School District Revenue Shocks, Resource Allocations, and Student Achievement: Evidence from the Universe of U.S. Wind Energy Installations

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Abstract

We use data on the timing and location of the universe of wind energy installations in the U.S. from 1995 through 2016 to examine the impacts of wind energy installation on school district revenues, expenditures, resource allocations, and student achievement. We find that wind energy installation led to large, exogenous increases in local revenues to school districts, with only minimal offsetting reductions in state-aid. Per-pupil expenditures increased accordingly, with the majority of the revenues spent on capital outlays, causing dramatic increases in capital expenditures, but only modest increases in current expenditures and modest declines in pupil teacher ratios. We find fairly precisely estimated zero impacts of wind energy installation on school district average test scores through several years after wind energy installation, suggesting that the capital investments on which these districts spent most of the marginal dollar, while perhaps having other benefits to students, had little or no detectable impact on their achievement.

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I. Introduction

Does increased school funding improve student outcomes? Providing a well-identified, generalizable answer to this question has proven difficult due to a lack of nationwide, plausibly exogenous variation in school funding. Several studies have overcome this challenge by examining the nationwide impacts of state school finance reforms (Hoxby, 2001; Card & Payne; 2002; Jackson, Johnson, & Persico, 2016; Lafortune, Rothstein, & Schanzenbach, 2018; Klopfer, 2017; Candelaria & Shores, 2019; Biasi, 2019; Brunner, Hyman, & Ju, 2018). Other work has examined shocks to school funding in a single state, either due to a school finance reform (e.g., Downes, 1992; Papke, 2005; Hyman, 2017), a kink or quirk in the state aid formula (Kreisman and Steinberg, 2019; Gigliotti and Sorensen, 2019), or local capital campaigns (Cellini, Ferreira, & Rothstein, 2010; Neilson and Zimmerman, 2014; Martorell, Stange, & McFarlin, 2016; Lafortune and Schonholzer, 2018). While state-specific studies provide important contributions, generalizability is always a concern. School finance reform is the only studied policy that has increased school funding on a national scale,[1] and while it is an important reform, its effects on student outcomes may not be generalizable to other types of school revenue shocks or policies affecting school funding.

In this paper, we provide evidence on the impacts of increased school funding from a novel source of variation affecting most states since the 1990s: wind energy installation. Wind energy production has grown substantially in the U.S. over the past decades, with less than 2 GW of capacity in 1995, and over 96 GW in 2018 (Energy Information Administration, 1995; AWEA, 2019). Furthermore, it is estimated that new wind projects will provide $8 billion in annual tax revenues for local jurisdictions between 2017 to 2020 (Navigant Consulting, 2017). The growth in wind energy production over time, coupled with the significant variation both across and within states in the geographical location of wind energy production, provides an ideal setting to examine how wind energy installation has impacted school district finances and student outcomes.

We use data on the timing and location of the universe of wind energy installations in the U.S. from 1995 through 2016 to examine the impacts of wind energy installation on school district revenues, expenditures, resource allocations, and student achievement. We geocode wind energy installations to school districts, and combine these data on the timing and capacity of wind installations with National Center for Education Statistics (NCES) and Schools and Staffing Survey (SASS) school district data on revenues, expenditures, staffing, enrollments, and teacher salaries, and with student microdata from the National Assessment for Education Progress (NAEP) on student achievement. We use event-study and

[1] Jackson, Wigger, and Xiong (2018) examine the closely related question of whether *decreases* in school funding matter, by exploiting negative shocks to school spending due to the Great Recession. The Great Recession is clearly national scale, but the question of the impacts of decreases in spending is substantively different from the question of the impacts of spending increases.

difference-in-differences methodologies that exploit the plausibly exogenous timing of wind energy installations.

We find that wind energy installation led to large, exogenous increases in total per-pupil revenues due to increases in local revenues, with only minimal offsetting reductions in state-aid. Per-pupil expenditures increased accordingly, with the majority of the revenues spent on capital outlays, causing dramatic increases in capital expenditures, and only modest increases in current expenditures, and modest decreases in class size. Importantly, we find no evidence that any of our outcomes of interest were trending higher or lower prior to wind energy installation. Turning to student achievement, we find fairly precisely estimated zero impacts of wind energy installation on school district average test scores through several years after wind energy installation, suggesting that the capital investments on which these districts spent most of the marginal dollar, while perhaps having other benefits to students, had little or no detectable impact on their achievement.

Finally, we explore an additional way in which school districts may benefit from wind energy installation. A large literature in public economics examines the extent to which local jurisdictions, such as school districts, respond to exogenous increases in revenue by providing property tax relief. The large increases in local revenues from wind energy installation suggest that districts are certainly not taking all of these windfalls as property tax relief, but are they taking any? To shed additional light on this question, we use historic school district property tax rate data in Illinois and Texas, two of the largest wind producing states, to examine the impact of wind energy installation on school district property tax rates. We find that, in Illinois, districts respond to the increased revenues from wind installation by reducing their property tax rates and taking part of the windfall as property tax relief. In Texas, where state laws incentivize districts with wind energy installations to pass new bonds to promote capital spending and to pay for these bonds by increasing property tax rates, we subsequently see tax rates slightly increase after wind energy installation.

Our study makes several contributions to the literature. First, it provides the first nationwide study of the impacts of wind energy installation on school district finances and student achievement. Wind energy is becoming increasingly common across the country as states and municipalities aim to decrease their reliance on fossil fuels. It is important to understand the impacts of this shift on local school districts finances and student achievement. Prior work has examined the impacts of wind energy installation on school finances in Texas and Oklahoma (De Silva et al., 2016; Reategui & Henderson, 2011; Ferrel & Conaway, 2015; Kahn, 2013; Castleberry & Greene, 2017; Loomis & Aldeman, 2011).[2] However, our

[2] A small number of studies have also examined the impact of the shale energy boom in Texas on school district finances (Weber et al., 2014; Newell & Raimi, 2014; Marchand & Weber, 2015).

study is the first to examine the effects of wind energy installation across multiple states and on student achievement.

Second, our paper contributes to the public economics literature on flypaper effects. Some studies in this literature find substantial or even complete flypaper (Feiveson, 2015; Dahlberg et al., 2008), while others find little or no flypaper (Knight, 2001; Gordon, 2004; Lutz, 2010; Cascio, Gordon, & Reber, 2013). While some states, such as Illinois, reduce their local property tax rates in response to wind energy installation, the large increases in local revenue that we find imply strong flypaper effects. Further, as in other recent work, we find that local context affects the extent to which revenue shocks are taken as property tax relief instead of increasing school budgets (Brunner et al., 2018).

Finally, our study provides nationwide evidence on the effects of increased school spending on student achievement from an exogenous source of variation in spending other than school finance reform. Our finding that most of the increases in school spending are devoted to increased capital expenditures and that these have no discernible impacts on student achievement, contributes to the small literature on the impacts of capital expenditures on student achievement. This literature finds mixed results: Cellini et al. (2010) and Martorell et al. (2016) find zero impact of local capital campaigns on student achievement in California and Texas, respectively. In contrast, Neilson and Zimmerman (2014) and Lafortune and Schonholzer (2018) finds positive impacts of capital spending in Connecticut and California, respectively, while Conlin & Thompson (2017) find negative short-term effects of capital spending but long-term positive effects in Ohio. Our paper provides the first national evidence on the impacts of capital spending, finding zero impacts, as in Cellini et al. (2010) and Martorell et al. (2016). Every year, hundreds of districts across the country use the large revenue inflows from wind energy installation to improve their schools' physical infrastructure, and while this may be improving students' well-being in some way, it does not appear to be improving their academic achievement.

II. Wind Energy and Tax Revenue

As noted previously, wind energy production in the United States has increased substantially over the last several decades, growing from less than 2 GW of total capacity in 1995 to over 96 GW in 2018. Furthermore, there is wide variation across states and localities in their support and implementation of wind energy installation. For example, wind energy currently comprises 36%, 34%, and 32% of generated electricity in Kansas, Iowa, and Oklahoma, respectively, and 3%, 0.7%, and less than 0.01% in New York, Massachusetts, and Connecticut. Commercial wind installations or projects in the United States typically consist of several individual turbines, usually ranging in capacity from 1 to 3 megawatts (MW) each. By 2018, there were over 1,600 commercial wind installations in the United States comprised of over 55,000 individual turbines. The mean and median number of turbines in a commercial wind

installation or project as of 2018 was 40 and 22 respectively, while the mean and median capacity of commercial wind projects was 63 and 30 MW, respectively.[3]

Figures Ia – Id document the geographical location and growth of wind energy production in the continental United States between 1995 and 2016. The figures illustrate installed wind turbine capacity (in megawatts) by county and year. In 1995, wind energy production was extremely rare and was concentrated almost entirely in California and to a lesser degree in Texas. By 2002, wind energy production had begun to spread across the mid- and north-west while also expanding throughout Texas counties. As illustrated in Figure 1d, by 2016, wind energy production had spread across 38 states in the continental US, the main exception being the southeastern US.[4]

There is substantial variation across states in the property tax treatment of commercial wind energy projects. Specifically, as noted by the American Wind Energy Association (AWEA, 2017), property tax treatment typically falls into five broad categories: 1) states that offer no special property tax treatment, implying wind installations are taxed just like other real property; 2) states that adopted specific formulas for taxing wind energy installations; 3) states where local jurisdictions or the state have the authority to offer special property tax treatment; 4) states that utilize an income generation or production tax method for wind energy installations; and 5) states that offer full or partial property tax exemptions.[5]

The property tax treatment of wind energy projects is even more complex than suggested by the state laws and policies discussed above given that many states allow local jurisdiction to offer commercial wind projects special tax treatment through mechanisms such as payments in lieu of taxes (PILOTS), property tax abatements, and tax increment financing. For example, while Oregon offers no special property tax treatment to wind energy installations, counties can establish Rural Renewable Energy Development Zones (RREDZ) which provide commercial wind projects located within the zone with a 3 to 5-year local property tax exemption.[6] Maine also offers no special property tax treatment to wind energy installations but counties can approve the creation of a tax increment financing (TIF) districts that provide tax relief for the developers of wind installations. Similarly, while Minnesota has a wind energy production tax, wind farm owners may negotiate with the county in which the farm is located for payments in lieu of the wind energy production tax (PILOTS), with the revenue from the PIILOT going towards the maintenance of public infrastructure and services. As a final example, New York provides

[3] Authors calculations based on data from the United States Wind Turbine Database (USWTDB).
[4] See Appendix Figures Ia – Id for analogous maps of county-level installed wind turbine capacity per-pupil (in kilowatts), which look very similar to main Figures Ia – Id.
[5] For more details on the property tax treatment of wind energy, see "Property Tax Treatment of Commercial Wind Projects", American Wind Energy Association and Polsinelli PC, 2017.
[6] The state also has a Strategic Investment Program (SIP) that provides a 15 year partial property tax exemption.

wind energy installations with a 15-year property tax exemption. However, it also allows local jurisdictions, including school districts, to mandate PILOTs for up to 15 years, and as of 2019, no commercial wind project in New York has been built without a PILOT agreement that provides significant property tax relief.[7]

Because most school districts in the United States are independent jurisdictions with their own taxing authority, when a wind energy installation begins operation within the boundaries of a school district, the district will typically benefit financially from the expansion of its property tax base. However, the degree to which a school district benefits from a wind energy installation will depend on both the state and local laws and ordinances governing wind energy property taxation discussed above and the interaction of those laws with state school finance formulas. For example, in California, school districts are subject to revenue limits which limit the total amount of revenue a district can collect from local property taxes and state aid. Each district's revenue limit is set by the state. When local property tax revenue increases, state aid is decreased proportionally so that a district remains within its revenue limit. As a result, increases in a school district's tax base that result from wind projects have little effect on school district operating revenues.[8] Similarly, Wyoming has a centralized system of school finance and thus any revenue that is generated from wind energy projects is captured by the state and redistributed through the state's school foundation program.

Texas is another example where state laws governing the taxation of wind energy installations and state school finance formulas result in a complicated system of local taxation of wind energy. School districts in Texas may approve a tax abatement agreement, known officially as a Chapter 313 agreement, which allows a temporary, 10-year limit on the taxable value of a new wind project. Chapter 313 agreements apply only to school district taxes levied for maintenance and operations (M&O). Taxes for debt service, known as interest and sinking (I&S) fund payments are not subject to the limitation. Furthermore, Chapter 313 requires some portion of the increase in assessed value due to a wind project to go on a school district's tax rolls for M&O while the full increase in assessed value goes on a school district's tax rolls for I&S.[9] Because Chapter 313 agreements increase a school district's tax base, and state aid in Texas is tied to a district's tax base, state aid generally declines when a Chapter 313

[7] PILOTs are typically based on some fixed amount of the value of the wind project property. PILOT revenue is distributed to the counties, towns and school districts in which the wind project resides typically in proportion to the mill rates of those taxing jurisdictions.

[8] If a school district's tax base is large enough that even without state aid it would exceed its revenue limit, then the state allows the district to keep the revenue. Such districts are known as basic aid districts. To date, however, no district with a wind energy project is a basic aid district, implying none have the ability to use wind project tax revenues to increase their current expenditures.

[9] The minimum limitation value under a Chapter 313 agreement for M&O varies by school district from between $10 million to $100 million in property value.

agreement goes into effect. However, because only part of the assessed value of a wind project is added to the tax rolls for the abatement period, Chapter 313 agreements typically result in a small decline in state aid during the period when the abatement agreement is in effect. Once the tax abatement period ends, a wind project is taxed at full value resulting in a large decline in state aid. Specifically, once a Chapter 313 agreement ends, most of the property tax revenue generated from a wind project goes back to the state due to the Chapter 41 Recapture law in Texas (commonly referred to as Robin Hood). Because revenue designated for I&S (debt service) is not subject to recapture and furthermore because the full increase in assessed value due to a wind project immediately goes on a school district's tax rolls for I&S, there is a strong incentive for school districts in Texas to pass a bond for school capital projects and use the wind project revenues to "subsidize" the capital improvement projects.

As a final example, Illinois has a uniform wind energy tax that is considered a model for property taxation of wind projects. In 2007, the Illinois legislature set the real property cost basis of a wind energy devices at $360,000 per megawatt of nameplate capacity. The wind energy tax formula used in Illinois is also adjusted annually for inflation using the CPI and for depreciation via a transparent and uniform formula that applies to all wind projects. The tax revenue from wind projects that a school district receives is based on a percentage of the assessed value of the property within the boundaries of the school district. When a district's tax base increases due to a new wind project, the amount of state aid the school district receives is reduced. However, state aid is not generally reduced dollar-for-dollar with increases in local revenue. As a result, school districts generally benefit from increases in local property tax payments resulting from a wind project. The usage of any additional revenues is up to the discretion of local school districts and therefore can be used to increase current or capital expenditures or to reduce local tax rates.

Appendix A provides more information on state and local laws and ordinances governing wind energy property taxation and how those laws interact with state school finance formulas. We present that information for the 15 states with the largest installed capacity as of 2018. These state account for approximately 88% of the total installed wind capacity in the nation.

III. Data

We construct an original panel dataset that combines information on: 1) the universe of wind energy installations in the continental United States; 2) school district revenues, expenditures, pupil-teacher ratios, and teacher salaries; 3) student achievement, as measured by standardized test scores; and 4) census data on the socio-economic characteristics of school districts.

National data on installed wind capacity comes from the United States Wind Turbine Database (USWTDB). The USWTDB contains information on the date each wind turbine became operational, the wind capacity of each turbine measured in kilowatts, and the longitude and latitude of each turbine. We

use this information to geocode every turbine to a single school district using 1995 school district boundary files maintained by the National Center for Education Statistics (NCES). [10] We then create a panel dataset containing annual data on total installed wind capacity in each school district by aggregating information on the capacity of every turbine in operation in a school district in a given year up to the school district level.

We combine the annual data on school district installed wind capacity with annual data on district revenue and expenditures from the Local Education Agency Finance Survey (F-33) maintained by the NCES. The F-33 surveys contain detailed annual revenue and expenditure data for all school districts in the United States for the period 1994-95 to 2015-16. In the empirical work that follows we utilize the following eight revenue and expenditure outcomes: 1) local revenue, which is primarily composed of property tax revenue; 2) state revenue, which primarily consists of state aid (grants) to local school districts, revenue in lieu of taxes, and payments on behalf of school districts; 3) federal revenue; and 4) total revenue, which is the sum of local, state and federal revenues. The expenditure outcomes are: 1) current expenditures, which consists of expenditures for daily operations such as teacher salaries and supplies; 2) capital outlays, which consist of expenditures for new school construction and modernization as well as the purchase of equipment and land; 3) other expenditures, which consists of adult and community education, interest on debt, and payments to other governments (such as the state) and school systems (such as charter and private schools); and 4) total expenditures, which is the sum of current expenditures, capital outlay, and other expenditures. All of these variables are divided by enrollment to obtain per-pupil measures and are adjusted to real 2017 dollars using the Consumer Price Index (CPI).

We merge our combined dataset with several other data sources. First, for the period 1994-95 to 2015-16, we merge in data from the annual common core of data (CCD) school district universe surveys that provide staff counts for every school district. We then construct district-level estimates of the pupil-teacher ratio by dividing total full-time equivalent teachers (FTE) by total district enrollment.[11] Second, we combine our dataset with data from the Special School District Tabulations of the 1990 Census on median household income, fraction of the population at or below the poverty line, fraction white, fraction rural, fraction age 65 or older, and fraction of adults 25 and older with a Bachelor's degree.[12] Third, we

[10] The matched USWTDB and school district boundary data includes 1,916 "behind the meter" turbines. Because these turbines are intended for on-site use rather than being part of a larger wind energy project designed for commercial electrical generation, we drop these turbines from the analysis. We note, however, that all of our results are robust to including these behind the meter turbines.

[11] Because staff counts tend to be noisy, we follow Lafortune et al. (2018) and set values of the pupil teacher ratio that were in the top or bottom 2% of the within state-year distribution to missing.

[12] 1990 district demographic data is missing for a small number of school districts. Rather than excluding these districts, we matched school districts to counties and then replaced the missing district-level values of each variable with their county-level equivalent.

also combine our dataset with information on teacher compensation. Teacher salaries are typically a lock-step schedule based on years of experience and whether or not a teacher has a Master's degree. While district average teacher salaries are provided in the CCD, these conflate changes to the teacher salary schedule with changes in hiring of new teachers that are usually paid less than the average teacher in the district. Because information on district teacher salary schedules are not available in our primary CCD data, we use salary schedule information from the U.S. Department of Education Schools and Staffing Survey (SASS), which surveys a random cross-section of school districts every few years about staffing, salaries, and other school, district, teacher, and administrator information. We focus on district base teacher salary, which is available in every wave and particularly informative about average teacher salaries given the high rate of teacher attrition and relatively large degree of compression in teacher wages. Unfortunately, given the limited number of years and overlap of districts across waves, we lose about 94 percent of our sample size.

