Southern Economic Journal 2010, 76(4), 1076–1093

The Impact of State Government Subsidies and Tax Credits in an Emerging Industry: Ethanol Production 1980–2007

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This article examines the effects of state economic development incentives in the emerging ethanol industry. We compiled data on ethanol production capacity and subsidies/tax credits for all states for the years 1980–2007, a period that covers the complete emergence of the biofuel industry in the United States. Importantly, this time period was characterized by the passage of several state-level subsidies and tax breaks aimed at increasing ethanol production. Hence, this panel documents a substantial amount of within-state variation in policies from which to identify an effect. We find that some incentives directed at ethanol production have a significant effect on a state's production capacity.

JEL Classification: H71, Q58, R3, R5

1. Introduction

In 1980, ethanol production in the United States was virtually nonexistent, but by 2007, production had expanded to 6500 million gallons. Federal subsidies and mandates requiring ethanol to be mixed with gasoline are notable driving factors in the emergence of the biofuel industry in the United States.[1] Currently, the federal government subsidizes ethanol blended with gasoline at a rate of 51 cents per gallon.[2] Federal subsidies have received much attention from supporters as well as critics. Much less focus, however, has been on the subsidies and tax credits provided at subnational levels of government. Many states offer subsidies and/or tax breaks for the production and/or consumption of ethanol, and in a number of cases, these are substantial: Some states offer 20 cents per gallon, and in a few cases, as much as 40 cents per gallon are offered to ethanol producers. To illustrate, consider Wisconsin, which offers an annual subsidy at the rate of 20 cents per gallon up to 15 million gallons. According to the National Corn Growers Association, a 40 million gallon plant employs 32 full-time workers.

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Financial support for this research was provided by the U.S. Department of Agriculture/CSREES administered through the Michigan Agriculture Experiment Station.

Received July 2008; accepted March 2009.

[1] See the U.S. Department of Energy (2007) for a summary of federal incentives encouraging alternative fuel production and use.

[2] It is important to note that a 54 cent per gallon tariff on imported ethanol protects U.S. producers from international competition.

On a per worker basis for the average-size plant in Wisconsin (53 million gallons), this subsidy is equivalent to about $71,400 per worker. This is a sizable and costly subsidy if the goal is to generate jobs, but clearly the goals of such subsidies are much broader than job creation.

Beginning in the 1980s, state and local governments increasingly began to rely on subsidies and tax breaks to stimulate growth in employment and business activity. Between 1984 and 1993, the number of states offering various incentives increased from 27 to 44 (Chi 1994). A significant focus of within-state incentive packages is generating economic activity in economically distressed rural areas (Greenberg and Reeder 1998). More recently, it has been argued that one of the benefits of ethanol production and consumption is job creation in rural areas.[3] What is less clear is whether such incentives actually stimulate economic development. Much of the academic research evaluating the impacts of economic development incentives suggests that such incentives are costly in terms of direct payments or forgone taxes, and the ultimate gains in development are limited (Bartik 1991). Nearly all of this work has sought to evaluate the impacts of incentives on general business activity or activity in well-established markets.

The present study makes several contributions to the body of work on the emerging biofuel industry and the research that has sought to evaluate the effectiveness of development incentives. First, while we have detailed and accurate national data on ethanol production dating back to 1980, state-level data on ethanol production are not systematically collected. Using information from multiple sources, we constructed annual data on ethanol production capacity dating back to 1980 for each state. These data may be of interest to researchers seeking to understand the evolution and emergence of the ethanol industry in the United States. Second, we compiled a detailed list of all state-level tax credits and subsidies with imposition dates over the 1980–2007 period. We use these data to evaluate the role of incentives offered by subnational governments on the location of ethanol production plants. To date, little is known about the role of state subsidies in the emerging biofuel industry, particularly in terms of influencing location decisions. This research also contributes more generally to the literature evaluating the importance of incentives in fostering the development of an emerging industry.

As a prelude to our results, we find that incentives directed at ethanol production (particularly per gallon credits) have a significant influence on plant location/production. However, we also show that the magnitudes of our estimates are sensitive to estimation technique. Next, we provide a brief review of the most relevant research on the emerging biofuel industry and the research on effectiveness of development incentives. In section 3, we present our data and empirical analysis, and section 4 concludes.

2. Literature Review and Theoretical Discussion

In this section, we present a review of the recent research in the emerging biofuel industry, as well as the extensive body of work that has sought to evaluate the effectiveness of state and local government economic development incentive programs.

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[3] For example, even conservative political commentator Patrick Buchanan (1999, p. 1) stated that "…just as I support the independence of the family farm, I support a policy of U.S. energy independence that includes a strong stand for ethanol. This industry creates 40,000 jobs, adds $12 billion in net farm income each year…."

Ethanol Production

Much of the research on ethanol production is only peripherally related to state government incentives. For example, Gardner (2007, p. 19) employs a cost-benefit analysis to evaluate the net societal benefits of relying more heavily on ethanol as a renewable fuel source. His analysis evaluates the market impacts and deadweight loss resulting from the 51 cents per gallon federal ethanol subsidy. He concludes that "ethanol subsidies and mandates are unlikely to generate social gains." While such subsidies clearly have an appeal for certain farm interests (for example, corn producers), the net societal gains of such policies are questionable. Similarly, Hahn and Cecot (2007) also employ a cost-benefit method to evaluate current federal biofuel policies. Consistent with Gardner (2007), they conclude that under current policies, the costs of increased production are likely to exceed the benefits.

Hahn and Cecot (2007) regard federal as well as state and local government subsidies and regulations as the driving force of the ethanol industry. The following are some of the incentives that "corn states"[4] are using: Illinois grants up to $5.5 million for the production of new plants; Indiana offers a 0.125 cents per gallon production tax credit; Iowa offers 0% interest loans up to half the cost of the production project; and Missouri offers tax incentives of 20 cents per gallon of ethanol produced. Even many states that are not typically thought of as corn states are using such measures in an attempt to attract the industry. Some of these states and the provisions they offer include: Hawaii, which has a tax credit equal to 30% of nameplate capacity; Maine, which has a tax credit of 0.05 cents per gallon; and Vermont, which provides loans to assist research and planning for the production of biofuels. To our knowledge, no studies have evaluated the importance of state government subsidies and tax credits in ethanol plant location decisions. While it is clear that state officials are using incentives as tools to compete for ethanol plants, the effectiveness of such policies remains open to debate. There is, however, a substantial literature evaluating the effectiveness of general economic development incentives, and we turn to this research next.

