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Abstract

The construction of wind turbines is a highly contested political issue due to the perceived negative externalities that these turbines create. Opposition groups share common complaints and concerns that nearby turbines will negatively affect their property values. This paper analyzes how the installation of a wind turbine affects nearby property values at the zip code level. Using a difference-in-difference model across zip codes throughout the entire continental United States, this paper finds results that suggest there is no perceivable effect from the construction of wind turbines on the price per square foot of nearby homes.

1 Introduction

As fossil fuel emissions become a more salient political issue due to their contribution to global climate change and decreasing air quality, there will likely be increased pressure to pursue clean energy technologies. Traditionally, fossil fuels have been burned to create electricity. Burning fossil fuels emits carbon gas into the air. This carbon was previously trapped in the earth in the forms of coal, oil, and natural gas. Carbon is a greenhouse gas that, when released into the atmosphere, leads to higher temperatures around the world. As of 2018, 63.5% of all electricity in the United States is produced by burning fossil fuels.[1] Renewable energy sources such as hydropower, solar, and wind power do not emit carbon. These, along with nuclear power, are likely to be the answer to the fossil fuel problem. Clean forms of energy can be used to reduce the world's reliance on fossil fuels and eventually lead to a carbon-free energy future in which atmospheric carbon levels and the climate are once again in equilibrium.

Unfortunately, the transition from fossil fuels to cleaner energy forms such as wind power does not come without its challenges. Despite the positive effects created by clean energy, wind turbines are considered to cause negative externalities on the local population. These externalities lead to many community concerns and opposition to wind turbines being constructed in rural areas. One of these concerns is that "the values of properties near wind developments may be reduced".[2] Some argue this might occur because of loss of aesthetic amenities due to wind turbines.[3] These amenities include the landscape views valued by many people who live in these rural locations. Other reasons people argue wind turbines might reduce

[1] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." What Is U.S. Electricity Generation by Energy Source? - FAQ - U.S. Energy Information Administration (EIA). https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.
[2] Hoen et al. (2013), 1.
[3] Gibbons (2015).

nearby property values are reported health effects due to turbine flicker (the pattern of light that occurs when a spinning turbine's shadow rests on a home) and noise (in the form of a noticeable hum) coming from the turbines.[4] These many negative externalities have been found to cause a negative effect on life satisfaction for those living within a radius of 4 kilometers from a wind turbine.[5]

This paper aims to analyze the claim that wind turbines negatively affect nearby property values. I use a difference-in-difference fixed effects approach to isolate how the construction of a local wind turbine influences home values at the zip code level. The data I use is comprised of the median price per square foot for homes in the United States at the zip code level retrieved from Zillow, Inc., and wind turbine data from the United States Wind Turbine Database. This paper adds to the literature by incorporating a large sample analysis and an unconventional data source – Zillow – that is not biased by a repeat sales methodology that might bias other studies.

Ultimately, my results indicate that there is no significant effect of wind turbines on the median price per square foot of homes at the zip code level. The number of turbines within a given zip code and their total capacity also do not seem to affect property values. However, when limiting my model to only treated groups, I find that the construction of a wind turbine correlates to a roughly 2.47% decrease in the price per square foot of nearby homes.

In the subsequent sections of this paper I will first discuss the existing literature in section two, then explain my method and model in section three, describe my data in section four, and discuss my results in section five. Finally, I will conclude in section six.

[4] Ibid.
[5] Krekel and Zerrahn (2017).

2 Literature Review

Hedonic analysis is the process of analyzing the value of nonmarket amenities based on consumer preferences. It has been prevalently used to find how much households value specific neighborhood qualities that cannot be quantified, such as crime, airport noise, and school quality.[6] These also include effects of reduced environmental quality and the negative externalities of nearby power plants (Davis 2011). This paper uses Hedonic analysis to estimate how consumer preferences might lead to wind turbines negatively affecting nearby property values.

While there is extensive literature on Hedonic analysis, there is relatively limited literature on how wind turbines specifically affect property values. The previous literature provides mixed results. Some studies find no statistically significant effect (Lang et al., 2014; Hoen et al., 2013), whereas others (Dröes and Koster, 2016; Gibbons, 2015; Heintzelman and Tuttle, 2011) find effects ranging from a 1.4% to 6% decrease in property values within a 2km radius of a turbine. Sunak and Madlener (2016) find the largest effect of a decrease, ranging from 9% to 14% of property values for homes with an unobstructed view of a wind turbine.

