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Geographic Price Granularity and Investments in Wind Power: Evidence From a Swedish Electricity Market Splitting Reform

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Geographic Price Granularity and Investments in Wind Power: Evidence From a Swedish Electricity Market Splitting Reform *

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Abstract

I evaluate the effect of the 2011 Swedish electricity market splitting reform on the allocation of wind power, exploiting a unique data set of all Swedish applications for wind power since 2003. By comparing investments in each price zone before and after the reform using a difference-in-differences (DiD) estimator, I find that 18 percent of all projects constructed by large firms after the reform were allocated to the high price zone due to the reform. This effect is not driven by geographic differences in approval rates, suggesting that the estimated effect also reflects investor preferences. Small, sometimes locally owned firms, did not react to the reform. A likely reason is that the locational choice set of small firms usually only include one of the price zones. A triple differences estimator using small firms as a control group, and a nearest neighbor matching estimator comparing areas with similar prerequisites for wind power, largely confirm the main DiD results. However, due to the comparatively few applications submitted prior to the announcement of the reform, the parallel trends assumption cannot be entirely verified, suggesting that results should be interpreted with care.

Keywords: Electricity market design, zonal market, electricity market integration, spatial price dispersion, wind power, wholesale electricity market, Nord Pool.

JEL: D22, D47, Q21, Q48

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1 Introduction

Electricity wholesale markets are typically organized as auctions, where market participants submit bids to a power exchange that computes market-clearing prices and quantities. Trade is enabled by transmission lines, with limited capacities. In European electricity markets, the auction design only takes into account a subset of these constraints, ensuring that prices are always uniform at least within certain predefined regions, or *zones*. As a consequence, the transmission system operator (TSO) has to activate succeeding mechanisms after the main auctions to redispatch generation until the physical transmission constraints are met.

During the last decade, Europe's wholesale markets have become increasingly integrated in the sense that wholesale auctions now allow for market based trade across the continent. This development has not been matched by corresponding investments in transmission capacity neither within nor across borders. Subsequently, transmission congestion has increased, exacerbated by significant investments in intermittent generation. Still, the zonal division has remained largely intact, with each country usually corresponding to one zone. Due to the inefficiencies arising from a mismatch between the auction design and the available transmission capacity, efficient congestion management is now a central topic of the Clean Energy Package (European Council, 2019), and European regulators are now examining the potential advantages of splitting countries into multiple price zones (ENTSOE, 2018).

A central rationale for increasing the number of price zones is that investments in generation are pushed toward areas where the marginal value of production is high, mitigating the need to increase transmission capacity. However, empirical evidence of investments effects following market splitting reforms is missing. One likely reason is that such reforms are rare [1], another is that detailed data on investor behavior is usually scarce. An exceptions is Sweden, which was split from one to four zones in 2011. In this study, I evaluate the effect on investments in wind power following this reform, exploiting a unique data set on all Swedish wind power applications since 2003. These data contain information about the application date of each project, the owner of the project, whether the project was approved and subsequently realized, as well as a large set of project characteristics. The value of examining application data is emphasized by the fact that lead times are usually several years. Therefore, the immediate effect on investor behavior can only be detected with any degree of precision when also evaluating application data. In addition, the effect on investors' investment preferences can be separated from the effect on actual investments by analyzing also applications that were rejected. Since a non-trivial share of the applications are rejected due to local opposition not only in Sweden but also throughout the continent, such frictions may be non-negligible.

By comparing investments in each zone before and after the reform using a difference-in-differences

[1] Except for Sweden, the only European countries involving more than one price zone are Norway, Denmark, and Italy. The latter three were partitioned already at the outset of liberalization, and a pre/post analysis is therefore not possible. In Norway, zonal alterations occur on a relatively frequent basis, but there are no studies on the investment effects of these alterations.

(DiD) estimator, I find that 18 percent of all projects constructed by large firms after the reform were allocated to the high price zone due to the reform. This effect is not driven by geographic differences in approval rates, indicating that the estimated effect also reflects investor preferences. Since the price effect of the reform was comparatively modest during the greater part of the sample period, I conjecture that the reform had a negligible effect on the total volume of projects, but that it affected investors' locational choice. In accordance to this assumption, I find that small, sometimes locally owned firms, did not react to the reform, likely since their locational choice set only include one zone.

Although the DiD estimator constitutes my main model, a drawback in terms of identification is that investments in wind power were relatively few before the announcement of the reform. Therefore, I complement the DiD analysis with two additional analyses. First, I estimate a triple differences estimator by comparing the relative investment effects for large vs. small firms, where the identifying assumption is that small and large firms are comparable in their investment decisions aside from that the locational choice set of small firms is limited to one price zone. Second, I construct a data set on the geographic characteristics of every 10 x 10 km of Sweden, allowing me to match areas in different zones based on variables related to wind power suitability. A nearest neighbor matching estimator then to compares investments across the matched pairs. Both additional analyses largely confirm the DiD results. Robustness results obtained by altering the definition of a large firm, the choice of matching variables, and the number of matches identified by the matching algorithm, also largely confirm the main results.

By contrast to the European experience, all electricity markets in the US have now abandoned zonal pricing. Instead, these markets have adopted auction designs that respect all transmission constraints, so that all different locations may face different prices at times of congestion. The theoretical basis for the short- and long run economic efficiency of locational pricing was developed by Schweppe et al. (1988).[2] Despite the conceptual difference between zonal and locational pricing, differences in market outcomes are decreasing in the number of zones, and in the limit the two designs are equivalent. An important reason for the early adoption of locational pricing in the US is that transmission congestion was severe already at the outset of the introduction of electricity wholesale markets, due to inefficient regulations of privately owned utilities (Wolak, 2011). Although studies of the investment effects of locational pricing are also lacking, several studies have demonstrated its short run benefits. For example, Wolak (2011) quantifies the economic benefits of moving to locational pricing from the Californian zonal pricing market that was very similar to the standard market design in Europe. He finds that the variable cost of production for fossil fuels units fell by two percent after the reform. In a similar study of the Texan electricity market, Triolo and Wolak (2021) find that the introduction of locational pricing reduced variable costs of thermal generation by four percent for a given level of output. An-

[2] In theory, a well designed zonal market with a redispatch mechanism could also lead to efficient short run outcomes under ideal circumstances. However, even with such a mechanism in place, payments to producers will be distorted, leading to inefficient investment incentives (Holmberg and Lazarczyk, 2015).

other finding is that locational pricing can increase the amount of trade that takes place between regions. Mansur and White (2007) demonstrate this by comparing the trade volumes between regions in the eastern US before and after they were integrated into a single locational pricing market. Although the difference in moving from a zonal to a locational auction design is more pervasive than merely increasing the number of zones, both reforms should give rise to similar effects.

The present paper also relates to studies of the determinants of wind power allocation in general. Previous studies on the determinants of wind power allocation in Sweden mainly examine political and geographical factors, but not prices. Ek et al. (2013) and Lauf et al. (2020) estimate statistical relationships between wind power generation across Swedish municipalities and a number of financial, geographical and political variables. These studies provide valuable information about regional differences in wind power development, but they do not examine the importance of regional price differences for the allocation of wind power. First, these analyses build exclusively on data from completed projects, i.e. those that have received municipal approval. Second, the analyses have been executed at a cross-sectional municipal level. Hence, unobserved differences across municipalities unrelated to the decision making process for wind power can potentially explain differences in wind power development. Case studies of Swedish wind power projects complement the above papers. An early example is Khan (2003) who compares the wind power planning process in three Swedish municipalities. Ek and Matti (2015) examine local attitudes towards a wind power project in northern Sweden. The international literature on wind power establishments examines regional difference in wind power development based on installed capacity. Examples are Xia and Song (2017) for China, Hitaj (2013) and Ross and Carley (2016) for the USA, as well as Hitaj and Löschel (2019) for Germany. Garrone and Groppi (2012) analyzes political decisions concerning generation capacity. That study analyzes gas-fired and coal-fired power plants in Italy, but not renewable generation.

2 The Swedish electricity market

2.1 The Swedish electricity market splitting reform

The national electricity markets in the Nordic countries were restructured one after the other during the 1990s, and integrated to create a common wholesale electricity market. Norway was the first country to deregulate in 1993, followed Sweden in 1996, and Denmark and Finland in 1999. This Nordic market was later expanded to include Estonia, Latvia, and Lithuania. Full market coupling with continental Europe was recently implemented.

The main trading platform for physical energy is the day-ahead market, *Elspot*, operated by the Nordic power exchange, *Nord Pool*. Elspot trades more than 80 percent of all electricity produced in the region. It works as follows. Every day at noon, market participants submit bids to Nord Pool for each of the 24 hours of the following day. Each participant can submit hourly bids consisting of quantity/price pairs. Each bid is tied to a price zone. When computing the market clearing price for the different price zones, Nord Pool takes into account the available trading transmission capacity across zones. If there is no congestion, all zones clear at the same price. But if transmission capacities are insufficient, Elspot can be divided into as much as 15 different price zones.

The national TSOs decide how much of the transmission capacities that should be available for export to other countries. Domestic TSOs often artificially reduce export capacity to prevent intra-country congestion and increased domestic prices, at the expense of higher prices abroad and a reduction of total social welfare. See Tangerås (2012) for an account of how misaligned preferences among TSOs may lead to inefficient transmission capacity curtailments. With an increased number of domestic zones, the effects of such arbitrary curtailments become limited, as they mainly affect prices in the exporting zone. During the first decade after deregulation, when Sweden consisted of one price zone, the Swedish TSO used to implement such curtailments by reducing exports to Denmark. However, in 2006, two Danish umbrella organizations representing Danish energy firms made a claim to the European Commission that the Swedish TSO was abusing its dominant position by limiting export capacity to Denmark. This was the first, and to this date, the only time that a TSO has been reported to the commission for limiting export capacity.

It was soon understood that the commission would likely require Sweden to split into two or more zones, running from north to south. In 2007, a report was produced jointly by the Swedish Energy Markets Inspectorate, the TSO, Swedenergy (an umbrella organization representing the producer side) and the Confederation of Swedish Enterprise (Energy Markets Inspectorate, 2007). The aim of the report was to investigate the possibility of a market split. The report was commonly known by its Swedish acronym POMPE. It proposed a split of Sweden into two price zones. An interview with an industry representative from the wind power industry also confirmed that the POMPE-report was commonly seen as the first step towards a market split (OX2, 2021). The interview also confirmed that there was an increase in project applications in the south zone during the period following the POMPE-report, since many investors believed that the high prices of continental Europe would primarily influence the southern part of Sweden as export transmission capacities increased.

