Capital versus Output Subsidies: Implications of Alternative Incentives for Wind Investment

Joseph E. Aldy, Todd D. Gerarden, and Richard L. Sweeney*

May 18, 2015 Draft; Comments Welcome; Do Not Cite

Abstract

From a public finance perspective, is it better to subsidize inputs or outputs? We examine the choice between a capital subsidy and an output subsidy in the case of wind energy in the United States where, in some cases subsidies support investment in a specific technology, while in other cases subsidies support output from qualifying technologies. Exploiting a natural experiment in which wind farm developers could choose between investment and output subsidies, we estimate the impact of this choice on project productivity, and then use these estimates to evaluate the public economics of U.S. wind energy subsidies. Using a fuzzy regression discontinuity modeling framework, we find that wind farms choosing the capital grant realize 11% lower generation than those wind farms selecting the output subsidy. The Federal government expends about one-quarter more per kilowatt-hour of power produced under the capital subsidy than the output subsidy.

Keywords: energy subsidies, instrument choice

JEL Codes: H23, Q42, Q48

*Aldy: Harvard Kennedy School, Resources for the Future, National Bureau of Economic Research, and Center for Strategic and International Studies; joseph_aldy@hks.harvard.edu. Gerarden: Harvard Kennedy School; gerarden@fas.harvard.edu; Sweeney: Harvard Kennedy School; rich_sweeney@hksphd.harvard.edu.
Jeff Bryant, Napat Jatusripitak, Carlos Paez, Jun Shepard, and Howard Zhang provided excellent research assistance. Thanks to Jud Jaffe for assistance with the 1603 grant program data; Scott Walker for assistance with wind speed data; and John Horowitz and Adam Looney for assistance with historical tax policy information. This work has been supported by the Alfred P. Sloan Foundation (grant 2015-13862) and the Harvard University Center for the Environment. We have benefited from feedback provided by seminar participants at Columbia and Harvard as well as from Alberto Abadie, Paul Goldsmith-Pinkham, and Jim Stock.

1 Introduction

Once policy-makers decide to intervene in markets to advance important societal objectives, the question turns to consideration of the most effective way to design and implement policy. For example, the government can pay for the construction of low-income apartment buildings, or provide subsidies to landlords who rent to low-income tenants. The government can fund pharmaceutical research and development, or commit to subsidize the price of a qualifying drug when it comes to market. These choices raise questions about the efficiency of this choice: from a public finance perspective, is it better to subsidize inputs or outputs? We examine the choice between a capital subsidy and an output subsidy in the case of wind energy in the United States where, in some cases subsidies support investment in a specific technology, while in other cases subsidies support output from qualifying technologies. Exploiting a natural experiment in which wind farm developers could choose between investment and output subsidies, we estimate the impact of this choice on project productivity, and then use these estimates to evaluate the public economics of U.S. wind energy subsidies.

Between 2004 and 2014 wind power capacity in the United States increased tenfold (authors' estimate based on EIA-860 survey data). An array of implicit and explicit renewable energy subsidies have contributed to this surge in investment. For example, wind farms may generate credits under state renewable portfolio standards, receive Federal and state tax credits, receive accelerated depreciation benefits, and qualify for loan guarantees (Metcalf, 2010; Schmalensee, 2012; Aldy, 2013). Prior to 2009, the production tax credit represented the primary Federal subsidy and provided an eligible taxpayer with approximately 2 cents/kWh for all output in the first ten years of a wind farm's operation. The 2009 Recovery Act introduced novel flexibility in the choice of Federal subsidy available to a wind project developer. For the first time, a developer could elect to claim the production tax credit (PTC) – an output subsidy – or one of two types of capital subsidy – the investment tax credit (ITC) or the section 1603 grant in lieu of the ITC. In practice, the choice came down between the PTC and the section 1603 grant, since the latter yielded equivalent value to the ITC but did not require tax liability for monetization.

The section 1603 grant was a truly unique and unexpected policy innovation. It was designed to address the unprecedented challenges of monetizing tax credits during the financial crisis (Aldy, 2013).[1] We exploit this natural experiment, to evaluate the impacts

[1]The approach of providing a taxpayer the option of claiming a tax credit or a cash payment in lieu of

of the subsidy choice on wind farm productivity. Under the 2009 Recovery Act, which Congress initially drafted in January 2009 and then passed into law in February 2009, only projects placed into service on or after January 1 of that year were eligible for the 1603 grant. Given the long development timeline for wind projects, the timing of this policy created a plausibly exogenous shock to the subsidy choice of wind developers. We use the unexpected temporal discontinuity in 1603 grant eligibility to implement a fuzzy regression discontinuity research design, instrumenting for cash grant recipient status with a binary indicator for exogenous grant eligibility. This allows us to isolate the local average treatment effect of cash grant receipt on subsequent electricity generation outcomes, isolating this causal effect from the effect of selection by firms.

In our baseline analyses, we evaluate the impact of subsidy choice with a sample of wind farms coming online +/- 12 months around the January 1, 2009 policy innovation (in complementary analyses, we test for sensitivity to choice of bandwidth around this date). In our ordinary least squares models, we find that 1603-recipient wind farms produce 6 to 18% less power over 2010-2013 than PTC recipients. In our fuzzy RD, we use 1603 grant eligibility as our instrument, which is fairly strong (F-statistics of 90 or greater across specifications). In these two-stage least squares models, we find that 1603 grant receipt results in 7 to 20% less power generation than PTC receipt, with our preferred estimate of an 11% reduction in production.

To assess whether our results could simply represent an artifact of long-term trends in wind farm characteristics, we undertake a placebo analysis that effectively compares generation for wind farms coming online the 12 months before to those coming online 12 months after arbitrary fictitious policy innovation dates over 2007-2011. The results of this placebo analysis provide mixed support for our approach. The true reduced-form of January 2009 is near the top of the distribution and it appears more extreme than its nearest neighbors, who are also affected by the policy since we use a bandwidth of +/- 1 year. We should note, however, that interpretation of these results is complicated by the fact that none of these coefficient estimates are statistically distinguishable from one another.

These findings suggest the form of subsidy available to wind investors has important implications for the social benefits of investment. The primary motivation for Federal

the tax credit was also unprecedented; according to Treasury Office of Tax Policy staff, such an approach had never been implemented in any tax policy context before the 2009 Recovery Act (John Horowitz, Office of Tax Policy, U.S. Treasury, 2015).

wind power subsidies is reducing damages due to environmental externalities created by conventional sources of electricity generation. Thus, the quantity of electricity generation induced by a given policy is a proxy for the policy's social benefits. Our findings suggest the 1603 cash grant induces less electricity generation than the PTC, even for otherwise equivalent projects.