Subnational Incentives and Economic Development

Given that this literature is now very extensive, it is not within the scope of this article to review this entire body of work. Rather, our goal is to summarize some of the key findings of the existing research in the context of the objectives of the present study.

Perhaps it is appropriate to begin with the text by Fisher (2007), who provides an excellent summary of the existing research. Generally, state and local governments use three basic types of fiscal incentives to attract business: (i) financial incentives, including loans below market-level interest rates, direct grants, and loan guarantees; (ii) tax reductions, including the use of credits, deductions, abatements, and specialized rates; and (iii) direct grants of goods or services, including land, labor training, and infrastructure. According to Fisher, "Most states offer all these incentives in one way or another, developing a package of specific incentives from the general list for each potential investment project" (Fisher, 2007, p. 647). The primary goal behind these provisions is to offset real or perceived business cost differences among states.

[4] A "corn state" is defined by Hahn and Cecot (2007) as a state that grows greater than 1 million bushels of corn per year.

Regarding the implementation of subsidies and other fiscal provisions, the evidence as to whether such policies are effective is mixed. Citing many references, Edwards (2007) argues that policy instruments and financial assistance payments are largely ineffective. Rather, the more important driving forces in firm location decisions are as follows: (i) proximity to the product market, (ii) the quality of labor, and (iii) the quality of transportation networks. Edward concludes that government incentives distort markets and lead to inefficient outcomes.

There is, however, some work showing that incentives may influence some firm location decisions. For example, Bartik (1991) shows that in the long run, the elasticity of business activity with respect to state and local taxes lies in the range of −0.1 to −0.6 for business location decisions. Wasylenko (1997) furthers the argument by noting that significant differences among states' incentives must exist in order for an impact to be felt as a result of the incentives. He argues that an impact substantial enough to be measured will occur only when a state's policies are significantly different from those offered by other states. Bartik reviewed 30 studies, of which 60% find statistically significant positive effects on business activity. The work of Bartik (1989), Garcia-Mila and McGuire (1992), and Tannenwald (1996) suggests that the success of the incentives may depend on the type of business the region is trying to attract. Finally, Gabe and Kraybill (2002) show that establishments receiving incentives tend to overstate announced employment targets.

Our work adds to both these lines of research. In terms of biofuel research, little is known about the ways in which state incentives influence location decisions of ethanol plants. With regard to the general research evaluating the effectiveness of economic development incentives, our work makes two contributions. First, we evaluate the role of incentives in an emerging industry as opposed to already existing industries. Second, as we discuss in greater detail in section 4, we address important endogeneity and time trend issues.

3. Empirical Analysis

Data

Our goal is to evaluate the role of state subsidies/tax credits in the location of ethanol production. Unfortunately, ethanol production data has only been systematically collected at the regional or national level. These aggregated data prevent state-level policy analysis. To overcome this data constraint, we collected detailed information on ethanol plant capacity from the Annual Industry Outlook reports produced by the Renewable Fuels Association (RFA), which collected information on plant capacity, along with their locations, for the entire United States for the years 2001–2007. We utilized information from all RFA annual reports available, which allowed us to construct state-level capacity levels from detailed plant capacity data for years 2001–2007.[5] However, data on plant capacity for each state prior to 2001 were not available in any single public or private document. Fortunately, the 2001 RFA annual report provided a list of all existing plants (with information on location and capacity) as of 2001. We used this information to conduct a search to identify the start dates of each pre-2001 plant. The

[5] These data were collected directly from the Renewable Fuels Association's (2007) website (http://www.ethanolrfa.org/).

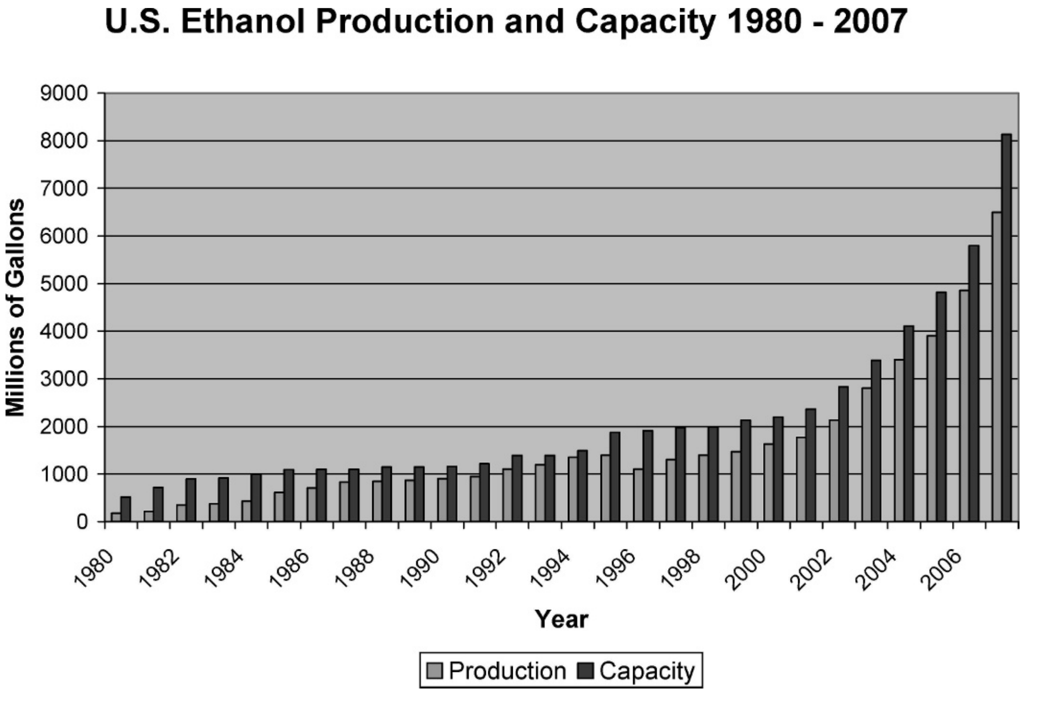

Figure 1. U.S. Ethanol Production and Capacity 1980–2007

search was exhaustive and required contacting numerous sources. For a number of plants, we were able to obtain start dates from companies directly, but some cases required a more extensive search through newspapers, contacting local governments, etc.[6] Figure 1 presents national actual production data collected by the U.S. Department of Energy along with our production capacity data aggregated to the national level for years 1980–2007. While the match is quite good, note also that our capacity data systematically overstate actual production. The use of production capacity as a proxy for actual production is a potential concern, but through discussions with the Energy Information Administration (EIA), we have learned that the vast majority of ethanol plants in the country operate close to capacity and that most changes in production are the result of increases in capacity. While these claims are impossible to verify at the state level (due to the lack of state-level production data), we are able to measure the relationship between production and capacity over time at the national level, and a very strong correlation ($r = 0.9945$) exists between national ethanol production and capacity. Hence, we conclude that the capacity data should accurately capture variation in production during the sample time frame studied.