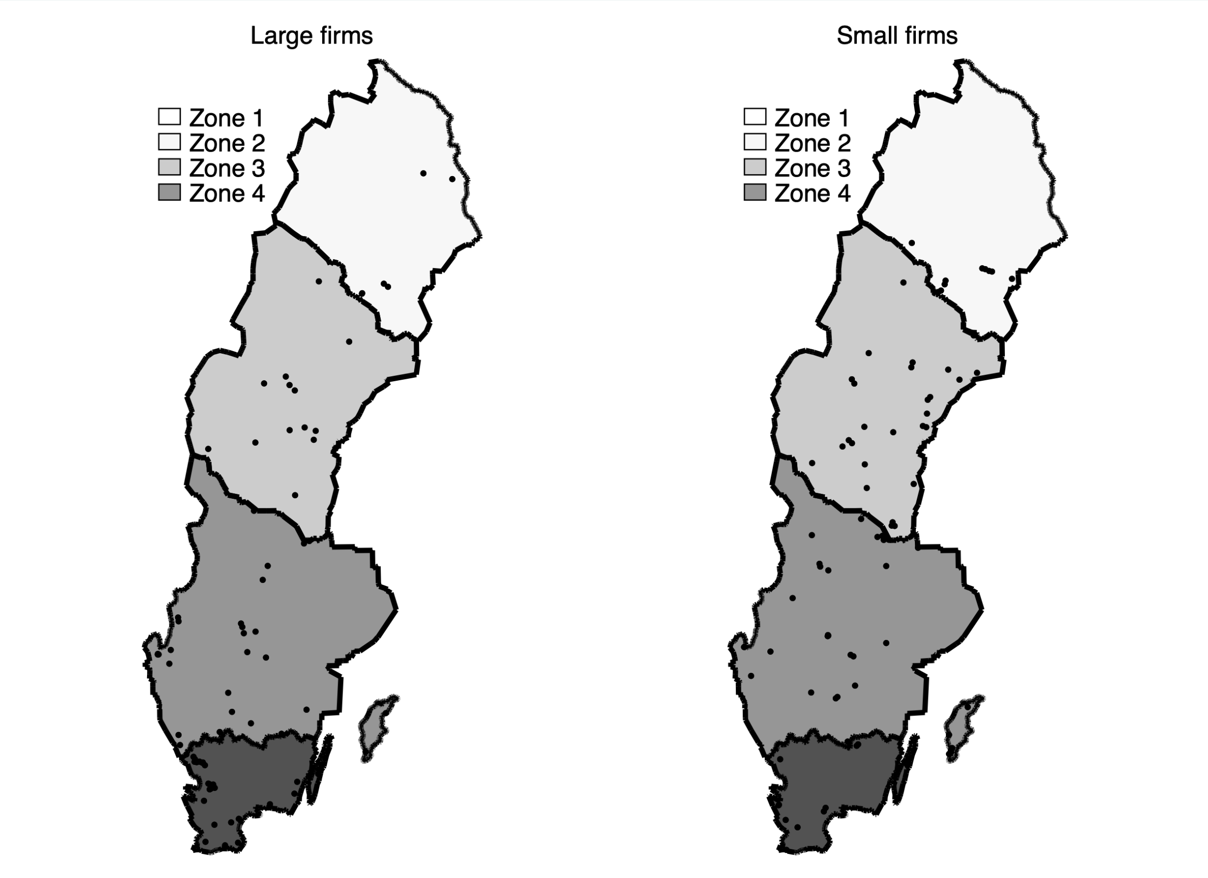
In 2010, after several years of investigations, the commission released its decision to impose a Swedish zonal partitioning by 2012 (European Council, 2010). Shortly after, the Swedish TSO formally announced that Sweden would be partitioned into price zones beginning Nov 1 2011. Formally, Sweden was split into four and not two zones as was originally proposed by the POMPE-report. The borders of these zones are depicted in Figure 1. The prize zones run from north to south, with zone 1 in the north and zone 4 in the south. Geographically, the two zones originally proposed by the POMPE-report corresponds exactly to zones 1-2 and 3-4 respectively. The trends in mean monthly prices in each respective zone are depicted in Figure 2, using the price in zone 4 as a reference. Zones 1 and 2 had almost identical prices throughout the sample period, with a mean of 91.3 percent of the price in zone 4 (the trends in zone 1 and 2 are visibly indistinguishable from each other). Further, the price in zone 3 was on average 97.2 percent of the price in zone 4. During the last sample year, prices in zones 1 and 2 dropped below 60 percent of the price in zone 4 (the corresponding figure for zone 3 is 82 percent). This relative price change can be explained by an unexpectedly high inflow to the hydro reservoirs in zone 1 and 2, the phase-out of a nuclear reactor (Ringhals 2) in zone 3 in December 2019, as well as a higher price level in the Baltic countries and Denmark, leading to exports and higher prices in the southern zones. However, since the vast majority of all wind power applications during the sample period were submitted before 2020, the current study does not capture the potential investment effects following this sudden price change. Since price levels up until the last sample year were similar in zones 1-2 and 3-4 respectively, in the analysis I henceforth treat zones 1-2 as the same low-price *northern* zone, and zones 3-4 as the same high-price *southern* zone (although the price difference between zones 3-4 was somewhat greater than the price difference between zones 1-2).

Will there be additional European market splitting reforms?

A few countries, namely Norway, Denmark, and Italy, were partitioned into multiple zones already at the outset of deregulation. Sweden is to this date the only country that has been explicitly obliged by the commission to implement a market split. However, European Commission has identified the lack of sufficient cross-border capacity as one of the main barriers to the integration of electricity markets, establishing that 70 percent of each country's cross-border transmission capacity should be available for trade at least within the end of 2025 (European Council, 2019). It is therefore expected that further market splitting reforms will be implemented throughout Europe during the upcoming years, in order to meet the 70 percent target.

There are several reasons why zonal partitioning has not been implemented spontaneously to any greater extent. A main reason is that consumers in different zones will then pay different electricity prices, leading to distributional consequences, which may be politically sensitive. An

Figure 1: Map of realized projects by firm size and price zone



Note: Each dot represent the location of a wind project for large (left) and small (right) firms respectively, by 2020. Also shown are the zonal borders. Only projects with five or more turbines are included in the map.

Figure 2: Electricity spot prices by zone

Note: Trends in the mean yearly electricity spot prices in each price zone, expressed as a percentage of the price in zone 4 (the most southern zone). The *north* zone is zones 1-2, while the *south* zone is zones 3-4.

illustrative example is Germany. The European Council has proposed that Germany should be split into two zones (ENTSOE, 2018), and simulations show that the geographic distribution of future wind power investments in Germany would vary significantly with the degree of spatial price granularity (Schmidt and Zinke, 2020). But due to a strong German opposition, the split has not been implemented. In this respect, it is worth noting that Tangerås and Wolak (2020) demonstrate that, under fairly general conditions, productive efficiency could improve under a market design where all consumers face the same price, but where producers meet geographically heterogenous prices.

2.2 Wind power in Sweden

Before the turn of the century, large scale wind power plants were virtually non-existent in Sweden. A green electricity certificates system was introduced in 2003. It works as follows. For every MWh of wind power injected to the grid, a certificate is awarded to the owner of the plant. Also bio-fuelled thermal, solar, or small-scale hydro production are awarded certificates. A market for certificates is created by imposing consumers to buy certificates to cover a certain quota of their consumption. At the time of market splitting in 2011, the quota was 18 percent. In 2020 it was decided that the quota would be gradually phased out until 2035 (Swedish Government, 2020). The certificate price has varied substantially throughout the sample period, but since the certificate price does not vary with the geographic location of the plant, it is unlikely that the certificates system has had any first-order effects on the geographic distribution of wind power investments. After the introduction of the certificate system, wind power investments grew rapidly with a sharp increase from 2007 and onward. Wind power is still expanding steadily, with the rate of increase being approximately constant during the last decade. However, the number of applications peaked in 2011-2012, and has since then been declining. In other words, the majority of plants now being constructed have been granted permits several years ago.

There are two distinct rationales behind wind power investments. First, there are commercial projects that involve multiple turbines. These projects are often investor-owned, although they may also be owned by smaller firms or local consumer-owned economic associations. These projects usually comprise five turbines or more, with the purpose of generating profit. Of all project applications in the sample, only about one third fall into this category. Second, individuals and consumer-owned economic associations often also initiate small scale wind power projects (< 5 turbines) with the combined purpose of generating electricity for its members, and also due to an intrinsic preference for carbon-neutral electricity generation. As discussed further below, the interest of the present study lies in large, commercially viable projects, that are more likely to be affected by the price reform than the smaller projects. Since there is no reason to believe that the smaller projects would respond to the comparatively marginal price incentives created by the zonal reform, I disregard these smaller projects from the analysis.

Application process

Applications for wind power are submitted to the municipality where the project is intended to be located. All applications have to be approved by the local government, which means that the possibilities of approval may depend on the composition of the local government. Local elections are held every four years in each of the 290 municipalities. There are seven main parties, and usually, a ruling coalition consisting of several parties is formed. One party that distinguishes itself as the strongest proponent for wind power is the Environmental Party (EP). During the sample period, it was a member of the ruling coalition in about 30 percent of all municipalities. In addition to approval by the local government, larger projects also have to be approved by the environmental board of the county administration. For a more detailed account of the application process, see Appendix A.

3 Data

Data have been collected from several public sources, including the Energy Agency, the Land use Authority, the Election Authority, Statistics Sweden, and the IFN Serrano database. Data sources are described in detail in Appendix A.

3.1 Outcome variables

First, I estimate the effect on the number of realized projects, using the application year as the reference year for each project. Since investors should respond shortly after the publication of the POMPE-report in 2007, I use 2007 as the year of treatment. By visual inspection of the upper diagrams of Figure 3, it is evident that the comparatively sharp increase in applications in the south zone that took place after the announcement was only present for large firms. The lower diagrams depict the same projects as above, but where the reference year is instead the year of construction. From these diagrams, it is evident that lead times vary substantially across projects, and therefore I only estimate the model using the application year as the reference year.

Second, I estimate the effect on the number of project applications submitted, irrespective of project realization. The upper diagrams in Figure 4 depict this variable for large and small firms respectively. It is evident that most project applications have not been realized. For both large and small firms, the share of project applications submitted before 2012 that have been realized during the sample period is around 30 %. For reference, the lower diagrams depict similar figures, but exclude rejected applications. The acceptance rate (i.e. the number of accepted applications divided by the total number of applications) is rather similar across firm size, although somewhat higher in the north for both groups, at around 0.4 versus 0.3 in the south.

By estimating the effect on applications unconditional on acceptance, I obtain a more precise estimate of investor preferences, which is less affected by geographic differences in acceptance rates than the number of realized projects. Still, it is not expected that this variable *exactly* reflects investor preferences, since rational investors should only submit applications in locations where the probability of approval is comparatively high, or equivalently, where the expected profit from a project application (net of application costs) is positive.