We also investigate the expected fiscal outlay per MWh of production to wind farms claiming the PTC and the 1603 grant. We project generation for PTC- and 1603-recipient wind farms out 10 years, and compare the average PTC outlay per MWh to the average 1603 outlay per MWh. We find that the Federal government will pay more per kWh of production for about three-quarters of 1603 recipients than it would have under the production tax credit. The average outlay per MWh for a 1603 recipient is $29, about one-quarter greater than the PTC of $23.

A number of papers have studied the impact of subsidies on renewable energy. Hitaj (2013) analyzes the drivers of wind power development in the United States, focusing on government renewable energy incentives and transmission policy. She finds that the Federal PTC, state-level sales tax credit and production incentives play an important role in promoting wind power. Metcalf (2010) shows how the PTC affects the user cost of capital and illustrates the adverse impact of lapses in the PTC on wind capacity investment. Using data on hourly outputs and prices for 25 wind and nine solar generating plants, Schmalensee (2013) evaluates the impacts of subsidies on the value of these plants' outputs, the variability of output at plant and regional levels, and the variation in performance among plants and regions. He notes the policy implications of high generation when power prices are negative. Our paper represents the first attempt to distinguish the impacts by type of subsidy instrument. Moreover, by focusing on the taxpayers choice of policy instrument based on an exogenous policy innovation, we can identify causal impacts even in the presence of a complicated, overlapping policy landscape that often undermines statistical identification.

The rest of this paper proceed as follows. Section 2 provides a brief introduction to the economics of wind energy and a review of the relevant policies. Section 3 discusses our empirical strategy and data. Section 4 reports the results and 5 discusses policy implications and concludes.

2 Background

2.1 The Economics of Wind Power

In 2014, 4.6% of US electricity generation came from wind, up from less than 1/2 of 1% a decade earlier (EIA Monthly Energy Review March 2015). Over this time period, the maximum capacity of new wind farms coming online each year has increased just as the maximum capacity of individual wind turbines has likewise increased.

A wind turbine consists of three long rotor blades connected to a gearbox atop a large tower. As wind passes through the blades, the rotors in turn spin a series of gears before a generator converts this kinetic energy to electrical energy . The amount of power generated by wind turbine is determined by nameplate capacity of the turbine and the speed of the wind blowing through it, which in turn reflects the direction of the wind and the orientation of the turbines that can modified (subject to constraints) by a wind farm operator. Nameplate capacity, denominated in megawatts (MW) is the maximum rated output of a turbine operating in ideal conditions. While obviously no power is generated if the wind isn't blowing fast enough to spin the turbine, if the wind is blowing too fast it will damage the turbine. Wind turbines typically operate at rated capacity at wind speeds of 33 mph, and shutdown when the wind exceeds 45 mph.

The following equation summarizes the realized output y_{ih} generated by a wind turbine at a given point in time t,

$$y_{it} = a_i e(w_{it}, m_{it}) k_i$$

where $a \in \{0, 1\}$ is an indicator for whether the turbine is available for operation that period and k_i is the nameplate capacity of the turbine. The turbine's efficiency $e \leq 1$ is a function of the wind speed and quality that period (w_{it}) and the turbine's state of maintenance (m_{it}). Turbines need to be monitored and serviced regularly in order to operate at peak efficiency (Wiser and Bolinger 2014). The gearbox, in particular, contains a complicated set of parts that, if not serviced, can reduce the fraction of wind power harnessed or cause the unit to be taken offline entirely. U.S. wind farms typically have operations and maintenance costs on the order of \$5 to \$20 per MWh, with a few outliers in 2013 with O&M costs in excess of \$60/MWh (Wiser and Bolinger 2014).

Building a wind farm involves large investment costs. It takes 9 to 12 months to complete a wind project, with site permiting and turbine lead times often double that (Brown and Sherlock, 2011, p. 6). Turbines are ordered up to 24 months before ground is broken, and, at that point, the size and location of a project is fairly fixed.[2]

Although wind turbines do not incur fuel costs, there are a number of variable costs associated with running a wind farm efficiently once installed. Most of these costs related to minimizing downtime or increasing each turbine's "availability factor". Placing more emphasis on routine maintenance can reduce the probability of failure, and, conditional on failure, turnaround times vary considerably across operators.

2.2 Policy Background

The United States has implemented many policies – at Federal, state, and even local levels – to promote investment in wind power. Since 1992, the leading Federal subsidy for wind farm developers has been the production tax credit (PTC). The PTC is a per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the operator to an unrelated party during the taxable year. Congress initially set the PTC at 1.5 cents/kWh, but automatic inflation adjustments made it worth 2.3 cents/kWh for qualifying generation in 2014. A qualifying generation source can claim the PTC for only the first ten years of generation after the facility is placed into service. Prior to the 2008 financial crisis, wind farm developers typically monetized tax credits by partnering with a financial firm in the tax equity market.[3] During the financial crisis, more than half of the suppliers of tax equity departed the market, which introduced financing challenges for wind farm developers that did not have nor anticipate to have sufficient tax liability to monetize the tax credits on their own (U.S. PREF, 2010).

In this financial context, wind farm developers sought new ways to realize the value of the PTC. During the 2008-2009 Presidential Transition, representatives of the wind industry advocated for making the PTC refundable and/or to create long carry-back provisions to the Presidential Transition Team and Congressional staffers, but these ideas were not acceptable to the bill writers.[4] In early January 2009, Congressional and Presidential Tran-

[2]According to NREL 2012, turbine lead times approached 2 years during the peak demand period in the first half of 2008. Market fundamentals have since changed, and lead times have dropped significantly. Nevertheless, there is a natural lag between turbine contract and power purchase agreement signing and project commissioning such that turbines ordered in early 2008 were still working their way through projects that were completed in 2010.

[3]For example, in 2007, Lehman Brothers, AIG, Merrill Lynch, among others, provided equity to wind developers and in return these financial firms claimed the production tax credit (and accelerated depreciation benefits) for the project.

[4]One of the authors served as one of two staff representing the Obama Presidential Transition Team who negotiated the energy provisions of the Recovery Act. He regularly met with representatives of the

sition Team members discussed for the first time the idea of availing investment subsidies to all renewable power sources (at that time, the ITC primarily benefited solar). Moreover, the bill negotiators agreed to provide an option for effectively converting the ITC to a cash grant. When the bill became law the following month, Congress agreed to make the three policy options – the PTC, ITC, and 1603 cash grant – available retroactively to projects placed into service on or after January 1, 2009.