[6] There are a few small ethanol production plants for which we were not able to find start dates. We also note that we were able to identify several plant closings, and we have incorporated these closings into our data. These are as follows: Florida—4 million gallons per year (mgy) plant closed in 2002; Idaho—3 mgy plant closed in 2003; Idaho—3 mgy plant closed in 2004; Louisiana—35 mgy plant closed in 1990; Louisiana—a plant opened and then closed in the same year (1987); Washington—a small plant (actual production capacity unknown) closed in 2004. Unfortunately, no source exists from which we can determine whether we have omitted any other significant plant closings.

We matched the production capacity data to detailed information on state-level ethanol subsidies and tax breaks, which were obtained from the U.S. Department of Energy[7]. However, a thorough search through state statutes was required to identify specific dates of implementation.[8] Our research focuses on 1980–2007, a period which covers the complete emergence of the biofuel industry in the United States. Importantly, this time period was characterized by the passage of a multitude of state-level subsidies and tax breaks aimed at increasing ethanol production and capacity. Hence, this panel provides us with a substantial amount of within-state variation in policies from which to identify an effect. Table 1 provides an overview of key ethanol policies that were implemented for all states during the time period that we study and some details about those policies for each state. Specifically, one can see that there is a significant amount of variation in the timing and location of policy adoption. For example, per gallon tax credits range from zero in a number of states to nearly 50 cents a gallon in Wyoming by the end of 2007. Moreover, there is also significant variation in the production capacity measures, both within and across states. As an illustration, ethanol production was almost nonexistent in the United States in 1980, but by 2007, two states (Iowa and Nebraska) each had the ability to produce well over 1 billion gallons of ethanol a year.

We also collected other variables at the state level that are used at various points in the analysis as controls or as a basis for restricting the sample. Specifically, measures of the most important input costs that vary by state over time, state-level corn prices, average hourly wages, natural gas prices, and gasoline prices were collected from the U.S. Department of Agriculture (USDA), the Current Population Survey (CPS), and U.S. Energy Information Administration (EIA). Information on the level of corn production in each state was also obtained from the USDA. Summary statistics, definitions, and data sources of all nonpolicy data for all states as well as treatment and control groups are provided in Table 2 and Appendix A, respectively.

Methodology

Several methods and approaches could be utilized to estimate the impact of different ethanol policies on production capacity. We begin by pooling the states passing ethanol-based policies (the treatment group) and the remaining states in the United States (the control group). We will, however, also utilize different empirical approaches with narrower samples later to examine the sensitivity of our findings, which prove robust.[9]

Our core analysis begins with the following fixed-effects regression model:

$$E_{st} = \alpha_s + \tau_t + \beta_1 TC_{st} + \beta_2 PGC_{st} + \gamma' X_{st} + \varepsilon_{st}, \tag{1}$$

where subscript s denotes state, and subscript t denotes year. The terms α_s and τ_t are the state and time fixed effects. The inclusion of state and time fixed effects is imperative in this context

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[7] http://www.eere.energy.gov/afdc/progs/all_state_summary.php/afdc/0.

[8] Several states also offer subsidies for the consumption (as opposed to production) of ethanol. For example, Illinois exempts gasoline blended with ethanol from sales taxation. While consumption subsidies may increase the demand for ethanol, they are not location specific, and so it is difficult to identify their overall impacts in the state-level analysis we employ.

[9] Specifically, we will impose the restriction that there was at least some capacity to produce ethanol in the state during the sample time frame. It seems appropriate to test the robustness of the result under a sample restricted to these ethanol-producing states, since they may provide a useful alternative sample for testing the effect of ethanol subsidies on ethanol production.

Table 1. State Ethanol Production and Ethanol Subsidy Policies, 1980–2007

State	Tax Credit/ Subsidy	Grants/Loans	Per Gallon Tax Credit/Subsidy	Maximum Per Gallon Tax Credit Offered (in 2007 Dollars)	Ethanol Production Capacity, 2007 (in Millions of Gallons)
Alabama	–	–	–	–	0
Alaska	–	–	–	–	0
Arizona	–	–	–	–	55
Arkansas	–	–	2007	0.200	0
California	–	2006–2007	–	–	69
Colorado	–	–	–	–	125
Connecticut	–	–	–	–	0
Delaware	–	–	–	–	0
Florida	2006–2007	–	–	–	0
Georgia	–	–	–	–	0.4
Hawaii	2002–2007	–	–	–	0
Idaho	–	–	–	–	4
Illinois	–	2003–2007	–	–	813
Indiana	–	–	1982–1986, 2004–2007	0.286	392
Iowa	2001–2007	1994–2007 1996–2007	–	–	1976.5
Kansas	–	–	2001–2007	0.088	398.5
Kentucky	–	–	–	–	37
Louisiana	–	–	–	–	0
Maine	–	1999–2007	2004–2007	0.055	0
Maryland	–	–	2006–2007	0.051	0
Massachusetts	–	–	–	–	0
Michigan	2003–2007	–	–	–	262
Minnesota	–	–	1986–2007	0.336	684.6
Mississippi	–	–	2002–2007	0.230	0
Missouri	–	–	2002–2007	0.230	195
Montana	–	–	1983–2007	0.367	0
Nebraska	1990–1999	–	2000–2007	0.207	1313.5
Nevada	–	–	–	–	0
New Hampshire	–	–	–	–	0
New Jersey	–	–	–	–	0
New Mexico	–	–	–	–	30
New York	–	–	–	–	0
North Carolina	2000–2007	–	–	–	0
North Dakota[a]	–	2007	2005–2007	0.424	140.5
Ohio	–	–	–	–	177
Oklahoma	–	–	2004–2007	0.437	2
Oregon	2006–2007	–	–	–	148
Pennsylvania	–	2006–2007	2005–2007	0.053	0
Rhode Island	–	–	–	–	0
South Carolina	–	–	2007	0.400	0
South Dakota	–	–	1996–2007	0.255	657
Tennessee	–	–	–	–	67