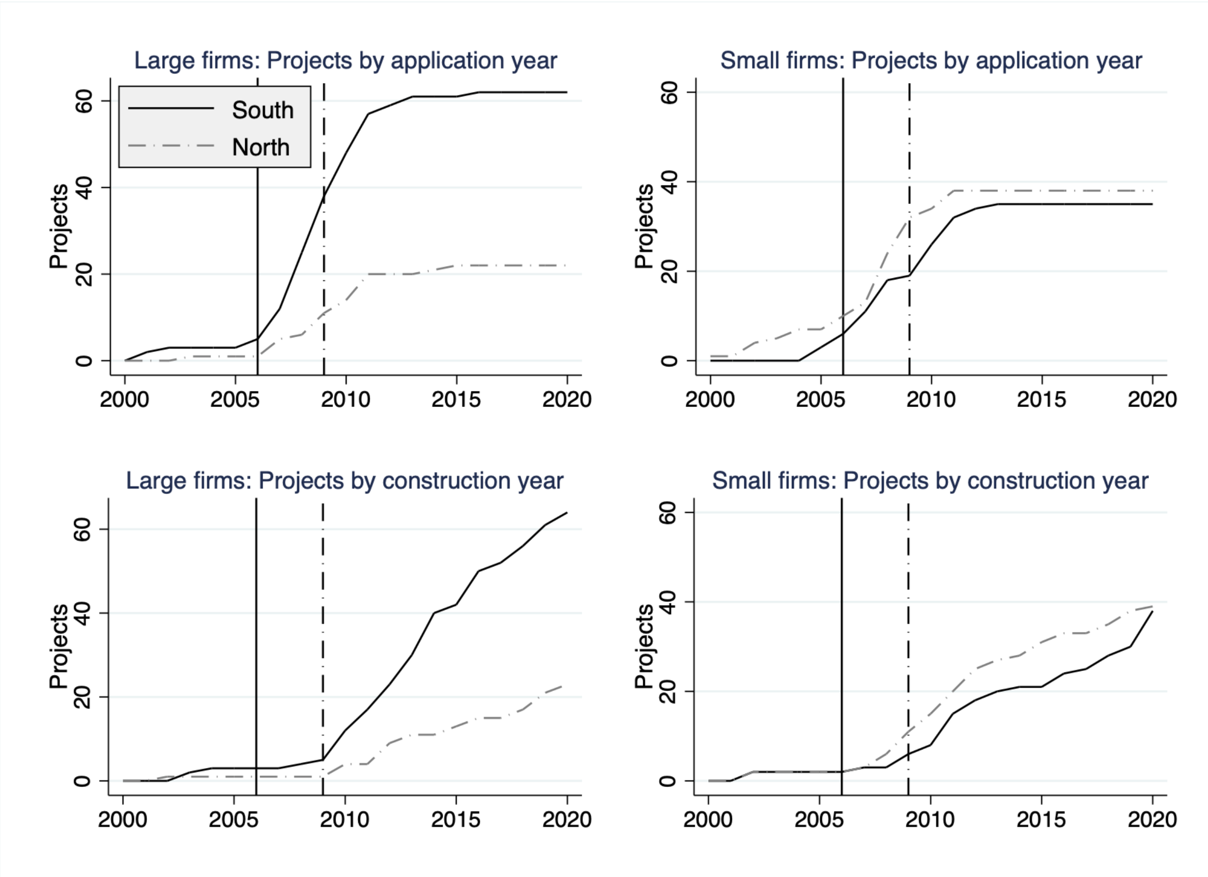
3.2 Ownership characteristics and control variables

Table 1 displays summary statistics for ownership characteristics and control variables, by project and firm size. A firm is defined as large if it has submitted at least ten wind project applications during the sample period. Out of 530 firms in the sample, only 35 are defined as large. This partitioning creates two groups of projects, with 529 (425) projects owned by large (small) firms respectively. All small projects have been removed from the sample, defined as projects with less than five turbines. A map showing the geographic dispersion of the projects by the end of the sample period, by zone and firm size, is displayed in Figure 1. For reference, Figure A1 constitutes a similar map, but where also small projects are included. Below, each group of variables is described in detail.

Ownership

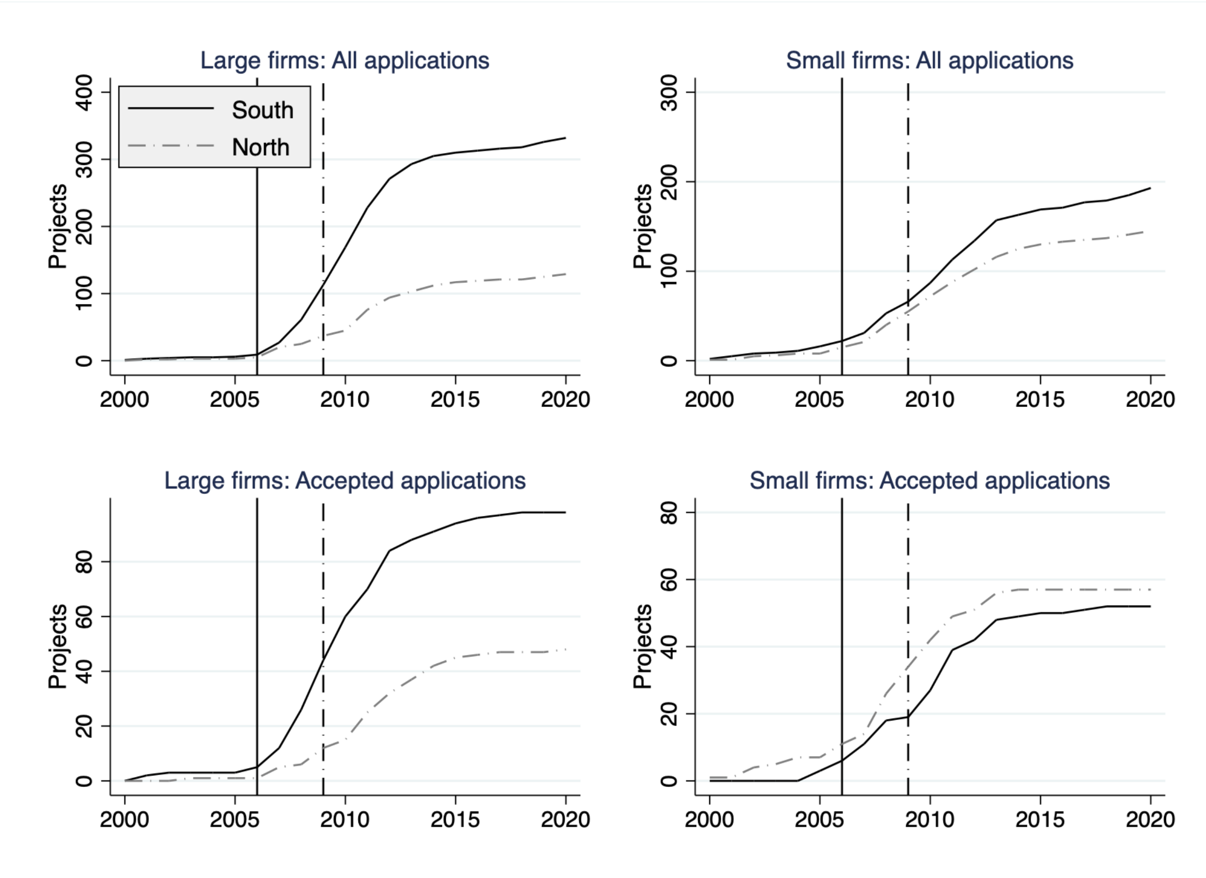
All of the ownership variables vary with firm size, both in terms of statistical and economic significance. The first variable is the time aggregated number of applications submitted by

Figure 3: Realized projects by zone and firm size



Note: Trends in realized projects by prize zone and firm size, aggregated over time. Upper diagrams are constructed using year of application, and lower diagrams are constructed using year of construction. Horizontal solid (dashed) lines are in 2006 (2009).

Figure 4: Applied projects by price zone and firm size



Note: Trends in all project applications by prize zone and firm size, unconditional on project realization, aggregated over time. Upper diagrams include also rejected applications. Lower diagrams exclude rejected applications, but include applications that were accepted but not yet realized during the sample period. Horizontal solid (dashed) lines are in 2006 (2009).

Table 1: Summary statistics by project and firm size

	Large firms		***Small firms***		***Large-Small***
	Mean	Sd	Mean	Sd	
Ownership					
Owner total no. projects	83.960	109.365	3.541	2.832	80.419***
Local owner (%)	3.025	17.142	14.502	35.265	-11.477***
Owner present in one muni only (%)	0.000	0.000	26.353	44.107	-26.353***
Application characteristics					
Installed capacity	44.434	49.095	65.078	153.733	-20.643*
Nr of turbines	18.665	36.456	21.398	36.798	-2.732
Accepted and realized	0.202	0.402	0.235	0.425	-0.033
Accepted	0.129	0.335	0.094	0.292	0.034
Rejected	0.136	0.343	0.132	0.339	0.004
Revoked	0.463	0.499	0.442	0.497	0.021
In process for decision	0.042	0.200	0.066	0.248	-0.024
Application year	2010.794	3.332	2010.712	4.374	0.083
Time to decision	2.680	1.720	2.373	1.669	0.306
Time to construction	4.875	2.492	4.889	2.925	-0.013
Geography					
Wind speed	6.569	1.223	6.271	1.251	0.298***
On designated area	0.467	0.499	0.456	0.499	0.011
Dist to road >7m wide	11.805	13.720	13.663	17.815	-1.858
Dist to regional transmission	11.330	12.135	10.643	11.358	0.686
Some nature reserve exists	0.092	0.289	0.115	0.319	-0.023
Military interest exists	0.357	0.480	0.333	0.472	0.024
Time-varying variables					
Employment rate	0.555	0.066	0.554	0.069	0.002
Wage	0.051	0.938	-0.063	1.071	0.114
Education level	-0.013	1.002	0.016	0.999	-0.029
EP in rule	0.300	0.459	0.282	0.451	0.018
Observations	529		425		954

Note: Descriptive statistics by project and firm size. Only projects involving five or more turbines are included in the sample. Time to decision and time to construction in years. Wind speed in m/s. Installed capacity in GW. Distances in km. Time-varying variables are computed with respect to the municipality where the project is located. Employment rate is continuous and may take any value between zero and unity. Wage and education level are standardized to unit variance and mean. EP in rule indicates if the Environmental Party is a member of the ruling coalition.

the owner of the project. For projects owned by large firms, the mean of this figure is 83.9 applications, while the corresponding number for small firms is 3.5. This is a notable difference, indicating that the locational decision making process is likely to vary with firm size. The second variable indicates if a project has a local owner, defined as a project where the physical address of the firm (or the parent company, if such exists) is located in the same municipality as the project itself. Only 3 percent of the projects owned by large firms are located in the same municipality as the owner, which is usually a densely populated city like Stockholm that is not suitable for wind power development. For the small firms, the corresponding figure is 14.5 percent. Further, none of the large firms are present in one municipality only. The corresponding figure for projects owned by small firms is 26 percent.

Application characteristics

In terms of statistical significance, the only variable that vary with firm size is the first variable, *installed capacity*, which is somewhat higher for small firms, at 65 MW compared to 44 MW for large firms. Since the identification assumption in the triple differences estimator described in Section 4.2 hinges on that small and large projects are similar in all respects except for their locational choice sets, it is reassuring that none of the other variables vary statistically with firm size. The following variable, *nr of turbines*, is also slightly higher for small firms , at 22 compared to 18 turbines. Further, *accepted and realized* indicates if the project has been accepted realized. The next variables, *accepted*, *rejected* and *revoked* indicates if the project has been accepted but not yet realized, rejected, or revoked by the owner. When a project is revoked by the owner, the reason is in principle always that the owner has received an informal indication from the decision makers that the project will get rejected, and that the owner therefore chooses to revoke the project before the final decision has been made. Therefore, although the formal rejection rate is only about 13 percent, the *de facto* rejection rate is above 50 percent for both groups. The next variable, *application year*, indicates the year when the application was submitted. As seen, the large boom in applications took place around 2010-2011 for both groups. The next variable, *in process for decision*, indicates if the project has not yet received a decision. This figure is low for both groups, since the majority of applications had been submitted already a decade ago. The next variable, *time to decision* (from the day of submission) is above two years for both groups, and the time to construction (from the day of approval) is slightly less than five years for both groups, which means that the total lead time between submission and construction is around seven years.