The Recovery Act thus provided wind power developers with a new, mutually exclusive subsidy choice: (1) they could claim the production tax credit (PTC) or (2) they could claim the section 1603 cash grant in lieu of tax credits. (Technically, the ARRA also provided developers with the option of taking an Investment Tax Credit (ITC). In practice, the choice came down between the PTC and the section 1603 grant, since the latter yields equivalent value to the ITC, processed in a matter of four to six weeks instead of on an annual tax reporting basis, and did not require tax liability for monetization [based on conversations with staff at the American Wind Energy Association].) This policy approach was novel and unexpected along two dimensions. First, wind power had never been supported by an investment subsidy and the policy proposals discussed by wind industry advocates focused on modifying the existing production tax credit. Second, providing a taxpayer with the option of a tax credit or a cash payment in lieu of the tax credit had never been pursued before the Recovery Act in any tax policy context (John Horowitz, Office of Tax Policy, U.S. Treasury, 2015).[5] These grants are made after project construction is completed and the wind farms begin generating electricity ("placed into service").

The 1603 program expired in 2012, with projects having to have completed "significant"

renewable industry, including staff to trade associations (including the American Wind Energy Association, the Solar Energy Industries Association, the Geothermal Energy Association, and the American Council on Renewable Energy), staff of wind power firms (including Vestas, GE, and Ibredola), and staff to various firms that finance wind power projects (including Chadbourne and Parke, GE Capital, Morgan Stanley, and the U.S. Partnership for Renewable Energy Finance). He met regularly with staff to the House Ways and Means and Senate Finance Committees in December 2008 and January 2009, as well as with career Treasury staff in the Office of Tax Policy. In January 2009, upon agreement with Congressional negotiators of what became the section 1603 cash grant in the Recovery Act, the principal investigator briefed a large meeting of the renewables industry at the Presidential Transition Team offices where the unexpected, novel nature of this policy was evident in the meeting participants' reactions.

[5]The Fall 2008 debate over a one-year extension of the wind PTC further illustrates the novelty of the cash grant policy. At that time, the PTC had been authorized by a 2006 tax law that established a December 31, 2008 sunset. On October 2, 2008, as a part of the Troubled Asset Relief Program (TARP) Bill, Congress extended the PTC sunset provision to December 31, 2009. Despite the obvious salience of the financial crisis in writing the PTC extension into the TARP Bill, Congress did not provide the investment tax credit or the cash grant option in the law. Put simply, the legislative action on the TARP Bill preceded the idea of giving wind developers options over their choice of subsidy.

construction by October 1, 2012 in order to be eligible for the program. In total the Treasury made 400 1603 awards to wind farms, dispersing over $12 billion.

These subsidies exist in a complicated energy and environmental policy space characterized by multiple, overlapping regulatory and fiscal policy instruments focused on wind power development. Since the major tax reform of 1986, wind project developers could employ a the modified accelerated cost recovery system that effectively permits a developer to depreciate all costs over five years, instead of the norm of twenty years for power generating capital investments.

Many wind farms enter into long-term contracts – power purchase agreements – with utilities that lock in a price (often with periodic escalators or inflation adjustments) for power, and occasionally power bundled with renewable energy credits that the purchaser may use for demonstrating compliance with a given state's renewable portfolio standard. As a result, the regulations mandating a renewable portfolio standard and, in some states, requiring long-term contracts, provide a stream of revenues in excess of what a producer would receive if the source of the power were not a qualifying renewable source. As Schmalensee (2012) notes, transparency into renewable energy credit markets is heterogeneous around the country and, in many states, quite poor. Nonetheless, in some years for some states, wind power generation has earned more than $50/MWh, or more than twice the value of the production tax credit. States also provide subsidies through state tax credits and property tax exemptions.

Since 2005, the Department of Energy loan guarantee program provided a mechanism for wind power developers to secure a Federal guarantee on project debt that could significantly lower the cost of financing the project. Prior to 2009, no wind farms made use of this program, but four wind farms secured loan guarantees through the Department of Energy section 1705 loan guarantee program. This modification of the 2005 program, established in the 2009 Recovery Act, covered the credit subsidy cost – the Federal government's expected liability for guaranteeing the project loan – through appropriations.

For purposes of the statistical analyses below, it's important to recognize that these policy instruments generally did not change contemporaneously with the policy innovation of the 1603 grants. For example, the Department of Energy loan guarantee program did not issue any loan guarantees to wind projects in 2009. The state renewable portfolio standards experienced only very modest changes in 2008 and 2009, with the exception of Kansas establishing a new RPS in May 2009, California increasing its 2020 RPS goal in September 2009, and Nevada adding post-2015 compliance schedule in June 2009. Given the development lead times necessary for wind farm investment, we do not believe that these changes in RPS policies would impact any wind capacity decisions in 2008 and 2009.

2.3 Data

The primary data sources for this paper are two publicly available Energy Information Administration (EIA) surveys covering all utility-scale wind farms in the United States. Form EIA-860, which is collected annually, contains the following variables:

- first date of commercial operation
- nameplate capacity
- number of turbines
- operator name
- location
- regulatory status (regulated or not)

This annual plant level information is combined with monthly generation data from survey EIA-923. We then supplement this EIA data with exact turbine level latitude and longitude for every wind farm from the American Wind Energy Association (AWEA). We merged these location data with wind speed data from the National Renewable Energy Laboratory (NREL). From NREL, we obtained a map of average annual wind resources for the conterminous United States, divided into grid cells 1/4 degree of latitude by 1/3 degree of longitude. Each grid cell was assigned a wind power class ranging from 1 to 6, with 6 being the windiest. For each facility in the EIA data, we used the mean and maximum wind zones within the county as proxies for the wind quality at that facility.

The final data set comes from the U.S. Department of Treasury. These data contain information on every recipient of a 1603 cash grant, including the amount awarded (equal to 30 percent of project investment costs), the date of the award, and the date placed in service. Based on the guidance provided by staff at the American Wind Energy Association, we have assumed that developers of non-1603 recipient wind farms claimed the PTC. We do not have tax data on the PTC claims, although we observe all power related data for presumed PTC-claimants through the EIA data described above.

Table 1 presents an annual summary of these data for the years available.

Table 1: Summary Statistics by Entry Date

Entry Year	Wind Farms	1603	Nameplate	No. Turbines	Windzone	Regulated	Capacity Factor
2002	25	0	46.72	58.32	2.38	0.21	0.28
2003	28	0	60.45	68.82	3.52	0.08	0.30
2004	20	0	24.37	37.78	3.67	0.15	0.25
2005	35	0	83.81	55.52	3.13	0.09	0.34
2006	46	0	41.55	26.09	3.14	0.17	0.32
2007	39	0	122.37	76.08	3.13	0.10	0.33
2008	92	0	92.13	53.12	2.99	0.13	0.32
2009	101	55	81.92	49.34	3.01	0.20	0.30
2010	67	43	78.69	45.53	2.95	0.10	0.31
2011	92	51	67.39	35.81	2.74	0.13	0.29
2012	123	50	99.35	48.78	2.83	0.12	0.32
2013	44	0	53.14	29.27	2.64	0.14	0.36

3 Empirical Strategy

3.1 Model

In order to estimate whether shifting subsidies from the intensive to the extensive margin reduced wind farm productivity, we assume a linear model for electricity generation outcomes as a function of subsidy regime and wind farm characteristics:

$$y_{it} = \alpha w_i + \beta X_{it} + \nu_t + \epsilon_{it} \tag{1}$$

where y is a production outcome variable of interest (electricity generation or capacity factor), w is an indicator for whether the wind farm took the 1603 grant and X is a vector of controls (e.g., wind farm capacity, wind quality, regulatory regime, presence of a power purchase agreement, location, etc.). The coefficient of interest, α, is the effect of the 1603 grant on production outcomes. For example, if wind farms were less productive under the 1603 grant, we would expect α to be negative.