Table 1. Continued

State	Tax Credit/ Subsidy	Grants/Loans	Per Gallon Tax Credit/Subsidy	Maximum Per Gallon Tax Credit Offered (in 2007 Dollars)	Ethanol Production Capacity, 2007 (in Millions of Gallons)
Texas	–	–	2004–2007	0.219	115
Utah	–	–	–	–	0
Vermont	–	–	–	–	0
Virginia	–	–	2007	0.100	0
Washington	2003–2007	–	–	–	0
West Virginia	–	–	–	–	0
Wisconsin	–	–	2001–2006	0.234	458
Wyoming	–	–	1998–2007	0.496	10.7

[a] North Dakota also has a per plant credit.

and helps alleviate one major concern of this analysis—specifically, that differences in production across states that are largely time-invariant, such as corn yield, and differences in production across time that are common in all states, such as variation generated due to changes in petroleum prices, economic shocks, or changes in federal policies, will not bias estimates.

E is defined in ordinary least squares (OLS) estimates as the log of the ethanol capacity in a given state-year.[10] The logarithmic specification would seem the most appropriate measure of the dependent variable because the median ethanol capacity for the state-years in the sample is less than the mean. Estimation of Equation 1 will therefore initially be by OLS, and standard errors are corrected to allow for nonindependence of observations from the same state through clustering (Arellano 1987; Pepper 2002; Bertrand, Duflo, and Mullainathan 2004).[11]

Our specification contains two distinct ethanol-based policy measures: *TC*, which is a dummy variable equal to one if a state has any type of tax credit or subsidy for ethanol-producing firms (except per gallon credit) in effect for a given year and equal to zero otherwise, and *PGC*, which represents the amount of per gallon tax credit and/or subsidy provided by a given state in a given year (in 2007 dollars).[12] Thus, the estimates of β_1 can be interpreted as the percent change in production after the passage of a fixed state tax credit relative to a control group of states that did not experience a change in the tax credit or subsidy status. Similarly, β_2 reflects the percentage change in production given an increase in the per gallon production tax credit/subsidy.

Even though the use of fixed effects deals with many of the problems that may be caused by differences in state characteristics that are unchanging over the sample period, there may exist some correlation between policy passage and changes in other important factors. We deal

[10] Because there are many cases in which a 0 is recorded for ethanol production capacity, we add 1 to all observations to avoid arithmetic error when taking logarithms.

[11] The nonzero and mostly integer nature of our dependent variable, in addition to significant overdispersion, would also suggest that a negative binomial regression (Hausman, Hall, and Griliches 1984) could be utilized. For these reasons, we will also test the robustness of the OLS estimates to this alternative econometric approach.

[12] Other subsidies such as low interest loans, grants, etc., are included as part of the tax credit dummy variable. It should be pointed out that these make up a very small proportion of the total amount of subsidies/credits that fall under this variable.

Table 2. Annual State Means for Nonpolicy Variables in the Analysis

	All States	States with Ethanol Subsidies	States without Ethanol Subsidies
Ethanol production capacity[a]	42.76	72.71	4.64
Natural gas price[b]	8.69	8.68	8.72
Hourly wage[c]	12.81	12.59	13.09
Corn price per bushel[c]	3.78	3.70	3.91
Corn production[d]	173,456	275,784	43,220
Number of observations (states)	1400 (50)	784 (28)	616 (22)

[a] In millions of gallons.
[b] Per million British Thermal Units (BTUs), in 2007 dollars.
[c] In 2007 dollars.
[d] In thousands of bushels.

with this possibility by including state-specific changes in important production factors in the X vector, which fluctuate between states and over time with some regularity.[13] Specifically, we add as controls the natural logarithm of corn prices, lagged corn production, gasoline prices, hourly wages, and natural gas prices in a state.[14] The within-state variations in the most important production factors across years are captured by these variables.

Results

Primary Findings

To provide the reader with some insight into the time trends present in the capacity data, with respect to our policy measures, we have undertaken a simple before-and-after analysis. Figures 2 and 3 present the time-series patterns in mean production levels in states that have adopted incentives and those that have not. Since production incentives are imposed at different times, the horizontal axis is years pre- or postadoption of the production incentive. For comparison, these figures also report a simple average of ethanol production capacity levels for all unaffected states for the relevant years.[15] In looking at the figures, it is apparent that in both cases, the treatment states produce more ethanol to begin with, but it is also true that these states see large increases in production capacity following the passage of incentives. A similar corresponding change is not apparent in the nontreated states. This said, these figures do not control for the potentially important influences of relevant covariates (or the different incentives), nor do they contain the degree of detail or sophistication that is necessary to draw any definitive conclusions. Nevertheless, Figures 2 and 3 clearly provide a basis for hypothesizing that these subsidies may affect production capacity over time and, as such, warrant more rigorous empirical investigation.

[13] Due to the presence of fixed effects, it is only necessary to include relevant variables if they fluctuate differently between states, and even then, it would only affect our outcomes if the fluctuations were correlated with being in the treatment group or control group.
[14] All dollar values were adjusted for inflation into 2007 dollars.
[15] For example, period $t-1$ in Figure 2 corresponds to 1981, 1982, 1985, 1995, 1997, 2000, 2000, 2001, 2001, 2001, 2003, 2003, 2003, 2003, 2004, 2004, 2005, and 2006 in the per gallon credit states. Thus, the value constructed for the non-per-gallon-credit states is the average ethanol production capacity in those years. It should be noted that some years appear more than once, and therefore carry a heavier weight than other years because there is more than one relevant observation in that year.