Although the results are mixed, it is expected that wind turbines would lead to a decrease in property values due to the negative externalities they produce. Taking a different approach, Krekel and Zerrahn (2017) are able to quantify this negative externality employing a "life satisfaction approach." Using a German Socio-Economic study, they find that a wind turbine's negative externality is valued at 564 Euros for homes up to 4km away, decaying over 5 years.

[6] Lang et al. (2014), 415.

This paper takes a slightly different approach than the others by using Zillow as a data source for home values. Zillow provides an advantage by not depending as heavily on recent selling prices of homes in an area. It is possible that bias can arise in studies that focus primarily on home sales to determine property values (Dröes and Koster, 2016; Hoen et al., 2013; Heintzelman and Tuttle, 2011).

3 Method

Wind turbines are not randomly distributed throughout rural areas in the United States. Because of this, a simple OLS estimation will not find an unbiased causal effect. The difference-in-difference approach allows for a way to estimate a causal relationship by comparing treated groups to untreated groups before and after the treatment occurs to isolate the effect of a turbine.[7] It is a quasi-experimental method that allows me to find an exogenous effect without relying on a randomized control trial.

When conducting Hedonic price analysis, it is important to isolate the effect of the specific amenity, or disadvantage in this case, by controlling for other factors that may affect a home's value. For this purpose, I center my analysis around the price per square foot of homes. This allows me to control for larger homes that may be valued more due to differences in the number of bedrooms, bathrooms, and lot size among other attributes of a home. By focusing on the dollar value per square foot, it does not matter how large a home is or how many rooms it contains. All that matters is the value of the land that the home is located on. I use the natural log of the median price per square foot in my estimation so that the dependent variable is more

[7] Ibid.

normally distributed. Otherwise, very large differences between specific zip codes might bias my estimation.

I use zip code fixed effects to account for zip code specific confounders such as demographic differences (income, education, age) and geographic attributes. I also use time fixed effects to account for time-dependent confounders that may bias my estimate across all zip codes. The most significant of these time-based biases to eliminate are business cycle effects along with the housing market crash. I study the time period from the year 2000 to 2018 because wind turbines were not very prevalent until the 21st century and Zillow's housing data is more accurate in this time period than before the year 2000.

I ran three different analyses on three different samples. The first sample consists of the entire United States excluding major population centers that are unrepresentative of locations where turbines would be cited.[8] These locations would never have wind turbines constructed within them because turbines require setbacks of up to a few thousand feet from any structures. Densely populated metro areas do not have enough open space to site wind turbines. I also exclude Hawaii and Alaska from my model because these states are not part of the continental United States. The second sample is made up of the same observations as the first, but I also exclude states in the southeast of the United States. I exclude these observations because these states currently have zero wind capacity installed and are likely to be unrepresentative of the treatment group.[9]

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[8] The excluded cities are: Phoenix, AZ; San Francisco, CA; Los Angeles, CA; Santa Ana, CA; San Diego, CA; San Jose, CA; Berkeley, CA; Long Beach, CA; Sacramento, CA; Glendale, CA; Inglewood, CA; New York, NY; Jersey City, NJ; Newark, NJ; Union City, NJ; Paterson, NJ; Chicago, IL; Philadelphia, PA; Miami, FL; Hialeah, FL; San Antonio, TX; Austin, TX; Memphis, TN; Kansas City, MO; Seattle, WA; Lowell, MA; Boston, MA; and Cambridge, MA

[9] The excluded states are: Florida; Arkansas; Louisiana; Mississippi; Kentucky; Alabama; Georgia; South Carolina; and Virginia

The third sample I run in my analysis consists of only zip codes that were treated or would be treated in the study period. Wind farm siting and construction, similar to conventional power plant siting and construction, is a highly political process. Because of this political process, power plants are opened in locations near neighborhoods with similar housing and demographic characteristics.[10] Despite the prerequisite of wind power potential, this assumption of similar demographic characteristics likely holds true for wind turbines as well. For this reason, I also estimate the effect of wind turbines on only zip codes that either already had turbines or would have one constructed by 2018.

