Wind electricity subsidies - A Windfall for landowners? Evidence from a feed-in tariff in Germany☆

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Abstract

Subsidies for renewable energy sources are increasing around the globe and amounted to more than 100 billion euro in 2013. This study aims to answer whether the subsidies only ensure that green electricity plants are profitable or whether other market participant - as, for example, landowners - benefit from the subsidy in the form of windfall gains as well. To identify the causal impact of the subsidies, we investigate the impact of the introduction of a price guarantee in the form of a feed-in tariff for wind electricity in Germany on land prices. We employ two different approaches. Both approaches exploit quasi-experimental variation in wind strength across 260 non-urban counties in combination with the introduction of the subsidies. Based on a difference-in-differences design, we find that land prices increased by roughly 1,100 euro in high-wind areas after the introduction of the subsidy. Using an instrumental variable estimator pins down that around 18% of expected wind turbine profits are capitalized into land prices. Further, we show that wind turbine subsidies account for 4% of overall agricultural income in 2007.

Keywords: Incidence, subsidy, renewable energy, wind turbines, land prices

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1. Introduction

Most countries subsidize investment in renewable energy sources (RES) as a higher share of green electricity is seen as key for alleviating global warming. Taking into account all the various support schemes, the International Energy Agency estimates that in 2013 around 100 billion euro (121 billion US dollars) were spent worldwide to promote green energy (International Energy Agency (2014)). These enormous amounts raise concerns about the distributional consequences and the efficiency of the subsidies. In particular, it is crucial to understand who benefits from the subsidies. Is it the investor, and consequently does the subsidy ensure that green electricity plants are profitable? Or to what extent do other market participants - as, for example, landowners - benefit from the subsidy in the form of windfall gains?[1] This paper aims to provide empirical evidence on this incidence question by investigating the effect of onshore wind turbine subsidies in Germany on administrative transaction prices for agricultural land between 1997 and 2004.

The setting in Germany is particularly suitable for our analysis. First, RES subsidies are important. In 2012, about 12 billion euro were spent on these subsidies, roughly the equivalent of 20% of Germany's tax revenue on corporate profits. Second, Germany uses a price guarantee for green electricity in the form of a feed-in tariff to foster investment in RES. The feed-in tariff was introduced in 2000 with the adoption of the Renewable Energy Act (REA). The central mechanism of a feed-in tariff is a guaranteed, fixed wholesale price for green electricity for a specific time period. To date, this support scheme is the most commonly used policy measure around the world (REN (2017)). Third, descriptive evidence based on aggregate statistics suggests that the REA had a sizable impact on the energy market. Following the introduction of the REA, electricity produced by RES, as a share of overall electricity consumption, increased from 6.2% in 2000 to 23.7% in 2012. Over the entire period, at least half of the overall electricity generated by RES came from onshore wind turbines.[2] Finally, landowners and investors

[1]By windfall gains we mean compensations that exceed the related loss in the agricultural value of land.

[2]Source: Federal Ministry for Economics and Energy 2015, available online

are likely to be the main beneficiaries as there is little labor involved in the electricity generated by wind turbines.[3]

In order to identify the causal effect of the subsidy on land prices, we propose two different approaches which exploit quasi-experimental variation in wind strength in combination with the introduction of the REA in 2000. First, we apply a difference-in-differences (DiD) estimator by comparing land prices in high-wind and low-wind non-urban counties before and after the introduction of wind electricity subsidies. Since this design only identifies the causal effect of the REA on land prices but does not allow the quantification of the incidence of the subsidy, we estimate in a second step the effect of expected wind turbines profits on land prices. This specification is motivated by Titman's work on the price of vacant land under uncertainty (Titman, 1985) which suggests that the price of each field on which a wind turbine can potentially be built increases with the subsidy. As expected wind turbines profits are not observed, we construct them based on simulated expected profits of a median-technology wind turbine for each county and year. We address the potential measurement error in our simulation due to the assumed technological choice, which would bias the OLS estimator, by employing an instrumental variable (IV) strategy. The excluded instrument is constructed using variation in wind strength across counties in combination with the introduction of the REA. To provide a deeper understanding of the incidence result, we analyze in the final part of the paper how large the additional income generated by wind turbines subsidies is in comparison to overall agricultural income.

Our results suggest positive incidence effects. In the DiD estimation, we find that land prices per hectare increased by around 1,300 euro for each additional meter per second (m/s) wind strength in a county after the introduction of the REA. In the IV estimation we show that around 18% of expected wind turbine profits are capitalized into land prices. The results are robust across a wide range of specifications. The estimated incidence share

at http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2014.pdf?__blob=publicationFile&v=4, last accessed: 17/12/2015

[3]Part of the profits may also reaped by manufacturers. However, given the worldwide competition we believe that their share is of minor importance. Further, the subsidy could induce general equilibrium effects related to a re-allocation of workers towards the renewable energy sector and the rise in electricity prices, see for example Lehr et al. (2012).

translates - based on 2004 values - into capitalized wind turbine subsidies of 4,000 euro per hectare or 25% of the average land price per hectare. Finally, using the estimated incidence share and taking into account the characteristics of the German agricultural land market, we show that wind turbine subsidies increased agricultural income by 4% on average.

Our paper contributes to previously published literature in several ways. First, we add to the literature on the incidence of subsidies in agricultural land prices. Our estimated incidence share is at the lower end of estimates for agricultural subsidies.[4] For the US, Kirwan (2009) estimates an incidence share of 25%. Hendricks et al. (2012) suggests that the long-run incidence in the US may be up to 40% as inertia in farmland rental rates and different types of tenancy agreements are likely to have biased prior estimates. This is similar to findings by Roberts et al. (2003).[5] Ciaian and Kancs (2012) report that in OECD countries around 20% of agricultural subsidies are reaped by landowners. Most comparable to our study is the work by Breustedt and Habermann (2011). They estimate an incidence share of 38% for agricultural subsidies for the German state of Lower Saxony.

Second, we build on the literature that quantifies the distributional impact of environmental policies. Fullerton (2011) discusses six ways in which environmental policies (mainly taxation) may have distributional impact, which are all likely to be regressive. Empirical literature confirms this presumption for environmental taxes (Parry (2004); Metcalf (1999); Hassett et al. (2009); Grainger and Kolstad (2010)). The driving force behind the distributional impact of a carbon tax is the fact that low income households spend a large share of their budget on polluting goods (Grainger and Kolstad (2010)). Metcalf (1999) suggests targeted tax cuts to make the policy distributionally neutral. Parry et al. (2005) question the regressive impact of environmental policies by pointing out that poorer households bear a dis-

[4]We suggest future demand as the reason why the incidence share for RES subsidies is lower than for agricultural subsidies, but greater than zero. Appendix B shows that even with excess supply of land today landowners reap a sizable share of profits if demand is expected to be high in the future. This suggests that the incidence for subsidies for established products is determined by the current market structure (e.g. Poterba (1996); Besley and Rosen (1999); Carbonnier (2007); Kirwan (2009)) and for new products by the expected market structure.

[5]A recent paper by Suárez Serrato and Zidar (2016) finds very similar results for the incidence of corporate income tax in the US.

proportionate share of environmental risk, which is reduced by these policies. However, the authors suggest also that environmental policies are capitalized into housing prices, which benefit mainly richer households as they are more likely to own their home. The distributional impact of subsidies for renewable energies has received less attention, although they are commonly used in practice and recent theoretical literature has provided a rationale for the observed policies. Eichner and Runkel (2014), for example, show that subsidizing RES in addition to taxing pollution reduces the distortion of the tax-subsidy system.[6] One of the few empirical studies that investigates subsidies for renewable energies is Groesche and Schroeder (2014). They focus on subsidized photovoltaic plants on owner-occupied houses in Germany and find that the German REA is mildly regressive.