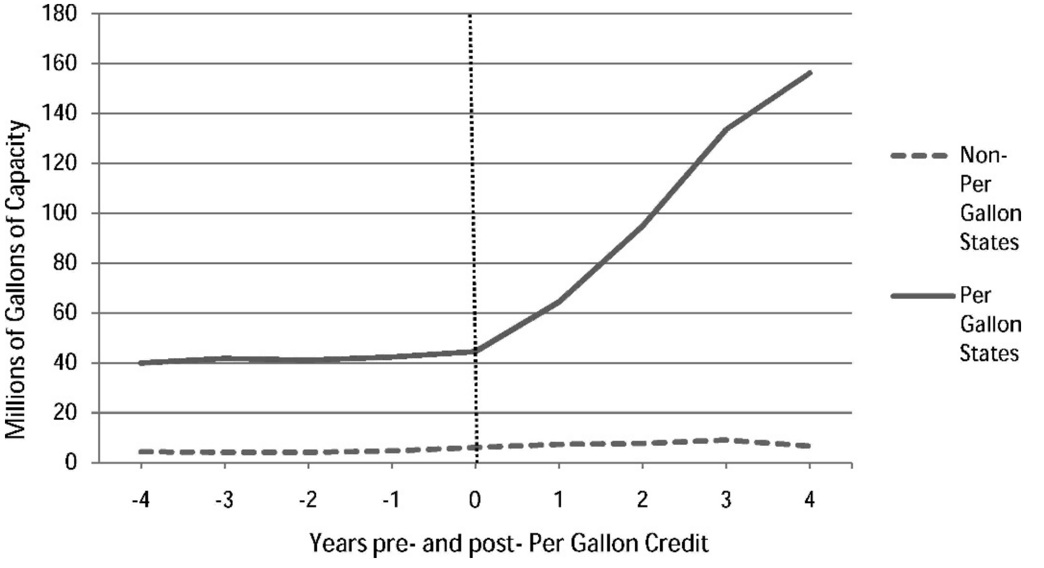

Figure 2. Ethanol Production Pre- and Post- Per Gallon Subsidy

To begin, we estimate Equation 1 by OLS for our primary sample, which consists of all 50 U.S. states. Column 1 of Table 3 provides the result using fixed effects with no other controls included, and the regression shows the positive effects of both the production tax credit and per gallon subsidies on state ethanol production. While the production tax credit is too imprecisely estimated to conclude that the coefficient is statistically different from zero, the magnitude of the coefficient suggests that some effect may be present. On the other hand, the coefficient on the per gallon tax credit variable is highly significant and indicates that a $0.10 increase in a

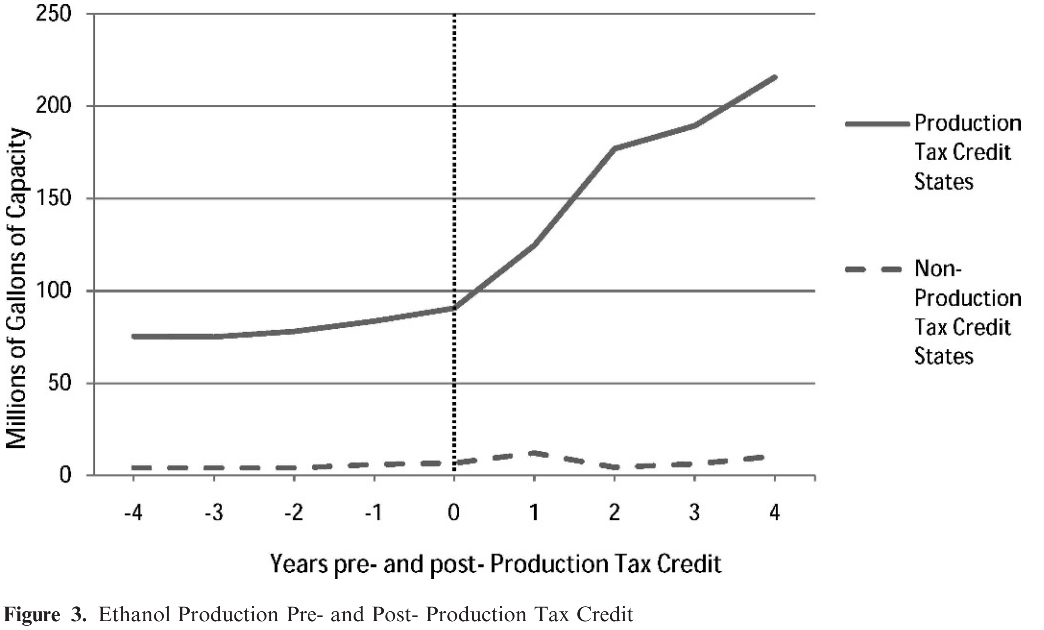

Figure 3. Ethanol Production Pre- and Post- Production Tax Credit

state's per gallon tax credit increases production by approximately 40%. Overall, these estimates indicate that per gallon incentives seem to play a very important role in stimulating production capacity, whereas other tax breaks, grants, or subsidized loans as characterized by the *TC* indicator variable may influence production in important ways, but statistical evidence prohibits strong inference about the degree or magnitude.

In the second column, we add controls for natural gas and hourly wages, which are both important input costs in the production process. The results suggest that there is very little effect on state ethanol production capacity as a result of changes in these covariates. This is not entirely surprising since changes in input costs, such as corn prices and natural gas prices, may effect short-run production decisions, but they are not likely to affect production capacity, which is much less variable in the short run. Regardless, the estimated effect of the subsidies remains relatively unchanged with the inclusion of these variables. Capturing changes in the corn market is also very important, given the vital nature of this input to the ethanol production process. To capture the impacts of variations in the corn market over time, in columns 3 and 4, we add one-year-lagged state corn production and state corn prices, respectively. In both cases, these variables take on signs that seem reasonable, although only the lagged corn production variable is statistically significant.[16] Nevertheless, the addition of these potentially relevant covariates does not qualitatively affect the estimates on the two policy variables in question.[17]

Given the fixed-effects approach utilized here, there may be some concern over the comparability of the treatment states and the control states. Specifically, there may be some concern that the inclusion of non-ethanol-producing states in the control group could bias our results toward finding a positive impact of these policies. So to test the sensitivity of our results to this concern, we restrict the analysis to include only states that have positive ethanol production capacity for a minimum of one year during the sample period. The results, presented in columns 5 and 6 of Table 3, are nearly identical to those from the expanded sample, which again suggests that per gallon tax credits play a significant role in the location of ethanol plants.[18]

Test of Endogeneity

Research on the impact of policy changes on economic activity is often hampered by endogeneity concerns, and this study is no exception. In this case, it is possible that subsidies are more likely to be introduced because ethanol producers who plan to locate a plant in a particular state may also successfully lobby for subsidies. In this sense, the timing of subsidy adoption may very well depend on plans for new plant location. We examine the possible

[16] The number of states analyzed falls when the corn price variable is included because nine states do not produce any corn, and hence, no price data are available.

[17] The results from columns 3 and 4 were duplicated with the addition of a state price of gasoline variable, but this inclusion had little impact on the earlier result and so was left out of Table 3. These estimates are available upon request.

