically, ethanol. In our empirical work, we use patent counts by private firms to study the impact of oil prices on ethanol technology. We identified the different types of research done by private companies across the ethanol supply chain and found that the highest concentration of research activity is in enzyme technology, followed by fuel blend technology and development of efficient distribution networks for ethanol.

The most significant result of our empirical study for policy makers was found to be government research grants and awards, which increase innovation of private firms. After controlling for the role that the price of oil plays in inducing ethanol-related innovations across a spectrum of technologies such as plant-breeding and enzyme technology, the most effective incentives for biofuel innovations are government research and development grants. In 2006, ethanol manufacturing companies received \$93 million in grants and financial awards and a total of \$36 million to biotech, genomics, and crop management companies combined. These investments clearly stimulated innovation. However, Popp (2002) finds the opposite trend in his study and he attributes the difficulty in interpreting government R&D to the

emphasis of federal grants, which may be on basic research in one time period or marketable technologies in another. In our data, we see that DOE grants after 2002 mainly focused on applied research and feasibility projects, but we do not have details of research emphasis prior to that. In their empirical study of different renewable technologies in the electricity sector, Johnstone, Hascic, and Popp (2008) found that R&D spending has a negative and significant coefficient for biomass, which they explain as public R&D possibly 'crowding out' private R&D.

Another determinant of technological change is the positive impact of oil prices on new innovations in alternative fuels, which is in line with the induced innovation theory. Similar results have been proved in studies by Popp (2002) and Wu, Popp, and Bretschneider (2007).

We expect that the number of innovations will be higher if the market size is larger. However, increase in annual ethanol production in the past year shows a strong, negative impact on innovation. The government policy of tax credits to ethanol producers may have ramped up ethanol production, but it does not provide incentive to firms to invest more research dollars.

In contrast, we find that the tax credit policy that encouraged the amount of ethanol production discouraged innovation in biofuels. Thus, while such policies may be justified for national security purposes or for other reasons, they cannot be justified on the basis of stimulating innovation. Our results contradict the findings of Johnstone et al. (2008) and Wu et al. (2007), who have shown a positive effect of tax policy on innovation and business R&D spending, respectively. One reason could be that Wu and colleagues use business R&D expenditures across nine countries from 1985-1995 as the dependent variable, whereas in our case, it is patenting activity. The Johnstone study (2008) looks at biomass such as biogas, renewable municipal waste, liquid biomass, etc., used in the process of electricity generation, and in contrast with the other renewable sources (wind, ocean, etc.), biomass responded positively to price-based instruments since it was relatively mature and competitive. In our work, we have looked at biomass solely as a source of transportation fuel. The mandate policy on the other hand is insignificant, indicating that imposing the RFS (since 2005) of 20% ethanol in gasohol has not affected research outputs along with the ban of MTBE from 2004. One reason for this could be the insufficient number of data points for this dummy (only 5 data points), and we can probably get a better indication of its impact in the coming years. Johnstone et al. (2008), in their study of effects of various govern-

ment policies on various renewable technologies in OECD countries from 1978-2003, found that mandates do not contribute to patenting activity.

The comparison of our Model 1 with Model 2 suggests that our model is not as robust as we expect. This suggests we need to look for more and better data in order to test the hypotheses suggested by economic theory.

In conclusion, this study suggests that federal policies can play an important role in innovative activity of private firms, whether it is financial grants for R&D or subsidies on production, but they can also work against each other. In this case, DOE and USDA support for R&D and pilot plants stimulated more R&D, while subsidies on ethanol production had a negative impact on R&D. So there is a clear choice for policymakers if stimulating R&D and innovation is their goal—funds for research in new biofuel technologies, and not for subsidies on production.

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Appendix

Methodology for Ethanol Related Patents

Search

Our aim is to identify US appropriate patent classes and sub-classes, and within those subclasses, to search for ethanol-specific patents by date of application. Johnstone et al. (2008) have used a similar approach in identifying patent applications with the European Patent Office (EPO) in renewable technologies such as wind, solar, etc. We present our results of different patent classes and their description in the Table A1.

Table A1. Ethanol-related patents.

US patent class number	Description	Ethanol-related sub-classes	Number of patents
800	Multicellular Living Organisms and unmodified parts thereof and related processes	278/284/288/ 290	5
435	Chemistry: Molecular Biology and Microbiology	97/99/101/105/ 161-164/135/ 202/209/277	400
44	Fuel and Related Compositions	378/388/451	40

Source: US Patent Office.

The first step was to use the US Patent Office website to search patent titles containing keywords such as ‘ethanol.’ Next, from the patent description we note the current US classification numbers associated with that patent. The third step was to use the class and subclass as keywords to get all patents in that category. As an example, when we searched the database for patents with ‘ethanol’ in the patent title, we found many patents in the 435.165 subclass. The description for this class is as follows:

“435.165—Substrate contains cellulosic material: Processes wherein ethanol is prepared by the biochemical treatment of a cellulose containing material.”

Searching for patents within the 435.165 class for a particular year gives us patents in cellulosic ethanol process in that year. We sum up the patents across all identified classes for a particular year to get our patent count dependent variable in the time-series data.