Geography

In terms of statistical significance, only *wind speed* varies with firm size, with on average 0.3 m/s greater for large firms. This is not surprising, since it is expected that large firms are somewhat more active in finding optimal locations than small firms. The next variable, *on designated area*, indicates if the project is located on an area proposed by the Energy Agency as a suitable place for wind power. These areas constitute only about 1.5 percent of Sweden's total area, so the fact that more than 40 percent of all applications are located here is notable. The next variables, *distance to regional transmission* and *distance to road > 7 meter* measure km from the centroid of the project to the closest point of connection to the regional transmission network, and any road greater than 7 metres wide, respectively. Naturally, both of these variables are cost drivers, due to connection fees and transportation costs. The last variables, *some nature reserve exists* and *military interest exists* indicate if the project is located on areas that are less suited for wind power. It is notable that more than 30 percent of all projects are located on areas where some type of military interest exists, and it is not uncommon that projects get rejected due to a conflict of interest with military activities.

Table 2: Summary statistics by project and price zone

	South		***North***		***South-North***
	Mean	Sd	Mean	Sd	
Ownership					
Owner total no. projects	54.911	95.326	34.122	78.663	20.789***
Local owner (%)	9.507	29.357	3.425	18.217	6.082***
Owner present in one muni only (%)	11.353	31.749	12.540	33.171	-1.187
Application characteristics					
Installed capacity	32.666	33.405	96.205	177.001	-63.539***
Nr of turbines	14.215	30.731	31.601	44.284	-17.387***
Accepted and realized	0.212	0.409	0.228	0.420	-0.017
Accepted	0.078	0.268	0.186	0.390	-0.109***
Rejected	0.151	0.358	0.100	0.300	0.051*
Revoked	0.498	0.500	0.363	0.482	0.134***
In process for decision	0.031	0.174	0.096	0.296	-0.065***
Application year	2010.337	3.790	2011.601	3.704	-1.264***
Time to decision	2.494	1.649	2.642	1.797	-0.148
Time to construction	4.226	2.579	6.018	2.528	-1.792***
Geography					
Wind speed	6.718	1.194	5.769	1.095	0.949***
On designated area	0.443	0.497	0.510	0.501	-0.067
Dist to road >7m wide	10.259	11.209	18.305	22.093	-8.046***
Dist to regional transmission	10.383	11.492	12.628	12.425	-2.244*
Some nature reserve exists	0.087	0.283	0.137	0.344	-0.049*
Military interest exists	0.371	0.483	0.289	0.454	0.082*
Time-varying variables					
Employment rate	0.561	0.068	0.540	0.063	0.021***
Wage	0.120	1.021	-0.250	0.907	0.370***
Education level	0.081	1.058	-0.168	0.844	0.249***
EP in rule	0.330	0.471	0.212	0.409	0.119***
Observations	643		311		954

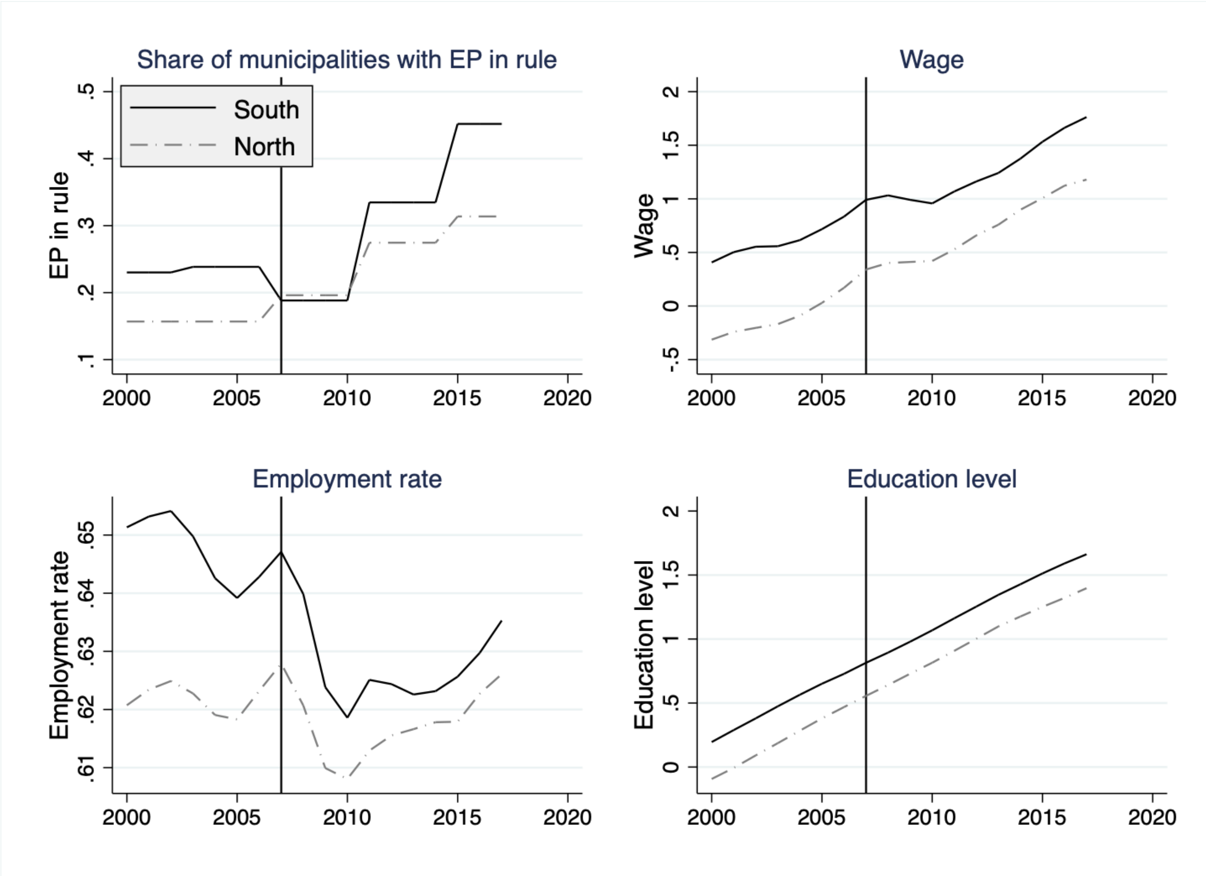
Note: Descriptive statistics by project and firm size. Only projects involving five or more turbines are included in the sample. Time to decision and time to construction in years. Wind speed in m/s. Installed capacity in MW. Distances in km. Time-varying variables are computed with respect to the municipality where the project is located. Employment rate is continuous and may take any value between zero and unity. Wage and education level are standardized to unit variance and mean. EP in rule indicates if the Environmental Party is a member of the ruling coalition.

Time-varying variables

The time-varying variables are measured with respect to the mean in the municipality where the project is located. *Employment rate* is continuous and may take any value between zero and unity. *Wage* and *education level* are standardized to unit variance and mean. *EP in rule* indicates if the Environmental Party is a member of the ruling coalition of the municipality. In terms of statistical significance, only wage level varies with firm size, but the difference is only significant at the ten percent level.

Table 2 displays summary statistics for the same variables, by price zone instead of firm size. By contrast to Table 1, the difference between north and south is statistically significant for almost all variables. The fact that the prerequisites for wind power vary between north and south imposes challenges on the identification strategy, and is discussed in greater depth in Section 4.

Figure 5: Trends in time-varying variables



Note: Trends in control variables. Each variable is computed as a yearly mean for the municipalities in each respective zone. Wage and education level are standardized to unit variance and mean.

Trends in time-varying variables

Most of the variables in Table 2 only exhibit trivial variation over time. However, the last four variables exhibit at least some variation over time, which potentially could influence also trends in wind power investments. Figure 5 illustrates these trends, by zone and sample year. At least from visual inspection, it does not appear that trends are notably different in the north compared to the south, although absolute levels differ. On average, all socioeconomic indicators are somewhat higher in the southern zone. This is expected, since most major cities are located here. A similar relationship is expected for the support for the Environmental party, since it covaries positively with education, and has a strong support among urban populations.

4 Econometric model

4.1 A basic DiD approach

A natural starting point for examining the effect of the price reform is the DiD-estimator. In a conventional DiD-setup, one group is assigned to a treatment, while the other group serves as a control. The current setup is somewhat different, since the price reform merely imposes a change in the relative prices between the price zones. In its basic form, the DiD-estimator may be formalized as:

$$Y_{it} = \alpha + \beta_1 South_i + \beta_2 post_t + \delta[South_i \times post_t] + \boldsymbol{\gamma}\mathbf{X}_{it} + \varepsilon_{it} \tag{1}$$

Where Y_{it} is the outcome of interest, for example the number of constructed projects in zone i in year t. Further, α is a constant, $South_i$ is a south zone indicator variable, and $post_t$ is a post-reform indicator variable taking the value one for all observations in the year 2007 and after. Further, δ is the coefficient of interest, estimating the effect of the interaction variable $South_i \times post_t$. Further, $\mathbf{X}_{it}$ is a set of time-varying zone-specific political and sociodemographic characteristics with its associated coefficient vector $\boldsymbol{\gamma}$, and ε_{it} is the error term following a Newey-West autocorrelation structure.

Decision making in small vs. large firms

For a meaningful interpretation of δ, it is useful with a more detailed understanding of investors' decision making processes. For large firms, the financing of a project is usually determined before the location is decided. The locational choice set usually includes both prize zones, since these firms are active all across Sweden and sometimes also abroad.[3] For smaller investors, on the other hand, the locational choice set usually includes one or a few municipalities located close to the investor's head office. Since the price effect of the reform was comparatively modest during the first eight years, it is likely that it only had a modest effect on the *total* volume of wind power investments for both large and small firms. The decision whether to invest or not is likely more sensitive to expectations about the absolute price level (including the price for green certificates, which is harmonized across Sweden). However, it is still plausible that the reform had an effect on the locational decisions of the large firms. Therefore, it is crucial to estimate the effect on large and small firms separately. Given that the decision making process of large firms follows these steps, the number of projects that switched location due to the reform is $\frac{\delta}{2}$. To exemplify, assume that ten projects are constructed in each period. Before the reform, five projects are constructed in each zone, but after the reform, two projects that would otherwise have been constructed in the north instead moved to the south. In this case, the DiD-estimator is: $\hat{\delta} = (y_{south1} - y_{south2}) - (y_{north1} - y_{north2}) = (5-3) - (5-7) = 4$.

[3] While a conventional DiD approach may give important insights about the aggregate effect of the reform on wind power investments, it says little about how the reform affects the *probability* that an investor will choose a certain zone. In principle, it would be possible to combine a DiD-approach with a model of discrete choice, such as the logit model. However, interpreting the corresponding interaction effects such the treatment coefficient *South x post* in a DiD-setting is generally not informative about the change in probabilities that an investor will choose to locate in the high price zone (See Karaca-Mandic et al. (2012) for a formal review of the general case). Therefore, the current identification strategy does not lend itself to a model of discrete choice. From a policy perspective, it is also more useful to estimate the aggregate investment effect.