Estimating this equation using OLS is problematic due to the fact that w_i was chosen. The PTC pays the project approximately $23 for every MWh generated (and this amount will be adjusted higher for inflation over time), while the ITC reimburses developers for 30 percent of there up-front investment costs. Intuitively, plants that expect to have high

Table 2: Comparison of 2009 projects by policy choice

	PTC	1603	Difference	(p-value)
Nameplate Capacity	66.82	94.49	-27.67	0.03
Turbines	40.05	57.09	-17.03	0.04
Median Wind Zone	3.44	2.65	0.80	0.00
Regulated	0.36	0.07	0.28	0.00
Capacity Factor	0.32	0.28	0.04	0.00

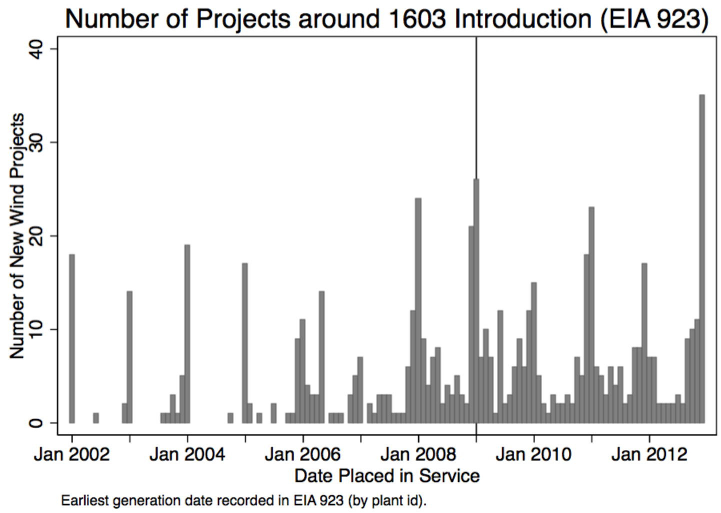
Notes: 46 PTC facilities and 55 1603 facilities coming online in 2009

output relative to their investment costs would prefer the PTC, while plants with relatively high investment costs per unit of expected output would prefer the 1603 grant. Thus, OLS estimates would confound any reduced marginal effort due to the 1603 program with the fact that less productive plants are likely to have selected into it.

While the 1603 cash grant was not randomly assigned, its creation came as a plausibly exogenous shock to the industry. This suggests that the timing of the Recovery Act might provide a source of identification. Data on wind project entry dates provides evidence on the exogeneity of the 1603 cash grant program. We plot the number of new projects coming online each month using EIA Form 923 data and highlight the January 1, 2009 date when wind power developers gained access to the the policy choice described above (Figure 1). This plot highlights the seasonal variation in projects coming online. On the whole, projects are more likely to come online in the first and last months of the year than in other months. In some years, such as 2004, this variation is driven by uncertainty around the expiration of the PTC. The frequency of project entry around the introduction of the 1603 cash grant policy in the last months of 2008 and the first months of 2009 are not statistically different from entry rates in the same months (or same quarters) in other years dating to 2001. Thus, project developers did not appear to adjust the timing in entry to the policy innovation.

We analyze the effect of investment and output subsidies on electricity generation outcomes using an instrumental variables research design, harnessing the natural experiment created by the 1603 cash grant program. We use the exogenous change in eligibility of wind projects for 1603 cash grant, which depends on the date of initial electricity generation. We implement a fuzzy regression discontinuity research design, using a binary indicator for

Figure 1: Evidence of Seasonal Variation in Entry



initial date of electricity generation to instrument for cash grant recipient status,

$$w_i = \gamma \cdot 1\left\{1603 \text{ eligible}\right\}_i + \delta X_{it} + \nu_i \tag{2}$$

where $1\left\{1603 \text{ eligible}\right\}_i$ is an indicator for 1603 program eligibility based on the date of initial electricity generation. We then use the predicted values from this first stage, $\hat{w}$, to estimate α using our main estimating equation in a two-stage least squares (2SLS) framework.

3.2 Identification

We make four assumptions to identify α and interpret it as a local average treatment effect:

1. *Conditional Independence:* The instrument must be uncorrelated with the error term in our main model, ϵ, conditional on the other covariates in our model.

2. *First Stage:* The conditional covariance between the instrument (1603 grant eligibility) and the endogenous variable (1603 grant receipt) must be non-zero (i.e., $Cov(w, Z|X) \neq 0$).

3. *Monotonicity:* The probability of receiving the 1603 grant must weakly increase when eligible for the grant: $Pr(w_1 \geq w_0|X) = 1$. This rules out the possibility of "defiers"

who would elect to receive the 1603 grant in the pre-period if possible but would not elect to receive the 1603 grant in the post period when it is available.

4. *Homogeneous Treatment Effect*

The first assumption, conditional independence, implies the exclusion restriction: the instrument can only affect outcomes through its effect on the endogenous variable. This assumption is not testable. To mitigate concern over time-varying shocks that generate persistent differences in electricity generation outcomes, we first evaluate the plausibility of the exclusion restriction using descriptive analysis in this section. We attempt to address possible violations of the assumption through a series of sensitivity analysis using additional covariates, alternative bandwidths, and a placebo test (see Section 4).

We plot the trends of key variables over the period 2002 to 2011 to assess the exclusion restriction in Figure 2. In each plot, the vertical dashed line represents the time when the 1603 cash grant policy became available to new wind farms.

The first chart plots the average nameplate capacity (i.e., size) of new wind farms over time. There is no clear trend in average capacity over this period, although the variance does appear to be decreasing over time. Wind speeds – defined as the median wind zone within a wind farm – appear to be trending downward over time. This could be a result of the best sites having been taken in previous periods or improvements in technology that allow economic investments at lower wind speeds. This trend highlights the importance of including time-varying observable characteristics in our model. It also suggests caution in interpreting results given the possibility of other, unobservable covariates that we cannot include in our model. We use various bandwidths to further assess the strength of the exclusion restriction (see Section 4).