Finally, our results add to literature that discusses the efficiency of different policy instruments to promote renewable energies (e.g. Menanteau et al. (2003); Haas et al. (2011); Requate (2014)). Whether a price-based (such as a feed-in tariff) or a quantity-based system (such as tradable green electricity certificates or quotas) is preferable to foster investment in RES is often evaluated through three criteria: costs, installed capacity, and technological development (see Menanteau et al. (2003)). Different distributional implications are not discussed, although they are important and likely to differ.

The outline of the paper is as follows. Section 2 describes the relevant institutions and in particular the REA. The data is presented in section 3, followed by the methodology in section 4. Results on capitalization and incidence share are presented in section 5, while the distributional consequences of the wind turbine subsidies are discussed in section 6. Section 7 concludes.

2. Institutional Background

To alleviate the rise in global warming and to increase the share of RES to 20% in 2020 as agreed in the Kyoto Protocol and the Lisbon program, Germany introduced a technology-specific price guarantee for green electricity with the adoption of the REA in 2000. This particular support scheme

[6] Heutel and Kelly (2016) study the impact of non-environmental subsidies on pollution and find that decreasing these subsidies is likely to have a greater welfare effect than raising pollution taxes as they increase capital allocation efficiency as well as reduce pollution.

for RES seems to be the most prominent measure in the world as, to date, it has been adopted in over 100 countries (REN (2017)).[7]

In Germany as well as in many other countries the price guarantee is designed as a feed-in tariff: The REA specifies a minimum price for electricity produced using RES for 20 years after the installation of the plant. Further, the REA obliges grid operators to accept the feed-in of green electricity into the grid and to remunerate the feed-in electricity at the guaranteed price. Grid operators, however, do not bear the costs of the subsidy, which is equivalent to the difference between the wholesale market price of electricity and the guaranteed price, but are reimbursed from a fund to which all consumers contribute.[8] On average, the guaranteed price amounts to around 8 eurocent per kWh and is thus substantially above the market price of approximately 3 eurocent per kWh. In Table C.1 in the Online Appendix we provide detailed information about the structure of the tariff and how the structure changed over time.

The REA replaced the Electricity Feed-In Act (EFA), which guaranteed a wholesale price for green electricity as well, but the price was set to 90% of the end-consumer price (two years ago) and it was only paid for as long as the law was in effect. Thus, the REA reduced investors' risk in two important dimensions: first, it guarantees an absolute wholesale price for energy, and second, it guarantees how long that price is paid.

In 2005 and 2009 the REA was reformed. Most important was the introduction of a binding minimum return requirement for wind turbines in 2009 which changed the REA substantially.[9] In the main empirical analysis we therefore only focus on the years until 2004; in a sensitivity analysis we include in addition the time period 2005-2008 as the 2005 reform changed only marginally the generosity of the REA.[10]

[7]Other measures include, for example, investment grants, quotas and tenders. See Klessmann et al. (2011) for an overview of measures used by different EU countries.

[8]Energy-intensive industries (with more than 10 GWh power consumption) are exempt on application. The rule was tightened over time.

[9]If it could not be proven that a wind turbine would generate at least 60% of the reference plant defined in the law, no subsidy was paid. The minimum return requirement was introduced in 2005 but it applied only to large plants and could easily be avoided by building several small turbines instead of one large turbine. This loophole was closed with the 2009 reform. Since our analysis relies on county-level data, we are not able to account accurately for the changes implemented with the 2009 reform.

[10]The feed-in tariff consists of three parameters, i.e. a high and a low tariff and a

3. Data and Descriptive Statistics

The empirical analysis of this paper is carried out at the county level, as average prices for agricultural land without buildings (our dependent variable) are reported by the Statistical Offices of the German states at this level. In our sample period, Germany is divided into 323 non-urban and 116 urban counties, with an average size of 1,100 and 150 square kilometers respectively. Our sample includes all non-urban counties in Germany for which land prices are available between 1997 and 2008 and which had no changes in their administrative boundaries.[11]

We focus on transaction prices for agricultural land as this is the main building ground for wind turbines due to a required minimum distance from population areas. To ensure that the transaction prices are representative, we exclude counties with less than ten transactions per year and drop counties with extreme (top or bottom 1%) changes in transaction prices. This leaves us with an unbalanced panel for the period 1997 to 2004 including 262 counties and 1,942 county-year observations.[12] The counties covered in our sample account for roughly 80% of the wind turbines in Germany (see Table A.1, Appendix A).

High/low-wind counties: In the main DiD specification, we define high-wind counties as those with an average wind strength (80 meters above ground) above the median; low-wind counties have a wind strength equal to or below the median.[13] In additional specifications, we use the wind strength as treatment intensity to exploit the full variation in wind strength. We start with the binary indicator, as this allows us to report descriptive statistics for high-wind and low-wind counties and to illustrate the common trend and

parameter which determines the period for which the higher tariff is paid. The reform in 2005 reduced the low tariff but also increased the length for which the higher tariff is paid and thus had only a limited impact on overall profitability of wind turbines.

[11]Due to missing information, counties in Schleswig-Holstein, North Rhine Westphalia and Bavaria are not included for the year 1997. Due to changes in the administrative boundaries during the time period studied, counties in Sachsen-Anhalt and Thuringia are not included in the sample.

[12]Results are almost unchanged if we use a (un)balanced panel for 1998 to 2004.

[13]Information on the (1981 to 2000) average wind strength per square kilometer raster 10 and 80 meters above the ground is provided by the German Weather Service. We mapped the data to the municipality level and then constructed an agricultural land weighted county average.

the effect of the REA graphically. Figure 1 documents that wind strength varies substantially between German counties. Although there is a north-south decline in wind strength, there exists also regional variation due to topographic differences. Thus, counties that are located close to each other do not necessarily benefit to the same extent from the subsidies. The reform period includes all years after 1999 as the REA was introduced in 2000. Anticipation effects are not likely in our setting, as the draft for the REA was discussed the first time in parliament on December 13, 1999. The law came into force at the end of March 2000.[14]

One concern for our analysis at the county level is heterogeneity of wind speed within counties. We analyze the distribution of within-county wind speed by plotting the difference between wind speed at different percentiles and the average county wind speed for each county in our data set (see Figure A.1, Appendix A). Although there is some variation, the within-county wind speed distribution is very similar for the majority of counties. We find that for 92% of all counties, the difference between the mean and the 25th (75th) wind strength percentile is less than 0.5 m/s. Further, we plot the distribution of the within-county wind speed difference between the 10th and 90th percentile (see Figure A.2, Appendix A). For 65% of the counties the difference is less than 1 m/s and for 90% less than 1.5 m/s. To assess the sensitivity of the results with respect to the few counties with a very high wind speed dispersion, we exclude in a sensitivity analysis counties with a wind speed dispersion in the top 20% of the distribution.[15]

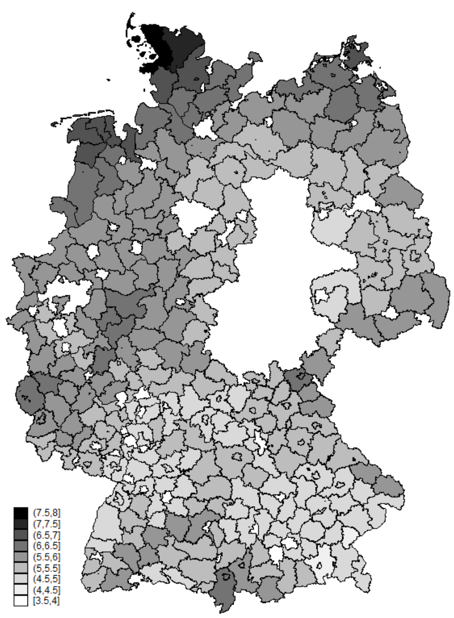
Further, in an additional sensitivity check we use the wind speed at the 25th and 75th percentile instead of the mean wind strength as treatment intensity.