Lastly, I incorporate Granger causality testing to check for the parallel trends assumption. Although the parallel trends assumption cannot be directly tested for, Granger causality testing allows me to view any anticipatory effects that may bias my estimate. For this purpose, I incorporate three leads that check for differences between the treated and control group three years leading up to the treatment of a turbine being installed.

3.2 Model

To determine the effect of wind turbines on nearby property values at the zip code level, I estimate the following difference-in-difference model:

$$Y_{zt} = \beta_0 + \beta_1 X_{zt} + \gamma_z + \delta_t + \varepsilon_{zt}$$

Where:

- Y represents the natural log of median dollar value per square foot for each zip code **z** at time **t**

[10] Davis 2011, 1.

- X represents the independent variables used in separate regressions:
    - A turbine indicator variable equal to 1 if zip code **z** contains a turbine at time **t**, and 0 otherwise
    - The total number of turbines within a zip code **z** at time **t**
    - The total capacity of turbines within a zip code **z** at time **t**
- γ_z represents the zip code fixed effects for zip code **z**
- δ_t represents the time fixed effects for time **t**
- ε_{zt} represents the error term

I will use this model to test three null hypotheses:

H_{01}: The construction of a local wind turbine does not affect nearby property values

H_{02}: The number of local wind turbines does not affect nearby property values

H_{03}: The total capacity of local wind turbines does not affect nearby property values

The purpose of analyzing the total number of turbines as well as the total capacity of these turbines is that larger turbines typically exhibit a greater amount of capacity. Therefore, by taking into account both of these variables, I am able to analyze the effect of larger turbines.

For the Granger causality test, I incorporate a model similar to Autor (2003):

$$Y_{zt} = \beta_0 + \sum_{n=0}^{3} \beta_1 X_{zt+n} + \gamma_z + \delta_t + \varepsilon_{zt}$$

I choose three leads for this test because three years is a reasonable amount of time to test for anticipatory effects of a wind turbine being constructed. This is because of the extensive planning and public announcements that occur before a turbine is sited.

4 Data

4.1 Dependent Variable – Price Per Square Foot

I gathered data for the median price per square foot for homes in a given zip code from Zillow, Inc. Zillow calculates a Zestimate for more than 100 million homes throughout the United States. A Zestimate is an estimate of value for each home. The Zestimates are calculated by integrating information "from prior sales, county records, tax assessments, real estate listings, mortgage information, and GIS data".[11] This median price per square foot is calculated by taking the estimated home value for each home in a given region and dividing it by the home's square footage.[12] The home value estimates are unbiased for each region and price tier they are in, meaning they are equally as likely to overstate as understate the value of a home. Arguably, Zillow's method is more accurate than valuations using repeat sales methodology. Repeat sales methodology measures price change by collecting the data on resold homes within a given region.[13] Repeat sales methodology is more likely to be biased in smaller geographic regions where houses are not sold as frequently. Rural areas can be characterized similarly, where almost all wind turbines are located. However, one drawback of Zillow's data is that it does not have property value information for every zip code within the United States. That means that zip codes missing from Zillow are also not included in my analysis.

To Illustrate the accuracy of Zillow's home value calculation, I compiled the National Association of Realtors' (NAR) and Zillow's average and median home values for counties with the most wind power in the United States. I did not list counties in which either Zillow or the

[11] https://wp.zillowstatic.com/3/ZHVI-InfoSheet-04ed2b.pdf
[12] https://www.zillow.com/research/data/
[13] Ibid.