Identification issues related to the parallel trends assumption

A crucial assumption of the DiD estimator is the parallel trends assumption, stating that pre-treatment trends in outcomes across treatment and control groups should be identical, although absolute levels may differ. Parallel trends strengthen the plausibility that the observed difference in outcomes would have remained constant in absence of the reform. By visual inspection of the diagrams in Figure 3, it appears that this assumption is fulfilled (except for in the upper right diagram displaying the trend in projects by application year for small firms). However, the number of applications were close to zero in both zones during the pretreatment period, since the industry was still in its infancy. This casts doubts on the relevance of the observed parallel trends. To exemplify, assume that the conditions for wind power investments were inherently better in the south than in the north, but that these differences were only materialized as the industry began to grow. Since this happened around the time of the announcement of the reform, the estimated treatment coefficient in equation (1) may therefore also capture elements that are not related to the reform itself. At worst, it *only* reflects the fact that the southern zone may be relatively better suited for wind power.

In addition to the DiD estimator, I therefore outline two ways to address this identification issue, relying on two different identifying assumptions. First, I propose a triple differences estimator relying on that small and large firms are comparable in their investment decisions, aside from that the locational choice sets of small firms are limited to one price area only. Second, I propose a matching algorithm that compares investments in smaller regions in the south to similar regions in the north, after matching on geographic characteristics that determine wind power suitability.

4.2 A triple differences estimator

Under the assumption that small and large firms are comparable in their investment decisions aside from their locational choice sets, small firms may serve as a control group for large firms. If one price zone is better suited for wind power than the other, this will be reflected in the investment decisions of small firms, and this effect is therefore possible to econometrically disentangle from the true effect of the reform. Table 1 demonstrates that the type of projects initiated by small and large firms did not differ notably in terms of other observable characteristics, strengthening the case that small firms may in fact be used as a control group for large firms.

A commonly used estimator in this type of setup is the so-called triple differences estimator. Triple differences is an extension of the DiD estimator and was introduced by Gruber (1994). Informally, the triple difference estimator can be thought of as the difference between two DiD estimators, in our case depending on firm size. To arrive at a causal interpretation of the estimated treatment coefficient, it requires that there is no contemporaneous shock that affects the relative outcomes of small vs. large firms. In this case, we can use this difference to estimate what would have happened to the relative outcomes of small vs. large firms in the southern vs. northern prize zone in absence of the reform. Formally, the triple differences estimator may be conveniently expressed as a transformed version of a DiD estimator. For a derivation of the equivalence between a triple differences estimator and a DiD estimator, see Olden and Møen (2020). In the present setup, such a transformation yields:

$$Y_{it}^{large} - Y_{it}^{small} = \alpha + \beta_1 South_i + \beta_2 post_t + \theta[South_i \times post_t] + \boldsymbol{\gamma}\mathbf{X}_{it} + \varepsilon_{it} \tag{2}$$

Where $Y_{it}^{large} - Y_{it}^{small}$ is the difference between outcome Y between large and small firms in zone i in year t. There are no superscripts for the covariates, since these are identical for large and small firms within the same zone. By visual inspection of Figure 3, it appears that the volume of investments in the southern and northern regions in principle follow identical trends for small firms, and we should therefore expect that the triple differences estimator would produce similar results to the conventional DiD specification in equation (1), when estimated on large firms.

4.3 A nearest neighbor matching estimator

An alternative identification approach is to ensure that the prerequisites for wind power are similar across zones by matching smaller areas in the south with smaller areas in the north, based on similarity in observable geographic characteristics that determine wind power suitability. Then, wind power investments in each of the matched pairs can be compared before and after the reform.

To decide the determinants of wind power suitability, I begin by partitioning Sweden into approximately 4000 squares of 10 x 10 km each, with the north and south zones approximately equal in terms of area.[4]. I then perform a LASSO selection regression according to:

$$appl_s^{2020} = \alpha + South_i + \boldsymbol{\beta}\mathbf{X_s} + \varepsilon_s \tag{3}$$

Where $appl_s^{2020}$ is the accumulated number of project applications submitted to square s by 2020, $South_i$ is a south zone dummy (to account for the fact that more applications are expected in the south due to the reform), and $\mathbf{X_s}$ is the set of geographic variables described in Table 2, with its associated coefficient vector $\boldsymbol{\beta}$. Contrary to the control variables in the DiD approach, which by design have to vary with time, the geographic matching variables are static. Since the level of the original data collection is by km^2, most of these variables can now be expressed as a percentage, reflecting how large share of a square that is covered by each respective ground type. For the variables *distance to regional transmission* and *wind speed*, I instead compute the average distance within each large square s. The following variables are selected by the LASSO: *Share of arable land, share of open ground* (as opposed to e.g. forest and mountains), *share of Energy Agency designated wind power area, mean distance to regional transmission*, and *mean*

[4]The official GIS-grid used by Statistics Sweden has one observation per km^2. I use this grid as a template, and let every tenth square serve as the north-west coordinate for the new grid.

wind speed. I then proceed to find the closest match to each square in the other price zone, based on the mahalanobis distance[5] computed using the variables chosen by the LASSO. For each of the matched pairs, the average of the difference is then computed for the outcome variable of interest.[6]

Since the main outcome of interest is the total number of projects by the end of the sample period, I use the time aggregated values for each outcome during 2007-2020. Following the logic of the DiD estimator, I also subtract the corresponding value from the years predating 2007 for each observation. When including all matched pairs, the estimator corresponds to the Average Treatment Effect (ATE). This is the expected effect of the reform if a random square would have been assigned to the high price zone, and its match to the low price zone. If instead computing the effect using only southern squares and their northern counterparts, the estimator corresponds to the Treatment On the Treated (TOT), i.e. the expected effect if a random *southern* municipality had been assigned to the high price.

5 Results

Below, I describe the results separately for each model. Robustness results are discussed separately at the end of each section, and Table A9 provides a compilation of all robustness results.

5.1 DiD results

Table 3 displays results from the main specification in equation (1), with results for large firms in columns (1)-(4). In columns (1)-(2), the dependent variable is the number of applications submitted, conditional on project realization (see the top left diagram in Figure 3 for the corresponding DiD-graph). The main specification, which includes covariates, is column (2), in which the treatment coefficient $\hat{\delta}$ is estimated precisely at about 26 projects. The interpretation is that, in absence of the reform, 26 more projects would have been realized in the north compared to the south. Under the assumption that the total volume of projects was not affected by the reform, this implies that $\frac{\hat{\delta}}{2} = 13$ projects switched location due to the reform. Expressed as a percentage of the total number of realized projects applications submitted by large firms in 2007 or after, the corresponding figure is $\frac{13}{72} = 18$ percent. If instead expressed in terms of installed capacity, this corresponds to 0.4 GW. [7]

In the next two specifications (3)-(4), the dependent variable is instead the total number of

[5]The malalanobis distance is based on the inverse of the covariates' variance–covariance matrix, and is the most widely used metric in nearest neighborhood matching. It corresponds to the euclidean distance given that variables are transformed to a unit variance. Matching is done using resampling, so that one square may serve as the match for several other squares.

[6]I estimate the model using Stata's built-in *teffects* command, obtaining standard errors by implementing the bias-corrected estimator proposed by Abadie and Imbens (2011) to correct for inconsistency when matching on continuous variables.

[7]This figure was computed by taking the mean installed capacity of all large projects realized in the south in 2007 or after, multiplied by 13.

Table 3: Basic DiD results

	Large firms				Small firms			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
South x post ($\hat{\delta}$)	32.4***	26.2***	150.6***	137.6***	−0.79	−5.18*	27.1	19.5
	(7.83)	(4.53)	(54.3)	(27.4)	(5.73)	(2.67)	(34.6)	(12.0)
Wage		−8.16		35.1		−9.35		−29.3
		(23.4)		(151.3)		(14.2)		(59.8)
EP in rule		46.1*		312.6		17.4		212.9***
		(24.8)		(188.7)		(10.7)		(43.3)
Edu level (1-7)		29.5		113.6		26.9*		117.3*
		(23.9)		(154.3)		(13.8)		(68.8)
Emp rate		−413.0		−1720.0		−251.0		−681.4
		(262.8)		(1401.8)		(176.9)		(626.4)
Application type	Realized	Realized	All	All	Realized	Realized	All	All
N	42	42	42	42	42	42	42	42

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Estimation results from equation (1). The dependent variable is the number project applications submitted. In specifications (1)-(2) and (5)-(6), only applications that were realized during the sample period are included. Standard errors are Newey-West with lag 4.

applications, irrespective of project realization. When including covariates in column (4), $\hat{\delta}$ is precisely estimated at 138. Expressed as a percentage of the total number of projects applications submitted by large firms in 2007 or after, the corresponding figure is $\frac{138/2}{402} = 17$ percent, which is only marginally different from the previous figure, indicating that geographic differences in approval rates do not drive the results.

The following columns (5)-(8) display results for small firms (see the top right diagrams in Figure 3 and 4 for the corresponding DiD-graphs). As expected, $\hat{\delta}$ is estimated imprecisely in all specifications. All of the coefficients are also economically comparatively insignificant. Therefore I do not comment further on these results.

Robustness

In Table 3, a firm is defined as large if it submitted at least ten applications during the sample period. Since this cutoff is arbitrary, I also estimate specifications (2), (4), (6) and (8) while letting the cutoff to vary between five and fifteen applications. The corresponding treatment coefficients are depicted graphically in Figure A2, together with 95 percent confidence intervals.

All treatment coefficients corresponding to specifications (2) and (4) are estimated precisely, which is reassuring. The coefficients attains their highest value when the cutoff is defined at ten projects, as in the main specification. The respective minimum values for the treatment coefficients are 19 and 125 respectively, which is not notably different from the original estimates of 26 and 138.

The coefficients corresponding to specification (6) are imprecisely estimated throughout, as in the main specification. Quantitatively, the coefficients vary between -5 and 2, which is economically

Table 4: Triple differences results

	Realized		All	
	(1)	(2)	(3)	(4)
South x post ($\hat{\theta}$)	33.1***	31.4***	123.4***	111.0***
	(3.63)	(4.37)	(23.4)	(17.8)
Wage		1.19		−23.0
		(16.5)		(84.7)
EP in rule		28.7*		213.4*
		(16.8)		(114.6)
Edu level (1-7)		2.62		53.4
		(15.2)		(83.3)
Employed		−162.0		−882.8
		(308.7)		(912.6)
N	42	42	42	42

* p < .10, ** p < 0.05, *** p < 0.01
Note: Estimation results from equation (2). The dependent variable is the number project applications submitted. In specifications (1)-(2), only applications that were realized during the sample period are included. Standard errors are Newey-West with lag 4.

insignificant. Some of the coefficients corresponding to specification (8) are estimated somewhat more precisely than the original estimate, although this only holds for less than half of the robustness specifications. However, coefficients are still notably smaller than the corresponding figures for large firms.

5.2 Triple differences results

Results are displayed in Table 4. In columns (1)-(2) the dependent variable is the number of applications submitted, conditional on project realization. The main specification, which includes covariates, is column (2), in which the treatment coefficient $\hat{\theta}$ is estimated precisely at about 31 projects. Under the assumption that the total volume of projects was not affected by the reform, this implies that $\frac{\hat{\delta}}{2} = 16$ projects switched location due to the reform, which is comparable to the corresponding DiD-estimate at 13. Since the trends in applications for small firms were similar across zones, it is not surprising that the triple differences results are similar to the DiD results.