Net present value of expected wind turbine profits: To quantify the incidence share, we use the net present value of expected wind turbine profits in a county as explanatory variable. It is constructed in two steps. First, we calculate the expected profits per hectare of a median-technology

[14]Nevertheless, we assessed the sensitivity of our results by excluding 1999 or 2000. Estimated coefficients (not reported) are within the range of the estimates presented below but less precisely estimated.

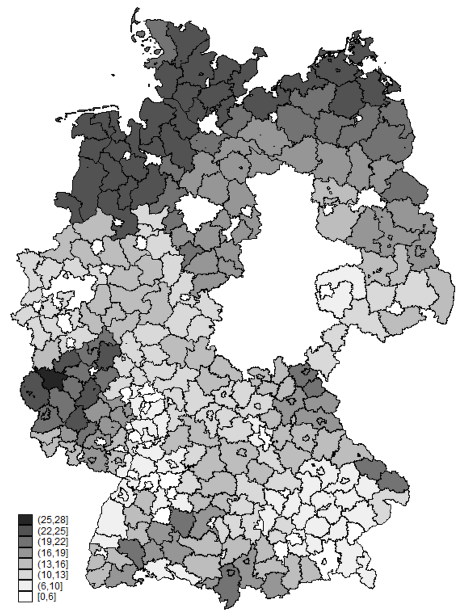
[15]Wind strength variability is less likely to be a concern; according to the International Electrotechnical Commission wind strength follows a Rayleigh distribution (IEC 61400-12-1).

Figure 1: Average Wind Strength in m/s



Notes: White counties are not included in the analysis. The figure shows the average wind strength in meter per second for each German county.
Source: Authors' calculations based on data from German Weather Service.

Figure 2: Change NPV Wind Turbine Profits per Hectare 1998 to 2002 in thd. euro



Notes: White counties are not included in the analysis. The figure shows the change in the net present value of expected wind turbine profits per hectare for each German county between 1998 and 2002. For more details see the description in the text.
Source: Authors' calculations based on data from German Weather Service and Operator database, 1990 and 2002.

wind turbine for each German county and year.[16] Second, we scale the county-year representative net present value of profits per hectare with the regional share of suitable land to build wind turbines published by the German Environment Agency (2013). In this way we account for the fact that turbines cannot legally be built on all agricultural land. Figure 2 illustrates the change in the net present value of wind turbine profits between 1998 and 2002 which mirrors the heterogeneity in wind strength in the cross-section.

Variables capturing the agricultural value of land: To control for the agricultural value of land, we use the following control variables: share of farmland or grassland (base category: permanent crop); the share of cereal, root crop or forage crop (base category: trade plants); the harvest per hectare of wheat, potatoes and silo corn (and the interactions with the respective land usage variables, e.g. wheat for cereal); and the share of land used by farms with stock breeding.[17] In addition, we include variables capturing the impact of urban proximity. These are population, population density, average wage income, rate of unemployment, and inverse distance-weighted average of neighboring counties' population. Further, we control for the average property tax on agricultural land and the average business tax.

[16] We start by calculating the energy produced by a representative county-year wind turbine and deriving the expected discounted income stream using the feed-in tariff that applied in a particular year and a discount rate of 3%. For wind turbines built before the REA was introduced, we assume that investors expected to receive the guaranteed price of 90% of the end-consumer price for three years after the installation of the plant, and afterward the average market price for electricity of 3 cent per kWh. Then, we deduct expected investment and finance (including equity) costs. Investment costs are approximated based on installed capacity. The share of bank financing, maturity and interest rate are based on descriptive statistics in DAFNE (see Online Appendix C.2). Finally, we derive the expected net present value of wind turbine profits per hectare by dividing profits by the amount of land used. The land usage accounts for the baseplate as well as the minimum distance to the next wind turbine, which is determined by law. We approximate the required minimum distance based on the published ratio of installed capacity to minimum distance, which is 6 hectare per MW (German Environment Agency (2013)). A detailed description of the calculation can be found in Online Appendix C.1.

[17] We further include interaction effects with a dummy variable that is one for West German counties and the share of forage crop (and its interaction with the harvest of silo corn) to control for a recent finding by Breustedt and Habermann (2011). Their results show that the introduction of subsidies for biomass plants with the REA increased farmland rental rates in proportion to the share of land used for corn in West Germany but not in East Germany.

In a robustness check, we also account for a potential spatial dependence of agricultural land prices by including the inverse distance-weighted average transaction price in neighboring counties.

Descriptive statistics for our main variables are shown in Table 1. The average transaction price is 16,700 euro, the expected net present value of wind turbine profits amounts to 17,300 euro per hectare, the expected net present value of wind turbine revenues amounts to 35,500 euro per hectare. In comparison the profits of built turbines amount to only 326 euro per hectare. This reflects the fact that, until 2004, wind turbines have been built on less than 0.5% of the potential agricultural land.

Table 1: Descriptive Statistics

Variable (N = 1,942)	Mean	P25	P50	P75	SD
Land price/ha in euro	16,698	8,663	14,537	23,213	11,038
Wind strength in m/s	5.4	5	5.4	5.8	0.5
NPV WT profits/ha in euro	17,300	7,331	15,492	23,619	12,910
NPV WT revenue/ha in euro	35,523	25,252	32,364	42,937	14,278
NPV built WT profits/ha in euro	326	0	31	328	654

Notes: ha stands for per hectare, NPV for net present value and WT for wind turbine. For further details see text.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2004, and Statistical Offices of the Laender 1997-2004.

4. Methodology

We propose two different approaches to evaluate the incidence of the subsidy: a DiD and an IV estimator. Both estimators exploit regional variation in wind strength in combination with the introduction of the REA to identify the causal effect of the subsidies on land prices.

4.1. Difference-in-Differences Strategy

To answer the question whether subsidies for wind electricity introduced with the REA are capitalized in land prices, we use a DiD design: we estimate how average land prices at the county level ($LP_{j,t}$) are affected in counties with a high-wind strength (High-Wind$_j$) after the introduction of the REA (Introduction REA$_t$) while controlling for the return from agricultural land ($AR_{j,t}$); $\omega_{j,t}$ is an i.i.d. distributed error term. High-wind and reform dummy themselves are not identified in the model since we include county (a_j) and time fixed effects (μ_t). Moreover in all regressions we include linear and quadratic state-specific time trends.

$$LP_{j,t} = a_j + \mu_t + \alpha \text{High-Wind}_j * \text{Introduction REA}_t + \gamma AR_{j,t} + \omega_{j,t} \quad (1)$$

In additional specifications we use the wind strength as treatment intensity instead of the binary indicator for high-wind counties. This allows us to exploit the full regional variation in wind strength.