[18] As mentioned earlier, due to the non-negative and mostly integer nature of the dependent variable, we could also have utilized a negative binomial regression approach. To test the robustness of our results to the OLS approach, all estimates reported in columns 1–7 of Table 3 were duplicated using negative binomial regression. These results were qualitatively very similar across all variables, although the magnitudes of the effects were in some cases larger. Details of these regressions are available from the authors upon request.

Table 3. Effects of Ethanol Subsidies on Ethanol Production Capacity

	OLS						IV
	1	2	3	4	5	6	7
Production tax credit/subsidy	0.5170	0.5180	0.2920	0.6709	0.3297	0.5732	6.6930*
	(0.4151)	(0.4168)	(0.3746)	(0.4696)	(0.5361)	(0.5409)	(3.6316)
Per gallon credit	4.0182**	4.0189**	3.6928**	3.6281**	3.3428**	3.4672**	18.0111*
	(1.4365)	(1.4301)	(1.2658)	(1.3774)	(1.3980)	(1.5202)	(9.9275)
Log state natural gas price	–	0.0372	−0.4769	−0.2815	−1.2218	−0.5966	0.4603
		(0.4687)	(0.4289)	(0.5849)	(0.7406)	(0.8009)	(0.7695)
Log state hourly wage	–	−0.0447	0.2283	0.8816	4.1148	4.4094	−0.3271
		(1.3320)	(1.1519)	(2.1008)	(3.0938)	(3.4747)	(2.2386)
Lagged corn production (in millions of bushels)	–	–	0.0003**	–	0.0002*	–	–
			(0.0001)		(0.0001)		
Log state corn price	–	–	–	−0.0704	–	−0.2127	–
				(0.6754)		(1.3471)	
Adjusted R^2	0.7873	0.7870	0.8180	0.7819	0.7901	0.7691	–
Sample size (number of states)	1400	1400	1350	1148	729	756	1350
	(50)	(50)	(50)	(41)	(27)	(27)	(50)
Sample period	1980–2007	1980–2007	1981–2007	1980–2007	1981–2007	1980–2007	1981–2007

Each column is from a separate regression that includes both state and year fixed effects. The dependent variable is the log of ethanol production capacity +1 in a state-year. The standard errors in parentheses are corrected to allow for nonindependence of observations within a state through clustering. ** and * denote statistical significance at the 0.05 and 0.10 levels, respectively. Samples sizes in columns 1–3 and 7 incorporate all fifty U.S. states. Column 4 results are estimated from only 41 states, since corn price data are only from the states that produce corn. Estimates in columns 5 and 6 utilize a sample of 27 states that have positive ethanol production capacity for a minimum of 1 year during the sample period. Prices are in 2007 dollars.

endogeneity of subsidies directed at ethanol production more rigorously by undertaking an instrumental variable approach, which requires that we identify at least three variables that determine subsidy adoption but that do not directly determine ethanol production capacity in the state. Importantly, given that we are using a fixed-effects framework, we must use instruments that vary over time. Based on these criteria, we identified five instruments that prove effective for these purposes. Specifically, the instruments are two indicator variables indicating Democrat and Republican rule, a variable indicating the length that the National Corn Growers Association (*NCGA*) has been present in a state, the dollar amount of check-off revenue generated in each state-year, and a state gubernatorial election year indicator variable. The Democratic rule variable (*DEM*) is equal to one when the governor is a Democrat, and the Democratic Party has majority control in both the Senate and House, and equals zero otherwise. Republican rule (*REP*) is equal to one when the governor is a Republican, and the Republican Party has majority control in both the Senate and House, and equals zero otherwise.[19] We hypothesize that political control by one party or another may influence the propensity to which a state imposes ethanol subsidy legislation. The *NCGA* variable indicates the number of years that a state has had an affiliation with the corn growers association. This variable may reflect the political "clout" or "sway" that corn farmers may hold in their state, thus influencing the likelihood of the introduction of incentives. The check-off revenue instrument (*CKOFF*) requires a brief explanation. The check-off is something like a tax on corn, but the revenues from the check-off are used to promote, market, and lobby on behalf of corn growers. The size of the check-off ranges from 0.25 cents per bushel to 1 cent per bushel. To obtain the revenues generated from the check-off, we multiplied the per bushel check-off by the total number of bushels produced annually in the state. We hypothesize that the more revenue generated by the check-off, the greater will be the influence of corn growers in the political process of that state. We note that over our sample period, numerous states became affiliated with the National Corn Growers Association and introduced check-offs.[20] Lastly, the election year variable (*ELECT*) indicates each year that a particular state held a gubernatorial election during the sample period. State elections may lead to an environment that is more conducive to new policy implementation.

To move forward with our instrumental variables (IV) approach, we must first demonstrate that these variables are valid instruments. Utilizing a two-stage least squares approach, the first stage estimates the following model:

$$\begin{aligned} POLICY_{st} = {} & DEM\mu_1 + REP_{st}\mu_2 + NCGA_{st}\mu_3 + CKOFF_{st}\mu_4 + ELECT_{st}\mu_5 \\ & + V_{st}\mu' + S_s + T_t + \varepsilon_{st} \end{aligned} \tag{2}$$

in state s in period t. $POLICY$ represents the per gallon tax credit in one first-stage regression and the tax credit dummy in the other. DEM_{st} is an $n \times 1$ vector that indicates Democratic Party control in the n state-years in our data set, μ_1 measures the effect of this measure on the

[19] The omitted category is state-years in which neither the Democrats nor the Republicans have full control.

[20] We list the states and years they joined the NCGA and introduced check-offs, respectively: Arkansas—1997, 1998; Colorado—1979, 1987; Georgia—1984, 1996; Illinois—1971, 1982; Indiana—1971, 2007; Iowa—1967, 1977; Kansas—1975, 1977; Kentucky—1982, 1990; Louisiana—1985, 1985; Maryland—1977, 1991; Michigan—1973, 1993; Minnesota—1978, 1990; Mississippi—1993, 2006; Missouri—1978, 1984; Nebraska—1973, 1978; New York—1988, no check-off; North Carolina—1978, 1979; North Dakota—1987, 1991; Ohio—1977, 1989; Oklahoma—1996, no check-off; Pennsylvania—1973, no check-off; South Carolina—1991, no check-off; South Dakota—1986, 1988; Tennessee—1986, no check-off; Texas—1989, 1990; Virginia, 1979, 1980; Wisconsin—1975, 1982.