Finally, we use restricted-access microdata from the National Assessment of Educational Progress (NAEP) to examine student achievement. The NAEP provides representative samples of math and reading test scores in grades four and eight from over 100,000 students nationwide every other year since 1990. In each wave, representative samples of school districts from across the U.S. are required to have their students take the NAEP math and reading test in grades four and eight.[13] We restrict the data to the NAEP reporting sample and to public schools. Rather than providing a single score for each student, NAEP provides random draws from each student's estimated posterior ability distribution based on their test performance and background characteristics. We use the mean of these five draws for each student, essentially creating an Empirical Bayes "shrunken" estimate of the student's latent ability. Following Lafortune, Rothstein, and Schanzenbach (2018), we then standardize the mean score by subject and grade to the first year each subject and grade was tested. We then aggregate these individual-level scores to the district-subject-grade-year level, weighting the individual scores by the individual NAEP weight. We merge the data to our primary dataset using the NCES unique district ID that is available in the Common Core of Data (CCD) and in the NAEP data from 2000 onward.[14]

While the NAEP provides nationally representative test score data back to the 1990s, it suffers from small sample sizes relative to our baseline data because it is only every other year and a sample of districts. We attempt to partially remedy these drawbacks by merging the NAEP with a new source of test score data: the Stanford Education Data Archive (SEDA). For every state and for grades three through eight, researchers at Stanford collected district test scores from 2009-2015 and standardized those test

[13] The NAEP also tests other subjects such as writing, science, and economics, but we focus on math and reading because they were tested most consistently across years.
[14] Prior to 2000, the NAEP data did not include this unique district ID. NCES provided us with a crosswalk that they developed in collaboration with Westat to link the NAEP district ID and the NCES district ID for those earlier years.

scores to the NAEP scaling (Reardon et al., 2018).[15] We start with the NAEP grade 4 and 8 data from 1996-2015, and then fill in for 2009-2015 SEDA grade 4 and 8 scores for any district*year without a NAEP score. The result is a test score from a sample of districts every other year from 1996-2007, and scores for the universe of districts every year since 2009. We standardized all scores to mean zero and standard deviation one within year, grade, and subject.

We restrict our main sample in several ways. First, we limit the sample to traditional school districts, namely elementary, secondary and unified school systems, and thus drop charter schools, college-grade systems, vocational or special education systems, non-operating school systems and educational service agencies.[16] Second, we drop states (and thus all districts within a state) without any wind energy installations over our sample time period of 1995-2016.[17] Third, we drop districts with observed wind energy installations if the maximum wind capacity over our sample time frame was less than 2 megawatts (MW).[18] Fourth because the NCES finance data tends to be noisy, we restrict the sample to school districts with enrollment of 50 students or more in every year of our sample. Fifth, we drop Kansas from the analysis since the state provides a full life time exemption from property tax payments, and thus school districts do not benefit from wind energy projects. We similarly drop California and Wyoming from the analysis because their school finance systems prevent revenue generated from wind energy installations from flowing to local school districts (see Section II). We show in Table 4 that the results are nearly identical when we include California, Kansas, and Wyoming.

Our final sample consists 10,157 school districts located in 34 states over the period 1995-2016.[19] Among the 10,157 districts in our sample, 618 had a wind energy installation at some point between 1995 and 2016. Table 1 presents summary statistics for the outcome measures used in our analysis. The table presents means and standard deviations for the full sample and separately for districts with and without

[15] These test scores are part of state standardized exams used for accountability purposes.
[16] We also drop a small number of observations associated with the following types of educational agencies: 1) Regional education services agencies, or county superintendents serving the same purpose; 2) State-operated institutions charged, at least in part, with providing elementary and/or secondary instruction or services to a special-needs population; 3) Federally operated institutions charged, at least in part, with providing elementary and/or secondary instruction or services to a special-needs population; and 4) other education agencies that are not a local school district.
[17] Those states are: Alabama, Arkansas, Connecticut, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina and Virginia.
[18] According to U.S. Department of Energy, early commercial scale wind turbines had an average capacity of 1.5 MW. Turbine capacity has increased over time with the average capacity of a turbine being 2.15 MW in 2016. Thus, by limiting the sample of school districts with wind energy installations to those with 2 MW or more, we are essentially eliminating districts with a single turbine. We show in Table 4 that our results are robust to including districts with aggregate wind capacity of less than 2 MW.
[19] The states are: Arizona, Colorado, Delaware, Idaho, Illinois, Indiana, Iowa, Main, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, West Virginia, and Wisconsin.

wind energy installations. Districts with wind energy installations have slightly lower per-pupil local and total revenue and also slightly lower per-pupil total and current expenditures. Districts with wind energy installations also have lower pupil-teacher ratios and base teacher salaries.

To provide additional context about how districts with and without wind energy installations differ, Table 2 presents summary statistics for our outcomes and control variables at baseline. For the outcome measures and enrollment, baseline corresponds to the 1994-95 year. For all the control variables other than enrollment, baseline corresponds to 1989-90. Similar to Table 1, districts with wind energy installations have lower per-pupil local and total revenues and lower per-pupil total and current expenditures, although the differences are larger in Table 2 than in Table 1. Not surprisingly, districts with wind installations tend to be smaller and significantly more rural. They also tend to contain households with lower income and lower educational attainment.

IV. Methodology

To examine the effect of wind energy installation on school district revenues, expenditures and resource allocations, we employ a difference-in-differences identification strategy. We begin with a non-parametric event-study specification of the following form:

$$y_{ist} = \sum_{j=-6}^{8} \gamma_j T_{j,ist} + X_{is}\theta_t\kappa + \delta_i + \lambda_{st} + \eta_{ist}, \quad (1)$$

where y_{ist} denotes an outcome of interest for district *i* in state *s* in year *t*; $T_{j,ist}$ represents a series of lead and lag indicator variables for when a wind energy installation became operational in district *i*, X_{is} is a vector of school district characteristics at baseline interacted with a linear time trend, θ_t; δ_i is a vector of school district fixed effects; λ_{st} is a vector of state-by-year fixed effects, and η_{ist} is a random disturbance term. We re-center the year a wind energy installation became operational so that $T_{0,ist}$ always equals one in the year the wind project became operational in district *i*. We include indicator variables for 1 to 6 or more years prior to a wind project becoming operational ($T_{-6,ist} - T_{-1,ist}$) and 1 to 8 or more years after the beginning of operation ($T_{1,ist} - T_{8,ist}$). Note that T_{-6ist} equals one in all years that are 6 or more years prior to the wind project becoming operational, and $T_{8,ist}$ equals one in all years that are 8 or more years after the beginning of operation. The omitted category is the year the wind project became operational, $T_{0,,ist}$.

The coefficients of primary interest in (1) are the $\gamma_j's$, which represent the difference-in-differences estimates of the impact of wind energy installation on our outcomes of interest in each year from t_{-6} to t_8. The estimated coefficients on the lead treatment indicators ($\gamma_{-6}, \ldots, \gamma_{-1}$) provide

evidence on whether our outcomes were trending prior to the time a wind energy project became operational in district *i*. If wind energy induces exogenous increases in district revenues, expenditures etc., these lead treatment indicators should generally be small in magnitude and statistically insignificant. The lagged treatment indicators ($\gamma_{+1}, \ldots, \gamma_{+8}$) allow the effect of wind energy installations on our outcomes of interest to evolve slowly over time and in a nonparametric way. Given that treatment (wind energy installation) occurs at the district level, in all specifications we cluster the standard errors at the school district level.

The inclusion of state-by-year fixed effects in equation (1) implies that our estimates are identified off of within state variation in school district exposure to wind energy installations. Thus, our specifications control nonparametrically for differential trends in our outcomes of interest that are common to all districts within a state and across time. In our most parsimonious specification, X_{is} includes 1995 district enrollment and 1990 district median income and the fraction of adults 25 and older who have a Bachelor's degree. We then add 1990 district fraction of the population at or below the poverty line, fraction white, fraction 65 or older, and fraction rural. We exclude time-varying characteristics because they could be affected by the installation of a wind energy project within a school district (i.e., endogenous controls). Therefore, we include each characteristic interacted with a linear time trend to allow for differential trending by districts with different baseline values of these characteristics.

Given the substantial effect of statewide school finance reforms (SFRs) on district finances and student achievement during our sample period, we additionally control in all models for the impacts of SFRs by including a dummy for the implementation of a SFR using SFR codings from Brunner et al. (2018). We allow the effects of SFRs to vary by district income by interacting the SFR dummy with dummies for terciles of the within-state 1990 median income distribution.

We complement the event-study specification with a standard difference-in-differences model to increase our precision by pooling estimates across post-wind energy installation years:

$$y_{ist} = \alpha_1 Treat_{ist} + X_{is}\theta_t + \delta_i + \lambda_{st} + \varepsilon_{ist}, \quad (2)$$

where $Treat_{ist}$ is an indicator that takes the value of one in all years after a wind project becomes operational in district *i*, ε_{ist} is a random disturbance term, and all other terms are as defined in equation (1). The coefficient of primary interest in equation (2) is α_1 which represents the difference-in-differences estimate of the effect of treatment (wind energy installation) on our outcomes of interest.

Finally, to account for the fact that the capacity of wind energy projects varies across districts, in our preferred specifications we allow for continuous treatment by replacing $Treat_{ist}$ with the installed wind project capacity in a district:

$$y_{ist} = \beta_1 KWPP_{ist} + X_{is}\theta_t + \delta_i + \lambda_{st} + \upsilon_{ist}, \quad (3)$$

where $KWPP_{ist}$ is installed wind project capacity in district *i* in state *s* in year *t* measured in kilowatts per-pupil, υ_{ist} is a random disturbance term, and all other terms are as defined in equation (1). $KWPP_{ist}$ is equal to zero for district-years with no installed wind energy. The coefficient of primary interest in (3) is β_1 which represents the effect of a one-kilowatt per-pupil increase in wind energy capacity on our outcomes of interest.

V. Results

We begin our analysis by examining the impact of wind energy installation on school district revenues and expenditures using the event-study model described above. Specifically, we estimate equation (1) for our baseline sample of school districts from 1995 to 2016, and plot estimated $\gamma_j's$ and associated 90% confidence intervals from these regressions. Figure IIa shows that within two years of when a district first installs wind energy, local revenues increase by approximately $1,000 per pupil. This increase in revenue grows to between $1,500 and $1,900 per pupil several years after installation. This effect represents a very large increase given the mean local revenue in districts with installed wind energy of $6,138. Importantly, we see no evidence of a pre-trend in local revenue prior to installation.

Figure IIb shows similar, though slightly attenuated impacts of wind energy installation on school district total revenue. The magnitudes are between $1,500 and $1,600 several years out. Again, the point estimates are near zero and statistically insignificant prior to wind energy installation. Finally, given that the other large revenue source for districts aside from local revenue is state aid, Figure IIc examines impacts on district revenue from the State. We find small, marginally statistically significant declines in state aid after wind energy installation of between $100 and $300 per pupil. These decreases are consistent with the fact that many state aid formulas provide less aid to districts when local revenues are higher. Again we see no evidence of pre-trends.

We next examine whether these increases in revenues translate into increased expenditures, and what types of expenditures districts allocate the revenue increases toward after wind energy installation. Figure IIIa shows that total expenditures per pupil increase in a similar pattern over time as total revenues after wind energy installation, though with slightly higher magnitudes. Total expenditures increase by between $1,500 and $2,000 per pupil several years after installation. Current expenditures increase only slightly, by between $200 and $300 per-pupil relative to a mean of approximately $11,000 several years after (Figure IIIb). Districts spend a significant share of the revenues toward increased capital spending, which increases by $500 and $1,000 after wind energy installation, off a mean of $1,355 per pupil (Figure

IIIc). Finally, in Figure IIId we find that other expenditures, which is simply non-capital and non-current expenditures, increases substantially, also by between $500 and $1000 several years after wind energy installation. None of the figures examining district expenditures show any evidence of differential pre-trends.

We next examine whether any of these expenditure increases lead to impacts on commonly studied inputs to education production, for example, class size and teacher compensation. Figure IVa shows a small, and not quite statistically significant decline in the pupil-teacher ratio, which is our measure of class size, on the order of 0.1 pupils per teacher, relative to a mean of 13.4. This is less than a 1% decline in class size, consistent with the small (1-2%) increases in current spending. As shown in Figure IVb there is no apparent impact on base teacher salaries, however, given the far smaller sample using the SASS data, the results are too imprecise to gain much inference.

One noticeable pattern in the revenue and expenditure results is that the effects of wind energy installation apparently grow over time. It is not immediately clear why this would be the case, as another hypothetical effect could have been that the installation occurs and districts immediately and permanently reap the tax benefits, leading to a sudden increase in the level, but no change in the trend in revenues. We examine and rule out several possible explanations for this pattern. First, the effects on revenues and expenditures are per-pupil, so if installations cause enrollments to decline, then this would cause the pattern that we observe. We estimate the event-study model where the dependent variable is district enrollment and find no impact.[20]

A second possible explanation for the growing effects over time is that we are examining the impact relative to the year of the first wind energy installation in the district. However, 37.5% of districts in our sample with installed wind energy install additional wind turbines over time. To examine whether the growing effects are due to these districts with "multiple events," we drop those districts that install additional wind energy facilities in years following the initial installation. As shown in Appendix Figures III and IV, even after dropping districts with multiple installations we still observe a pattern of rising effects over time.

The final explanation is a combination of sun-setting tax abatements and other tax rules that delay the generation of tax revenue from wind energy installations. Many states and local jurisdictions enter into some type of agreement in order to encourage wind development that allows wind developers a grace period in which they do not pay property taxes. For example, under Iowa's wind energy conversion tax ordinance, a wind project is taxed at 0% during the first year of operation and then in the second through sixth assessment years, a wind project is taxed at an additional 5% of net acquisition costs for each year

[20] See Appendix Figure II. There is evidence of a small negative pre-trend in enrollment, with no noticeable impact post installation.

(5% in year 2, 10% in year 3, etc.) until the seventh year when taxes are capped at 30% of net acquisition cost. While we cannot confirm empirically, laws and agreements such as those in Iowa appear to be the most likely reason for the growing effect over time.

A. Difference-in-Difference Estimates

We present difference-in-differences (DD) estimates of the impact of wind energy installation in Table 3. Results based on equation (2) with binary treatment are presented in columns 1 and 2, while columns 3-5 present results based on equation (3) with continuous treatment. Row 1, column 1 shows that installation causes a $1,109 per pupil increase in local revenue. Column 1 includes the basic set of controls: baseline enrollment, 1990 median income, and 1990 fraction earning a BA or higher, all interacted with a trend; and a dummy for school finance reforms interacted with terciles of the 1990 within state median income distribution. The effect is very similar, $1,030 per pupil, or 16.8%, relative to the mean of $6,138, after including the expanded set of controls that adds 1990 percent poor, 1990 percent white, 1990 percent age greater than 65, and 1990 rural status, all interacted with a trend. The effect on total revenues (column 2) is $837 (6%), and the effect on state revenues is -$116 (-2%).

Focusing on our preferred specification in column 2, total expenditures increase by $1,068 (8%), over $200 per pupil more than total revenues increase. The reason that total expenditures can increase more than total revenues is that revenues do not include proceeds from bond sales, while expenditures include the spending resulting from bond sales. For example, when a district passes a bond to finance a capital project, the proceeds do not count toward revenue, but the capital spending on the project is included in capital, and therefore total, expenditures. Current expenditures increase by $136 per pupil, an increase of only 1% relative to the mean current spending in wind energy districts of $11,015. On the other hand, capital expenditures increase by $455 per pupil, or 34%, relative to the mean of $1,355. Finally, other expenditures increase by a similar amount, $477 per pupil, or 45%.

Given the small effect on current expenditures, it is unlikely there would be large impacts on either teacher hiring (i.e., class size) or on increasing teacher compensation. Accordingly, we find negative, but near zero impacts on class size reduction of under 0.1 pupils per teacher (marginally statistically significant in column 1; insignificant in column 2). The magnitude of the -0.07 class size estimate from column 2 represents a half percent decrease. Similarly, we find no evidence of impacts on base teacher salary, with an insignificant point estimate of -$540 (representing a 1.5% decrease).

While the estimates from the basic DD model with binary treatment are useful, there are two aspects of the model that are suboptimal. First, as in the event-study analysis, the binary treatment variable turns on when the first installation in a district occurs, and so it does not further capture the increased capacity of subsequent installations for the 37.5% of districts with multiple installations over

time. Second, the binary treatment variable misses the important variation stemming from different wind energy installations having very different installed capacity, and local property tax generation from wind energy installation almost always reflects installed capacity. For example, the 10th percentile of installed capacity per pupil in our sample among districts and years with wind energy installed is 11 KW/pupil, while the 90th percentile is 642 KW/pupil. These installations would clearly have very different tax implications, but the binary installation variable treats them identically.

Given the limitations of the binary treatment results, in columns 3-5 we present results based on equation (3) where we use a continuous measure of treatment, namely installed kilowatts per pupil. In district*years without installed wind energy, this variable equals zero. Once again, the results in column 3 (basic controls) and column 4 (expanded controls) are very similar, so we focus on column 4. Row 1 shows that one additional KW/pupil of installed capacity leads to $3.77 per pupil of additional local revenue. Column 5 multiplies the point estimate by 254, which is the mean level of installed capacity per pupil among districts and years with installed wind energy. For example, a district with the mean level of installed capacity per pupil experiences an increase of $959 in local revenue. Total revenues increase by $3.59 with a 1 KW/pupil increase in capacity, for a $912 increase at mean capacity. While the previous event-study and binary DD models found small, statistically significant decreases in state revenue, here we find no statistically significant impact on state revenue: a $0.25 decrease per KW/pupil, which corresponds to a $63 decrease at the mean.

Turning to expenditures, total, current, capital, and other expenditures increase by $4.82, $0.88, $2.13, and $1.81 per one KW/pupil increase, respectively, which corresponds to a $1,223, $223, $540, and $460 increase at the mean level of installed capacity. To aid in interpretation, for the continuous DD we multiply the pupil teacher ratio by 1,000. Thus, a 1 KW/pupil increase in capacity causes a marginally significant decrease of 0.00016 pupils per teacher, which is equivalent to 0.04 pupils per teacher at the mean. While this is marginally significant, it is essentially zero. Note that the increase in current expenditures is approximately 2% while the pupil teacher ratio decreases by substantially less than 2%. Thus, one interpretation of these finding is that districts are not spending the increases in current expenditures on hiring new teachers, although we do not have enough statistical precision to be confident in this claim. We conservatively interpret these effects as consistent with the prior results that there are very small, near zero impacts on current spending, and subsequently on class size reduction. As in the previous models, there is no impact on teacher salary, though in the continuous DD model, the zero effect at the mean is quite precisely estimated.

In summary, districts that install wind energy see large increases in local revenues, that are only minimally offset by reductions in state aid, leading to large increases in total revenue. The districts spend these increases primarily on capital outlays, and on other, non-current and non-capital expenses.

B. Sensitivity Analysis

In this section, we conduct six sensitivity checks to examine the robustness of our results to decisions about the way we construct our sample and implement the difference-in-differences analysis. We proceed with our preferred specification, which is the continuous DD model with the expanded set of controls (Table 3, column 4). The first row of Table 4 replicates our baseline preferred model for comparison purposes.

In our first check, we include the eleven states, primarily in the South census region, with no installed wind energy during our sample period. In the second check, we include the three states, California, Kansas, and Wyoming, which we removed because their laws prevent wind energy taxes from being directed toward local school districts. In our third check, we include districts with a maximum installed wind energy capacity during our sample period of less than 2 MW. In all of these checks, the results are nearly identical to our baseline estimates.

In our fourth check, we restrict to counties with installed wind energy. In our baseline sample, we include counties with no installed wind energy if they are in a state with installed wind energy, even though these counties may be quite different from counties in that state with installed wind energy. This check is meant to create a control group of school districts without installed wind energy that looks more like the treated school districts, by drawing within state comparisons (due to the state-by-year fixed effects), between school districts with wind energy and those without, but that are in counties with school districts with wind energy. In spite of the sample size dropping from 218,851 district*years to 42,767, the point estimates are very similar.

In our fifth check, again in an attempt to create a control group of non-wind school districts that better resembles the treated districts, and given that treated districts tend to be smaller than untreated districts, we drop large untreated districts. Specifically, we drop districts with no installed wind energy that have enrollment greater than the 90th percentile of enrollment among treated districts. The estimates are nearly identical to those using our preferred specification. As a final attempt to make the treated and control districts more comparable, we use propensity score weighting to weight higher those non-wind districts that are observationally similar to districts with wind energy.[21] The estimates using the propensity score weighting are very similar, and for some outcomes slightly higher than baseline (e.g., $4.00 compared to $3.77 for local revenue).