The DiD estimator is unbiased if high-wind and low-wind counties would have followed the same trend in the absence of the reform.[18] To assess the plausibility of this assumption, we first consider descriptive statistics before the introduction of the REA (in 1999) for high-wind and low-wind counties (Table A.2 in Appendix A). The two groups differ in the land price per hectare as well as the return from agricultural land and land use. To control for the land price level difference, we include in all regressions county-fixed effects. Further, to control for a potential time-varying impact of the level differences on land prices we include interaction effects between land use, return from agricultural land and a full set of year dummies, as well as interaction effects between population variables and a full set of year dummies.[19] Next we compare the evolution of land prices between 1998 and 2004 for high-wind and low-wind counties (see Figure 3). The figure provides evidence of a common trend before the introduction of the REA and shows an increase in land prices for high-wind counties after the reform has been implemented. This is consistent with a capitalization effect. We do not observe county-level land prices before 1998.[20] Therefore we focus in addition on district land prices as a proxy for county land prices, which we observe for a longer period: namely from 1996 to 2004 (see Figure 4). On average 19 counties

[18]Another threat to our estimation strategy is a systematic change in the composition of the transacted land due to wind turbine subsidies. We assess this by investigating whether the number of transactions in a particular county and year, the amount of land sold in a particular county and year and the quality of the land sold in a particular county and year changed significantly after the introduction of the subsidy in high-wind and low-wind counties, and whether there is an impact of expected wind turbine profits on these variables using the IV strategy described later. We do not find evidence for a significant impact on these variables. Results are available upon request from the authors.

[19]This controls, for example, for price changes for agricultural products over time or changes in population preferences for regional products.

[20]For the year 1997 we have land price information only for a small number of counties.

form one district. District prices are available for 7 of the 13 German non-city states.[21] The longer pre-trend analysis supports the assumption of a common trend before the introduction of the REA.

One remaining concern regarding the DiD strategy is confounding events, such as the increase in demand for residential properties in high-wind areas due to population increase or an increase in disposable income that spills over into agricultural land prices. To address these concerns, we plot the evolution of population density, wages and gross domestic product for high-wind and low-wind areas between 1996 and 2004 (see Figure A.3, A.4 and A.5, Appendix A.). The figures reveal that population density, wages and gross domestic product per worker declined after 2000 in high-wind areas compared to low-wind areas. This rules out that an increase in demand for residential properties caused the increase in agricultural land prices. Another co-founding event could be an increase in demand for agricultural products in high-wind areas. Figure A.6 plots the evolution of gross value added per hectare of agricultural land for high-wind and low-wind counties. We do not find evidence for a different trend between the two groups.

4.2. Instrumental Variable Strategy

Although the estimates of the DiD strategy allow a causal interpretation of the effect of the REA on land prices, it is not possible to directly quantify the incidence of the subsidy. Therefore, we additionally estimate the effect of the net present value of expected profits per hectare $WP_{j,t}$ on the county level land price $LP_{j,t}$ while controlling for the return from agricultural land $AR_{j,t}$.[22]

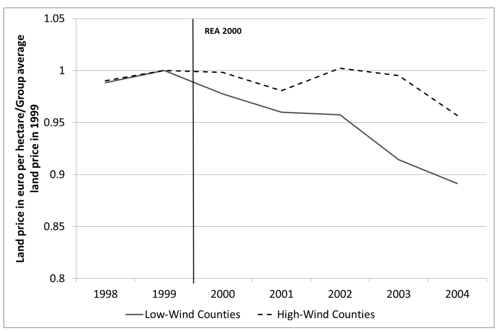
$$LP_{j,t} = a_j + \mu_t + \alpha WP_{j,t} + \gamma AR_{j,t} + \omega^*_{j,t} \quad (2)$$

It is important to note the following two points when interpreting the effects. First, we assume that wind turbines do not affect the return from

[21]District prices are not available for Schleswig-Holstein, Rhineland-Palatinate, Saarland, Brandenburg, Mecklenburg-West Pomerania and Thuringia since these states are not subdivided into districts. We excluded the district with the largest increase (>6000 euro) and the district with the largest reduction (<6000 euro) in one year from the sample.

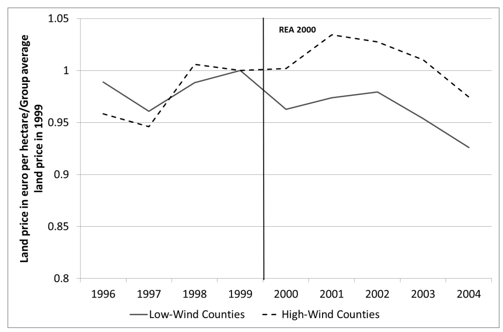
[22]We can interpret the coefficient α as the incidence share of the subsidies as we scale the expected profits per hectare in a county by the fraction of land in that county on which turbines can legally be built (see section 3).

Figure 3: Evolution County Land Price for High-Wind and Low-Wind Counties



Notes: County average land prices for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median. Low-wind counties have a wind strength equal to or below the median.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1998-2008.

Figure 4: Evolution District Land Price for High-Wind and Low-Wind Counties



Notes: County average land prices proxied by district average land prices for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median. Low-wind counties have a wind strength equal to or below the median. Sample includes all counties for which average district land prices are available.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1996-2004.

agricultural land. This assumption seems plausible as, the size of the baseplate is around 200 (14x14) square meters per installed megawatt (MW) and thus accounts for only 0.4% of the overall land usage of 6 hectare per installed MW.[23]

Second, our specification assumes that land prices of suitable fields are affected, independently of whether or not a turbine has been built on a field during our sample period. Titman (1985) shows that expectations about future demand, and thus land prices in the future, are included in the land price today. Landowners will ask, therefore, for compensation if they sell their suitable land to non-investors today, as the new owner may sell the land to an investor in the future. Since there is only one market price for a particular type of land, the price of land is independent of whether the land is bought by an investor or by a person that will not invest in a turbine. This implies α is positive, if landowners expect that turbines will be built in the future. For a more formal analysis of this argument see Appendix B.

To assess whether the option value is the driving force behind the incidence share, we extend the main specification (equation (2)) and allow the incidence share to increase with expected profits, i.e. we introduce a linear and quadratic term of the net present value of expected profits per hectare. This specification captures investors' search for yield, which is another potential explanation why landowners reap part of the wind turbine subsidies. If the best fields can easily be identified by investors, there should be excess demand for them and thus a higher bargaining power of the owners of these fields. In consequence the incidence should be increasing with expected profits.

Since we have to simulate expected profits of wind turbines and do not observe potential investors' technological choice, but have to assume for all counties (and thus investors) and years the median technology for the simulation, the OLS estimate for α in equation (2) is likely to be downward biased due to classical measurement error.[24] We address the measurement error by

[23]Using the average size of land per transaction in our sample, which is 2.2 ha, as a proxy for the size of a piece of land the baseplate would account for less than 1% per field. Thus, even when accounting for a generous additional buffer zone, the loss in agricultural value remains small. One empirical argument in favor of a small impact is also that we do not find evidence that the number of wind turbines per hectare in a county is correlated with the land usage in that county.

[24]In principle, the observed technological choice could be used to reduce the measure-

using an IV estimator. The excluded instrument is constructed in a similar way to the DiD estimator using variation in regional wind strength across counties in combination with the introduction of the REA.

5. Estimation Results

DiD results - Effect on land prices: We start by presenting the results of the DiD approach (see Table 2). Columns (1) to (3) present results without control variables, all other specifications include the full set of control variables. All point estimates of our variables of interest are positive and statistically significant. This implies that the introduction of subsidies for wind turbines increased the average transaction price at the county level. In columns (1) and (2) we use the specification with the binary indicator for high-wind counties. While in column (1) all counties are included, column (2) includes only counties with a wind strength in the top and bottom 33% of the distribution. As expected the estimated effect is then larger. However this does not mean that the effect is non-linear. Taking into account the difference in wind strength between high-wind and low-wind counties in column (1) and (2), which is 0.84 and 1.15 respectively, shows that the estimated increase per m/s is similar (see bottom of Table 2). From column (3) onwards we use the average wind speed as treatment intensity. The resulting impact on land price per m/s is very similar to using the indicator variable, in particular with the full set of control variables (column (4)). In column (5), we exclude counties with a large dispersion in wind strength to address a potential bias due to its correlation with the average wind strength. The bias seems moderate as the point estimate is very similar to the baseline specification. Finally, in column (6) we use district prices as a proxy for county land prices; this allows us to include the years 1996 to 2004. Point estimate as standard errors are basically unchanged, despite clustering standard errors at the district level.