We also test for evidence of a break in electricity generation outcomes in the raw data to support our RD design. We compute capacity factor using electricity generation outcomes from 2012-2013 and plot this variable by entry date over time in the final panel of Figure 2. This plot shows heterogeneity over time in capacity factor with no clear trend. There is a drop in capacity factor from 2008 to 2009 as would be expected in an RD, but it is difficult to tell whether this is driven by the 1603 grant policy or just an anomaly given the variation in the data. This motivates a placebo test to formally evaluate whether the effect of the policy is statistically significant relative to estimates from randomly drawn fictitious policy discontinuities (see Section 4).

Figure 2: Trends

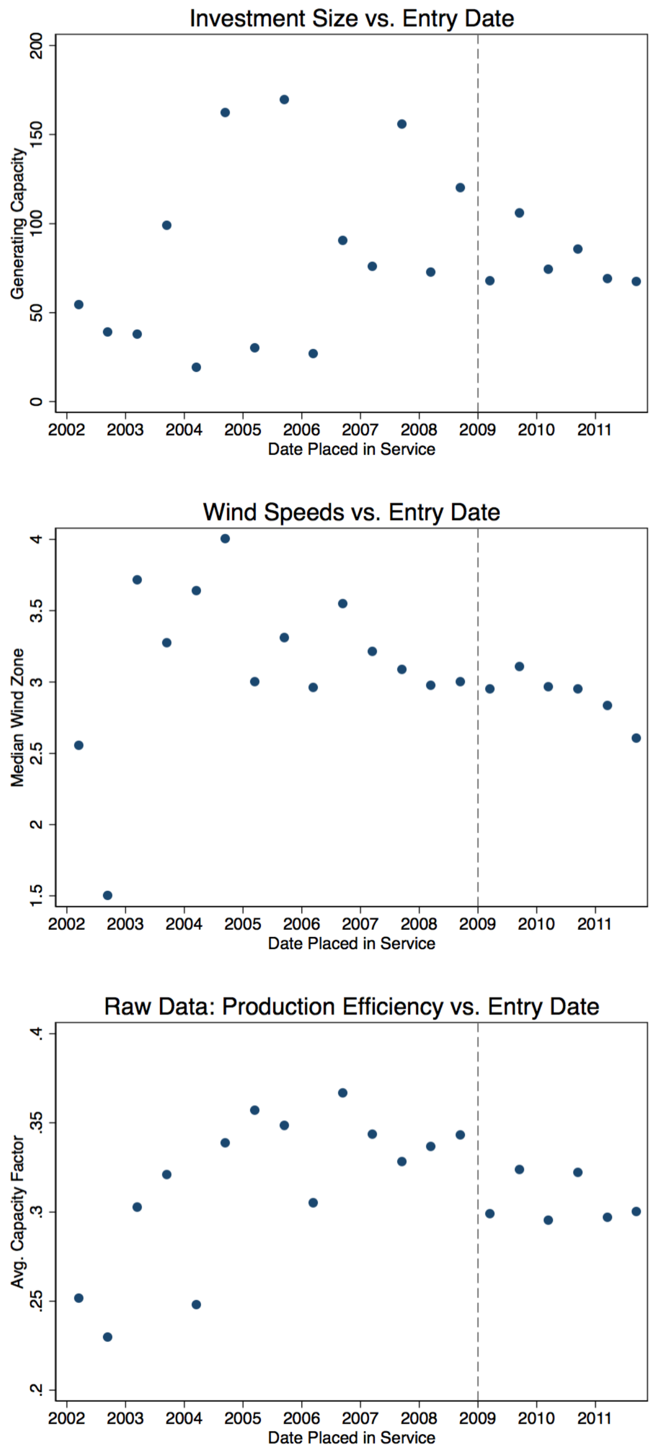


Table 3: Comparison of projects entering one year before and after the policy

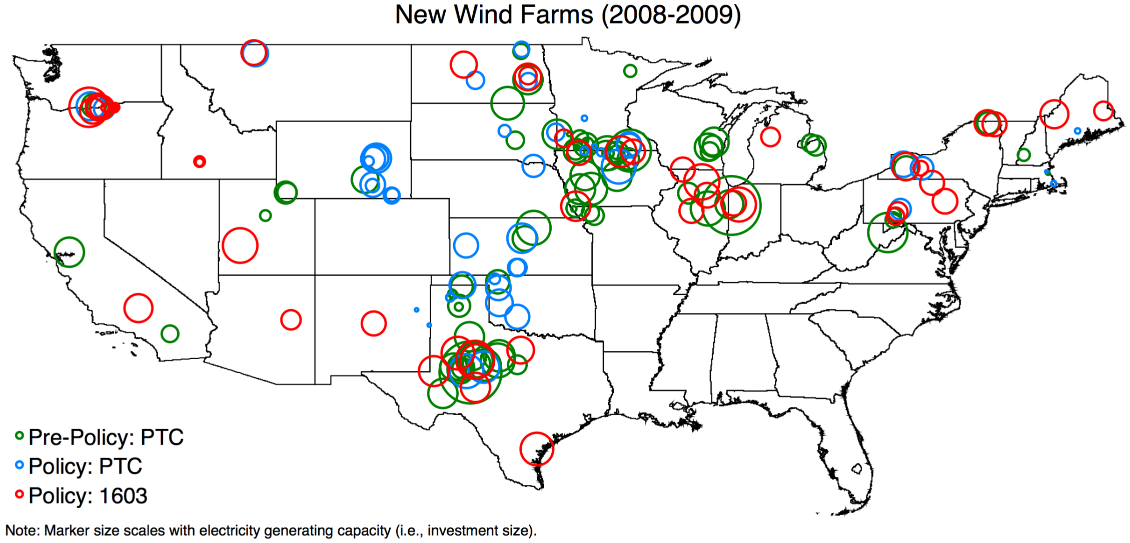
	2008	2009	Difference	(p-value)
Nameplate Capacity	96.13	81.89	14.24	0.25
Turbines	54.89	49.33	5.56	0.47
Median Wind Zone	2.93	3.01	-0.08	0.59
Regulated	0.12	0.20	-0.08	0.11
Capacity Factor	0.32	0.30	0.02	0.02

Notes: 100 facilities entering in 2008 vs. 101 entering in 2009.

Once the policy is established, it is possible that wind farm developers will make changes in how they develop and site future projects, which could violate the exclusion restriction. Our main RD specification therefore uses a bandwidth of one year on either side of the start date of the policy, relying only on a comparison of projects that came online in 2008 and 2009. This has two main advantages. First, long-run trends in wind turbine technology and electricity markets are less likely to influence our results. Second, projects that came online in early 2009 were planned and began construction in 2008, which implies that these facilities were originally designed for the PTC (Bolinger et al., 2010). This helps mitigate concern that 1603 grant recipients are fundamentally different, as may be the case in later periods. Table 3 presents t-tests for key project characteristics, comparing projects coming online in 2008 with those coming online in 2009. All characteristics – capacity, number of turbines, wind speeds, and regulatory status – are statistically indistinguishable. The only statistically significant difference is in the outcome variable of interest, capacity factor.