probability of an ethanol subsidy being in place in a particular state-year, and REP_{st}, $NCGA_{st}$, $CKOFF_{st}$, and $ELECT_{st}$ are the comparable counterparts. V_{st} is an $n \times k$ set of control variables (k is the number is controls), and μ_3 is a $k \times 1$ vector of parameters. S_s represents the state-specific effects, T_t is the set of time indicator variables, and ε_{st} is the residual. The results of the two first-stage regressions are presented in Appendix B. In column 1, estimates of μ_4 and μ_5 are positive and statistically significant, with t-statistics equaling 2.02 and 2.01, respectively, suggesting that states holding elections or with high levels of check-off revenues are more likely to adopt production tax credit/subsidy legislation. More importantly, the p-value for the test of excluded instruments was equal to 0.0423, indicating that the instruments are jointly significant. In the second first-stage regression (column 2), only the *REP* instrument is individually significant (t-statistic = 1.85), indicating that states coming under Republican control are more likely to adopt ethanol per gallon tax credit/subsidies, and again the excluded instruments are jointly significant (p-value = 0.0253).

Overall, this IV model successfully rejects the underidentification test (p-value = 0.0674), which suggests that the excluded instruments are relevant and correlated with the endogenous regressors.[21] While the underidentification test examines the relevance and correlation of the excluded instruments, it is also valuable to evaluate the strength of this correlation. A test of the joint strength of the instruments only provides marginal evidence of strength (Cragg-Donald F statistic = 5.603), indicating that the results may possibly suffer from issues associated with weak instruments, such as tests for significance having incorrect size and incorrectly estimated confidence intervals.[22] Lastly, it is also important to conduct a Sargan-Hansen test of overidentifying restrictions.[23] This examination tests the joint null hypothesis that the instruments are valid, that is, uncorrelated with the error term in the second stage. A rejection of this hypothesis would suggest that one or more of the instruments are correlated with the disturbance process and, hence, would cast doubt on the suitability of the instrument set. Fortunately, we are unable to reject the null hypotheses (p-value = 0.3747), indicating that the instruments are jointly valid.

The second-stage results are presented in the last column of Table 3. These estimates, while qualitatively similar to the estimates that do not correct for endogeneity, are substantially larger, and the coefficient on the production tax credit/subsidy indicator variable becomes significant. These results suggest that the OLS estimates are not biased upward, and in fact suggest that impacts may be even more substantial.[24] While the IV estimation does not provide evidence in opposition to the OLS findings, the magnitude of the results is dramatically larger, and the precision of the estimates is significantly lower (standard errors are much larger).[25] This lost efficiency may suggest that the OLS estimates are preferable when attempting to prescribe

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[21] The test is essentially the test of the rank of a matrix: under the null hypothesis that the equation is underidentified. A rejection of the null indicates that the matrix is full-column rank; that is, the model is identified. See Kleibergen and Paap (2006) for details.

[22] While a Cragg-Donald F statistic of 5.603 is not trivial, it is also not large enough to conclude with any certainty that the excluded instruments will not suffer from some of the potentially problematic issues associated with weak instruments.

[23] See Sargan (1958) for details.

[24] Given the growth patterns presented in Figures 2 and 3, the large estimated coefficients on both subsidy variables generated from the IV estimation procedure may not be entirely implausible.

[25] This outcome is not unusual, as is pointed out by Wooldridge, who states "[there is an] important cost to performing IV estimation…the asymptotic variance of the IV estimator is *always* larger, and sometimes *much* larger, than the asymptotic variance of the OLS estimator" (Wooldridge 2006, p. 516; emphasis added).

the potential magnitude of the effect of these policies. As a further examination, we use a Hausman test to evaluate OLS versus IV estimators, where the null hypothesis states that the OLS estimator is consistent and fully efficient. In our case, we reject the null hypothesis at the 10% level (p-value = 0.0637), suggesting that there is some endogeneity present. Nevertheless, due to the potential weakness of the instruments, the statistical significance and marginal effects estimated by the IV approach may be too large, and so we tend to favor the more conservative and precisely measured OLS estimates.

Intertemporal Analysis

Earlier we presented evidence in Figures 2 and 3 that suggested a positive effect of ethanol subsidies/credits on production over time. In Table 4, we present an intertemporal analysis of the effect of ethanol subsidies/credits over time by introducing 2 year lead effects and 2 year lagged effects, as well as a contemporaneous effect of each policy.[26] These estimates, presented in Table 4, include all control variables used in the third and fourth columns of Table 3.

The lead effects are informative because we can determine whether the positive effects from Table 3 do indeed stem from the per gallon credit or if they are the result of a preexisting trend. In both columns of Table 4, the two credit lead effects are insignificant and generally negative for both policies measures, suggesting that the estimates in Table 3 are not the result of trending differences between the treatment and control states. Turning our attention to the contemporaneous measures and the lagged measures of the production tax credit dummy variable, due to a lack of precision, we see no statistically significant coefficients, although the pattern of results is consistent with those observed in Figure 3. For the per gallon tax credit, the results are also consistent with Figure 2 in showing that it may take a couple of years before significant and noticeable increases in production capacity are seen. We find that the pattern presented in Table 4 is consistent with intuition about the ways in which businesses may react to new incentives. Namely, businesses respond to new incentives and increase production, but it may take some time before new plants can be made operational.

Overall, our analysis reveals a consistent positive relationship between the adoption of per gallon production subsidies and changes in ethanol production capacity. These findings prove robust to alternative samples, the inclusion (or exclusion) of important control variables, appropriate alternative estimation techniques, and the presence of preexisting trends.

4. Conclusion

In this study, we present evidence that state-level per gallon tax credits do indeed influence ethanol plant location patterns. Existing research on the emerging ethanol industry suggests that the social benefits of ethanol production and consumption are minimal, perhaps even negative. According the analysis by Gardner (2007), it is likely that federal subsidies and mandates for ethanol actually generate a substantial long-run deadweight loss in the range of \$3.5 to \$4 billion annually. Taking into account state subsidies only increases the magnitude of this deadweight loss

[26] For the intertemporal analysis, a dummy variable was used to represent the per gallon credit variable rather than the actual per gallon credit itself (as in Table 3). A dummy variable approach is often used to allow for easy interpretation of the lagged effects.