In the next two columns (3)-(4), the dependent variable is the total number of applications, unconditional on project realization. When including covariates in column (4), $\hat{\theta}$ is precisely estimated at 111 projects, which is somewhat lower than the corresponding DiD-estimate at 138. This is expected, since the trend for small firms increases somewhat more in the southern than in the northern zone, as depicted in the upper right diagram in Figure 4.

Robustness

Analogous to the DiD results, I estimate specifications (2) and (4) while letting the large firm cutoff vary between five and fifteen applications. Results are depicted graphically in Figure

Table 5: Variable balance before and after matching

	Standardized difference		***Variance ratio***	
	Observed	Matched	Observed	Matched
Nr. projects applied pre 2007	0.061	0.000	4.159	1.000
Arable land	1.311	0.135	27.771	1.363
Open ground area	0.748	0.206	3.834	1.452
Dist to regional transmission (mean)	−0.782	0.201	0.139	1.494
Designated wind power area	−0.001	0.000	0.993	1.000
Mean wind speed *(m/sec)*	1.040	0.128	1.345	1.035
Population	0.311	0.088	127.057	2.909

Note: Differences in observed and matched values for the matching variables. The standardized difference for the observed sample is $(X_{south} - X_{north})/X^{sd}$, and the variance ratio is $X^{var}_{south}/X^{var}_{north}$. Corresponding figures for the matched sample are defined equivalently, but every square is now compared to its matched counterpart.

A3. Coefficients are estimated precisely throughout. However, quantitatively, the treatment coefficient is sensitive to the cutoff in specification (2), ranging between 16 and 31 projects. Therefore, the exact magnitude of the effect should be interpreted with care. In specification (4), the treatment coefficient instead varies between 80 and 115 projects, which is much less variation if expressed in percentage terms, but still underlines that these results are sensitive to variations in the cutoff.

5.3 Nearest neighbor results

For a meaningful interpretation of the results, it is crucial that the matched variables are balanced across matched pairs. Table 5 displays the standardized differences, $(X_{south} - X_{north})/X^{sd}$, as well as the variance ratio, $X^{var}_{south}/X^{var}_{north}$, for the observed as well as the matched sample. Looking at the first column, it is evident that the observed sample is highly unbalanced with respect to all variables except *designated wind power area*. Notably, all of the variables indicate that the southern zone is better suited for wind power, except for the population variable, since increased population density constitutes a hindrance for wind power development. On the contrary, the matched sample is much better balanced, although the variable *open ground area* still has a standardized difference of around 0.206, reflecting a nontrivial difference within the matched pairs. Further, for most of the variables, the variance ratio is much smaller in the matched compared to the observed sample.

Results are displayed in Table 6, with coefficients for large firms in columns (1)-(4). In columns (1)-(2), the dependent variable is the number of applications submitted, conditional on project realization. The ATE in column (1) is precisely estimated at 0.012 projects per square. In a common DiD setup, results are directly comparable to the corresponding matching results. In the present basic DiD setup, however, the dependent variable is *aggregated* projects volumes within each zone. A back-of-the-envelope computation shows that the implied ATE when aggregating across squares is 0.012 x 2006 southern squares = 24, which is comparable to the results from the previous models. However, the TOT in column (2) is almost twice as large as the ATE, at

Table 6: Nearest neighbor matching results

	Large firms (Realized)		Large firms (All)		Small firms (Realized)		Small firms (All)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment effect	0.012***	0.020***	0.042***	0.070***	0.0031	0.0056	0.079	0.033
	(0.0039)	(0.0037)	(0.014)	(0.013)	(0.022)	(0.026)	(0.067)	(0.050)
Effect estimated	ATE	TOT	ATE	TOT	ATE	TOT	ATE	TOT
N	2106	4174	2106	4174	2106	4174	2106	4174

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Results from the nearest neighbor matching estimator described in section 4.3. Standard errors are obtained by implementing the bias-corrected estimator proposed by Abadie and Imbens (2011) to correct for inconsistency when matching on continuous variables. ATE is the average treatment effects, TOT is the treatment on the treated.

0.02. There is no apparent explanation as to why the TOT exceeds the ATE. One possible interpretation is that the southern units on appear relatively better suited for windpower compared to the northern units (see Table 5). Therefore, there may have been relatively many potential latent wind power sites in the south, that were only realized after the reform. Conversely, a large fraction of the northern units may not have been relevant for wind power investments even if they would have been assigned to the high-price zone.

The following columns (3)-(4) display results for all applications. Also here, the TOT is approximately twice the size of ATE. When expressed as percentages of the total number of applications, the ATE is somewhat smaller than the corresponding basic DiD estimate, at 11 instead of 17 percent.

The following columns (5)-(8) display the corresponding results for small firms. The effect is comparatively small and imprecisely estimated in all of the specifications, in accordance with the results from the previous models, and therefore I do not comment further on these results.

Robustness

I conduct robustness tests in two dimensions. First, I allow the matching estimator to identify up to five neighbors to each square, following the ranking of the mahalanobis distance to the squares in the other zone. Coefficients are depicted graphically in Figure A4, corresponding to specifications (1)-(4), and A5, corresponding to specifications (5)-(8). The variations in the coefficients are neither statistically nor economically different from the baseline estimate, except specification (7), which yields a precisely estimated treatment coefficient at 0.082 when including five neighbors (see the lower right diagram in Figure A5). In terms of economic significance, this figure is comparable to the corresponding baseline figure for large firms in specification (4).

Second, I examine the sensitivity to the choice of matching variables by iteratively removing one of the matching variables. Results are depicted in Table A1-A4 for large firms, and Table A5-A8 for small firms. For large firms, all coefficients are estimated precisely and generally do not vary notably across robustness specifications. An exception is specification (1), where the estimated effect ranges between 0.01 and 0.028, although most iterations are close to the main result at 0.012. The corresponding results for small firms reveal that every coefficient is estimated imprecisely, except for the last specification in Table A7, where the population variable has been removed. In this specification, the treatment effect is precisely estimated at 0.037.

6 Concluding discussion

I present empirical evidence of the effect of the 2011 Swedish electricity market splitting reform on the allocation of wind power investments. I exploit a unique data set of all Swedish applications for wind power since 2003, including information on the submission date of each project application, the owner of the project, and whether it was rejected or approved and subsequently realized. I find that 18 percent of all projects submitted by large firms after the reform were allocated to the high price zone due to the reform. This effect is not driven by geographic differences in approval rates, suggesting that the estimated effect also captures investor preferences. Qualitatively, results are verified using both a triple differences as well as a nearest neighbor approach. However, since there were relatively few applications submitted before the announcement of the reform, the parallel trends assumption of the DiD estimator cannot be entirely verified, suggesting that results should be interpreted with care.

Further, I find that small, sometimes locally owned firms, did not react to the reform. A likely reason is that the locational choice set of small firms usually only include one zone. Since the price effect of the reform was relatively modest during the majority of the sample period, it is unlikely that the reform would have an effect on the absolute volume of wind power investments, explaining the absence of an effect on small firms. Hence, it would be useful for policy makers to account for investor characteristics when evaluating, and potentially also forecasting, effects of further market splitting reforms throughout Europe.

A central rationale for market splitting reforms is that increased investments in production in high-price zones lead to an equalization of prices, eliminating the need to increase transmission capacity. Although the present study does not attempt to estimate the effect on prices, the results could be used as a basis for estimating such an effect.

Although it is beyond the scope of this study to examine the demand side effects of the reform, such a study would be a valuable complement to the present study. During the last decade, several data centers have chosen to locate in the northern zone. There is also an ongoing discussion about locating a large scale steal plant here in the near future, which would increase demand in the northern zone by around 30 percent. Future studies could examine the extent to which the locational decisions of such electricity intensive industries have been influenced by the reform. Given that the price divergence was most pronounces at the end of the sample period, it is expected that even greater supply- and demand effects could arise in the near future, underlining the value of continuous evaluations.

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Appendix A: Details of the application process

Information regarding the application process has been collected from www.vindlov.se.
Application process: Every wind turbine application is submitted to the municipality where the proposed site is located. If a project spans two municipalities, applications have to be submitted to both municipalities. Projects are divided into three main categories depending on their size:

1. Small projecs: **1 turbine $\leq$ 50 m**
   Decision is taken by the municipal land use committee. Members are often local politicians. The municipal council may also influence the decision directly. Application includes technical characteristics of the turbine, estimates of noise, shadows etc.

2. Medium projects: **1 turbine > 50 m or 2 or more turbines**
   Decision by municipal land use committee *and* the municipal environmental committee. Application also includes environmental consequences documentation.

3. Large projects: **2 turbines that both are > 150 m or 7 or more turbines each > 120 m**
   Decision by municipality, but the project also needs to comply with extensive environmental legislation. Compliance is tried at the county level by non-political officials. These projects account for about half of all project applications in the data. Municipalities are free to choose how to make the decision. According to the Energy Agency (2014), the ruling coalition decides in 46 percent of the municipalities, the municipal council decides in 22 percent, and in the remaining cases the decision making body is a non-political bureaucratic entity. These projects demand more thorough environmental consequences documentation.

Original decisions can be appealed. The appeal process for small and medium projects is handled by the county administration, but the county administrations only have the power to reject applications that have already been approved (so that the municipal veto to reject persists). Large projects can be appealed to the National Environmental Court. Also here, the municipal veto to reject persists.

Besides the approval process described above, the military also has the right to refuse a project if it is located in an area where there is a conflict of interest with military activities. A common reason is that military aircrafts should be able to fly through a landscape close to the ground without risking a collision with wind turbines.