The results are also very similar when using wind speed at the 25th percentile as treatment intensity, regardless of whether we exclude counties with a high wind speed dispersion or not (Table A.3 in Appendix A, columns (1) and (2)). When using wind speed at the 75th percentile as treatment intensity, counties with a high wind speed dispersion do influence the results, as the point estimate without excluding high wind strength dispersion counties

ment error for this group. However, this would introduce endogeneity as our simulation would be more precise for counties in which turbines have been built.

is reduced by half (Table A.3 in Appendix A, columns (3) and (4)). This suggests that it is not only the fields with very good wind conditions that drive the results. Further, we assess the sensitivity of the results by changing the time span using fewer (up to 2002) and more (up to 2008) years (Table A.3 in Appendix A, columns (5) and (6)). The effect seems to be increasing over time, which could be due to the increase in wind turbine profitability. Finally, we include a land productivity measure (gross value added in the agricultural sector/ha) interacted with year dummies to control for a productivity-year specific price. The point estimate is basically unchanged (results are available upon request). Overall, we conclude that, after 2000, land prices in Germany increased by around 1,300 euro for each additional m/s wind strength in a county due to wind turbine subsidies. This suggests that the incidence - studied in the next section - is positive.

Table 2: DiD Results

Dep. Var.	Land price/ha in euro					
Land price	County					District
Time Span	1997-2004					1996-2004
	(1)	(2)	(3)	(4)	(5)	(6)
D(WS>P50)*REA	1062***	1611***				
	(293)	(399)				
WS*D(>1999)			1086***	1318***	1365***	1330**
			(291)	(433)	(485)	(496)
R^2	0.034	0.053	0.036	0.140	0.162	0.484
Observations	1,942	1,303	1,942	1,942	1,637	2,302
Euro per m/s	1,267	1,408				
Control Variables				x	x	x
Without 2nd WS Tertile		x				
Without High WS Dispersion Counties					x	

Notes: Table shows estimated coefficient for the impact of being a high-wind county after the introduction of the REA on average land prices at the county level. High-wind counties in columns (1) and (2) include counties with a wind strength above the median. In columns (3) to (6) we use the average wind strength as treatment intensity. The reform dummy (REA) is one for the years after 1999. In columns (1) to (5) we use county land prices for the years 1997 to 2004. In column (6) we use district land price as a proxy for county land prices which allows us to include data from 1996. In column (2) we only include counties with a wind strength in the bottom and top 33%. In column (5) we exclude counties with a wind strength difference between the 10th and 90th percentile in the top 20%. Each regression includes a full set of county and time dummies (not reported). Robust standard errors, clustered at the county level (columns (1) to (5)) or district level (column (6)), in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2004, Statistik Lokal and Regional 1996-2004, and Statistical Offices of the Laender 1996-2004.

IV results - Incidence share: We present the regression results of the impact of expected profits of wind turbines on agricultural land prices in Table 3. In the first two columns the OLS coefficients with and without control variables are reported; in both specifications the coefficient is positive and significantly different from zero. Columns (3) to (6) present the IV results which address the potential bias of the OLS estimate due to measurement error. The excluded instrument in these specifications is the interaction between average wind strength and the reform indicator.[25] The F-statistic and Shea's partial R^2 suggest that our instruments are relevant in all specifications. Point estimates of the first stage regression are reported in the bottom of the table. Turning to the estimation results of the second stage, we find that the IV results are similar. The point estimates vary between 0.14 and 0.19, but the confidence intervals overlap.[26] The IV estimates are larger than the OLS estimates which is consistent with the downward bias due to classical measurement error in the OLS regression. In column (5) we allow for a non-linear incidence share to assess the role of investors' search for yield on the estimated incidence share. The point estimate for the squared term is close to zero and insignificant (p-value: 0.52), while the point estimate for the expected profits is 0.14 (p-value: 0.10) and thus close to the point estimate in the baseline specification.[27] This suggests that investors' search for yield does not have a meaningful effect on the incidence; instead the option value seems to be the main channel through which landowners reap part of the wind turbine subsidies. This result might be related to information: the search for yield requires information about the wind strength on a particu-

[25]Results are similar when using the interaction between high-wind and reform indicator. When using the interaction between wind strength and reform indicator as well as the squared interaction as excluded instruments as in column (5) but without including the squared NPV of WT profits, the point estimate is 0.175, significant at the 1% level.

[26]We do not report the coefficients for the control variables as they are all insignificant. Overall, however, the control variables increase the explained variation significantly (see Table 2 and 3). Results are available upon request.

[27]This result is in line with descriptive evidence. We find that turbines have not only been built in the counties with the highest wind strength. In Table A.4 in Appendix A, we report the share of land used by built wind turbines to overall agricultural land within a county for different wind quintiles based on average wind speed as well as wind speed at the 75th and 95th percentile. Although the results show that in counties with a high wind speed more turbines have been built, wind turbines have also been built in the second and third quintile.

lar field while the option value relies on the average wind strength. While the latter is available on a square kilometer raster for Germany, information about the wind strength on a particular field is not available. In column (6) we exclude counties with a large within-county wind strength dispersion. The point estimate is very similar to the baseline specification and significant at the 1% level.

Quantitatively, the results of our preferred specification, shown in column (4), suggest that an increase of 1 euro in expected wind turbine profits per hectare increases the land price per hectare by 19 cents. Since the costs of wind turbines are mainly fixed costs, the incidence for the subsidy can be approximated by the incidence for profits. Hence the incidence of an additional euro subsidy also amounts to 19 cents. Under the assumption that the incidence share is constant for each euro of profits, we can calculate the amount of capitalized wind turbine subsidies. Based on 2004 values, capitalized wind turbine subsidies amount to 4,045 euro per hectare or 25% of the average land price per hectare. For counties with a wind strength above the median, capitalized wind turbine subsidies amount to 5,550 euro per hectare or 42% of the average land price per hectare.

Sensitivity Analysis: We start assessing the sensitivity of the results by reducing (1997 to 2002, Table A.5 in Appendix A, column (1)) and extending the time period of our sample (1997 to 2006, column (2), and 1997 to 2008, column (3)). The point estimates vary between 0.15 and 0.23 and are thus very similar. Moreover, confidence intervals overlap. This implies that the incidence does not change significantly over time. The proposed option value theory does not provide a clear prediction about changes in the incidence share over time. According to this framework the incidence depends on market participants' beliefs about future demand, which is affected by multiple factors including changes in the compensation structure for wind electricity. The non-declining incidence share is, however, not consistent with investors' search for yield behavior. This would predict that the incidence share is declining over time as the most profitable wind turbines (within a county) should be built first. Thus, the results provide additional evidence that the option value of land and not the search for yield drive the estimated incidence share.