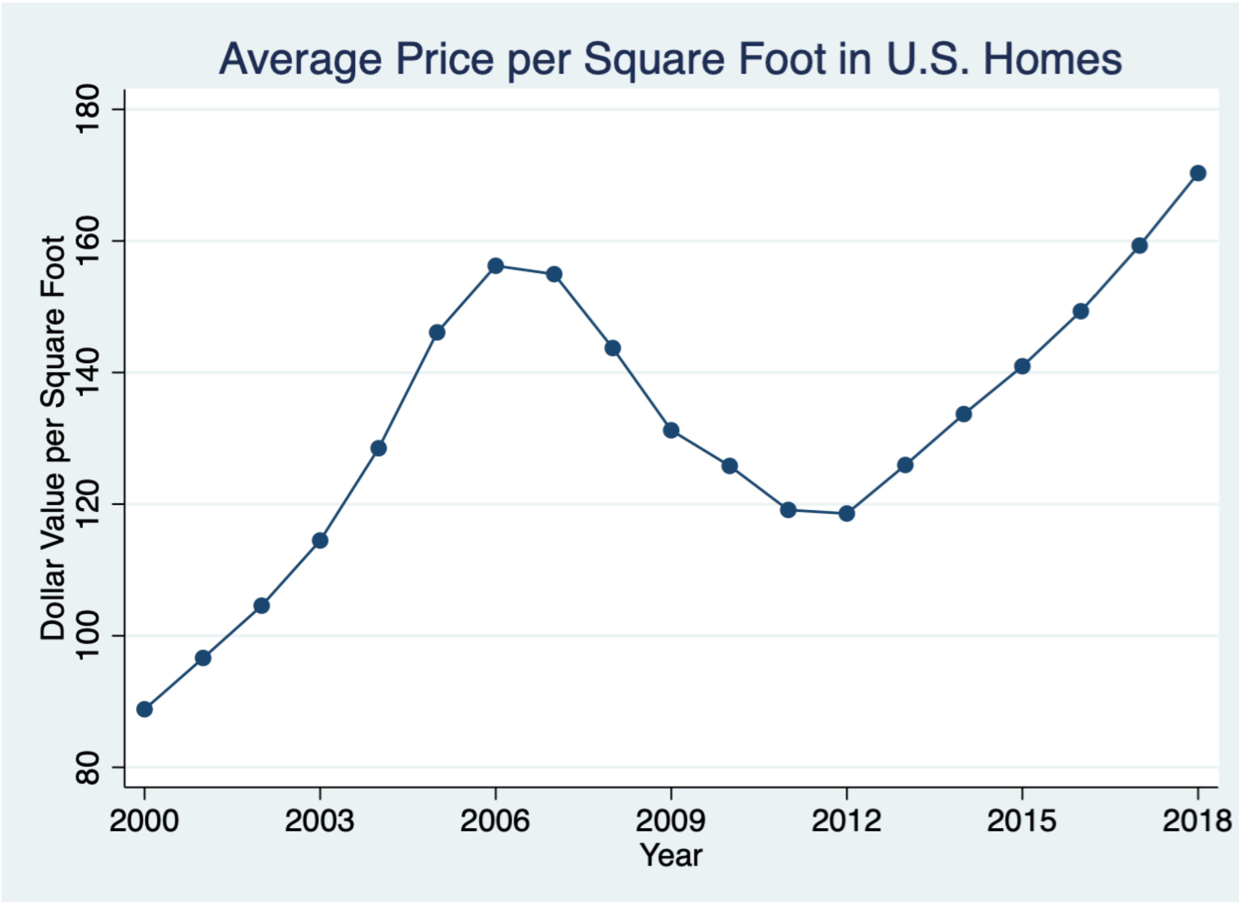
NAR did not have data for. Zillow's values were similar enough to the NAR's to affirm the data's accuracy.[14]

Figure 1 demonstrates that Zillow's data follows the expected trend of housing value over time throughout the United States. Specifically, property values begin to fall in 2008 following the housing market crash and only begin to recover after 2012.

4.2 Independent Variables

I gathered data for wind turbines in the United States from the United States Wind Turbine Database (USWTDB). This data was produced through a joint venture by the U.S. Department of Energy, American Wind Energy Association, Lawrence Berkeley National Laboratory, and the U.S. Geological Survey.[15] The dataset includes the year each turbine was constructed as well as model specifications including its total capacity. This dataset includes observations of over 58,000 wind turbines, 54,250 of which are in the continental United States making up a capacity of roughly 90 million megawatts.[16]

[14] Find this information in Table A1 in the appendix.
[15] https://eerscmap.usgs.gov/uswtdb/
[16] See Table A2 in the Appendix for a full list of turbine capacity by state.