Appendix B: Data Sources

- **Geographic characteristics:** Data are publicly available and may be downloaded from the Swedish Land Use Authority ("Lantmäteriet").
  www.lantmateriet.se/sv/Kartor-och-geografisk-information/oppna-data

- **Election data:** Data are publicly available and may be downloaded from the Election Authority ("Valmyndigheten").
  www.val.se/valresultat

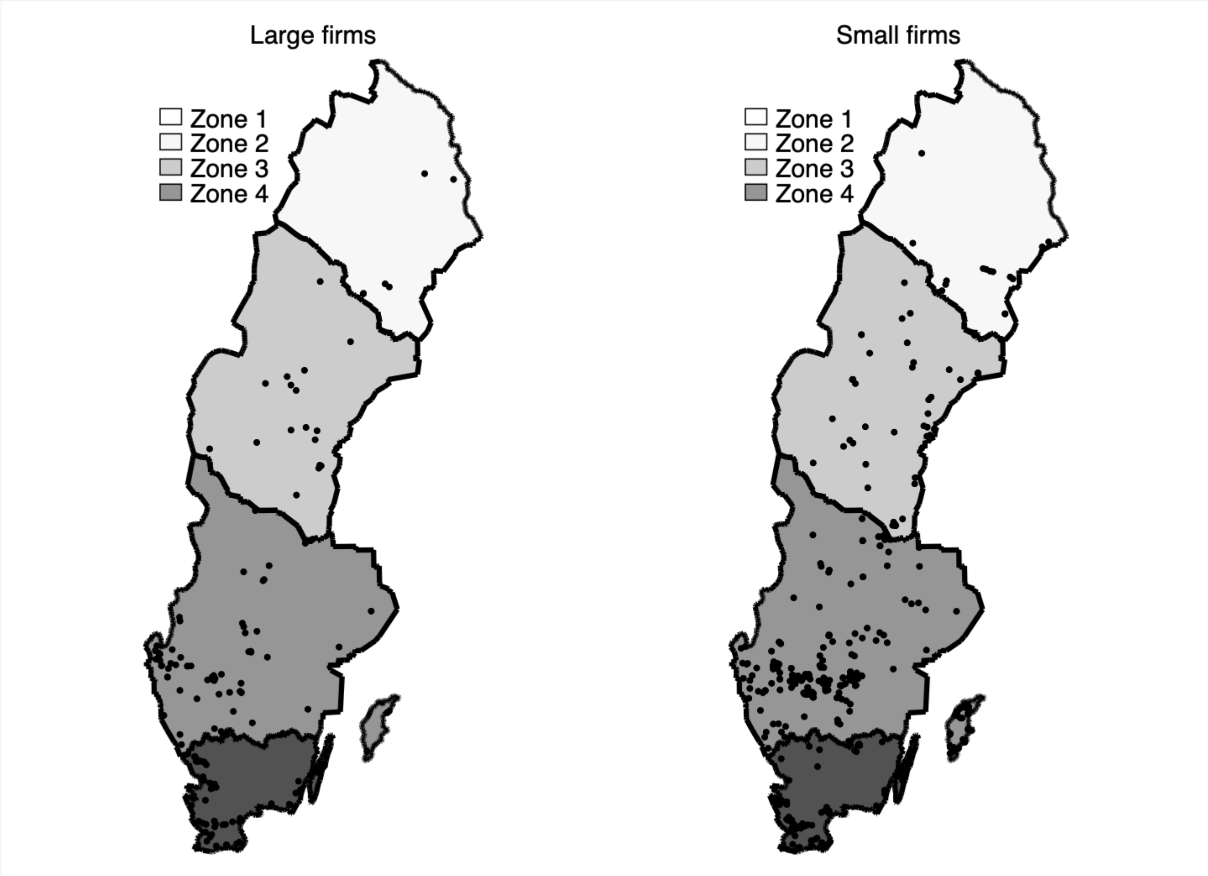
- **Wind turbine application data:** Data are publicly available and may be downloaded from the Energy Agency ("Energimyndigheten").
  www.vbk.lansstyrelsen.se

- **Wind turbine ownership data:** Data on turbine ownership from the Energy Agency data set are organization numbers. These numbers have then been merged with detailed ownership information, including parent companies (if applicable) and municipality of registration. This merge has been done using the private Serrano data-set of the Research Institute of Industrial Economics. Please contact the author directly for access to aggregate variables constructed using these data.

- **Sociodemographic data:** Data have been accessed using the LISA-database of Statistics Sweden. These data are not publicly available, but close to identical variables are publicly available from the Kolada data base of SKR.
  www.kolada.se

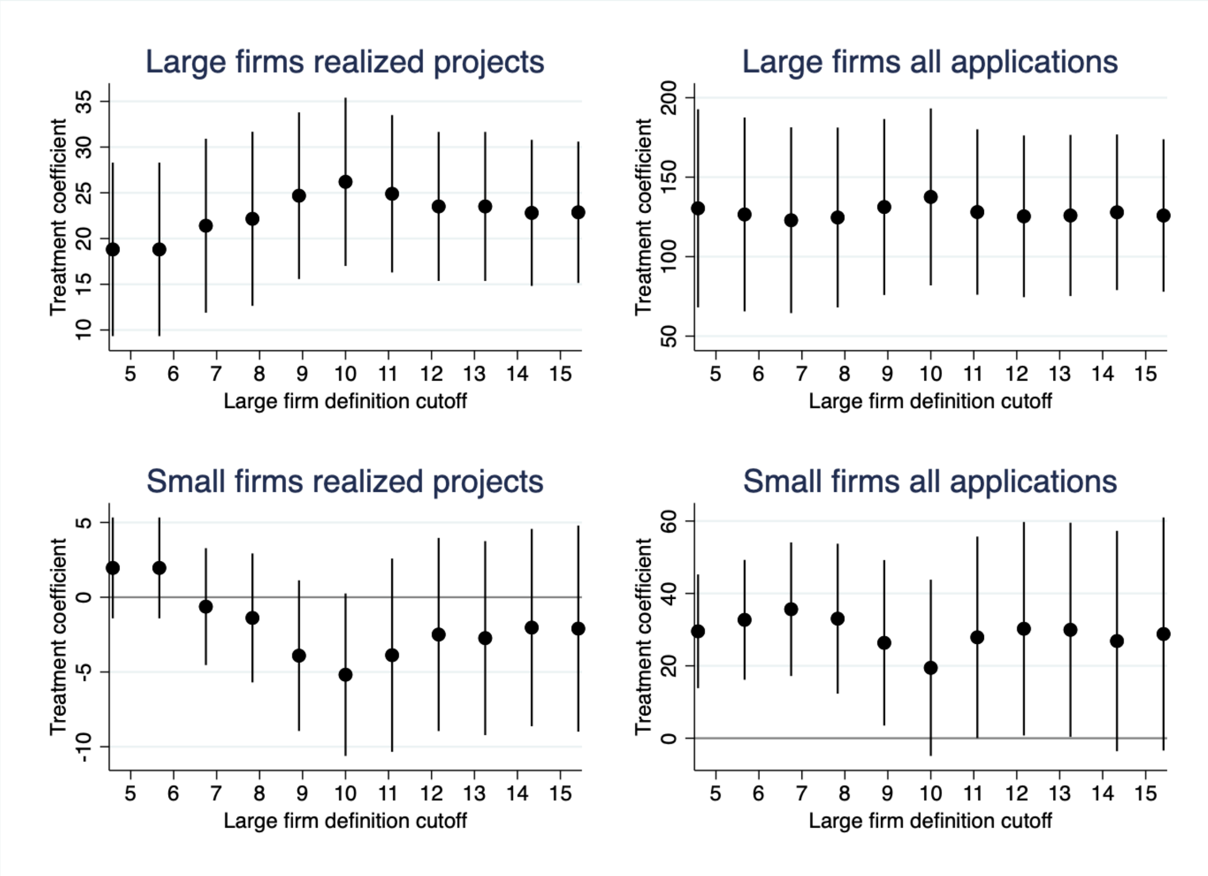
Appendix C

Figure A1: Map of realized projects by firm size and price zone, including small projects.



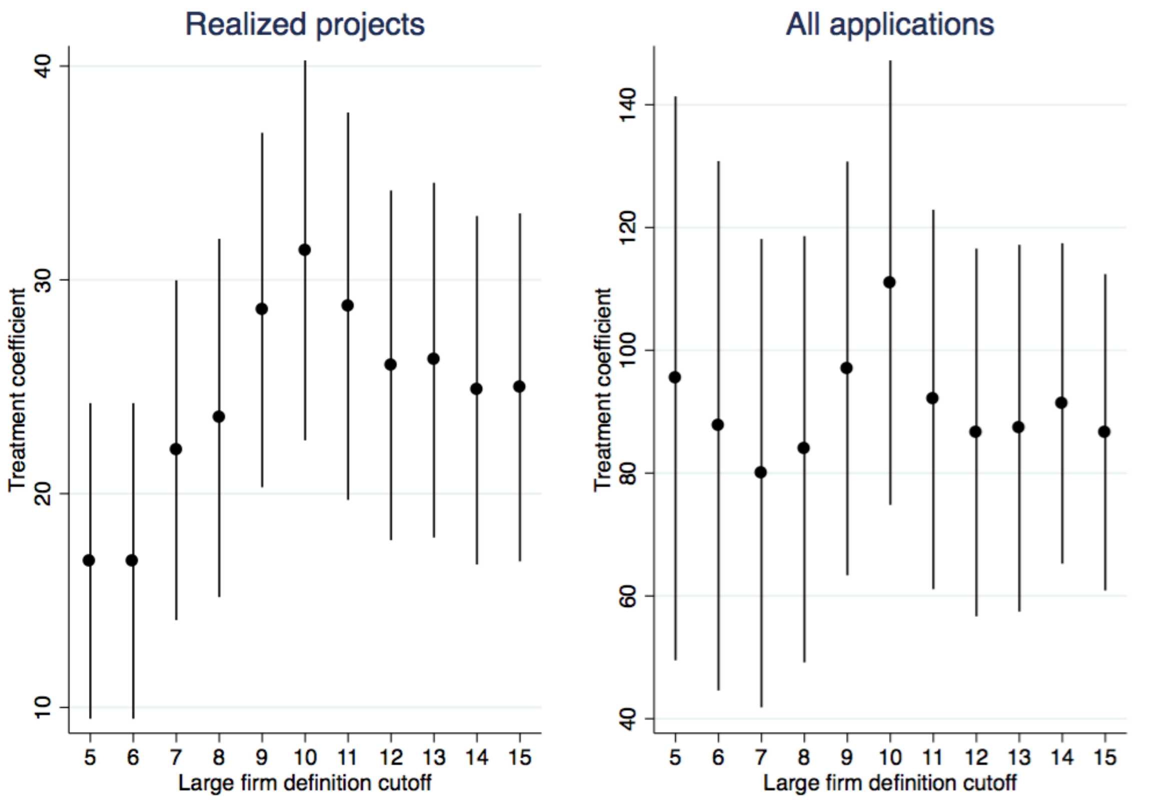
Note: Each dot represent the location of a wind project for large (left) and small (right) firms respectively, by 2020. Also shown are the zonal borders. All projects are included, also those with less than five turbines.