In additional robustness checks we alter the calculation of the net present value of wind turbine profits. First, we use the net present value of wind turbine profits per hectare based on built wind turbines' profits (Table A.5 in Appendix A, column (4)). Second, we changed investors' expectations

Table 3: Main Results

Dep. Var.	Land price/ha in euro					
Method	OLS		IV			
	(1)	(2)	(3)	(4)	(5)	(6)
NPV WT profits/ha	0.119***	0.135***	0.142***	0.188***	0.135	0.176***
	(0.028)	(0.050)	(0.037)	(0.059)	(0.083)	(0.059)
NPV WT profits/ha, sqrd.					0.000	
					(0.000)	
R^2	0.037	0.139	0.036	0.139	0.139	0.161
Observations	1,942	1,942	1,942	1,942	1,942	1,637
Control Variables		x		x	x	x
Without High WS						
Dispersion Counties						x
FirstStage						
Point Estimate (Wind)			3,306***	3,208***	-1,698**	3,320***
Point Estimate (Wind, sqrd)					724***	
Shea's partial R^2: I			0.651	0.594	0.680	0.656
F-Statistic: I			289	158	627	490
Shea's partial R^2: II					0.624	
F-Statistic: II					362	

Notes: Table shows estimated coefficients for the impact of the net present value of wind turbine profits per hectare on average land prices at the county level. WS stands for wind strength, and NPV WT profits/ha for net present value of wind turbine profits per hectare. Columns (1) and (2) present OLS estimates, columns (3) to (6) IV estimates. The excluded instrument is the interaction between the average wind strength at the county level and the reform indicator, which is one for years after the introduction of the REA. In column (5), we include the NPV wind turbine profits squared to allow for a non-linear relationship. In column (6) we exclude counties with a wind strength difference between the 10th and 90th percentile in the top 20%. Each regression includes a full set of county and time dummies (not reported). Robust standard errors, clustered at the county level in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2004, Statistik Lokal and Regional 1997-2004, and Statistical Offices of the Laender 1997-2004.

up to 2000. In the baseline specification, we assumed investors expected to receive the subsidy for 3 years; in column (5) in Table A.5 we assumed that investors expected the EFA to be in force until the next federal election. The point estimates for the two sensitivity checks are very similar to the results of our baseline specification.

Further, we allow for a different time trend in East and West Germany in the estimation, as before 2000 a large share of agricultural land in East Germany was held by the *Bodenverwertung- und Verwaltung GmbH (BVVG)*, which was established to sell collectively owned land in East Germany until 1990 in the years following the reunification (Table A.6 in Appendix A, column (1)). The next sensitivity check concerns our dependent variable. In the baseline analysis, we required at least 10 transactions per county-year.

Column (2) in Table A.6 presents the results when requiring at least 20 transactions per county-year. Finally, we account for spatial dependence in transaction prices and include in columns (3) and (4) the inverse distance-weighted transaction price of the neighboring counties. Since the neighboring counties land price is likely to be endogenous, we instrument it in column (4) using the inverse distance-weighted wind strength in combination with the introduction of the REA as excluded instrument.[28] The point estimates for these sensitivity checks vary between 0.14 and 0.24 and are, thus, again very similar to our baseline estimate. Overall we conclude that our estimated incidence share is robust across different specifications and around 0.18.

6. Impact of the Subsidies on Agricultural Income

In this section, we use the estimated incidence share to calculate the impact of wind turbine subsidies on agricultural income. To this end it is important to distinguish between turbines that are built on leased land and turbines that are built on investors' own land. In the first case landowners receive a yearly payment for 20 years; in the latter case landowners receive a single one-off payment. Further, lease payments only increase if a turbine is built; in contrast, capital gains capture profits of wind turbines that may be built in the future.[29] Since we do not observe the fraction of turbines built on leased land, we use a state-specific ratio of leased farmland to overall farmland in 2010 to approximate the share of turbines built on leased land. The underlying idea is that investors interested in a particular field cannot choose whether to buy or to lease, as this is determined by the landowner. The average share of leased farmland is 60% and ranges from 50% to 84% (German Federal Statistical Office (2011)).

We calculate the lease payment for each wind turbine built in Germany based on a contract length of 20 years and a present value of the lease payments at the start of the contract that is equivalent to 18% of the net present

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[28]Since the wind strength in one county and the inverse distance-weighted wind strength in neighboring counties are correlated, we additionally include the interaction between wind speed squared and the reform dummy as instrument.

[29]This is in line with one of the explanations proposed by Grainger (2012) on why housing values react more strongly than rents to (current) improvements in air quality. If current improvements increase the likelihood of future improvements in air quality, house prices should respond more strongly than rents, as future improvements are only priced by sellers and buyers. Renters pay only for current air quality.

value of profits of the turbine.[30] The single lease payments are then aggregated for all plants within a county in a particular year and the resulting sum is scaled by the share of wind turbines built on leased land. Capital gains are calculated by multiplying the expected increase in the price per hectare due to the subsidy (18% of the net present value of expected wind turbine profits per hectare) by the amount of land sold in a county suitable to build wind turbines. The latter is approximated by multiplying the amount of land sold by the fraction of suitable land in the county.

In Table 4 we report the simulated additional income due to wind turbine subsidies. For the counties in our sample, the overall additional income for the years 1997 to 2008 amounts to 5.20 billion euro. The additional income in 2007 amounts to 0.53 billion euro. On average between one third and one quarter of the additional income is due to lease payments, while the remainder is due to capital gains. To put these numbers into perspective, we relate them to overall agricultural income. Since agricultural income is not reported for incorporated firms, we focus on West Germany for the comparison as in this part of Germany 99% of all agricultural land is owned by individuals or partnerships (German Federal Statistical Office (2011)).[31] For these landowners, we observe agricultural income in the income tax data. For the comparison, we use the latest year in our sample period for which the data is available (2007).[32] Using the agricultural income from the income tax statistic, the additional income due to wind turbines amounts to 4.1% (see Table 4). When considering only counties with a wind strength above the median (above the 75th percentile), the share increases to 6.5% (7.8%). Thus, wind turbine subsidies have a measurable impact on agricultural income.

We validate the simulated tax base increase as well as the underlying estimated incidence share using a simple regression framework and agricultural income from the tax statistic as dependent variable. If our estimation and the calculation are correct, agricultural income should over time exactly increase by the calculated additional income - holding all our factors constant. Since the income tax data is also available for 1998, 2001 and 2004, we construct a county-year level panel that covers all West German counties included in

[30] The calculation is based on the following standard annuity formula and a discount rate of 3%: $lease_i = NPVWT_i * (1.03^{20} * 0.03)/(1.03^{20} - 1)$.

[31] The fraction in East Germany is only 50%. Further, a huge share of land in East Germany is owned by the BVVG.

[32] The data is a stratified sample of the almost 40 million taxpayers in Germany.

Table 4: Quantification Impact on Agricultural Income

Sample	Wind turbine income			Agric. Income mio. euro	Agric. Land mio. ha
	Lease Payments	Capital Gains	Overall to Agric. Income		
	in billion euro				
Full Sample, 1997-2008	0.90	4.29			
Full Sample, 2007	0.15	0.38		14.6	
West Germany 2007	0.09	0.22	4.1	7.68	10.4
West Germany 2007, WS > P50	0.08	0.18	6.5	4.04	5.6
West Germany 2007, WS > P75	0.07	0.14	7.8	2.66	3.6

Notes: WS stands for wind strength, P50 for the median and P75 for the 75th percentile.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2007, income tax statistic 2007, and Statistik Lokal and Regional 1998-2007.

the main analysis. The main explanatory variable is our calculated additional income due to wind turbine subsidies. We further include the number of single and joint taxpayers and all control variables from our land price specification.[33] Descriptive statistics for the sample are shown in Table A.7.

The regression results are shown in Table 5. Columns (1) and (2) report the point estimate for the additional income based on an incidence share of 18%. Column (1) shows the results without including any control variables, column (2) with the inclusion of the control variables. In column (2) the point estimate is 0.99, significant at the 5% level and not statistically different from one. In columns (3) and (4) we use the simulated increase in taxable income based on an incidence share of 16% and 20%, respectively.

7. Conclusions

In this paper, we estimate the price effect and the incidence of wind turbine subsidies for agricultural land. For identification we exploit regional variation in wind strength across counties in combination with the introduction of the REA. Our estimation results suggest positive incidence effects. We find that due to the introduction of the REA land prices increased by an average of 1,300 euro for each additional m/s wind strength in a county.