As a final piece of descriptive evidence, we map the location of new wind farms in 2008 and 2009 in Figure 3. We distinguish between projects that came online in 2008 and 2009. For those that came online, we further distinguish between PTC and 1603 recipients. This map suggests there are regional factors that affect subsidy choice. Wind farms electing to receive the PTC tend to be located in certain regions and states, while 1603 recipients are located in other areas. This selection is not surprising and does not undermine our empirical strategy, as our RD compares firms entering in the policy period (2009) to similar firms entering in the pre-policy period (2008). Most projects completed in 2009, the policy period, are located near a facility built in 2008.

Figure 3: Wind Farm Locations by Period



In sum, these descriptive results suggest that wind farms built just before and after the January 2009 policy change are broadly similar in cross-sectional characteristics, and yet the average capacity factor of the projects coming online in 2009 is significantly lower than that of the projects coming online in 2008. This provides support for our research design and is suggestive of a causal effect of the 1603 cash grant policy on electricity generation.

4 Results

Table 4 reports the main results. All models are run on the restricted sample of wind farms that come online in 2008 or 2009. The dependent variable in each regression is the log of monthly net generation. Appendix Table A.1 reports the results using capacity factor as the dependent variable. The first four models present OLS results and the last four rerun the same second stage specification instrumenting for 1603 status with an indicator for whether wind farm was eligible for the 1603 program. The sample is a balanced panel of monthly generation from 2010 to 2013 and all models contain time dummies.

The primary coefficient of interest (α) appears in the second row of the table, on the variable 1603 Recipient. Just controlling for log capacity, 1603 projects are 17 percent less productive than their PTC counterparts. Adding controls for wind zone and state dummies reduce this estimate to 11.2 and 5.8 percent respectively. The fourth column allows to time

Table 4: Log Generation Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Capacity)	1.005***	1.020***	1.005***	1.008***	1.006***	1.021***	1.008***	1.008***
	(0.0112)	(0.0124)	(0.0118)	(0.0114)	(0.0120)	(0.0127)	(0.0129)	(0.0116)
1603 Recipient	-0.176***	-0.112***	-0.0577**	-0.0624**	-0.202***	-0.148***	-0.113**	-0.0712*
	(0.0302)	(0.0311)	(0.0256)	(0.0240)	(0.0537)	(0.0444)	(0.0468)	(0.0397)
Turbine Size (MW)		-0.00735	-0.0321	-0.00709		-0.00860	-0.0326	-0.00756
		(0.0344)	(0.0276)	(0.0271)		(0.0334)	(0.0268)	(0.0261)
Regulated		0.00789	-0.0363	-0.0240		0.00137	-0.0376	-0.0254
		(0.0357)	(0.0341)	(0.0315)		(0.0362)	(0.0341)	(0.0324)
Constant	5.409***	5.203***	5.071***	5.094***	5.413***	5.220***	5.121***	5.096***
	(0.0496)	(0.106)	(0.0758)	(0.106)	(0.0469)	(0.103)	(0.0729)	(0.103)
Regression Type	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Wind Zone FE	N	Y	Y	Y	N	Y	Y	Y
State FE	N	N	Y	N	N	N	Y	N
Region*Time FE	N	N	N	Y	N	N	N	Y
Adjusted R-sq.	0.931	0.945	0.954	0.964	0.931	0.945	0.953	0.964
Observations	9263	8591	8591	8591	9263	8591	8591	8591
F-stat					120.6	140.1	89.79	106.1

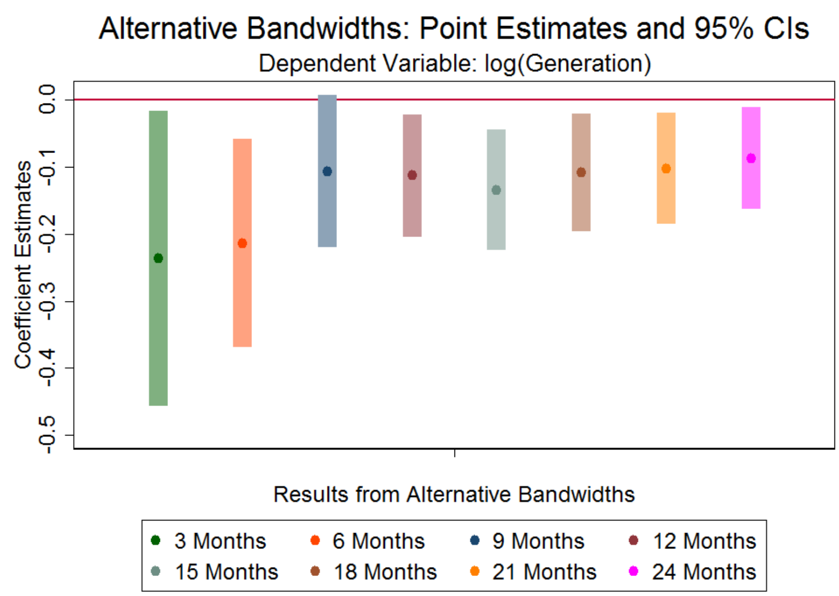
Data include a balanced panel of monthly observations from 2010 to 2013 for all wind farms.
All models contain time dummies. Standard errors clustered by wind farm reported in parentheses.

varying regional unobservables, and yields an estimate of -6.2 percent production. The next four columns rerun the same regressions after instrumenting for 1603 status with an indicator for whether the project came online after 2009. These IV estimates are higher than their OLS counterparts, although they are not statistically different. Our preferred specification, with state and wind zone fixed effects (column 7), generates a treatment affect of -11.3 percent productivity loss associated with the 1603 program.

Bandwidths One concern with this research design is the possibility that firms respond quickly to the policy by designing wind farms specifically for the 1603 cash grant, rather than simply opting for the grant given their pre-existing design. In this case, our empirical analysis would not be able to isolate the causal effect of the investment subsidy on intensive outcomes from producer responses on the extensive margin. We address this concern by varying the temporal bandwidth in our fuzzy regression discontinuity design.

To the extent that investors cannot respond immediately to the introduction of the

Figure 4: Alternative Bandwidths: Generation



Note: Regressions contain time, state, and windzone dummies.