Figure A2: DiD sensitivity to the definition of a large firm



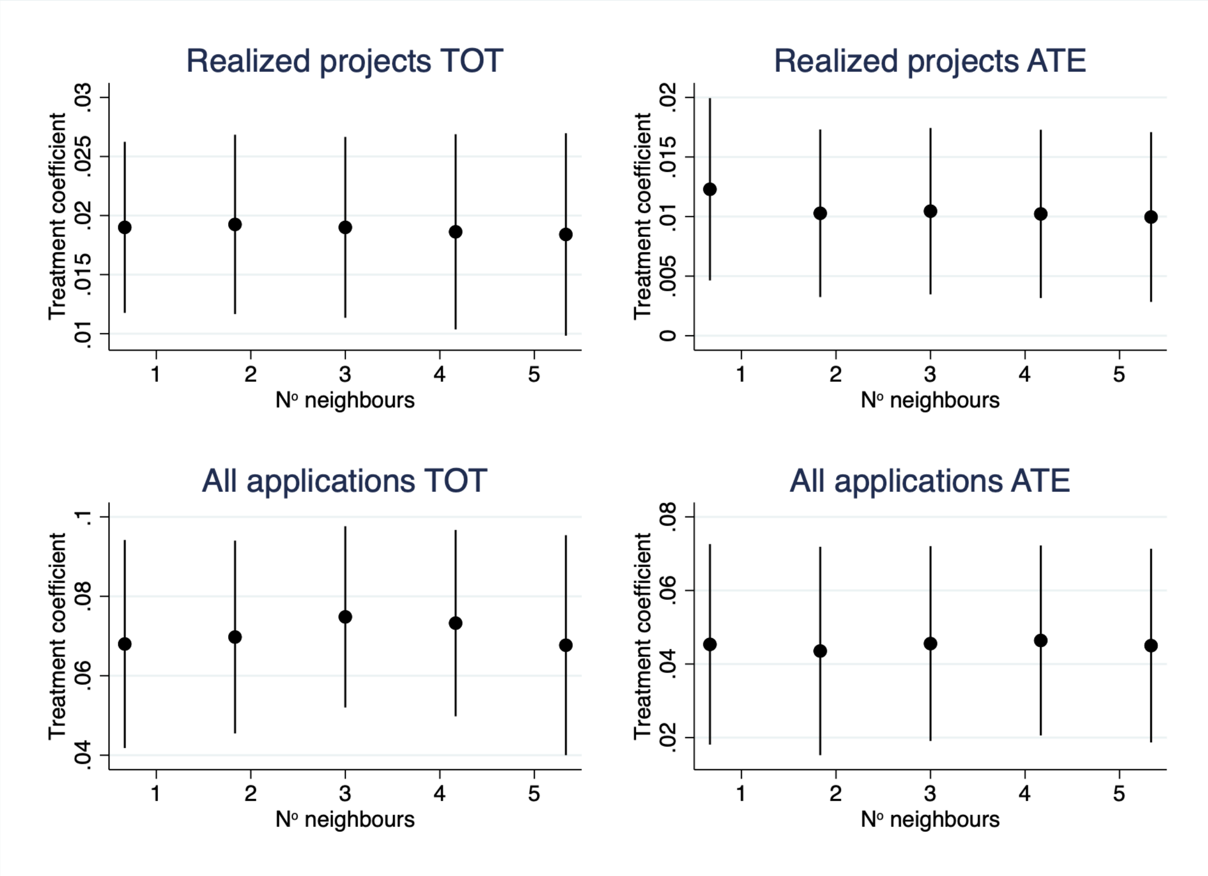
Note: Results when estimating specifications (2), (4), (6), and (8) in Table 3 and varying the number of applications required for a firm to be defined as large between 5-15. Treatment coefficients are displayed as dots. Vertical lines are 95 percent confidence intervals.

Figure A3: Triple differences sensitivity to the definition of a large firm



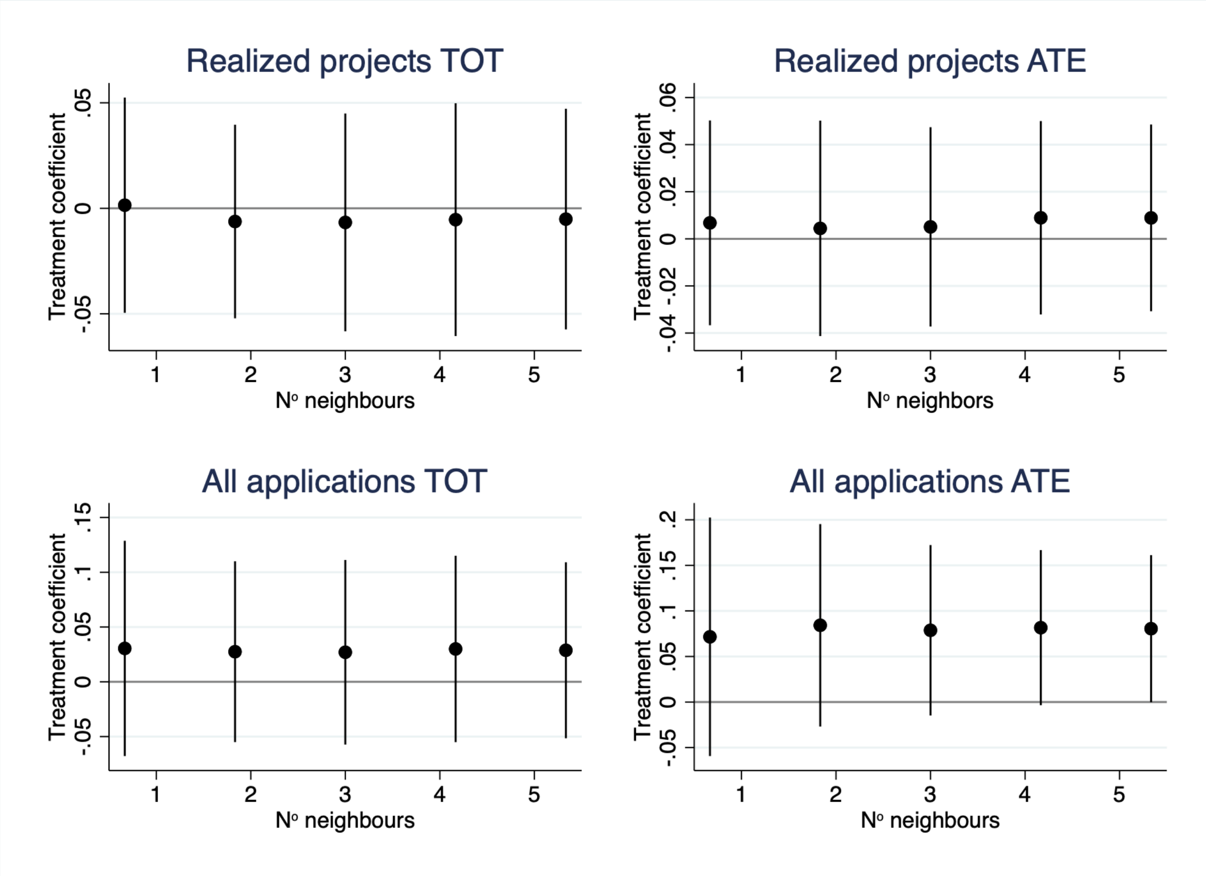
Note: Results when estimating specifications (2) and (4) in Table 4 and varying the number of applications required for a firm to be defined as large between 5-15. Treatment coefficients are displayed as dots. Vertical lines are 95 percent confidence intervals.

Figure A4: Nearest neighbor sensitivity to the number of neighbors, large firms



Note: Results when estimating specifications (1)-(4) in Table 6 and letting the matching estimator identify up to five neighbors. Treatment coefficients are displayed as dots. Vertical lines are 95 percent confidence intervals.

Figure A5: Nearest neighbor robustness results, small firms



Note: Results when estimating specifications (5)-(8) in Table 6 and allowing the matching estimator to identify up to five neighbors. Treatment coefficients are displayed as dots. Vertical lines are 95 percent confidence intervals.

Table A1: Leave-one-out: Large firms, ATE, realized projects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.013***	0.0095***	0.021***	0.013***	0.010***	0.013***	0.028***
	(0.0039)	(0.0034)	(0.0050)	(0.0040)	(0.0038)	(0.0040)	(0.0074)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* p $<$ .10, ** p $<$ 0.05, *** p $<$ 0.01
Note: Nearest neighbor results corresponding to specification (1) in Table 6 when iteratively leaving out one of the matching variables.

Table A2: Leave-one-out: Large firms, TOT, realized projects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.020***	0.020***	0.020***	0.020***	0.020***	0.020***	0.019***
	(0.0037)	(0.0039)	(0.0037)	(0.0038)	(0.0036)	(0.0037)	(0.0039)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Nearest neighbor results corresponding to specification (2) in Table 6 when iteratively leaving out one of the matching variables.

Table A3: Leave-one-out: Large firms, ATE, all applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ATE							
Treatment effect	0.019***	0.017**	0.021***	0.025***	0.015**	0.020***	0.025***
	(0.0052)	(0.0066)	(0.0053)	(0.0058)	(0.0061)	(0.0052)	(0.0064)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Nearest neighbor results corresponding to specification (3) in Table 6 when iteratively leaving out one of the matching variables.

Table A4: Leave-one-out: Large firms, TOT, all applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.046***	0.041***	0.043***	0.042***	0.037***	0.046***	0.041***
	(0.0074)	(0.011)	(0.0073)	(0.0069)	(0.0082)	(0.0066)	(0.0087)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Nearest neighbor results corresponding to specification (4) in Table 6 when iteratively leaving out one of the matching variables.

Table A5: Leave-one-out: Small firms, ATE, realized projects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.0058	−0.0019	0.0024	0.015	0.0057	0.0031	0.0032
	(0.022)	(0.0047)	(0.0088)	(0.044)	(0.023)	(0.020)	(0.011)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* $p < .10$, ** $p < 0.05$, *** $p < 0.01$
Note: Nearest neighbor results corresponding to specification (5) in Table 6 when iteratively leaving out one of the matching variables.

Table A6: Leave-one-out: Small firms, TOT, realized projects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.012	0.0020	0.0086	0.0075	0.010	0.0062	−0.013
	(0.026)	(0.0066)	(0.017)	(0.053)	(0.028)	(0.016)	(0.015)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* p < .10, ** p < 0.05, *** p < 0.01
Note: Nearest neighbor results corresponding to specification (6) in Table 6 when iteratively leaving out one of the matching variables.

Table A7: Leave-one-out: Small firms, ATE, all applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ATE							
Treatment effect	0.030	0.0055	0.0064	0.028	0.031	0.027	0.037**
	(0.038)	(0.024)	(0.015)	(0.068)	(0.038)	(0.033)	(0.016)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* p < .10, ** p < 0.05, *** p < 0.01
Note: Nearest neighbor results corresponding to specification (7) in Table 6 when iteratively leaving out one of the matching variables.

Table A8: Leave-one-out: Small firms, TOT, all applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment effect	0.029	0.0092	0.025	0.027	0.027	0.022	0.0062
	(0.049)	(0.028)	(0.031)	(0.10)	(0.051)	(0.027)	(0.0099)
Left out variable	Pre 2007	Arable	Open	Transmission	Designated	Wind	Pop
N	4719	4719	4719	4719	4719	4719	4719

* p < .10, ** p < 0.05, *** p < 0.01
Note: Nearest neighbor results corresponding to specification (8) in Table 6 when iteratively leaving out one of the matching variables.

Table A9: Compilation of robustness results

Type of test	**Large firms**	**Small firms**
Large firm def	**DiD**	
Realized projects	19-26 [26]	ns [ns]
All applications	125-134 [134]	24-37 [ns]
	Triple diff	
Realized projects	16-32 [32]	n/a
All applications	80-111 [111]	n/a
№neighbors	**Matching**	
ATE, realized proj	0.01-0.012 [0.012]	ns [ns]
TOT, realized proj	0.018-0.020 [0.020]	ns [ns]
ATE, all applications	0.041-0.042 [0.042]	0.082-0.082 [ns]
TOT, all apps	0.070-0.075 [0.070]	ns [ns]
Leave-one-out		
ATE, realized proj	0.01-0.028 [0.012]	ns [ns]
TOT, realized proj	0.019-0.020 [0.020]	ns [ns]
ATE, all applications	0.015-0.021 [0.042]	0.037-0.037 [ns]
TOT, all applications	0.037-0.046 [0.070]	ns [ns]

Note: Compilation of treatment coefficients for various robustness tests. The first figure in each row is the lowest coefficient obtained in the test, and the second figure is the highest. The figure in brackets is the corresponding baseline coefficient. Coefficients are only printed out if $p < 0.05$, otherwise they are recorded as not significant (ns).