[21] Specifically, we run a logit regression of a dummy for a district having wind energy on 1990 rural status, median household income, fraction BA or higher, fraction age 65 or older, fraction white, fraction poor, and baseline enrollment. We then create a propensity score from that regression, which is simply the predicted probability that a district has wind energy. Finally, we create inverse propensity score weights, equal to wind / pscore + (1-wind)/(1-pscore).

C. State Heterogeneity

As described in Section II, there is substantial heterogeneity not only in state laws regarding taxation of wind energy installation, but also in school finances laws. The interaction of these two quite heterogeneous sets of laws could create very different impacts of wind energy installation in different states. While the average national effect of wind energy installation we have presented thus far is of primary interest, it is also important to understand how the results vary by state and whether our results are driven in part by any particular state or set of states.

Table 5 presents our preferred specification (continuous DD with expanded controls) separately for the 8 states in our sample with the highest installed wind capacity.[22] We begin, in column 1, by presenting estimates for Texas, which is by far the largest producer of wind energy in the country: in 2016, Texas produced 30.5% of wind capacity in our national baseline sample. Given that Texas comprises almost a third of wind capacity in our sample, we also show effects dropping Texas from our baseline sample (column 2). We find much larger impacts in Texas on local revenue and total revenue of $7.78 and $8.04 per pupil from a 1 KW/pupil increase in capacity. In column 2, where we drop Texas, the point estimates for local and total revenue are substantially smaller at $2.32 and $1.99 respectively. Also, in column 2, the reduction in state revenue increases slightly in magnitude and becomes marginally significant, though it is still quite small ($-0.48). Total, current, capital, and other expenditures in Texas increase by $10.03, $0.88, $4.33, and $4.82, respectively. The effect on current is identical to the baseline estimates, but the other three outcomes have much larger point estimates (i.e., an even smaller share of the expenditure increase is devoted toward current spending). Importantly, Texas completely drives the large increases we observed on other expenditures: without Texas, the coefficient on other expenditures drops from $1.81 to $0.70 and becomes statistically insignificant. Finally, the effect on the pupil teacher ratio without Texas is slightly larger (0.28) and statistically significant at the 95% level, though still small (2%).[23]

The large impacts in Texas on other expenditures begs the question of what specific type of expenditure is driving that effect. In Appendix Table 1, we show, by state, effects on the sub-categories of other expenditures. The effect in Texas comes completely from payments to the state government. This result is a function of the Texas school finance laws, whereby property tax revenue from districts with high property tax bases is recaptured by the state and redistributed to districts with low property tax bases, a policy commonly referred to as Robin Hood. The large impact on other expenditures, therefore does not

[22] Of course, our specification simplifies slightly when estimating results in a single state, as the state-by-year fixed effects reduce to year fixed effects, and the school finance reform dummies become collinear with the year fixed effects.

[23] We present all of our main event-study figures dropping Texas in Appendix Figures V, VI, and VII.

actually reflect school district spending on any productive education input, but rather a different form of state aid reduction. This implies that while the effects on total revenue and expenditure appear to be double the baseline effect we estimated, once you subtract off the payments to the state, the effects are only somewhat larger than our national baseline estimates. Furthermore, as discussed previously, the laws in Texas incentivize the wind energy money to be spent on capital and not current spending, or else it would be recaptured by the state, which is why the effects are concentrated so highly in capital expenditures relative to current. Clearly, Texas provides a stark example of how a state's laws can influence the effects of wind energy installation on school district revenues and expenditures.

Columns 3 through 9 present results for the other seven top wind producing states in our sample. While all seven states show statistically significant increases in local revenue between $2 and $5 per KW/pupil, there is substantial heterogeneity in effects on state aid, and therefore on total revenue. Iowa, Oklahoma, Oregon, and Colorado see substantial reductions in state aid that drastically reduce the impacts on total revenue. Alternatively, Illinois sees no reduction, and Minnesota and Washington actually see increases in state aid. There is also substantial heterogeneity as to the allocation of expenditures, with Oklahoma, Illinois, and Minnesota, spending more on current than capital expenditures (in raw dollars, not in percent), and the other states spending more on capital. While most states see no impact on other expenditures, three states, Iowa, Minnesota, and Washington experience positive, statistically significant impacts. These are driven by increases in payments to other school systems in Iowa, by increases in interest on debt, payments to other school systems, and community and adult education spending in Minnesota, and by increases in community and adult education spending and interest on debt in Washington. Finally, two states, Illinois and Minnesota, which both saw large increases in current expenditures, see larger reductions in class size. Unfortunately, given the small sample sizes in the SASS for examining teacher salary, we do not attempt to explore these results by state.

D. Student Achievement

In this section, we examine to what extent, if any, the increases in revenues and expenditures from wind energy installation translate into improvements in student achievement. Unlike effects on revenues and expenditures, there is no reason to expect that the effects of wind energy installation would immediately impact achievement, even if expenditures were affected immediately, given that achievement would be affected slowly over time as students are exposed to additional years of increased school funding. Consequently, we first present the event-study figures, where the outcome variable is district test scores. We then present the DD model, but we modify it to allow the impact to evolve linearly during the post period instead of including a single post indicator as we do in equation (2):

$$NAEP_{ijgst} = \phi_0 + \phi_1 Treat_{ist} + \phi_2 YearsPost_{ist} + \phi_3 (YearsPost_{ist} * Treat_{ist}) + X_{is}\theta_t + \delta_i + \lambda_{st} + \pi_{jg} + \omega_{ijgst} \quad (4)$$

where $NAEP_{ijgst}$ is the average score in district *i*, in tested subject *j* and grade *g*, in state *s*, and year *t*, $Treat_{ist}$ is the dummy for whether a district has installed wind energy, $YearsPost_{ist}$ is a relative-year trend variable that captures the number of years since wind energy was installed (this is negative prior to installation, positive after installation, and zero during the installation year and for districts without wind energy), and $YearsPost_{ist} * Treat_{ist}$ is the interaction of the two, which gives the number of years since installation during the post period. The coefficient on $Treat_{ist}$ gives the jump in the level of test scores, while the coefficient on $YearsPost_{ist}$ shows whether there is any pre-trend, and the coefficient on the interaction term gives the additional increase in scores for every 1 year after installation. We include subject-by-grade fixed effects, π_{jg}, given that the unit of observations is now district*year*subject*grade.

Figure Va shows the event-study analysis, where the outcome is standardized district NAEP scores. Relative years are grouped into pairs to help with precision given the smaller sample size. There is no evidence of a pre-trend, and scores remain flat after installation. There is no evidence of any positive effect on scores, and if anything, there appears to be a very small, and statistically insignificant decrease. We can rule out increases of about 5% of a standard deviation. Given the starkly different results in Texas, and somewhat different results in our baseline sample after dropping Texas, we also show the effects on achievement dropping Texas. The picture looks nearly identical, with no detectable pre-trend or effect post-installation.[24]

We present the results from equation (4) above in Table 6, Panel A. Effects are nearly identical with and without expanded controls: in our baseline sample and in the sample dropping Texas, as in Figure V, there is no statistically significant coefficient on the trend variable, suggesting no pre-trend, or on the Post or post*trend variable, suggesting no impact. We show the calculated impact 5 years out, which is a statistically insignificant negative 1 percent of a SD for the baseline sample, and a statistically insignificant 1/10 of a percent of a SD increase for the sample without Texas. Five years post, we can rule out positive impacts of about four percent of a SD.

Figures Vc and Vd show the impacts on test scores using the combined NAEP and SEDA achievement data, with and without Texas, respectively.[25] Recall, that while the NAEP data is available only every other year and for a sample of districts, the SEDA data is available annually from 2009 – 2015 for the universe of school districts. Again, we see no evidence of any positive impact of wind energy

[24] We obtain a similar, though noisy, null result when we restrict our sample to only Texas. Results available upon request.
[25] Appendix figure VIII and Appendix table 2 show zero impacts on test scores using only the SEDA data.

installation on achievement, and can rule out increases of about 0.05 SDs. We show results from the DD model in Panel B of Table 6. As in Panel A, with the NAEP only, we again see no statistically significant coefficients on any of the three parameters of interest, nor on the effect 5 years post installation. The effects 5 years post are -0.041 and -0.031 with and without Texas, respectively, but again neither is statistically significant. Given the standard errors of 0.026 and 0.027, we can rule out positive impacts of approximately 1 or 2 percent of a SD. While these estimates do suggest a negative effect, we hesitate to interpret them as such given the imprecision of the estimates, and prefer to conservatively infer a lack of positive impacts. It is worth noting, however, that a negative impact on achievement is not entirely implausible. There are small to zero impacts on class size reduction and teacher salary improvements, and to the extent that the large increases in capital are building new schools, in the short-run switching schools has been shown to be detrimental to student achievement (Brummet, 2014; Conlin & Thompson, 2017).

E. Flypaper and Local Tax Rates

Given that there appear to be no benefits to school districts of wind energy installation in the form of higher student achievement, how else might districts benefit? One possible way is through taking some of the revenue increase as property tax relief. A large literature in public economics examines the extent to which local jurisdictions reduce local tax effort in the face of a windfall of revenues that are designated for a particular purpose (e.g., education), versus the extent to which the money "sticks where it hits," a phenomenon often dubbed the flypaper effect.[26] Some studies find substantial or even complete flypaper (Feiveson, 2015; Dahlberg et al., 2008), while others find little or no flypaper (Knight, 2001; Gordon, 2004; Lutz, 2010; Cascio, Gordon, & Reber, 2013). In our context, we clearly find at least some flypaper, given the large increases in local revenue. But isolating the precise magnitude of flypaper is challenging, given the heterogeneity in state and local laws governing wind energy taxation.

In theory, one could use information on wind energy taxation laws and pre-installation local tax rates to predict the amount of revenue that should flow to local school districts from a 1 KW/pupil increase in installed capacity, and then compare this predicted amount to our estimated effect on local revenue – any difference between the two would be the estimated amount of property tax relief. Unfortunately, as described in Section II, laws governing wind energy taxation are extremely opaque, usually interact in a complicated manner with school finance formulas, and are often determined at the county or local level, preventing us from undertaking this calculation for our main sample. To our knowledge, Illinois is the only state that during our sample period had relatively clear and straightforward state-level laws determining the flow of revenues from installed wind energy capacity to school districts.

[26] See Hines and Thaler (1995) and Inman (2008) for detailed discussions of and evidence on the flypaper effect.

In Appendix B, we use information on Illinois state laws and districts' pre-installation tax rates to conduct a back-of-the-envelope calculation comparing our estimated effect on local revenue to the effect of a one MW increase in installed wind energy on local district revenues as predicted from the state laws. We find that the predicted local revenue increase using tax laws and pre-installation tax rates, and therefore assuming no crowd-out, is $3,698, compared to our estimated effect for Illinois from Table 5 of $3,020. Thus, we estimate that property tax relief accounts for 18% (= ($3,698 - $3,020) / $3,698) of the total predicted revenue increase, while 82% of the revenue flows to schools. This is a non-trivial amount of local crowd-out, but is on the high end of estimated flypaper effects.

We provide additional evidence on the flypaper effect by directly estimating the impact of wind energy installation on local school district property tax rates for two states, Illinois and Texas, where we could obtain historic school district property tax rate data. These data are available for a somewhat shorter, more recent period than our baseline data: 2001-2017 for Illinois, and 2000-2018 for Texas. Given this difference in sample period between our main analysis and when the tax rate data are available, in Appendix Figures IX through XII we show the main event-study results for revenues and expenditures restricting to years 2001 onward for Illinois and 2000 onward for Texas, finding noisy, but similar results.

Figure VIa shows that in Illinois, wind energy installation leads to a statistically significant reduction in the tax rate of about $0.50 by six years out, which is a 13% decrease relative to the mean tax rate in Illinois of $3.75 (for every $100 of assessed value). This result implies that in addition to the local revenue increases after wind energy installation in Illinois, local school district residents are benefiting from property tax relief. In Texas, we see a different story (Figure VIb). Here we see near zero, slightly positive impacts on tax rates. While seemingly counterintuitive, this result is sensible given the Texas school finance laws described above. Specifically, the laws incentivize wind energy districts to pass bonds to raise capital expenditures, and these bonds require increasing tax rates to pay the bonds. Thus, because the particular formula and recapture aspect of the Texas laws (which focus on current expenditures), districts are incentivized to actually increase their tax rates after installing wind energy. While we could only obtain historic tax rate data from two states, these two states provide examples of: 1) how school districts in some cases are taking some of the benefit of wind energy as property tax relief, and 2) the significant degree to which local context matters for whether and to what extent local tax effort is crowded out (or crowded in) in the face of a windfall of tax revenue.

V. Conclusions

The only well-identified evidence on a national scale of whether increased student resources improve student outcomes comes from a single policy reform: statewide school finance reforms. In this paper, we provide evidence on the impacts of increased school funding from a novel source of variation

affecting most states since the 1990s: wind energy installation. We use data on the timing and location of the universe of wind energy installations in the U.S. from 1995 through 2016 to examine the impacts of wind energy installation on school district revenues, expenditures, resource allocations, and student achievement. We geocode wind energy installations to school districts, and combine these data on the timing and capacity of wind installations with National Center for Education Statistics (NCES) and Schools and Staffing Survey (SASS) school district data on revenues, expenditures, staffing, enrollments, and teacher salaries, and with student microdata from the National Assessment for Education Progress (NAEP) on student achievement. We use event-study and difference-in-differences methodologies exploiting the plausibly exogenous timing of wind energy installations.

We find that wind energy installation led to large, exogenous increases in total per-pupil revenues due to increases in local revenues, with only minimal offsetting reductions in state-aid. Per-pupil expenditures increased accordingly, with the majority of the revenues spent on capital outlays, causing dramatic increases in capital expenditures, and only modest increases in current expenditures. We find fairly precisely estimated zero impacts of wind energy installation on school district average test scores through several years after wind energy installation, suggesting that the capital investments on which these districts spent most of the marginal dollar, while perhaps having other benefits to students, had little or no detectable impact on their achievement.

Finally, we examine the impacts of wind energy installation on local school district property tax rates in two states, Illinois and Texas. In Illinois, districts respond to the increased revenues from wind installation by reducing their property tax rates and taking part of the windfall as property tax relief. In Texas, where state laws incentivize districts with wind energy installations to pass new bonds to promote capital spending and to pay for these bonds by increasing property tax rates, we subsequently see tax rates increase after wind energy installation.

Our study provides several contributions to the literature. First, we extend the literature examining the impact of wind energy installation on school districts by examining effects across multiple states and on student achievement, compared to prior studies that focused on a single state and only examined impacts on school finances ((De Silva et al., 2016; Reategui & Henderson, 2011; Ferrel & Conaway, 2015; Kahn, 2013; Castleberry & Greene, 2017; Loomis & Aldeman, 2011). Second, we contribute to the public economics literature on flypaper effects, finding strong evidence of flypaper, but also, as in other recent work, finding that local context affects the extent to which revenue shocks are taken as property tax relief instead of increasing school budgets (Brunner et al., 2018). Finally, our study provides nationwide evidence on the effects of increased school spending on student achievement from an exogenous source of variation in spending other than school finance reform. Our finding that most of the increases in school spending are devoted to increased capital expenditures and that these increases have

no discernible impacts on student achievement, contributes to the small literature on the impacts of capital expenditures on student achievement. We provide the first national evidence on the impacts of capital spending, finding zero impacts, as in Cellini et al. (2010) and Martorell et al. (2016).

Every year, hundreds of rural districts across the country use the large revenue inflows from wind energy installation to fund new capital projects and improve their schools' infrastructure. While we find that these investments are not improving student achievement in these districts, an important area for potential future research is whether these investments have impacts on other important short-run outcomes that we cannot measure in this paper, such as enjoyment of school or non-cognitive skills, or on longer-run outcomes, such as educational attainment, for which more time needs to pass before they can be examined.

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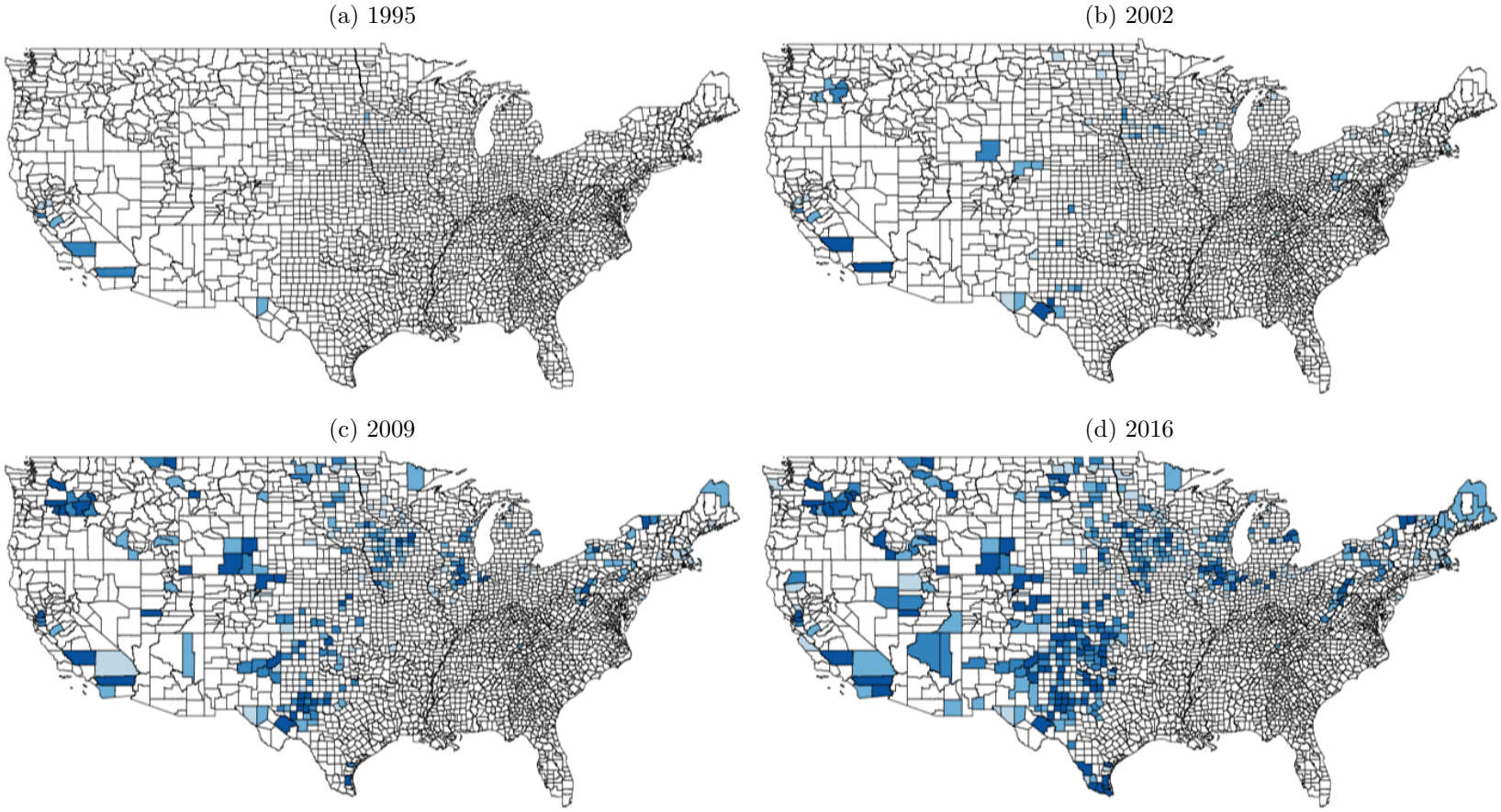
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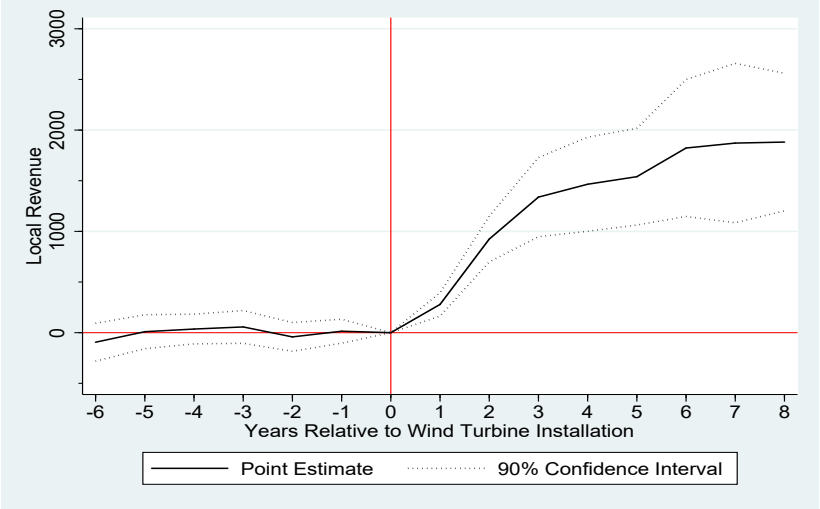
Figure I: United States County Map by Installed Wind Turbine Capacity