1603 grant program due to binding constraints (e.g., turbine contracts, permitting, etc.), smaller bandwidths are more representative of the true intensive margin effect of the investment subsidy. However, smaller bandwidths generate smaller samples, lessening statistical precision and generating concern over weak instruments. We present coefficients in graphical form for analyses of the effect of 1603 receipt on generation and capacity factor using alternative bandwidths ranging from three months to 24 months (Figures 4 and A.1). The results are consistent and reinforce our baseline findings: all specifications suggest receipt of the 1603 grant (investment subsidy) leads firms to produce less electricity than if they received the production subsidy. This analysis also implicitly addresses the concern over trends discusses in the previous sensitivity analysis.

Placebo Test Our identification strategy assumes wind farms coming online just before and just after the policy innovation are similar: our instrument, the time period during which a plant came online, must affect generation outcomes only through treatment. Failure of the exclusion restriction could undermine our estimates. We use a placebo test to provide additional evidence on this assumption beyond what was presented earlier (see section 3).

Ideally, we would estimate our baseline IV model many times around fictitious policy changes, adapting the sample to each policy change using the same bandwidth. We cannot estimate our full model on alternative time periods because we do not observe counterfactual treatment status for wind farms entering before the 1603 grant was available. Instead, we first construct a fictitious instrument for each placebo policy change based on whether a firm entered before or after the placebo date. We then estimate the two-stage least squares "reduced-form," regressing our outcome on this instrument and other covariates in our model:

$$y_{it} = \eta \cdot 1\left\{\text{Placebo eligible}\right\}_i + \beta X_{it} + \nu_t + \varepsilon_{it} \tag{3}$$

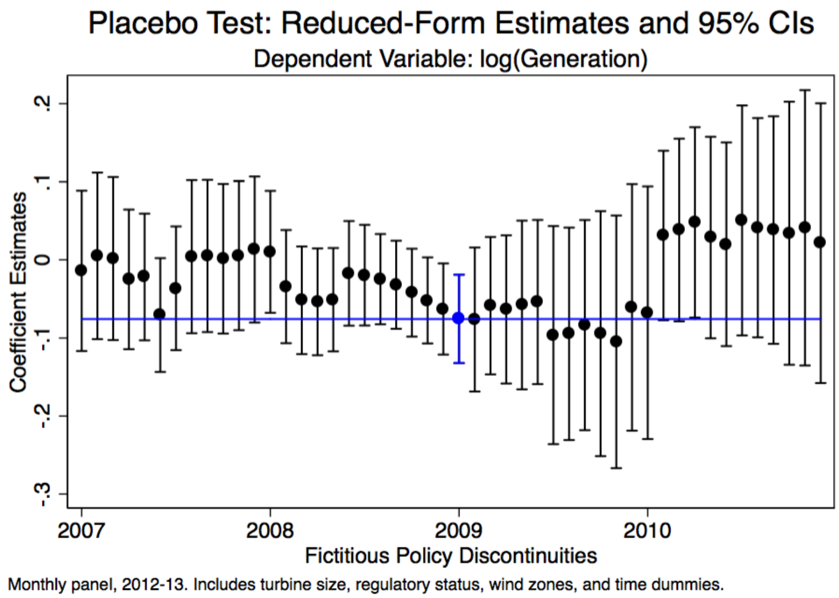
We repeat this exercise for every month from January 2007 to December 2010 and plot the resulting coefficients on the placebo instrument in Figure 5. The horizontal line is the level of the coefficient from the reduced-form model of the true policy innovation date (January 2009).

The results of this placebo analysis provide mixed support for our approach. The true reduced-form of January 2009 is near the top of the distribution, but there are several other dates that produce a similarly large negative coefficient. The true coefficient appears more extreme than its nearest neighbors, who are also affected by the policy since we use a bandwidth of one year. This provides some support for our approach: if our estimation results were an artifact of a long-term trend in wind farm characteristics, the reduced-form coefficient from the true policy discontinuity would not be expected to differ from the fictitious coefficients. However, interpretation of these results is complicated by the fact that none of these coefficient estimates are statistically distinguishable from one another.

4.1 Policy Discussion

This paper has focused on the productivity impacts of incentivizing wind on the margin. In order to provide some context for these results, it's useful to compare the subsidy they would have recieved under the PTC. Figure 6 plots the implied subsidy per megawatt hour under the first ten years of generation for each 1603 grant recipient. We predict post-2103 data for the 1603 recipient wind farms using the observed temporal decay rate in power generation for all wind farms in our data set, which represents virtually all utility-scale wind farms that have come online in the United States since the 1980s. The average

Figure 5: Placebo Test



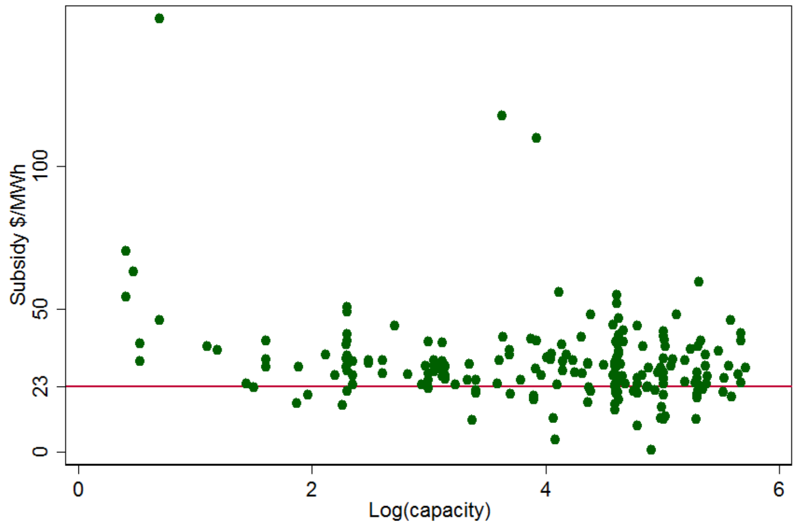
implied subsidy is $29/ MWh. For comparison purposes, the current production tax credit is $23 $/MWh for the first ten years of generation. About 75 percent of 1603 recipients appear to fare better under this capital subsidy, which is not surprising, given that they selected in to it.

5 Conclusion

This research provides evidence on the trade-offs between investment subsidies and output subsidies that is relevant to many areas of public finance. Investment and output subsidies are likely to generate different outcomes in other circumstances. In contexts where output determines (or proxies for) the social benefits of a policy, therefore, output subsidies may outperform investment subsidies. This highlights the importance of using policy to encourage activities that maximize social surplus directly rather than rewarding related activities that may only be loosely correlated with social surplus.