[33] The variables capturing the return from agricultural land are not measured as share but as the actual amount of land. Further, to avoid biased results due to reversed causality, we use the 1998 land usage and interact the variables with year dummies. Due to the interaction with the year dummies, we again control for a potential different impact of land usage after the introduction of the REA as well as average changes in land usage. Due to multicollinearity problems, we do not include the amount of grassland but only the amount of farmland.

Table 5: Results Taxable Agricultural Income

Dep. Var.	Agric. income in thd. euro			
Incidence Share	18%		16%	20%
	(1)	(2)	(3)	(4)
Add. income due WT subsidies	1.585***	0.994**	1.118**	0.894**
	(0.402)	(0.444)	(0.500)	(0.400)
R^2	0.236	0.502	0.502	0.502
Observations	890	890	890	890
Control Variables		x	x	x

Notes: Table shows estimated coefficients for the impact of calculated income due to wind turbine subsidies on agricultural income at the county level. Sample includes all counties in West Germany in 1998, 2001, 2004 and 2007, which are included in our main estimation sample. Each regression includes a full set of county and time dummies (not reported)s Robust standard errors, clustered at the county level, in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2007, income tax statistic 1998, 2001, 2004, 2007, and Statistik Lokal and Regional 1998-2007.

In addition, we show that around 18% of expected wind turbine profits are capitalized into land prices. Finally, we show that wind turbine subsidies increased overall agricultural income by 4%.

The implications of our study are at least twofold. First, renewable energy subsidies based on a feed-in tariff are likely to generate windfall profits for landowners, although the magnitude depends on the cost curve of investors. Renewable energy subsidies may thus affect the income distribution not only by increasing income of green electricity plant owners but also of landowners. If land ownership is highly concentrated, as for example in Latin America (e.g. United Nations (2008)), this may increase income inequality. One way to minimize the resulting effect on the income distribution is to use land taxes (related to the market value of land) to finance the subsidies.

Second, land prices react to expectations and, thus, to the expected subsidy paid. Consequently, the increase in land prices is much larger than the net present value of the subsidy of turbines built. Although redistribution can be achieved by taxing land rents accordingly, the increase in land prices may impact welfare directly if the most productive land buyers face financing constraints (e.g. Hart and Zingales (2013)). This may be less severe in countries with highly developed financial markets and/or competitive banking sectors. It is, however, likely to be an important issue in developing countries in which feed-in tariffs have been implemented as well (e.g. REN (2017)) and in which financing constraints are a barrier to market entry (e.g. Rajan and Zingales (1998); Cetorelli and Strahan (2006)). Another implication of our results, which is also important for more developed countries, is the impact of agricultural land prices on land usage. If the return of agricultural land increases, land is more likely to be used for agricultural production and less likely for business or residential purposes. The increase in land prices is thus likely to affect the size of cities as well (e.g. Brueckner and Fansler (1983); McGrath (2005)). This is consistent with descriptive evidence presented in this paper and an interesting avenue for further research.

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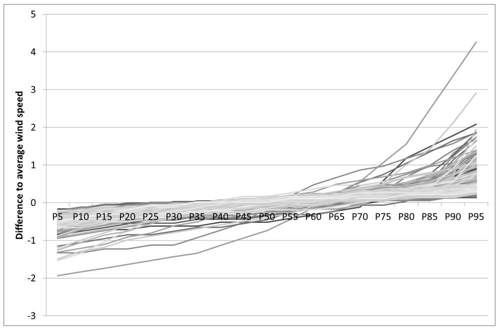
Appendix A. Additional Descriptive Statistics, Figures and Regression Results

Table A.1: Composition of the Sample and Representativity

	Germany		Sample	
Year	Produced wind electricity (WTE) in GWh	No. of plants	Produced WTE in % of total	No. of plants in % of total
1997	2,490	4,387	48.3	49.9
1998	3,480	5,346	90.9	88.8
1999	5,229	6,954	89.0	86.9
2000	7,687	8,447	86.7	85.5
2001	11,093	10,482	86.0	84.3
2002	15,639	12,743	85.8	84
2003	20,255	14,458	84.9	83.8
2004	24,118	15,642	84.3	82.9
2005	27,187	16,705	87.2	86.1
2006	30,359	17,902	86.5	85.5
2007	33,572	18,774	85.8	84.8
2008	36,317	19,581	86.2	85.2

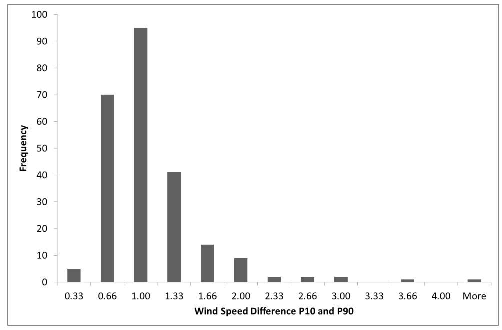
Source: Authors' calculation based on data from Operator Database 1990-2008.

Figure A.1: Within-County Wind Speed Distribution



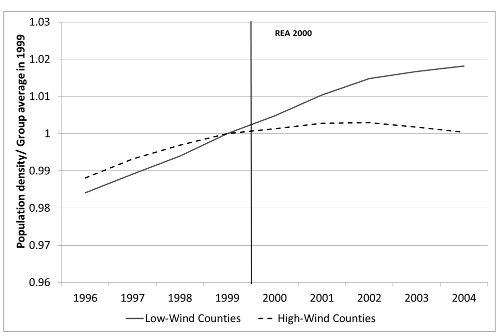
Notes: Figure shows difference between wind strength at different percentiles to average wind strength within a county.
Source: Authors' calculation based on data from German Weather Service

Figure A.2: Within-County Wind Strength Difference between 10th and 90th Percentile



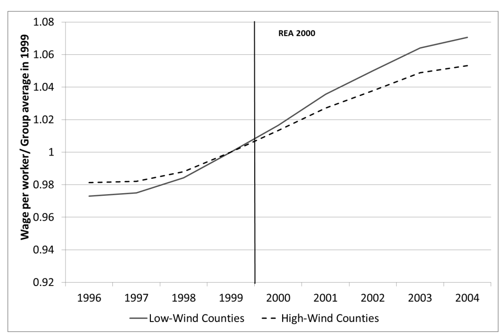
Notes: Figure shows distribution of within-county wind strength difference between the 10th and 90th percentile.
Source: Authors' calculation based on data from German Weather Service.

Figure A.3: Evolution Population Density for High-Wind and Low-Wind Counties



Notes: Population density for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median, low-wind counties a wind strength equal to or below the median.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1996-2004.

Figure A.4: Evolution Average Wages for High-Wind and Low-Wind Counties



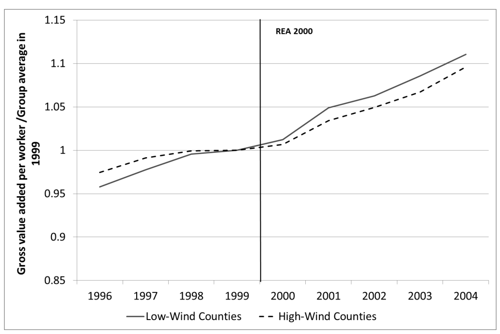
Notes: Average wages for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median, low-wind counties a wind strength equal to or below the median.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1996-2004.