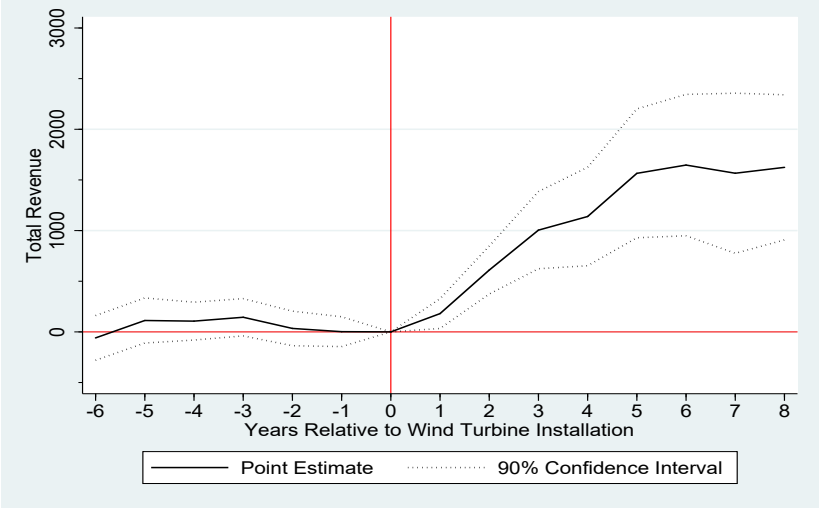
Notes: Map shows installed wind turbine capacity in megawatts (MW) by county and year. Unshaded counties have no installed capacity. The four shades ranging from lightest to darkest represent quartiles of 2016 installed capacity: <11.5 MW, 11.5-73.4 MW, 73.4-199.0 MW, and >199.0 MW, respectively.

Figure II: Effects of Wind Turbine Installation on School District Revenues

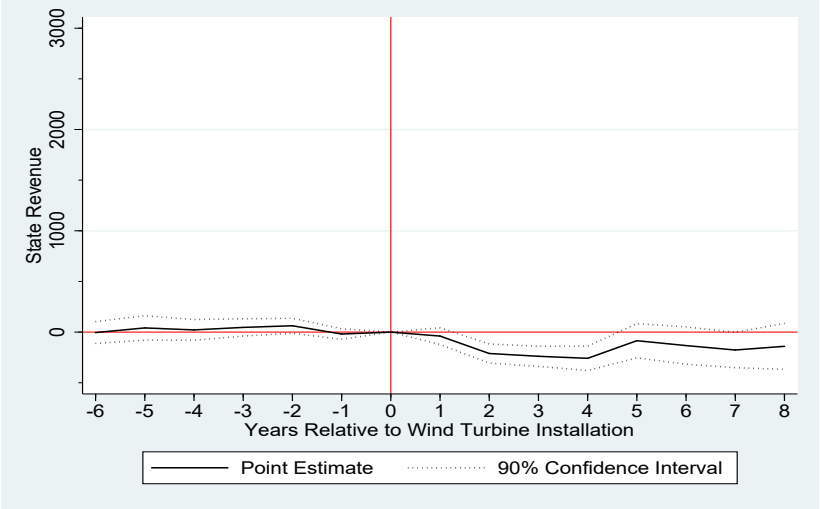
(a) Local Revenue



(b) Total Revenue



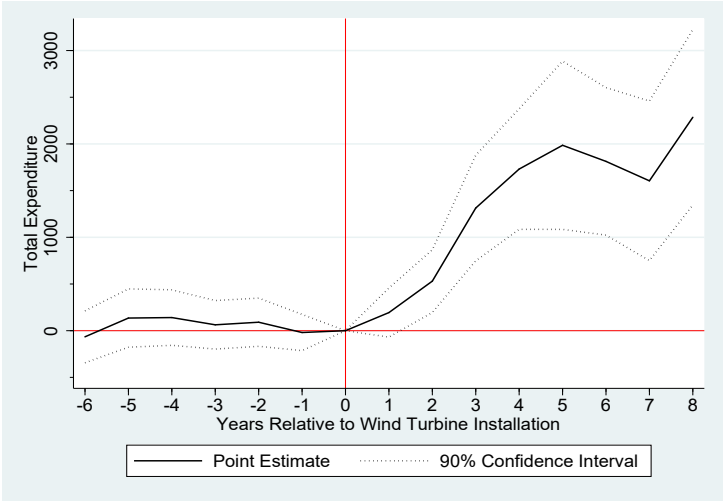
(c) State Revenue



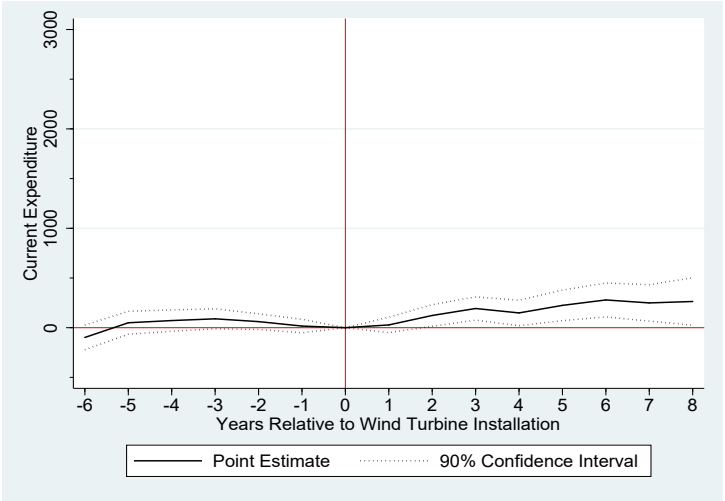
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district revenues. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Figure III: Effects of Wind Turbine Installation on School District Expenditures

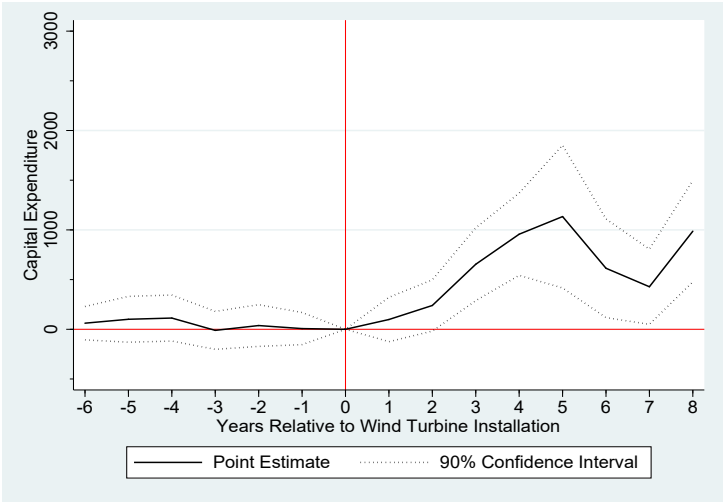
(a) Total Expenditures



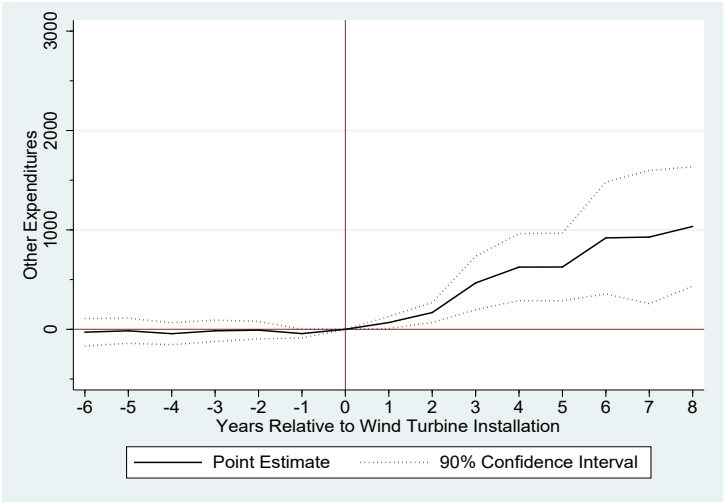
(b) Current Expenditures



(c) Capital Expenditures



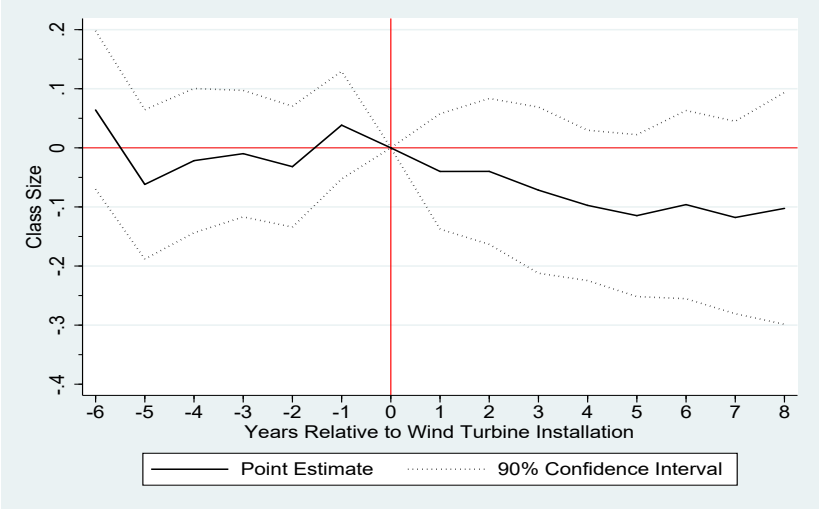
(d) Other Expenditures



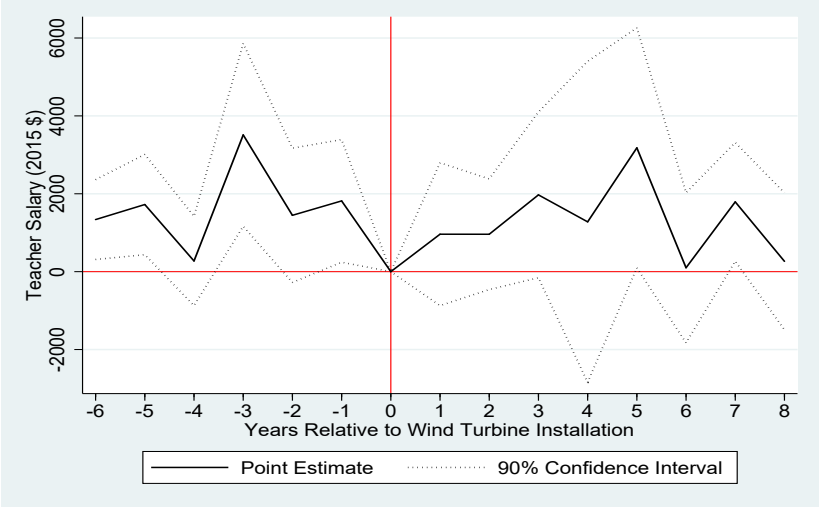
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district expenditures. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Figure IV: Effects of Wind Turbine Installation on Education Production Inputs

(a) Pupil-Teacher Ratio



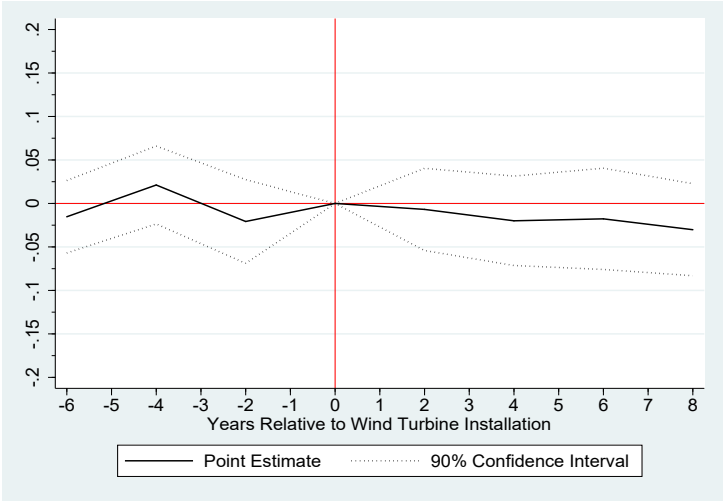
(b) Teacher Salary



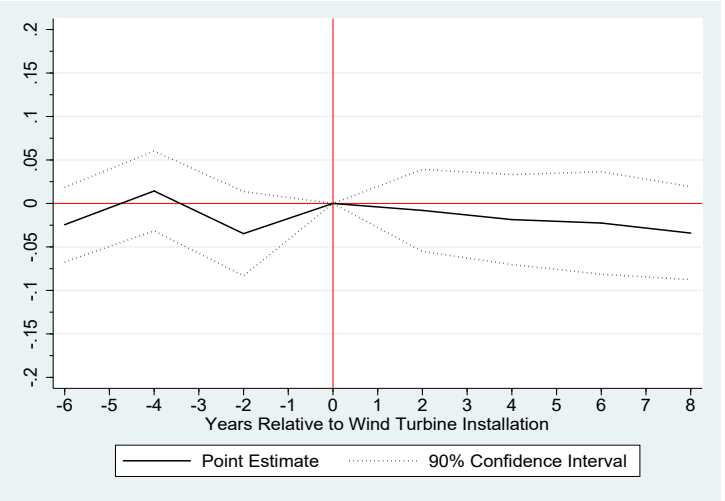
Notes: Figures show event study estimates of the effects of wind turbine installation on inputs to education production. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Figure V: Effects of Turbine Installation on Student Achievement

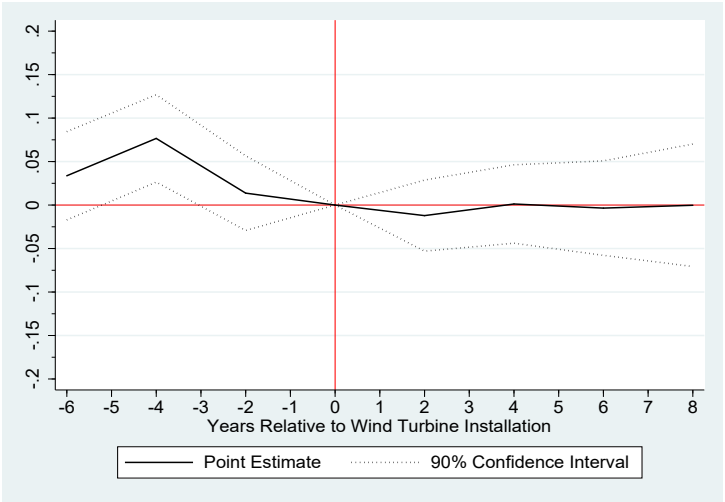
(a) NAEP, Baseline Sample



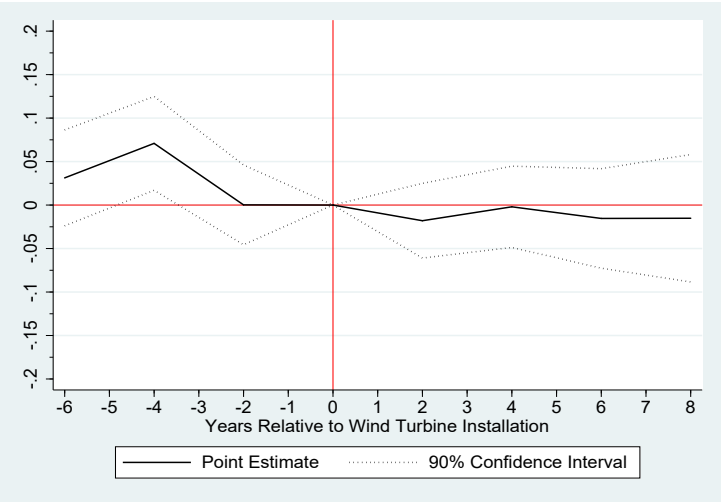
(b) NAEP, No Texas



(c) NAEP & Stanford Data, Baseline Sample



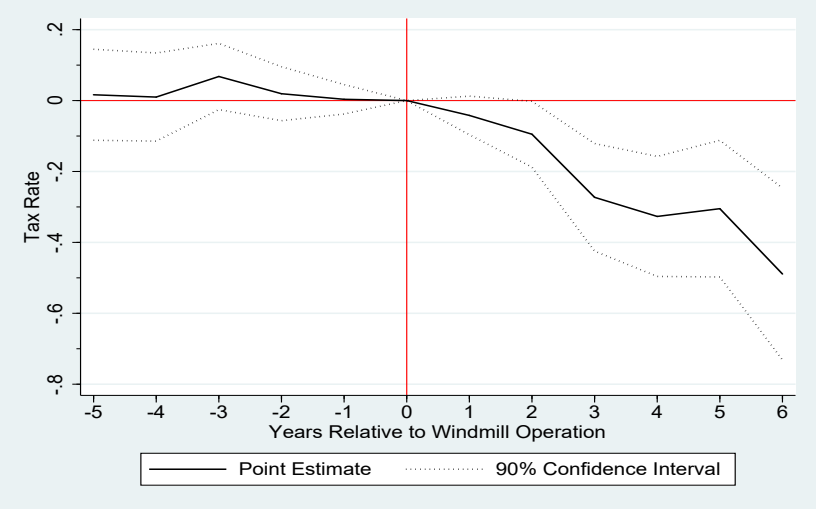
(d) NAEP & Stanford Data, No Texas



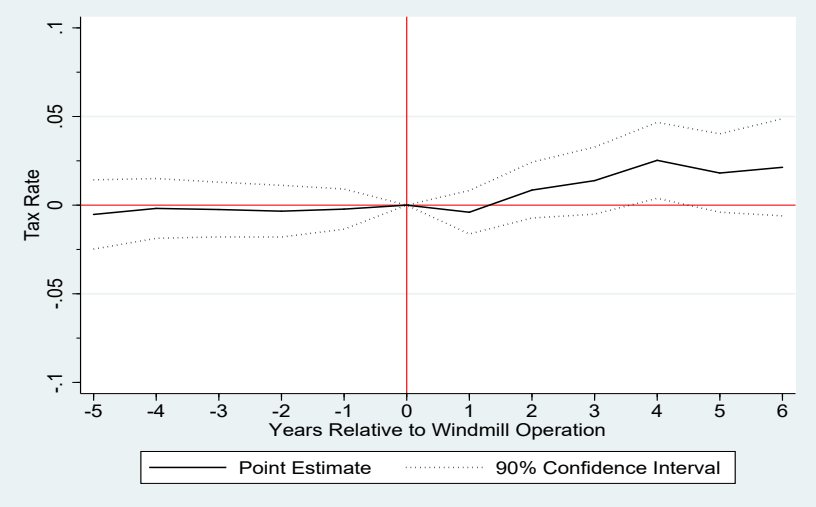
Notes: Figures show event study estimates of the effects of wind turbine installation on standardized district mean test scores. Subfigures (a) and (b) use NAEP scores. In subfigures (c) and (d), we supplement the NAEP scores with annual scores from the Stanford Education Data Archive for any school district with no NAEP score during 2009 to 2015. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Figure VI: Effects of Wind Turbine Installation on District Property Tax Rates

(a) Illinois



(b) Texas



Notes: Figures show event study estimates of the effects of wind turbine installation on local school district property tax rates. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Table 1: Summary Statistics, Outcome Variables

	Full Sample		Wind Turbine District		District Without Wind Turbine	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
	(1)	(2)	(3)	(4)	(5)	(6)
Per-Pupil Outcomes						
Total Revenue	13,642	5,716	13,418	6,010	13,657	5,696
Local Revenue	6,588	5,524	6,138	5,866	6,617	5,500
State Revenue	6,005	3,281	6,206	2,976	5,992	3,300
Total Expenditures	13,678	6,076	13,419	6,826	13,695	6,023
Current Expenditures	11,378	4,211	11,015	3,277	11,401	4,263
Capital Expenditures	1,248	2,604	1,355	3,394	1,241	2,544
Other Expenditures	1,052	2,254	1,049	3,359	1,053	2,164
Other Outcomes						
Pupil-Teacher Ratio	14.5	3.2	13.4	3.1	14.5	3.2
Teacher Base Salary	37,014	6,050	34,762	5,059	37,163	6,080
Number of Districts	10,157		618		9,539	
Number of Observations	218,851		13,293		205,558	

Notes: The sample is all school districts in the 34 continental United States that had wind energy installed between 1995 and 2016. We exclude California, Kansas, and Wyoming, because their states laws prevent taxes from wind energy installation from flowing to schools.