Average Price per Square Foot in U.S. Homes
Dollar Value per Square Foot
80
100
120
140
160
180
2000
2003
2006
2009
2012
2015
2018
Year

Figure 1

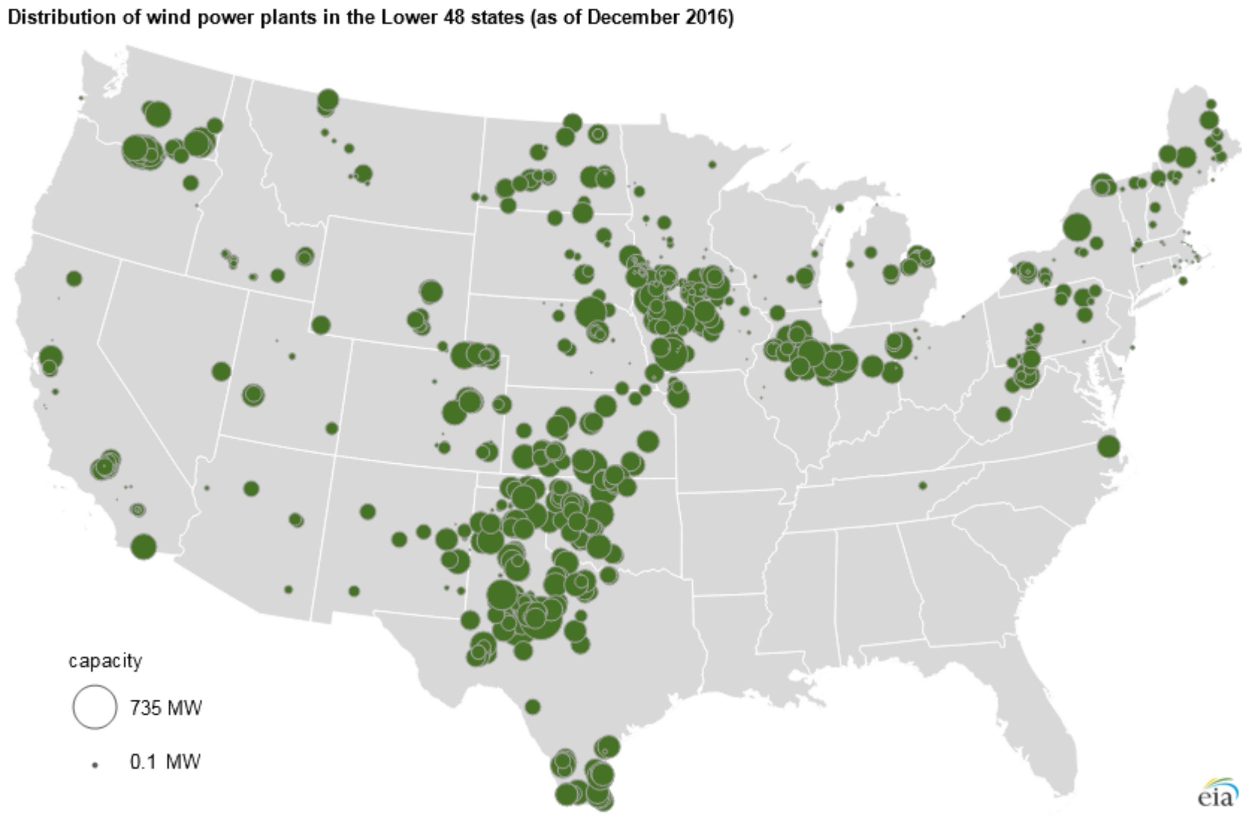


Figure 2[17]

Each turbine also has its longitude and latitude coordinates listed. The USWTDB verified the locations of all turbines to an accuracy of within 10 meters using high-resolution imagery.[18] Using ArcGIS Pro software, I mapped each one of these turbines to its respective zip code in the United States.

The three independent variables that I use in my analysis include a dummy for whether a turbine exists or not within a zip code, the total number of turbines within that respective zip code, and the total capacity of turbines within that zip code. By mapping each turbine to its respective zip code, I was able to calculate the summation for these variables. Some turbines in

[17] Beckford, Tosha. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Wind Turbines Provide 8% of U.S. Generating Capacity, More than Any Other Renewable Source - Today in Energy - U.S. Energy Information Administration (EIA). https://www.eia.gov/todayinenergy/detail.php?id=31032#tab1.
[18] https://eerscmap.usgs.gov/uswtdb/

the dataset had negative values for their capacity. I drop these observations from my analysis because a negative turbine capacity is not possible and will bias my estimate.

Lastly, I used the 2010 American Community Survey from the U.S. Census to find densely populated cities to drop from my analysis.