Table 4. Intertemporal Analysis

Lead and Lagged Policy Variables	Coefficient Estimates 1	Coefficient Estimates 2
Per gallon credit lead 2	0.0742 (0.2379)	−0.1214 (0.3246)
Per gallon credit lead 1	−0.0120 (0.2921)	−0.1175 (0.3437)
Per gallon credit contemporaneous period	−0.0998 (0.3219)	−0.2248 (0.3507)
Per gallon credit lag 1	0.2921 (0.4978)	0.2223 (0.4361)
Per gallon credit lag 2+	1.2743** (0.4447)	1.1678** (0.4635)
Production tax credit/subsidy lead 2	−0.2315 (0.2232)	−0.3440 (0.2961)
Production tax credit/subsidy lead 1	0.0765 (0.3775)	0.0907 (0.4227)
Production tax credit/subsidy contemporaneous period	0.3125 (0.3999)	0.1010 (0.4447)
Production tax credit/subsidy lag 1	0.2357 (0.5739)	0.3611 (0.6676)
Production tax credit/subsidy lag 2+	0.0036 (0.4026)	0.3280 (0.4942)
Log state natural gas price	−0.5894 (0.4445)	−0.4448 (0.5899)
Log state hourly wage	0.1638 (1.1315)	0.4777 (2.0232)
Lagged corn production (in millions of bushels)	0.0003** (0.0001)	–
Log state corn price	–	−0.1892 (0.6813)
Adjusted R^2	0.8227	0.7839
Sample size (number of states)	1350 (50)	1148 (41)

Each column is from a separate regression that includes both state and year fixed effects. The dependent variable is the log of ethanol production capacity +1 in a state-year. The standard errors in parentheses are corrected to allow for nonindependence of observations within a state through clustering. ** and * denote statistical significance at the 0.05 and 0.10 levels, respectively. Prices are in 2007 dollars.

measure. From the point of view of a particular state, however, state policymakers should consider offering certain subsidies if the objective is to be a leader in the emerging biofuel industry. In the context of the very recent and growing concern about the tradeoff between food and fuel, the broader implications of increasing subsidies for biofuel production, at least in the context of existing corn-based technologies,[27] should be carefully considered.

While it is difficult to directly measure the importance of federal subsidies in the emergence of the ethanol industry in the United States, our work is consistent with the notion that federal subsidies are very important. We cannot, however, disentangle the difference between the effect of state subsidies on the growth of national production capacity and the location of ethanol production. It seems likely that the underlying driving forces in national production are the federal mandates and subsidies, whereas state subsidies primarily influence location patterns. On the margin, however, state subsidies may have, to some degree, also increased total national ethanol production capacity.

More generally, our work contributes to the literature that has sought to evaluate the effectiveness of economic development incentives by examining the issue in the context of an emerging industry. Over the period 1980–2007, we observed the complete emergence of the ethanol industry, and we observed numerous state-level policy changes aimed at subsidizing the industry. Our work demonstrates that incentives appear to have played an important role in determining the

[27] It is possible to produce ethanol in states where climatic and soil conditions are suboptimal. It is, however, much more expensive to produce corn in these states. Scientists are working on methods of producing ethanol from cellulosic materials such as wood or switch grass. Under current technologies, it is much more expensive to produce ethanol from such materials. It is conceivable that at some point a breakthrough will enable ethanol producers to use a wider range of inputs in the production process, and this may change and/or expand the location of ethanol production nationwide. Currently, corn is the least costly approach given existing technological capabilities.

location of ethanol plants, although a general investigation of the data and the location of policy activity suggest that subsidies need to be substantial in order for them to be effective in states without strong potential to produce ethanol. For example, Oklahoma and Montana each have $0.40 (in nominal values) per gallon subsidies, but it seems unlikely that either state will ever be significant producers of ethanol, at least under corn-based ethanol technologies. This is because the conditions are not amenable to producing corn (too dry or too cold), and the costs of transporting corn are prohibitive. Nevertheless, it appears that subsidies are important in terms of attracting new plants in states where there is the potential for corn production.

Appendix A

Definitions and Sources of Variables

Variables	Definitions	Source
Hourly wage	Average hourly wage for all nonsalary workers in each state-year collected from the CPS-ORG.	CPS
Natural gas price	Price of natural gas sold to commercial consumers in each state-year in dollars per thousand cubic feet	DOE, EIA
Per gallon credit	Per gallon tax credit and/or direct subsidy in real 2007 dollars. A full listing of existing subsidies is available at http://www.afdc.energy.gov/afdc/incentives_laws.html.	DOE, C&S
Production tax credit/ subsidy	Indicator variable equal to one if the state has a production tax credit or subsidy, and zero otherwise. This variable includes an array of subsidies including: grants, loans, per plant subsidies, production tax credits, and infrastructure tax credits. A full listing of existing subsidies is available at http://www.afdc.energy.gov/afdc/incentives_laws.html.	DOE, C&S
State corn price	Average corn price per bushel in each state-year	USDA
Ethanol production capacity	Ethanol production capacity in each state-year	RFA, C&S
Corn production	State corn production in millions of bushels per year	USDA

Sources: CPS (Current Population Survey: www.census.gov/cps) (Accessed 17 April 2008), USDA (U.S. Department of Agriculture: www.usda.gov), DOE (U.S. Department of Energy: http://www.doe.gov), EIA (Energy Information Administration [part of DOE]: http://www.eia.doe.gov), RFA (Renewable Fuels Association: www.ethanolrfa.org), C&S (Chad Cotti and Mark Skidmore: compiled by the authors in this study).

Appendix B

First Stage IV Results from Table 3

	Production Tax Credit/Subsidy (1)	Per Gallon Credit (2)
Republican legislative control	−0.0055 (0.0283)	0.0214* (0.0115)
Democrat legislative control	0.0455 (0.0385)	0.0055 (0.0058)
Gubernatorial election year	0.0100** (0.0050)	−0.0010 (0.0027)
NCGA years	−0.0014 (0.0046)	0.0017 (0.0014)
Check-off revenue (in millions of 2007 dollars)	0.4580** (0.2270)	0.0002 (0.0554)
Log state natural gas price	−0.0970 (0.0698)	−0.0104 (0.0242)
Log state hourly wage	0.0205 (0.2691)	0.0644 (0.0667)
p-value: test of excluded instruments	0.0423	0.0253
Sample size (number of states)	1350 (50)	1350 (50)

Each column is from a separate regression that includes both state and year fixed effects. The standard errors in parentheses are corrected to allow for nonindependence of observations within a state through clustering. ** and * denote statistical significance at the 0.05 and 0.10 levels, respectively. Prices are in 2007 dollars.

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