Table 2: Summary Statistics, Baseline Outcomes and Controls

	Full Sample		Wind Turbine District		District Without Wind Turbine	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
	(1)	(2)	(3)	(4)	(5)	(6)
Per-Pupil Outcomes in 1995						
Total Revenue	10,929	4,092	10,541	3,809	10,955	4,108
Local Revenue	5,635	4,431	4,889	3,937	5,684	4,457
State Revenue	4,672	2,218	4,983	2,049	4,652	2,227
Total Expenditures	10,798	3,951	10,203	2,861	10,836	4,009
Current Expenditures	9,189	2,977	8,794	2,154	9,215	3,021
Capital Expenditures	885	1,760	917	1,621	883	1,769
Other Expenditures	723	1,246	493	664	738	1,274
Other Outcomes in 1995						
Pupil-Teacher Ratio	15.7	3.0	14.8	3.0	15.8	3.0
Teacher Base Salary	35,862	5,302	34,193	4,560	35,970	5,329
Control Variables						
Baseline Enrollment	2,687	12,921	1,725	5,194	2,749	13,264
Median Income in 1990	28,888	11,461	23,880	5,419	29,212	11,672
Fraction BA or Higher in 1990	0.150	0.098	0.117	0.046	0.152	0.100
Fraction Rural in 1990	0.646	0.478	0.800	0.400	0.636	0.481
Fraction White in 1990	0.900	0.160	0.896	0.182	0.901	0.158
Fraction Poor in 1990	0.128	0.084	0.153	0.081	0.126	0.084
Fraction Age 65+ in 1990	0.190	0.060	0.209	0.057	0.189	0.060
Number of Districts	10,157		618		9,539	
Number of Observations	218,851		13,293		205,558	

Notes: The sample is all school districts in the 34 continental United States that had wind energy installed between 1995 and 2016. We exclude California, Kansas, and Wyoming, because their states laws prevent taxes from wind energy installation from flowing to schools.

Table 3: Effects of Turbine Installation on District Revenues, Expenditures, and Resource Allocations

	Treatment: Wind Turbine Installed (0/1)		Treatment: Installed Turbine Capacity Per-Pupil (KW)		Effect at Mean Capacity
Dependent Variable	(1)	(2)	(3)	(4)	(5)
School District Revenues					
Local	1109.44***	1030.19***	3.91***	3.77***	958.69***
	(214.00)	(214.15)	(0.71)	(0.71)	(179.55)
Total	872.27***	837.03***	3.65***	3.59***	912.90***
	(221.28)	(221.70)	(0.82)	(0.83)	(210.23)
State	-144.39**	-116.02**	-0.30	-0.25	-63.46
	(58.91)	(58.56)	(0.26)	(0.26)	(67.12)
School District Expenditures					
Total	1094.89***	1068.47***	4.85***	4.82***	1223.13***
	(256.44)	(256.77)	(0.97)	(0.98)	(248.20)
Current	172.39***	135.79**	0.94***	0.88***	222.75***
	(64.65)	(63.98)	(0.20)	(0.20)	(51.45)
Capital	450.36***	455.28***	2.11***	2.13***	540.34***
	(100.87)	(100.89)	(0.44)	(0.44)	(111.25)
Other	472.15***	477.40***	1.80***	1.81***	460.03***
	(171.69)	(172.64)	(0.59)	(0.59)	(149.99)
Education Production Inputs					
Pupil-Teacher Ratio	-0.094*	-0.073	-0.197**	-0.159*	-0.040*
	(0.055)	(0.055)	(0.092)	(0.092)	(0.023)
Teacher Salary	-550.69	-540.49	0.23	0.23	59.20
	(354.87)	(354.15)	(0.25)	(0.29)	(72.81)
Expanded Controls	No	Yes	No	Yes	Yes

Notes: The sample is as in Table 1, and includes 218,851 district-by-year observations. Column 5 multiplies the coefficient and standard error from column 4 by the mean level of installed capacity of 254 KW/pupil. The pupil-teacher ratio is multipled by 1000 for columns 3 and 4, because the impact of a 1 KW/pupil increase in installed capacity would be tiny. Subsequently, column 5 then divides by 1000, so the interpretation is in pupils per teacher.
*** = significant at 99% confidence level; ** = 95%, * = 90%.

Table 4: Effects of Installed Turbine Capacity: Sensitivity Checks

	School District Revenues			School District Expenditures				Education Production Inputs		
	Local	Total	State	Total	Current	Capital	Other	Teacher Ratio	Teacher Salary	Sample Size
Specification/Sample	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Baseline	3.77***	3.59***	-0.25	4.82***	0.88***	2.13***	1.81***	-0.16*	0.23	218,851
	(0.71)	(0.83)	(0.26)	(0.98)	(0.20)	(0.44)	(0.59)	(0.09)	(0.29)	
Include States with No	3.79***	3.60***	-0.25	4.82***	0.88***	2.13***	1.81***	-0.16*	0.23	252,450
Wind Turbines	(0.71)	(0.83)	(0.26)	(0.98)	(0.20)	(0.44)	(0.59)	(0.09)	(0.28)	
Include CA, KS, and WY	3.71***	3.53***	-0.24	4.75***	0.87***	2.10***	1.77***	-0.17*	0.23	243,974
	(0.69)	(0.81)	(0.26)	(0.96)	(0.20)	(0.43)	(0.58)	(0.09)	(0.29)	
Include Districts with < 2	3.78***	3.60***	-0.25	4.82***	0.88***	2.13***	1.81***	-0.16*	0.23	220,525
MW Capacity	(0.71)	(0.83)	(0.26)	(0.98)	(0.20)	(0.44)	(0.59)	(0.09)	(0.29)	
Restrict to Counties with	3.51***	3.36***	-0.24	4.57***	0.81***	2.10***	1.65***	-0.17	0.43	42,767
Wind Turbines	(0.69)	(0.80)	(0.25)	(0.92)	(0.22)	(0.42)	(0.57)	(0.10)	(0.28)	
Drop High Enrollment	3.73***	3.53***	-0.26	4.71***	0.85***	2.09***	1.77***	-0.15*	0.32	172,655
Non-Wind Districts	(0.70)	(0.83)	(0.26)	(0.97)	(0.20)	(0.44)	(0.59)	(0.09)	(0.21)	
Propensity Score Weighting	4.00***	3.81***	-0.27	5.14***	0.89***	2.16***	2.09***	-0.16*	0.25	218,851
	(0.89)	(0.96)	(0.26)	(1.09)	(0.21)	(0.44)	(0.75)	(0.09)	(0.27)	
Expanded Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Notes: Each coefficient is from a separate regression of the outcome (listed in the column header) on installed wind turbine capacity (in KW) per-pupil. High enrollment non-wind districts are districts with no installed wind capacity that have enrollment larger than the 90th percentile of enrollment among districts with installed wind capacity. The propensity score weighting weights higher those non-wind districts that are observationally similar to wind-districts.

Table 5: Effects of Installed Turbine Capacity, By State

	Texas	Baseline, No Texas	Iowa	Oklahoma	Illinois	Minnesota	Oregon	Washington	Colorado
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
School District Revenues									
Local	7.78***	2.32***	2.11***	4.73***	3.02***	2.64***	2.00***	1.94***	2.57**
	(1.57)	(0.28)	(0.54)	(1.23)	(0.48)	(0.28)	(0.16)	(0.10)	(1.29)
Total	8.04***	1.99***	1.11**	3.55***	3.31***	5.05***	0.87***	2.54***	1.27
	(1.60)	(0.37)	(0.54)	(1.21)	(0.50)	(0.68)	(0.08)	(0.16)	(1.03)
State	0.39	-0.48*	-0.97***	-1.19***	0.04	2.13***	-1.11***	0.32***	-1.67***
	(0.37)	(0.28)	(0.27)	(0.40)	(0.17)	(0.35)	(0.07)	(0.11)	(0.49)
School District Expenditures									
Total	10.03***	2.92***	0.61	2.41***	3.70***	6.60***	0.82***	6.30***	1.99
	(1.85)	(0.93)	(0.67)	(0.79)	(0.45)	(1.51)	(0.26)	(0.35)	(1.35)
Current	0.88***	0.89***	-0.19	1.45**	2.92***	3.08***	0.30*	0.19*	0.71
	(0.32)	(0.25)	(0.62)	(0.65)	(0.38)	(0.41)	(0.18)	(0.10)	(0.59)
Capital	4.33***	1.33**	0.20	0.95*	0.52**	2.38**	0.53	3.34***	1.28
	(0.88)	(0.54)	(0.35)	(0.50)	(0.21)	(1.08)	(0.44)	(0.22)	(1.04)
Other	4.82***	0.70	0.60**	0.02	0.26	1.15***	-0.00	2.76***	-0.00
	(1.41)	(0.49)	(0.28)	(0.03)	(0.25)	(0.17)	(0.02)	(0.16)	(0.09)
Education Production Inputs									
Pupil-Teacher Ratio	0.14	-0.28**	0.46	-0.22	-0.71***	-1.35***	-0.35**	-0.08	0.08
	(0.15)	(0.11)	(1.00)	(0.20)	(0.23)	(0.38)	(0.13)	(0.09)	(0.28)
Teacher Salary	-	0.309	-	-	-	-	-	-	-
	-	(0.233)	-	-	-	-	-	-	-
Observations	22,099	196,752	7,650	11,382	18,728	6,991	3,676	5,880	3,617
Expanded Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each coefficient is from a separate regression of the outcome (listed in the row header) on installed wind turbine capacity (in KW) per-pupil for the sample listed in the column header.
*** = significant at 99% confidence level; ** = 95%, * = 90%.

Table 6: Effects of Turbine Installation on Student Achievement

	Baseline		No Texas	
	(1)	(2)	(3)	(4)
Panel A: NAEP Data				
Post	-0.005	-0.004	0.009	0.009
	(0.020)	(0.020)	(0.020)	(0.020)
Post*Trend	-0.002	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)
Trend	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Effect 5 Years Post		-0.010		0.001
		(0.020)		(.019)
Observations	80,720		77,641	
Panel B: NAEP and Stanford Data				
Post	-0.030	-0.028	-0.010	-0.010
	(0.023)	(0.023)	(0.024)	(0.024)
Post*Trend	-0.002	-0.002	-0.001	-0.001
	(0.005)	(0.005)	(0.006)	(0.006)
Trend	-0.001	-0.001	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.004)
Effect 5 Years Post		-0.041		-0.031
		(0.026)		(0.027)
Observations	243,002		221,994	
Expanded Controls	No	Yes	No	Yes

Notes: The level of observation is the district-year-grade-subject. The dependent variable is standardized student test scores. In Panel A, we use NAEP data, which are available for a sample of districts in every other year from 1996 to 2015 for grades 4 and 8. In Panel B, we supplement the grade 4 and 8 NAEP scores with annual scores from the Stanford Education Data Archive for any school district with no NAEP score during 2009 to 2015.
*** = significant at 99% confidence level; ** = 95%, * = 90%.

Appendix A: State Wind Energy Taxation Laws and School Finance Formulas

What follows is a description of how states tax wind installations and how wind installation tax revenue affects local school districts. We present wind energy taxation information for the top 15 wind production states in the nation based on installed megawatts as of 2018. These 15 states account for approximately 88% of the total installed wind energy capacity in the nation.

Texas: School districts may approve a tax abatement agreement, known officially as a Chapter 313 agreement, which allows a temporary, 10-year limit on the taxable value of a new wind project. Chapter 313 agreements apply only to school district taxes levied for maintenance and operations (M&O). Taxes for debt service, known as interest and sinking (I&S) fund payments are not subject to the limitation. Furthermore, Chapter 313 requires some portion of the increased assessed value due to a wind project to go on a school districts tax rolls for M&O while the full increase in assessed value goes on a school districts tax rolls for I&S. Because Chapter 313 agreements increase a school districts tax base, and state aid in Texas is tied to a districts tax base, state aid generally declines when a Chapter 313 agreement goes into effect. However, because only part of the assessed value of wind project is added to the tax rolls for the abatement period, Chapter 313 agreements typically result in a small decline in state aid during the period when the abatement agreement is in effect. Once the tax abatement period ends, a wind project is taxed at full value resulting in a large decline in state aid. Specifically, once a Chapter 313 agreement ends, most of the property tax revenue generated from a wind project goes back to the state due to the Chapter 41 Recapture law in Texas (commonly referred to as Robin Hood). Because revenue designated for I&S (debt service) is not subject to recapture and furthermore because the full increase in assessed value due to a wind project immediately goes on a school districts tax rolls for I&S, there is a strong incentive for school districts in Texas to pass a bond for school capital projects and use the wind project revenues to "subsidize" capital improvement projects. Since school bonds are backed by property tax increases which remain in effect until the bonds are fully repaid, this also implies that school district I&S tax rates will rise if voters approve a bond to protect wind project tax revenues from recapture or to take advantage of the fact that the district's tax base expands by the full amount of the assessed value of the wind project for I&S purposes.

Iowa: Counties in Iowa may enact a wind energy conversion tax ordinance that allows a county to assess wind projects at their net acquisition cost. If a county does not enact a wind energy conversion tax ordinance, state statutes provide that the taxable value of a wind project shall not increase for five years. Under a wind energy conversion tax ordinance, a wind project is taxed a 0% for the first year and then for the second through sixth assessment years, a wind project is taxed at an additional 5% of net acquisition costs for each year (5% in year 2, 10% in year 3, etc.) until the seventh year when taxes are capped at 30% of net acquisition cost. After the energy conversion ordinance expires, wind projects are valued at the market value. While school districts receive their portion (along with counties and other local taxing authorities) of the revenue from wind projects, Iowa's school finance law limits spending on maintenance and operations (daily operations funded through the general fund) via a state specified spending authority, which is the maximum amount a school district can spend. The limit is determined by multiplying a district's previous years enrollment by a cost factor per-pupil which is set by the state legislature. As a result, school district's may not use revenue from wind projects to increase spending on daily operations.

Oklahoma: Oklahoma exempts from ad valorem taxation for a five-year period, new, expanded, or acquired manufacturing facilities owned by a "qualifying manufacturing concern." Okla. Constitution Art. X § 6B(A); OKLA. STAT. tit. 68, § 2902(A), which includes commercial wind installations. However, the state reimburses school districts and counties for the lost tax revenue during the five-year property tax

exemption. Oklahoma's system of school finance is designed to equalize resources across school districts. Specifically, Oklahoma's school finance law specifies that if "per pupil revenue exceeds one hundred fifty percent (150%) of the projected state average per pupil revenue then the district's state aid shall be reduced by an amount that will restrict the district's projected per pupil revenue to one hundred fifty percent (150%) of the projected state average per pupil revenue." As a result, districts with significant revenue from wind projects may see declines in state aid.

California: Due to Proposition 13, property tax rates are capped at 1% of assessed value. As a result, wind projects are also taxed at 1% of assessed value. Due to school finance reform in California, school districts are subject to a revenue limit which limits the total amount of revenue a district can collect from local property taxes and state aid. Each district's revenue limit is set by the state. When local property tax revenue increases, state aid is decreased proportionally so that a district remains within its revenue limit. As a result, increases in a school district's tax base that results from a wind energy installation have little effect on school district operating revenues. If a school districts tax base is large enough that even without state aid it would exceed its revenue limit the state allows the district to keep the revenue. Such districts are known as basic aid districts. To date, however, no district with a wind energy installation is a basic aid district, implying none have the ability to use wind installation tax revenue to increase their current expenditures.

Illinois: Illinois wind energy tax is considered a model for property taxation of wind projects. In 2007, the Illinois legislature set the real property cost basis of a wind energy devices at $360,000 per megawatt of nameplate capacity. The wind energy tax formula used in Illinois is also adjusted annually for inflation using the CPI and for depreciation via a transparent and uniform formula that applies to all wind projects. The tax revenue from wind projects that a school district receives is based on a percentage of the assessed value of the property within the boundaries of the school district. When a district's tax base increases due to a new wind installation, the amount of state aid the school district receives is reduced. However, state aid is not generally reduced dollar-for-dollar with increases in local revenue. As a result, school districts generally benefit from increases in local property tax payments resulting from a wind project. The usage of any additional revenues is up to the discretion of local school districts and therefore can be used to increase current or capital expenditures or reduce local tax rates.

Kansas: Until 2015, wind projects in Kansas were granted a full life time exemption from property tax payments. Starting in 2015, however, new projects will receive a property tax exemption for the first 10 years after which the project is taxed based on its full value. Prior to 2015, wind projects often made Payments in Lieu of Taxes (PILOT) to hosting counties. These PILOTs generally provided relatively small payments to the counties and the use of PILOT funds was at the discretion of the county. As a result, school districts in Kansas benefitted very little from wind installations.

Minnesota: In 2002, Minnesota implemented a wind energy production tax. Tax rates range from 0.012 to 0.12 cents per kilowatt hour depending on the size of a project. Wind projects are exempt from property taxes, except for the land on which the system is situated. Under the law, 80% of wind project tax revenue goes to the county, 14% to cities and townships and 6% to school districts. In 2007, however, the state legislature changed the education finance formula and deducted all revenues stemming from wind projects from state aid payments, implying school districts no longer received the 6% of tax revenue from wind energy installations. Then in 2010, the state legislature changed the distribution of wind energy tax revenues again such that 80% of tax revenues went to the county and 20% to cities and townships with none going to local school districts. This had the effect of eliminating the state's ability to recapture the 6% of revenue that went to school districts. School districts may still benefit from wind energy projects through the establishment of educational foundations by wind energy producers or charitable

contributions from wind energy producers. As an alternative to the production tax, wind farm owners may negotiate with the county in which the farm is located for payments in lieu of the wind energy production tax. The PILOT payments must be used to maintain public infrastructure and services.