We have exploited an unprecedented natural experiment in tax policy implemented through the 2009 Recovery Act, which provided the taxpayer the choice of subsidy type. This facilitates a rigorous statistical analysis of the impacts of the choice of a capital or

Figure 6: Subsidy per MWh for 1603 Recipients



Of the 205 facilities which took the 1603, 159 had implicit subsidies higher than the current 23$/MWh production tax credit.

a production subsidy on power generation from a zero-carbon power source, wind power. We find that wind projects choosing the capital subsidy had 11% lower power generation than those projects choosing the output subsidy. As a result, the Federal government will spend about 25% more per MWh of generation for wind farms claiming the 1603 grant than it would have if they claimed the production tax credit.

Subsequent work will explore two avenues of related research. First, we will explore the use of a matching estimator. For example, we could envision using a matching analysis to further investigate the issue of selection. In effect, the matching analysis would permit us to decompose the effect of subsidy regime on generation into two components: the effect of selection and the effect of differing marginal incentives across subsidy instruments. One approach would be to estimate a propensity score regression on firms that began generating power when the 1603 cash grant was available to determine these firms' selection rule. We could use a rich set of project characteristics and multiple functional forms – linear probability model, probit, and logit – to limit the influence of modeling assumptions on our results. We would use these results to then predict whether firms that begin producing power before the cash grant was available would have chosen the 1603 cash grant if it had been available. In other words, we could predict counterfactual treatment status for firms who entered before the grant was available. We could then use this counterfactual treatment status to statistically isolate the effect of selection from the effect of the 1603 cash grant on generation outcomes.

Second, we intend to assess the longer-term dynamic implications of subsidy choice. In contrast to this current analysis, which focuses on short-run impacts of an unexpected policy innovation when wind farm developers cannot meaningfully adjust their project design and timing in response to the new policy, we plan to explore how providing subsidy choice affected wind farm entry and the amount of incremental capital investment. In other words, we will relax the assumption that capital is effectively fixed in the short run to determine the extent to which providing the choice of subsidy drew new capital into the wind power market.

References

Aldy, J. E. (2013, January). A Preliminary Assessment of the American Recovery and Reinvestment Act's Clean Energy Package. *Review of Environmental Economics and Policy 7*(1), 136–155. 1

Bolinger, M., R. Wiser, and N. Darghouth (2010, November). Preliminary evaluation of the Section 1603 treasury grant program for renewable power projects in the United States. *Energy Policy 38*(11), 6804–6819. 3.2

Brown, P. and M. F. Sherlock (2011). ARRA Section 1603 Grants in Lieu of Tax Credits for Renewable Energy: Overview, Analysis, and Policy Options. CRS Report for Congress R41635, Congressional Research Service, Washington, D.C. 2.1

Hitaj, C. (2013, May). Wind power development in the United States. *Journal of Environmental Economics and Management 65*(3), 394–410. 1

John Horowitz, Office of Tax Policy, U.S. Treasury (2015). Personal Communication. 1, 2.2

Metcalf, G. E. (2010, August). Investment in Energy Infrastructure and the Tax Code. In J. R. Brown (Ed.), *Tax Policy and the Economy*, Volume 24, pp. 1–33. Chicago: University of Chicago Press. 1

Schmalensee, R. (2012, January). Evaluating Policies to Increase Electricity Generation from Renewable Energy. *Review of Environmental Economics and Policy 6*(1), 45–64. 1

Schmalensee, R. (2013, October). The Performance of U.S. Wind and Solar Generating Units. Working Paper 19509, National Bureau of Economic Research. 1

U.S. PREF (2010, July). Prospective 2010-2012 Tax Equity Market Observations. 2.2

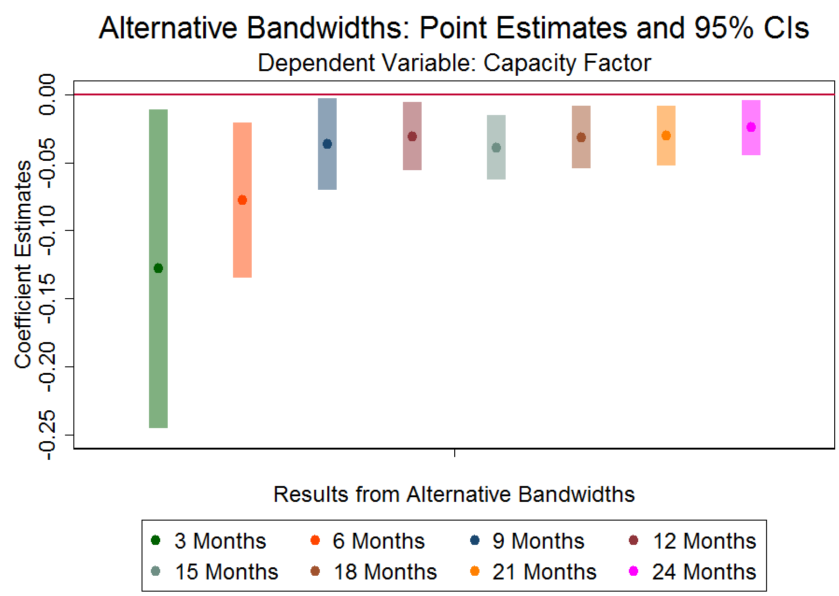
Table A.1: Capacity Factor Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1603 Recipient	-0.0494***	-0.0302***	-0.0176**	-0.0187***	-0.0536***	-0.0416***	-0.0307**	-0.0194*
	(0.00843)	(0.00823)	(0.00695)	(0.00655)	(0.0147)	(0.0124)	(0.0127)	(0.0115)
Turbine Size (MW)		-0.000412	-0.00843	-0.00136		-0.000699	-0.00811	-0.00139
		(0.00916)	(0.00768)	(0.00746)		(0.00898)	(0.00769)	(0.00720)
Regulated		-0.00104	-0.0133	-0.00905		-0.00313	-0.0139	-0.00915
		(0.0101)	(0.00985)	(0.00882)		(0.0105)	(0.00993)	(0.00919)
Constant	0.334***	0.280***	0.242***	0.288***	0.335***	0.286***	0.257***	0.229***
	(0.00491)	(0.0248)	(0.0155)	(0.0285)	(0.00549)	(0.0251)	(0.0177)	(0.0282)
Regression Type	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Wind Zone FE	N	Y	Y	Y	N	Y	Y	Y
State FE	N	N	Y	N	N	N	Y	N
Region*Time FE	N	N	N	Y	N	N	N	Y
Adjusted R-sq.	0.0396	0.386	0.474	0.588	0.0393	0.384	0.472	0.588
Observations	9263	8591	8591	8591	9263	8591	8591	8591
F-stat					120.2	134.3	86.86	103.8

Data include a balanced panel of monthly observations from 2010 to 2013 for all wind farms.
All models contain time dummies. Standard errors clustered by wind farm reported in parentheses.

A Appendix

Figure A.1: Alternative Bandwidths: Capacity Factor



Note: Regressions contain time, state, and windzone dummies.