5 Results

5.1 Empirical Findings

This paper's main empirical finding is that wind turbines have no perceivable statistically significant effect on the price per square foot of homes throughout the United States at the zip code level. Table 1 illustrates this through the point estimates and standard errors of my first two samples: the U.S. excluding metro areas and the U.S. excluding both metro areas and the southeast, respectively. Similarly, there is also no perceivable statistically significant effect of neither the total number of wind turbines nor the total capacity on the price per square foot of homes at the zip code level. The point estimates of the treatment are negative for both samples, and the point estimate is four times stronger in the sample excluding the southeast United States. However, because the standard errors are large relative to the point estimate, this result is not statistically significant. Given these results, I cannot disprove my null hypotheses for these samples.

Table 1:

Outcome of Turbines on Price Per Square Foot
Natural Log of Dollars/Sqft

	U.S. w/out Major Metro Areas			U.S. w/out South Eastern States		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables						
Turbine Exists (Dummy)	-2.63E-03			-8.61E-03		
	(7.90E-03)			(7.95E-03)		
Total Number of Turbines		1.59E-04			1.22E-04	
		(1.64E-04)			(1.58E-04)	
Total Capacity			1.91E-07			1.58E-07
			(1.16E-07)			(1.13E-07)
Constant	4.626***	4.626***	4.626***	4.663***	4.663***	4.663***
	(0.000105)	(0.0000786)	(0.0000459)	(0.000129)	(0.0000931)	(0.0000549)
Observations	3074422	3074422	3074422	2508464	2508464	2508464
Adjusted R-Squared	0.952	0.952	0.952	0.955	0.955	0.955

Note: Standard errors in parentheses
* p<0.05 ** p<0.01 *** p<0.001

Although there is no perceivable effect when analyzing across the entire United States, there is a statistically significant negative correlation between the installation of a wind turbine and the price per square foot for homes within zip codes containing wind turbines. Table 2 shows that, in the sample of treated zip codes, the installation of a wind turbine correlates with a decrease of 2.47% in the median price per square foot of homes at the zip code level. This association is statistically significant at the 5% level. Although there is a perceivable correlation between the installation of a turbine and property values for this sample, the same cannot be said for the number of turbines or the total capacity of turbines.

Table 2:

Outcome of Turbines on Price Per Square Foot

	Natural Log of Dollars/Sqft		
	US w/Only Turbine Locations		
	(1)	(2)	(3)
Independent Variables			
Turbine Exists (Dummy)	-0.0247*		
	(0.0110)		
Total Number of Turbines		1.38E-04	
		(1.75E-04)	
Total Capacity			1.82E-07
			(1.26E-07)
Constant	4.391***	4.377***	4.377***
	(0.00509)	(0.00288)	(0.00172)
Observations	89394	89394	89394
Adjusted R-Squared	0.953	0.953	0.953

Note: Standard errors in parentheses
* p<0.05 ** p<0.01 *** p<0.001

Table 3:

Granger Causality Test

	Natural Log of Dollars/Sqft	
	(1) US w/out Metro Areas & SE States	(2) US w/Only Turbine Locations
Turbine Exists (Dummy)	0.00213	-0.0105
	(0.00903)	(0.0102)
Lead 1 year	0.00287	-0.00300
	(0.00448)	(0.00507)
Lead 2 years	-0.00181	-0.00462
	(0.00333)	(0.00410)
Lead 3 years	-0.0127	-0.00901
	(0.00877)	(0.00971)
Constant	4.632***	4.363***
	(0.000168)	(0.00812)
Observations	2101968	73714
Adjusted R-Squared	0.955	0.952

Note: Standard errors in parentheses
* p<0.05 ** p<0.01 *** p<0.001

Lastly, Table 3 illustrates the results of the Granger causality test. This test does not indicate any anticipatory effects for the implementation of a wind turbine. That means that there is likely no effect on property values stemming from an announcement of turbines being constructed. This also shows that in each of the leads, years one through three before a turbine is constructed, there is no statistically significant difference between the treatment and control groups. Therefore, the parallel trends assumption holds for this analysis. This is true for both the sample without the Southeast U.S. and the sample excluding all non-treated zip codes.