Oregon: Oregon does not offer property tax incentives for commercial scale wind facilities. However, counties can establish Rural Renewable Energy Development Zones (RREDZ). Commercial wind projects within the zone are eligible for a 3 to 5-year local property tax exemption. RREDZ's must set a cap on the amount of a projects assessed value that can be abated with the maximum abatement set at $250 million. The state also has a Strategic Investment Program (SIP) that provide a partial property tax exemption for 15 years. In exchange, wind developers pay a fee to the county. For both the RREDZ and SIP programs, negotiations for payments made by wind developers occur at the county level. School districts may benefit from RREDZ and SIP programs based on the county-determined use of wind project tax revenues.

Washington: Wind projects are assessed at 100% of fair market value for property tax purposes. School districts can collect property tax levies for maintenance and operations (M&O), capital projects, debt service and transportation. State law limits school district M&O levies to 24% of the school district's state and federal funding for the previous school year. Wind developments within the boundaries of a school district that increase the tax base add to the property tax revenue of districts. Districts have used such revenues for maintenance and operations, to build new schools, and lower property tax rates.

Colorado: As of 2006, Colorado assesses the value of wind projects based on the income generated by the project. The state sets a tax factor that is applied to the sale price of wind energy to determine the projects assessed value. Funding to school districts is based on a per-pupil formula that calculates the districts spending limit known as the Total Program. A district can exceed its spending limit if gets approval from local voters during an override election which allows for additional property tax revenues. Staring in 2009-10, a district's override revenues were limited to 25% (30% for small rural districts) of its Total Program. When a district passes an override its state share of funding is not reduced.

North Dakota: Prior to 2015, wind turbines were valued at 3 percent of assessed value and subject to local property tax rates. Beginning in 2015, wind projects with a nameplate capacity of 100 kilowatts or more are centrally assessed for tax purposes. Wind projects completed after December 31, 2014 or are 20 years or more from the date of first assessment are subject to payment in lieu of taxes which consist of $2.50 per kilowatt multiplied by rated capacity and a 0.5 mill per kilowatt-hour of electricity generated during the tax period. All taxes are paid to the local governments where the wind projects are located. Taxes are distributed to local governments, including school districts, based on the mill rates of each tax jurisdiction. The state limits the amount of property tax revenue school districts can levy. Specifically, school must not exceed the dollar amount levied the prior year plus 12%. Districts may also levy 12 mills on the taxable valuation for miscellaneous purposes. Districts may also ask voters to approve a specified levy above the levy limits specified by the state.

Indiana: Most commercial wind projects in Indiana have negotiated property tax abatements with their host counties, typically for 10 years. Property tax abatements reduce the property tax liability associated with a wind project by a negotiated amount. Beginning in calendar year 2009, the State began funding 100% of costs for the school general fund. Property tax dollars are no longer used to support operating purposes of Indiana's school districts. Local property tax revenue can only be deposited into either the transportation fund, capital projects fund or rainy-day fund.

New York: As of 2019, no commercial wind project in New York state has been built without a PILOT agreement that provides significant property tax relief. Under the state's tax cap law, taxing districts,

including school districts, must "add any PILOTs that were receivable in the base year. The total amount of PILOTs receivable is to be included in the calculation of the tax levy limit. No adjustment is permitted." The Tax Cap limits the total levy set by school districts, not assessed value or tax rates. School Districts generally may not adopt a budget that requires a tax levy that exceeds the prior year's levy by more than 2% or the rate of inflation, unless they officially override the tax levy limitation.

Michigan: Prior to 2008, wind turbines were taxed as real property. Starting in 2008, wind turbines were taxed as industrial personal property with the assessed value of the turbines determined by their megawatts. Local school districts receive wind project tax revenue for debt millage. Only debt millage goes directly to local districts. If a district has no debt, it gets no direct tax revenue. Per Proposal A (1994), local school district general funds are redistributed on per-pupil basis. Local districts keep sinking/debt fund revenues.

Wyoming: Wind projects are centrally assessed by the state and are considered industrial property assessed at 11.5% of market value. Property tax revenue for wind projects is distribute 22% to the state general fund, 38% to the state School Foundation fund and 40% to local jurisdictions. Starting in 2012, wind projects are also subject to a $1 per megawatt hour production tax that is distributed 40% to the state general fund and 60% to the wind project's host county. School finance in Wyoming is highly centralized and school districts have little control over revenue or expenditures. If a local school district has revenue in excess of its state guarantee, it is recaptured by the state. All recaptured revenue is deposited in the state Foundation Program.

Appendix B: Using Local Wind Energy Tax Rules to Estimate Crowd-Out

In this appendix, we estimate the magnitude of local crowd-out of wind energy installation tax revenues by conducting a back-of-the-envelope calculation using wind energy tax laws and district pre-installation tax rates to determine the expected impact on local revenue from a one MW increased in installed wind energy and comparing this amount to the observed effect we estimate. As described in Appendix A, in nearly every state with substantial wind energy during our sample period, the tax laws determining the flow of tax revenues to local jurisdictions were either opaque, determined at the county or municipality level, or interact with school finance laws in a manner that is too complicated to allow for a straightforward calculation. To our knowledge, Illinois is the only state that during our sample period had relatively clear and simple state-level laws determining the flow of revenues from installed wind energy capacity.

In Table 5, column 6, we show that a one KW per-pupil increase in installed capacity in Illinois leads to a $3.02 increase in local revenue per pupil (or a one MW per-pupil increase in wind leads to a $3,020 increase in local revenue per pupil). Now assuming enrollments are relatively stable from year to year we can express this as follows:

$$\frac{Rev_t - Rev_{t-1}}{Enrl} = 3{,}020 * (\frac{MW_t - MW_{t-1}}{Enrl})$$

Since the change in MW is simply one, this simplifies to:

$$\frac{Rev_t - Rev_{t-1}}{Enrl} = 3{,}020 * (\frac{1}{Enrl})$$

Which further simplifies to:

$$\Delta Rev = 3{,}020$$

So our results suggest that a one MW increase in installed wind capacity leads to a $3,020 increase in local revenues. As a reminder, this estimated effect is net of any revenue taken by districts as property tax relief.

We now turn to examining how this estimate compares to what we would expect given Illinois tax formulas for wind turbines and using pre-installation tax rates, i.e., predicting what effect should be expected if there were no local crowd-out.

Illinois taxes wind using the formula: ($360,000 x trending factor) – depreciation = fair cash value. Where Depreciation = (age of turbine in years / 25) x trended RP cost basis. The local Mill rate is then applied to 33% of fair cash value.

First assuming no inflation (i.e. no trending factor) and no depreciation, a one MW increase in wind capacity should increase revenues by: (360,000/3) * Tax Rate.

The average tax rate in Illinois districts with installed wind capacity during the year prior to installation is $4.28 per $100. This implies:

Change in revenues of (360,000/3) * 0.0428=$5,136.

Incorporating estimated depreciation, the mean installation year in Illinois districts is 2010, suggesting that the average turbine has been installed for 7 years in our sample. This implies that the fair cash value of a one MW project is (once again assuming no inflation):

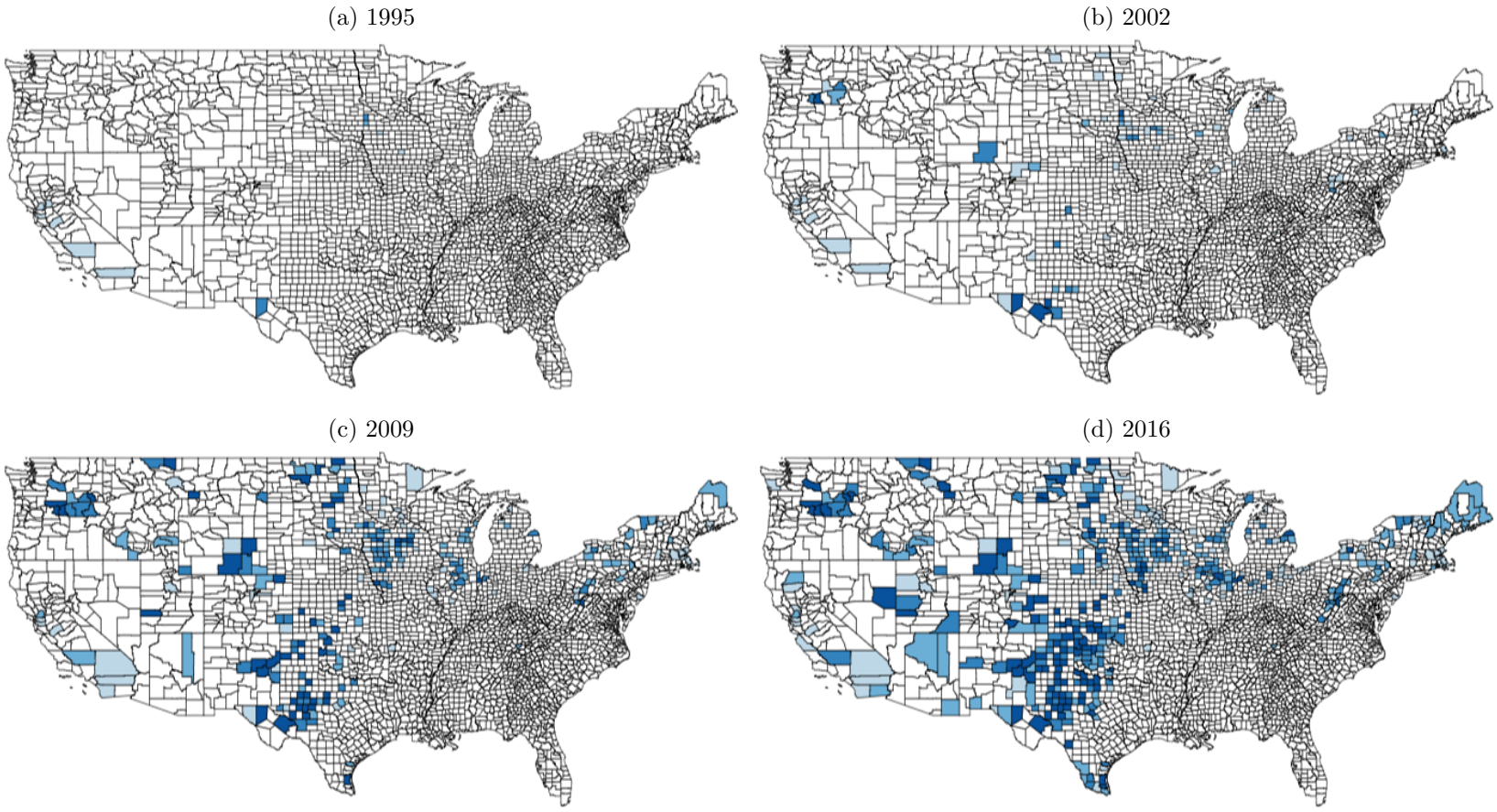
FCV=$360,000 - (360000 * (7/25)) = $259,200

Implying the change in tax revenue would be:

($259,200/3) * 0.0428 = $3,698.

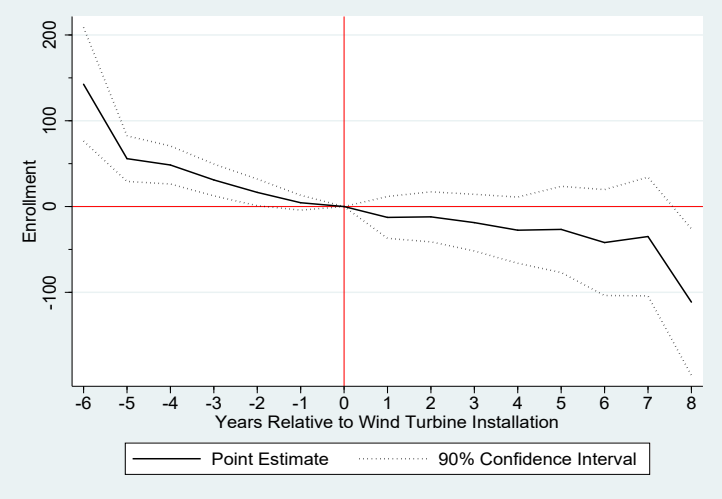
Thus, the predicted increase in local revenues from a 1 MW increase in installed capacity is $3,698, while our estimated effect including any reductions due to property tax relief, is $3,020, for a difference of $678, or 18% of the total revenue gain going toward property tax relief rather than local schools.

Appendix Figure I: United States County Map by Installed Wind Turbine Capacity Per-Pupil



Notes: Map shows installed wind turbine capacity per-pupil in kilowatts (KW) by county and year. Unshaded counties have no installed capacity. The four shades ranging from lightest to darkest represent quartiles of 2016 installed capacity per-pupil: <1.8 KW/pupil, 1.8-16.0 KW/pupil, 16.0-87.8 KW/pupil, and >87.8 KW/pupil, respectively.

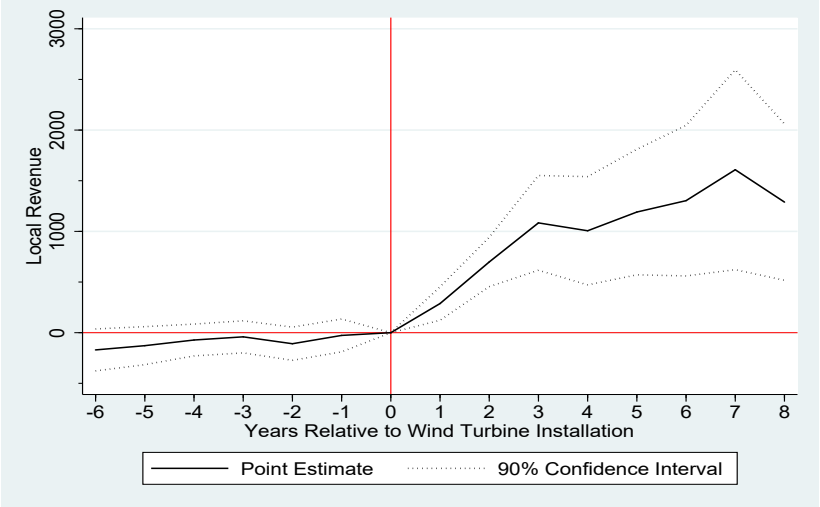
Appendix Figure II: Effects of Wind Turbine Installation on District Enrollment



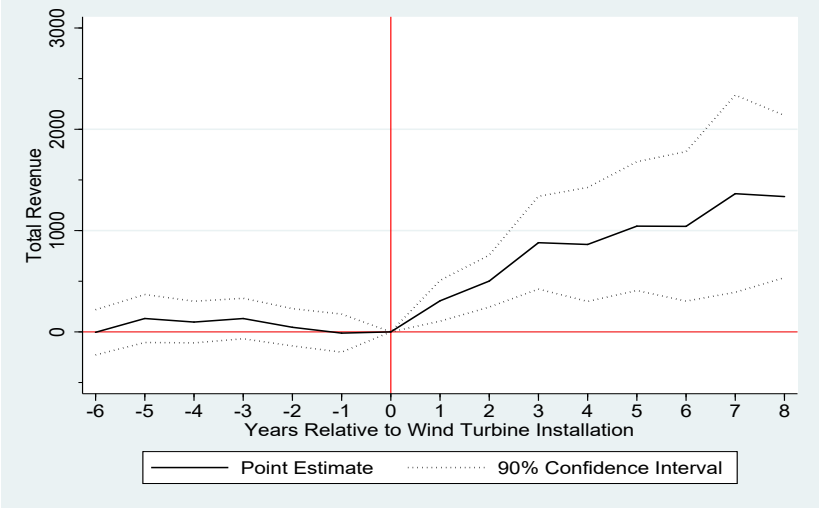
Notes: Figures show event study estimates of the effects of wind turbine installation on school district student enrollment. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure III: Effects on District Revenues Dropping Multiple Installation Districts

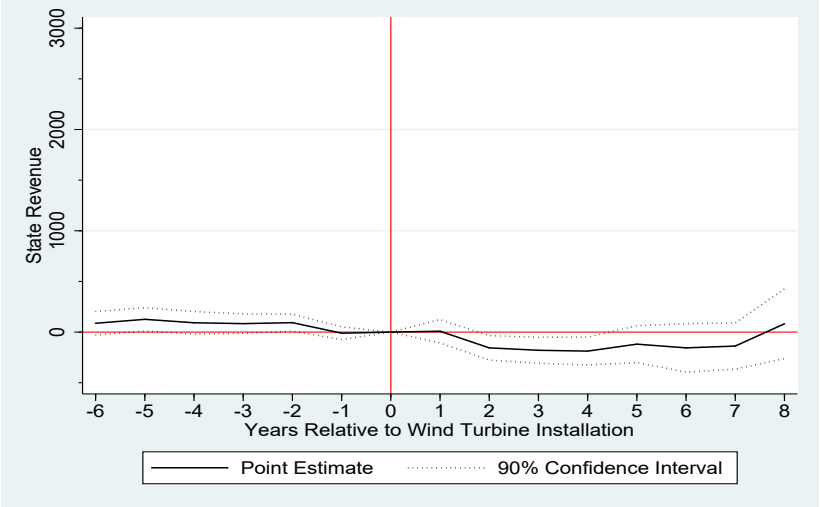
(a) Local Revenue



(b) Total Revenue



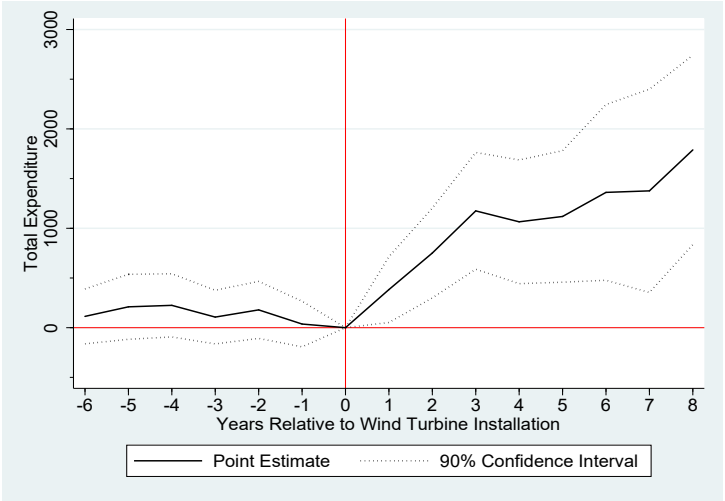
(c) State Revenue



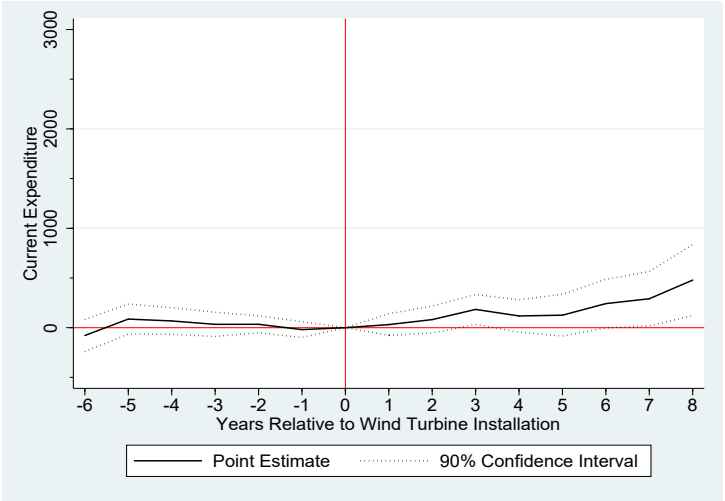
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district revenues after dropping districts that install multiple wind energy facitilies over time. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure IV: Effects on District Expenditures Dropping Multiple Installation Districts

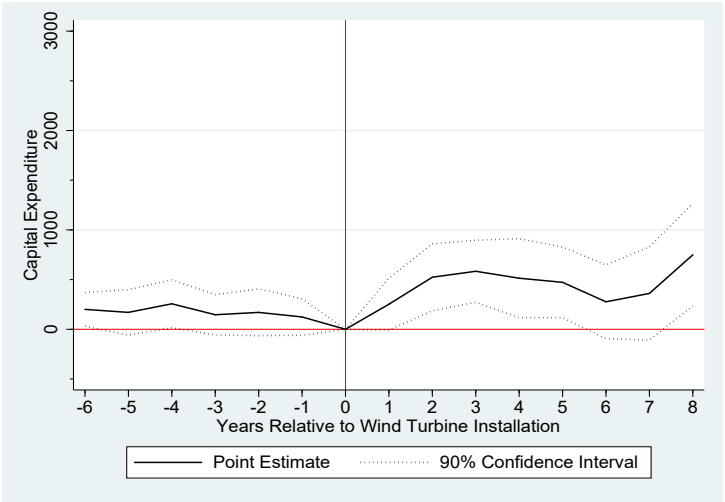
(a) Total Expenditures



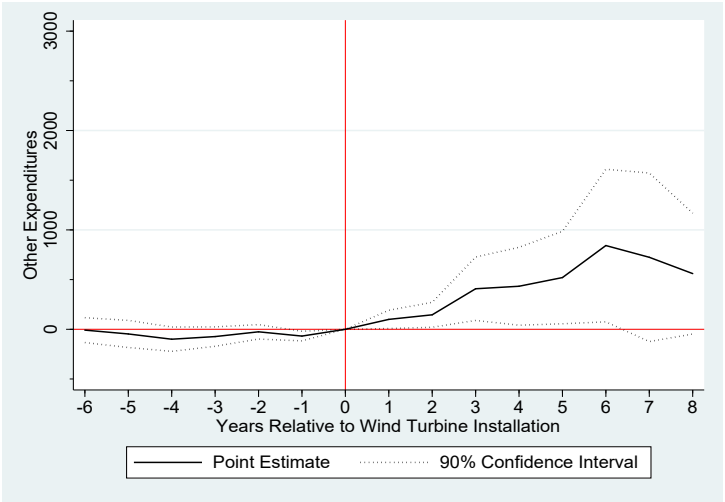
(b) Current Expenditures



(c) Capital Expenditures



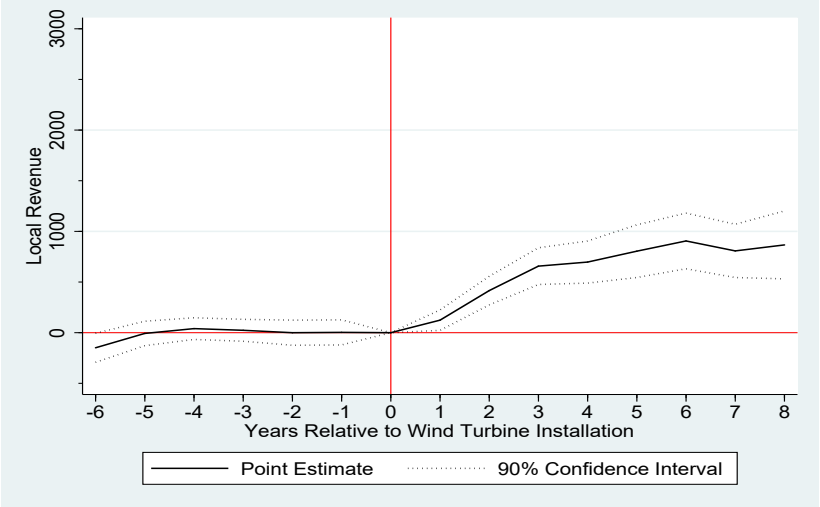
(d) Other Expenditures



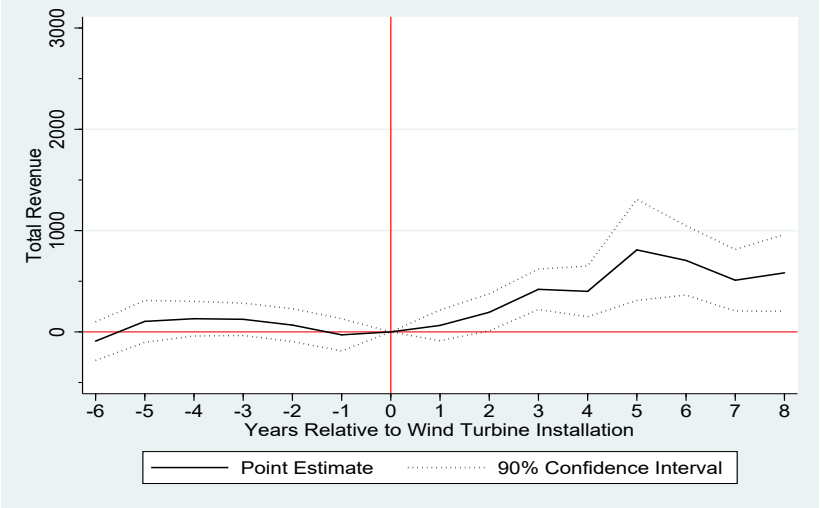
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district expenditures after dropping districts that install multiple wind energy facitilies over time. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure V: Effects on District Revenue, No Texas

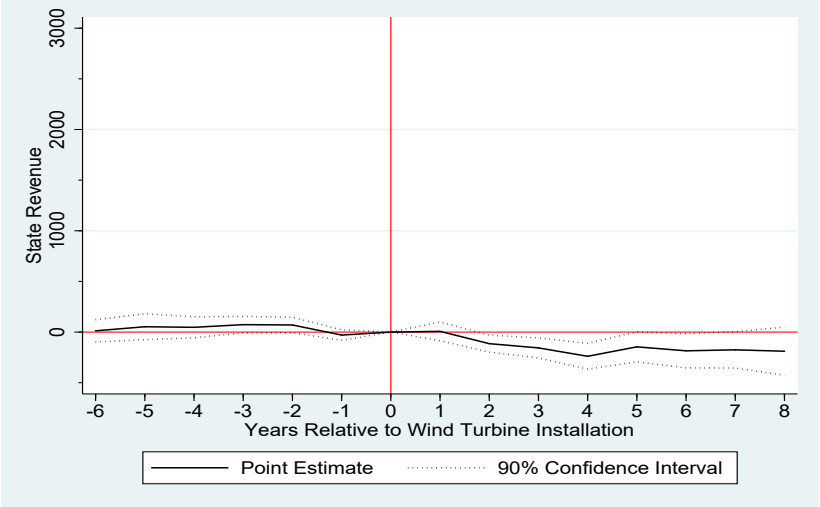
(a) Local Revenue



(b) Total Revenue



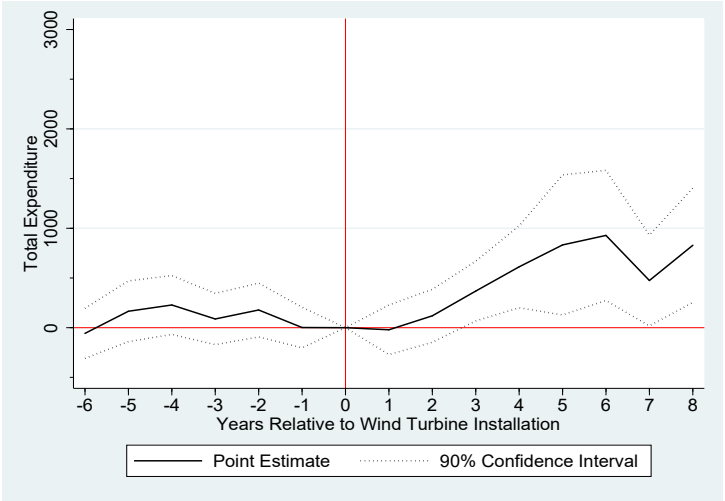
(c) State Revenue



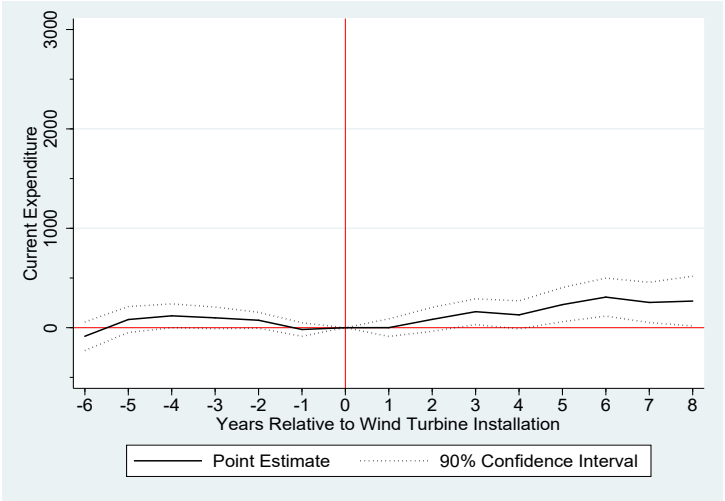
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district revenues after removing Texas from the baseline sample. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure VI: Effects on District Expenditures, No Texas

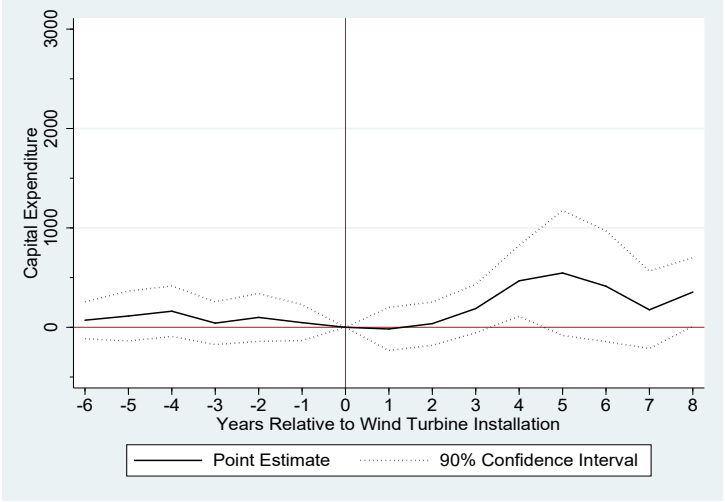
(a) Total Expenditures



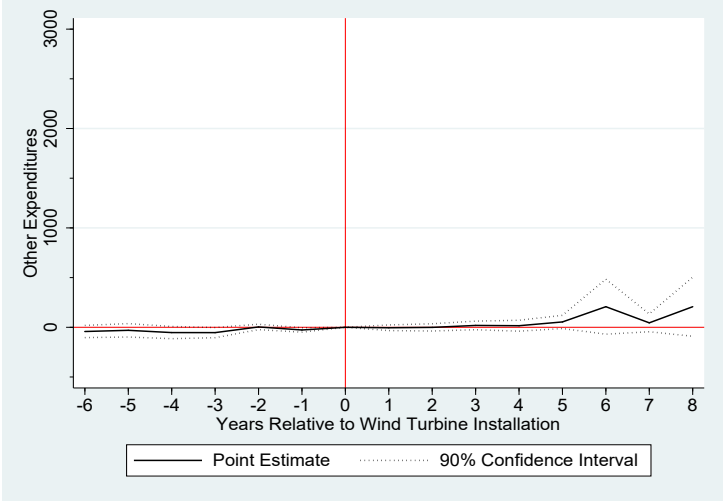
(b) Current Expenditures



(c) Capital Expenditures



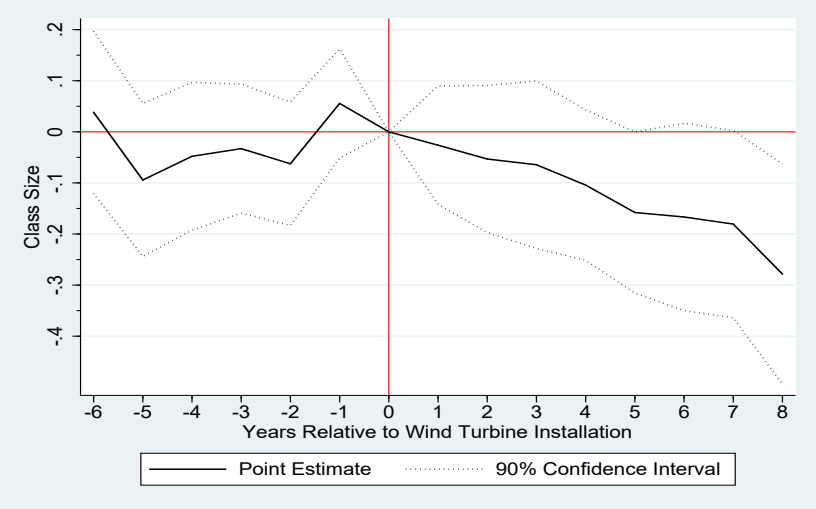
(d) Other Expenditures



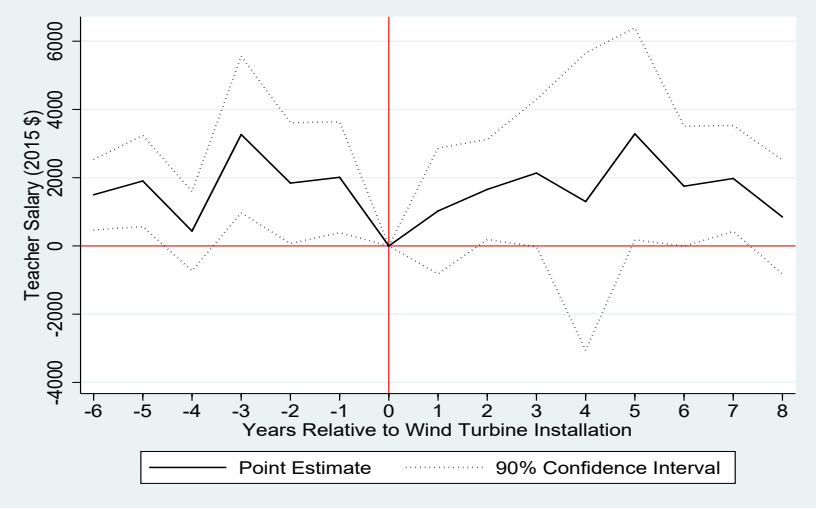
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district expenditures after removing Texas from the baseline sample. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure VII: Effects on Education Production Inputs, No Texas

(a) Pupil-Teacher Ratio



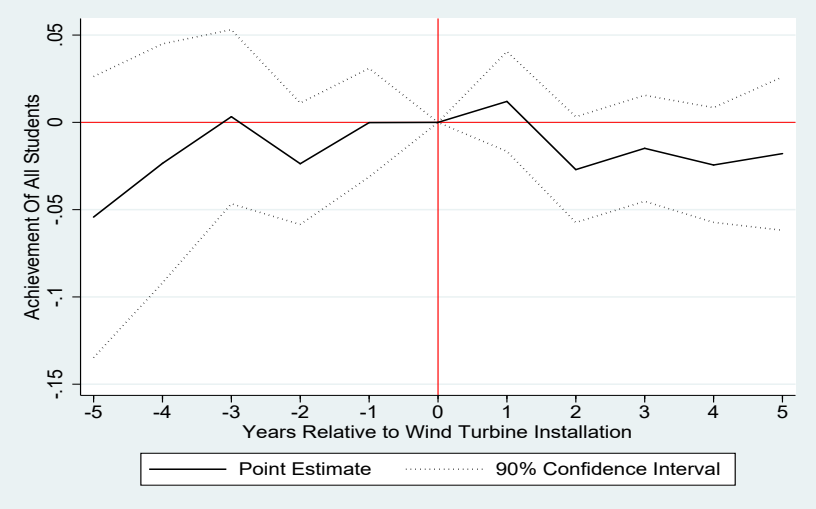
(b) Teacher Salary



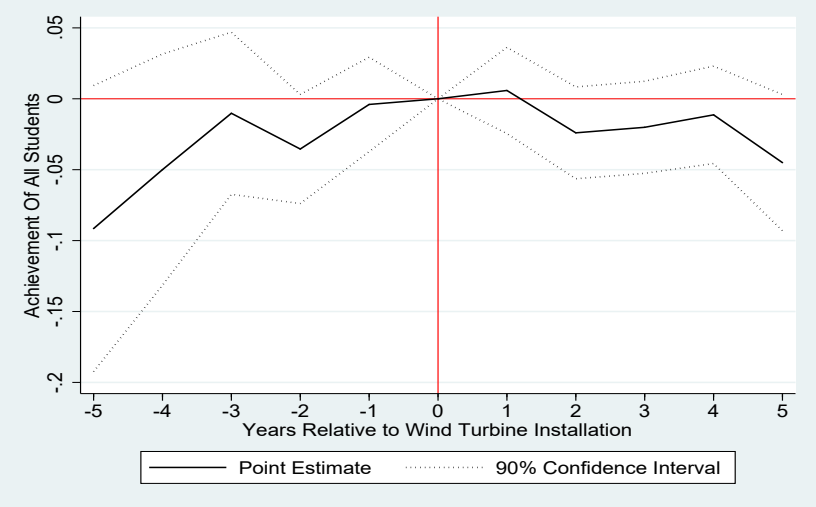
Notes: Figures show event study estimates of the effects of wind turbine installation on inputs to education production after removing Texas from the baseline sample. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure VIII: Effects on Achievement Using Only Stanford Achievement Data

(a) Baseline Sample



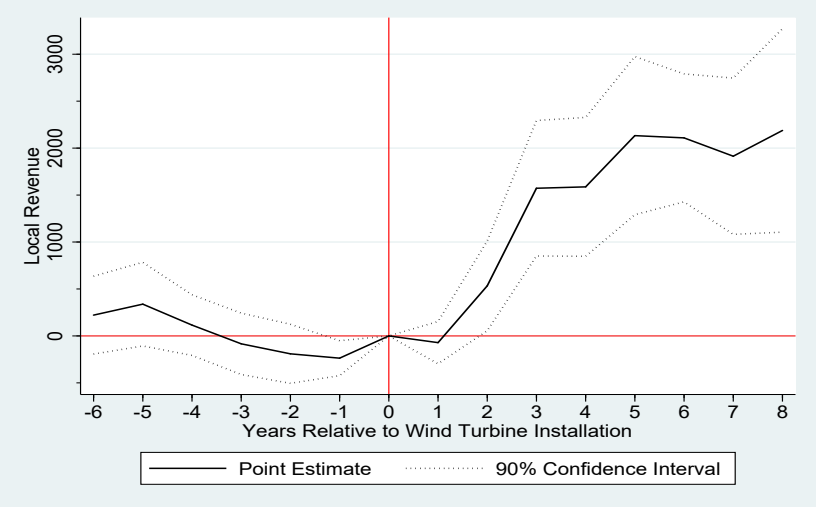
(b) No Texas



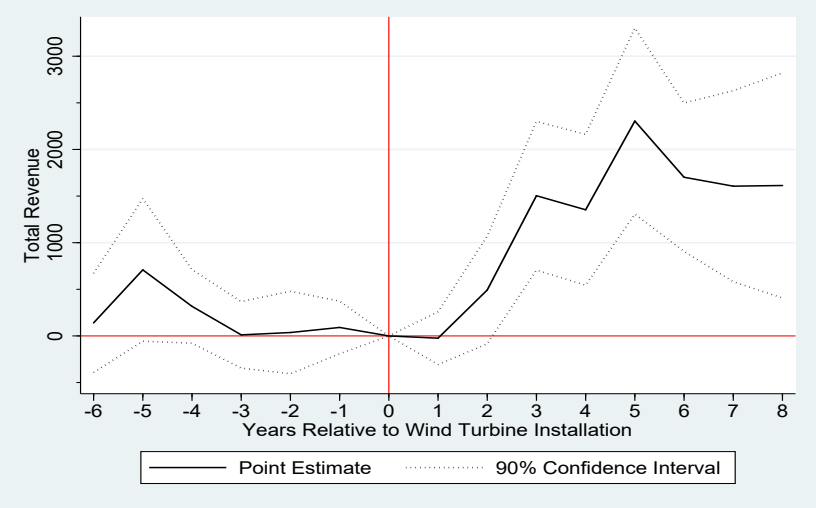
Notes: Figures show event study estimates of the effects of wind turbine installation on standardized district mean test scores using the Stanford Education Data Archive. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure IX: Effects on District Revenues in Illinois, 2001-2016