5.2 Discussion

In all three samples, the point estimates for the wind turbine treatment are negative. This is an unsurprising outcome because it is expected that the negative externalities of wind turbines would have a negative effect on the price per square foot of homes. However, what is surprising is that the point estimates are positive for the total number of turbines and total capacity independent variables. This could point to an interesting effect in which a greater number of turbines located in a zip code leads to a weaker negative effect on property values. However, it is much more likely that this effect is indistinguishable from zero given the relatively large standard errors.

I hypothesize that too many controls were used that are not representative of the sample and that perfect balance was not achieved. The ratio of nontreated zip codes to treated zip codes in this analysis is roughly between 25:1 and 30:1. It is probable that many of these controls do not share the characteristics of zip codes in which wind turbines were constructed. One of these factors could be different local political preferences for renewable energy infrastructure. Another factor may be a significant difference in wind power potential since many ideal locations for turbines have already been capitalized on. These possibilities lend more credibility to the third sample estimation (Table 2).

The sample containing only treated zip codes was the only one with a statistically significant result. However, this result is unlikely to be a causal estimation because of the exclusion of any controls. It is probable that all of these zip codes have a confounding variable in common that negatively influences the effect of wind turbines. This estimate is still interesting nonetheless because these zip codes are extremely likely to have similar demographic and geographic characteristics, as mentioned earlier in this paper.

6 Conclusion

Wind turbines have been constructed at different times in different locations throughout the United States. This paper uses Zillow home value data and estimates a difference-in-difference model incorporating location and time fixed effects to determine the average effect that wind turbines have on local property values. This paper does not find any statistically significant effect from the introduction of wind turbines on residential property values at the zip code level. This paper also does not find any effect stemming from the number of wind turbines or their total capacity on property values at the zip code level. While there is a statistically significant -2.47% correlation between the construction of a wind turbine and the price per square foot of homes at the zip code level in zip codes where turbines were sited, it is probably not exogenous.

Further work is necessary to truly isolate the effect of wind turbines on residential property values. If the negative externality effects on housing prices are overblown, then much opposition to wind turbine construction is caused by irrational fear. Otherwise, if wind turbines really do reduce the property values of nearby residences, then property owners should be fairly compensated by the government or the company profiting from the turbines. Furthermore, if it is true that wind turbines reduce local property values as previous literature has found, continuing literature should attempt to find what causes these effects. Once that is determined, turbine manufacturers can work with residential property owners to try to mitigate these issues.

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Appendix

Table 1A:
Zillow and National Association of Realtors County Data Comparison

County Name	Mean Zillow Value (07/2018)	Median Zillow Value (07/2018)	NAR Value
Kern County, CA	200,533	191,500	219,620
Taylor County, TX	147,843	120,200	129,311
Nolan County, TX	71,700	71,700	70,998
Mitchell County, TX	67,700	67,700	70,568
Jasper County, IN	130,500	118,100	161,208
Story County, IA	173,290	177,350	208,201
Macon County, IL	101,156	84,800	96,003
O'Brien County, IA	95,280	85,300	114,066
Carson County, TX	106,600	106,600	112,408
Haskell County, TX	65,000	65,000	52,845

Table A2:

State	Number of Turbines	Total Capacity (Megawatts)
AR	1	100
AZ	144	268,300
CA	6,898	5,567,376
CO	1,987	3,121,810
CT	3	5,800
DE	1	2,000
IA	4,156	7,323,234
ID	541	972,500
IL	2,574	4,413,858
IN	1,203	2,115,460
KS	2,792	5,103,335
MA	88	115,580
MD	80	191,050
ME	386	923,400
MI	1,048	1,904,330
MN	2,502	3,724,815
MO	503	967,810
MT	492	720,885
NC	104	208,000
ND	1,622	3,015,440

NE	789	1,443,730
NH	75	185,350
NJ	6	9,000
NM	1,005	1,681,580
NV	66	151,800
NY	1,052	1,827,010
OH	338	616,980
OK	3,716	7,490,510
OR	1,868	3,211,990
PA	734	1,379,400
PR	62	125,925
RI	25	53,885
SD	584	977,474
TN	18	28,980
TX	12,924	23,346,070
UT	205	390,675
VT	73	150,050
WA	1,739	3,109,930
WI	466	749,490
WV	376	685,800
WY	1,004	1,493,740
Total:	54,250	89,774,452