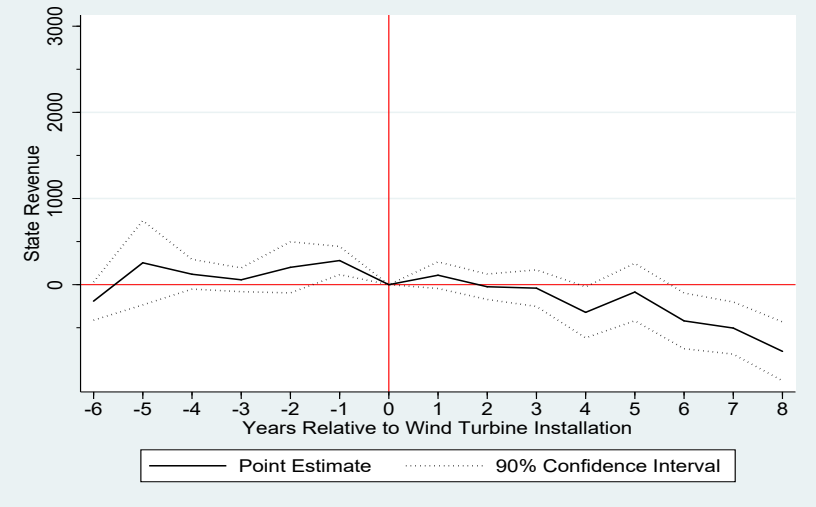
(a) Local Revenue



(b) Total Revenue



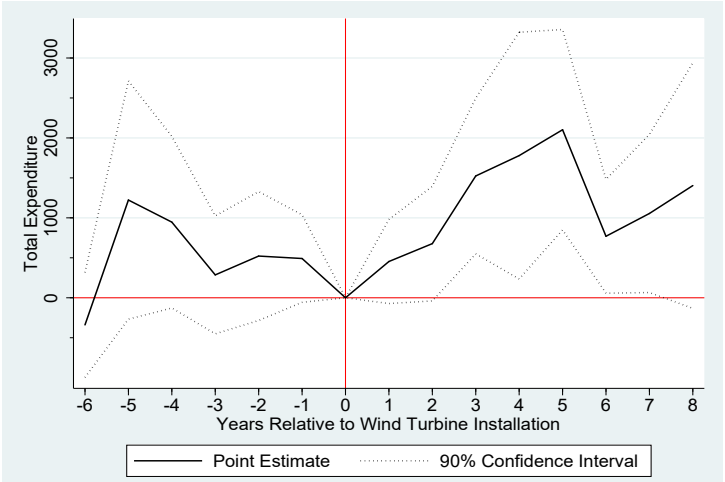
(c) State Revenue



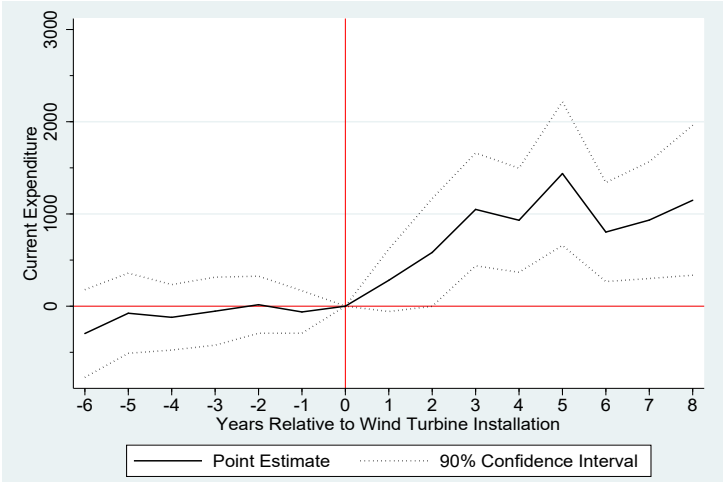
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district revenues in Illinois for a similar period to when property tax rate data are available. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure X: Effects on District Expenditures in Illinois, 2001-2016

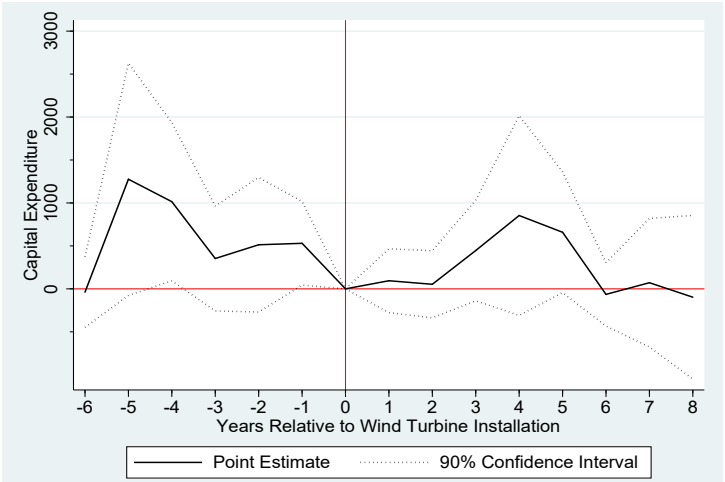
(a) Total Expenditures



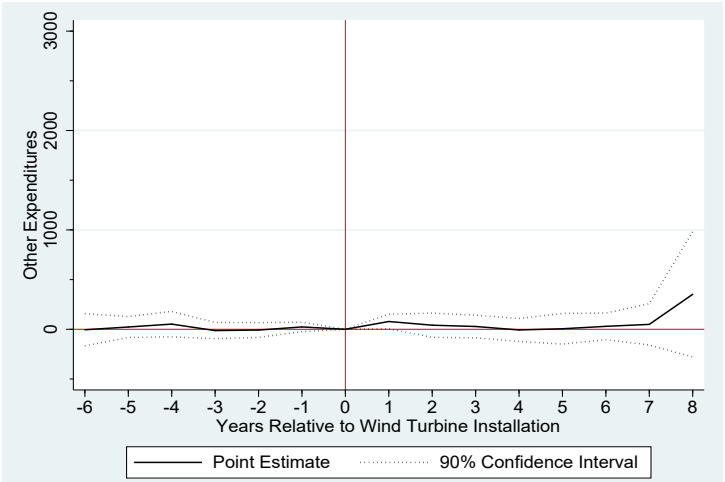
(b) Current Expenditures



(c) Capital Expenditures



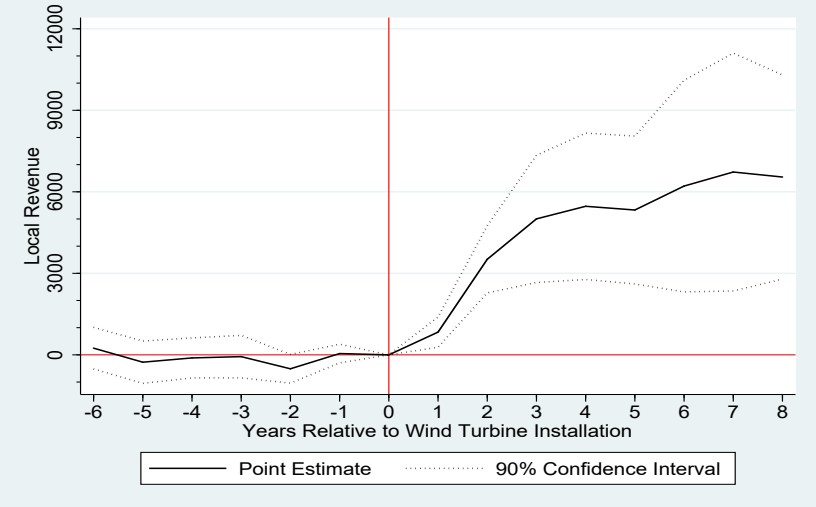
(d) Other Expenditures



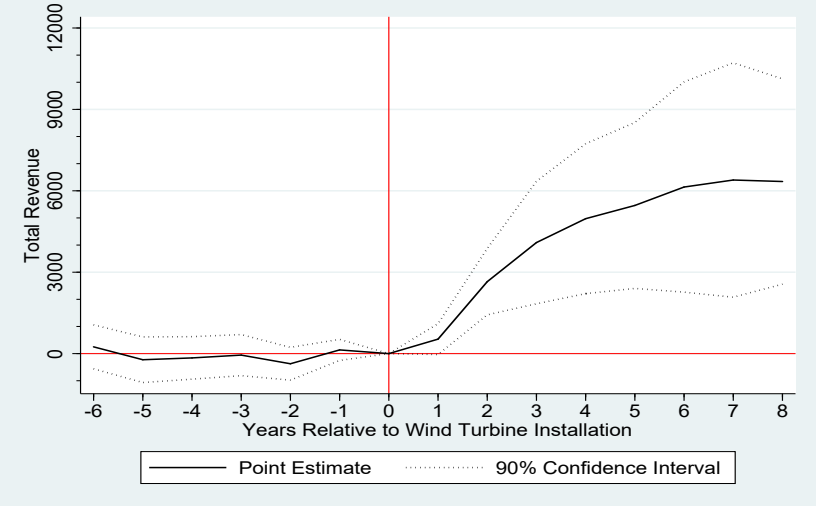
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district expenditures in Illinois for a similar period to when property tax rate data are available. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure XI: Effects on District Revenues in Texas, 2000-2016

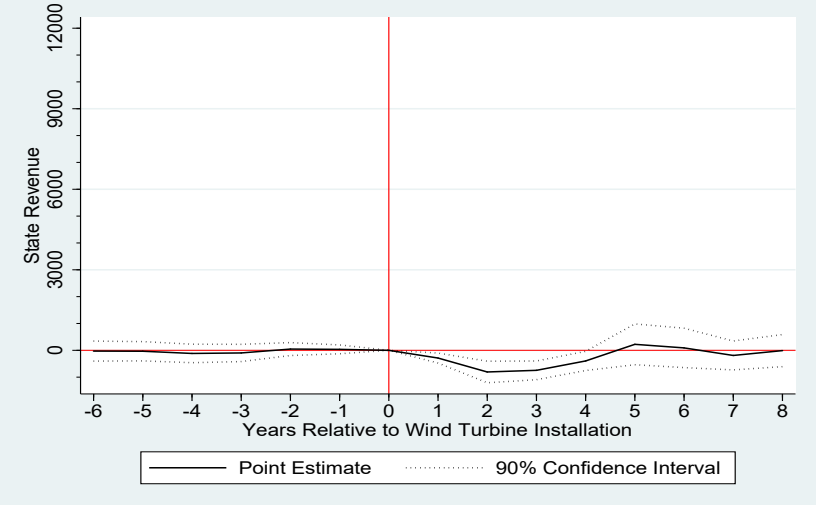
(a) Local Revenue



(b) Total Revenue



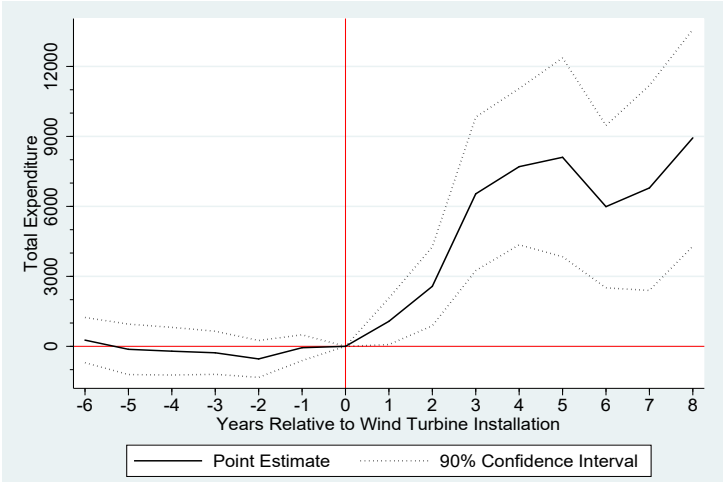
(c) State Revenue



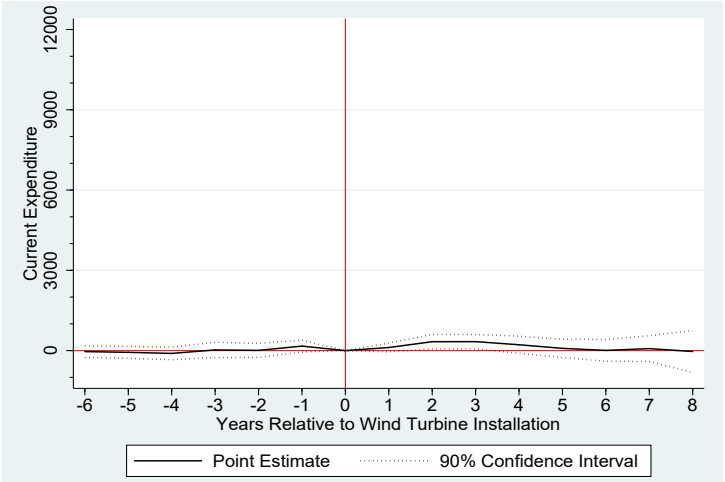
Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district revenues in Texas for a similar period to when property tax rate data are available. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Figure XII: Effects on District Expenditures in Texas, 2000-2016

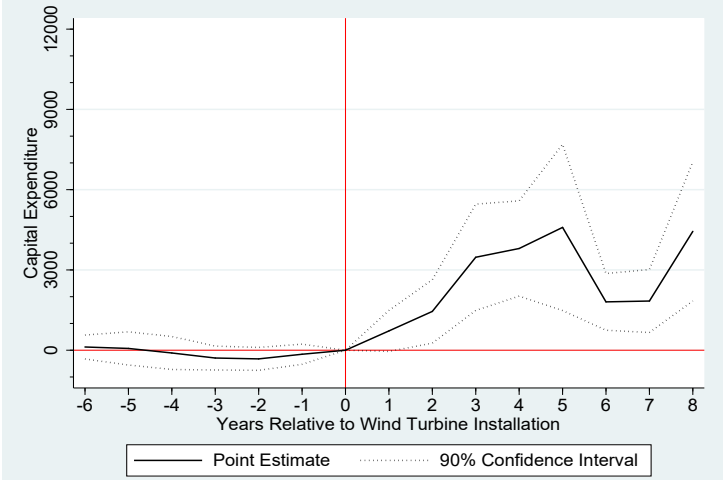
(a) Total Expenditures



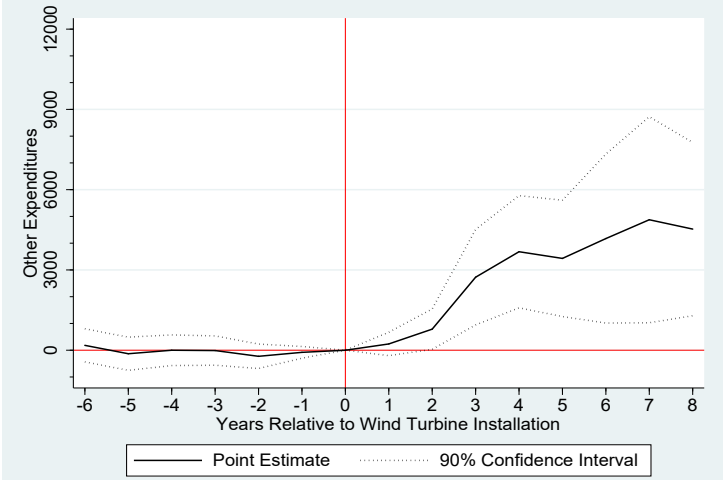
(b) Current Expenditures



(c) Capital Expenditures



(d) Other Expenditures



Notes: Figures show event study estimates of the effects of wind turbine installation on per-pupil school district expenditures in Texas for a similar period to when property tax rate data are available. Solid lines are point estimates, and dashed lines are 90% confidence intervals.

Appendix Table 1: Effects of Installed Turbine Capacity on Other Expenditures, By State

Dependent Variable	Sample Mean ($/pupil)	Texas	Baseline, No Texas	Baseline, No TX, WV, ID	Iowa	Oklahoma	Illinois	Minnesota	Oregon	Washington	Colorado
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Other Expenditures	$1,052.39	4.82***	0.70	0.70	0.60**	0.02	0.26	1.15***	-0.00	2.76***	-0.00
		(1.41)	(0.49)	(0.49)	(0.28)	(0.03)	(0.25)	(0.17)	(0.02)	(0.16)	(0.09)
Non-Elementary/Secondary	$83.26	-0.00	0.42	0.42	0.04	0.00	0.01	0.14**	0.02	1.78***	-0.01
Expenditures (Commuity Services &		(0.01)	(0.32)	(0.32)	(0.06)	(0.00)	(0.02)	(0.06)	(0.01)	(0.13)	(0.01)
Interest on Debt	$293.85	0.51***	0.23	0.23	-0.05	0.03	-0.03	0.74***	-0.03***	0.97***	-0.05
		(0.10)	(0.18)	(0.18)	(0.06)	(0.03)	(0.03)	(0.17)	(0.01)	(0.08)	(0.06)
Payments to State Government	$98.75	4.24***	0.00	0.00	0.00	0.00	0.00	0.01	0.02***	0.00	-0.00
		(1.36)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.01)
Payments to Local Governments	$27.44	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Payments to Other School Systems	$500.44	0.07	0.06*	0.06*	0.61**	-0.01**	0.27	0.25*	0.00	0.02	0.07***
		(0.05)	(0.03)	(0.03)	(0.30)	(0.01)	(0.24)	(0.15)	(0.00)	(0.04)	(0.02)
Payments to Private Schools	$75.52	0.00	0.00	0.00	0.00	-0.00	0.01	0.00	0.00	0.00	-0.00*
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)
Payments to Charter Schools	$21.96	0.00	-0.01	-0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00
		(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)
Observations		22,099	196,752	193,245	7,650	11,382	18,728	6,991	3,676	5,880	3,617
Expanded Controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each coefficient is from a separate regression of the outcome (listed in the row header) on installed wind turbine capacity (in KW) per-pupil for the sample listed in the column header.

*** = significant at 99% confidence level; ** = 95%, * = 90%.

Appendix Table 2: Achievement Effects Using Stanford Data Only

	Baseline		No Texas	
	(1)	(2)	(3)	(4)
Stanford Data				
Post	0.002	0.002	0.012	0.012
	(0.024)	(0.024)	(0.027)	(0.027)
Post*Trend	-0.008	-0.008	-0.005	-0.005
	(0.011)	(0.011)	(0.013)	(0.013)
Effect 5 Years Post		-0.036		-0.014
		(0.069)		(0.081)
Observations	628,262		565,974	
Expanded Controls	No	Yes	No	Yes

Notes: The level of observation is the district-year-grade-subject. The dependent variable is standardized student test scores. In this table, we use annual scores from the Stanford Education Data Archive for the universe of districts from 2009-2015 for grades 3-8.
*** = significant at 99% confidence level; ** = 95%, * = 90%.