Table A.2: Descriptive Statistics for High-Wind and Low-Wind Counties 1999

	High-Wind Counties		Low-Wind Counties		p-value
Variable	Mean	SD	Mean	SD	t-test
Land price/ha in euro	13,786	9,586	21,348	13,097	0.00
Wind strength 80m above ground in m/s	5.9	0.4	5	0.3	0.00
Land quality	42.4	9.3	48.5	10.8	0.00
Agricultural return:					
Share grassland in %	38.2	23.6	29.6	19.1	0.00
Share farmland in %	59.1	23.4	66.6	19.1	0.01
Share land cereal %	33.8	15	37.8	11.8	0.02
Share land root crop %	3.5	5.8	5.9	7.5	0.01
Share land forage crop in %	9	5.9	9.5	5.9	0.48
Harvest each hectare wheat in tons/ha	73	14	65	11	0.00
Harvest each hectare potatoes in tons/ha	328	90	325	61	0.73
Harvest each hectare corn in tons/ha	437	67	453	61	0.04
Share land farms with cattle rearing in %	0.8	0.1	0.7	0.2	0.00
Demand for agricultural products:					
Log(Population)	12	0.5	12	0.5	0.4
Neighbor log(population)	13.6	3.1	15.3	2.8	0.00
Population density	4.75	5.4	5.79	6.24	0.15
Average wage income in euro	27,899	2,769	29,471	2,879	0.00
Unemployment rate	0.09	0.04	0.07	0.03	0.00
Tax variables:					
Property tax on agricultural land	258	53	294	55	0.00
Local business tax	327	48	323	40	0.45

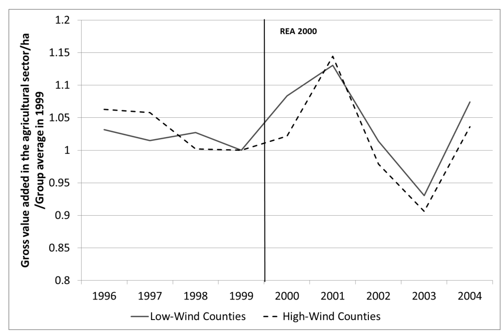
Notes: High-wind counties have a with wind strength 80 meters above ground above the median. Low-wind counties have a wind strength equal to or below the median. Property tax on agricultural land is the agricultural land weighted average multiplier in the county. To derive the tax rate the multiplier has to be multiplied by 6%. Local business tax is the agricultural land weighted average local business tax multiplier in the county. To derive the tax rate the multiplier has to be multiplied by 0.05%.
Source: Authors' calculation based on data from German Weather Service, Statistik Lokal and Regional, and Federal Statistic Offices of the Laender, 1999.

Figure A.5: Evolution Gross Domestic Product per Worker for High-Wind and Low-Wind Counties



Notes: Gross domestic product per worker for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median, low-wind counties a wind strength equal to or below the median.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1996-2004.

Figure A.6: Evolution Agricultural Gross Value Added per Hectare for High-Wind and Low-Wind Counties



Notes: Agricultural gross value added per hectare for high-wind and low-wind counties are shown, normalized by the group mean in 1999. High-wind counties have a wind strength 80 meters above ground above the median, low-wind counties a wind strength equal to or below the median.
Source: Authors' calculation based on data from German Weather Service and Statistical Offices of the Laender, 1996-2004.

Table A.3: Sensitivity Analysis DiD Results: Wind Strength Distribution and Time Span

Dep. Var.	Land price/ha in euro					
1997 -	2004				2002	2008
	(1)	(2)	(3)	(4)	(5)	(6)
WS 25th*D(>1999)	1318***	1382***				
	(440)	(479)				
WS 75th*D(>1999)			823**	1429***		
			(415)	(457)		
WS*D(>1999)					1037**	1420***
					(519)	(466)
R^2	0.140	0.162	0.137	0.163	0.144	0.166
Observations	1,942	1,637	1,942	1,637	1,186	3,035
Control Variables	x	x	x	x	x	x
Without High WS Dispersion Counties		x		x		

Notes: Table shows estimated coefficients of sensitivity analysis for the impact of being a high-wind county after the introduction of the REA on average land prices at the county level. In columns (1) and (2) we use the wind strength at the 25th percentile, in columns (3) and (4) the wind strength at the 75th percentile and in columns (5) and (6) the average wind strength as treatment intensity. The reform dummy is one for the years after 1999. In columns (2) and (4) we exclude counties with a wind strength difference between 10th and 90th percentile in the top 20%. The time span is 1997 to 2004 in columns (1) to (4), and 1997 to 2002 in column (5) and 1997 to 2008 in column (6). Each regression includes a full set of county and time dummies (not reported). Robust standard errors, clustered at the county level, in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2008, Statistik Lokal and Regional 1997-2008, and Statistical Offices of the Laender 1997-2008.

Table A.4: Share of Land used by Built Turbines per Hectare of Land in 2010 for Wind Strength Quintiles

	Quintiles based on	
Average WS	75th WS	95th WS
0.09	0.11	0.40
0.67	0.83	0.79
0.64	0.65	0.72
0.92	0.93	0.82
1.34	1.31	1.12

Notes: Table shows the share of land used by built wind turbines per hectare of agricultural land in 2010 for different wind strength quintiles.
Source: Authors' calculation based on data from German Weather Service, and Operator Database, 2010.

Table A.5: Sensitivity Analysis IV Results: Time Span and Modeling NPV WT Profits

Dep. Var.	Land price/ha in euro				
Time Span 1997 -	2002	2006	2008	2004	
Modeling WT Profits				Current WT Profits	EFA in force until next election
	(1)	(2)	(3)	(4)	(5)
NPV WT profits/ha	0.153**	0.230***	0.205***	0.204***	0.188***
	(0.065)	(0.064)	(0.066)	(0.076)	(0.060)
R^2	0.136	0.174	0.162	-0.013	0.138
Observations	1,441	2,486	3,035	1,942	1,942
Control Variables	x	x	x	x	x
Shea's partial R^2	0.591	0.565	0.543	0.031	0.497
F-Statistic	130	160	169	15	132

Notes: Table shows estimated coefficients of sensitivity analysis with respect to the time span, columns (1) to (3), and modeling NPV WT profits, columns (4) and (5). NPV WT profits/ha stands for net present value of wind turbine profits per hectare. In column (1), we use the years from 1997 to 2002, in column (2) from 1997 to 2006, in column (3) from 1997 to 2008, and in columns (4) and (5) from 1997 to 2004. In column (4) we use current WT profits to calculate the expected WT profits and in column (5) we assume that investors expected the EFA to be in force until the next election. All columns show IV regressions using the interaction between the average wind strength and a reform indicator that is one for the years after 1999 as excluded instrument. Each regression includes a full set of county and time dummies (not reported.) Robust standard errors, clustered at the county level, in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2008, Statistik Lokal and Regional 1997-2008, and Statistical Offices of the Laender 1997-2008.

Table A.6: Sensitivity Analysis IV Results: Sample and Control Variables

Dep. Var.	Land price/ha in euro			
	Time dummies*West Germany	# transactions > 20	Neighbor price OLS	Neighbor price IV
	(1)	(2)	(3)	(4)
NPV WT profits/ha	0.190***	0.139***	0.168***	0.237**
	(0.060)	(0.053)	(0.061)	(0.114)
Land price of neighbors			36.106	-118.404
			(23.525)	(185.353)
R^2	0.139	0.142	0.140	0.118
Observations	1,942	1,850	1,942	1,942
Control Variables	x	x	x	x
Shea's partial R^2: I	0.596	0.583	0.573	0.152
F-Statistic: I	157	145	139	418
Shea's partial R^2: II				0.016
F-Statistic: II				20

Notes: Table shows estimated coefficients of sensitivity analysis with respect to the chosen sample (column (2)) and with respect to including additional control variables (columns (1), (3) and (4)). NPV WT profits/ha stands for net present value of expected wind turbine profits per hectare. In columns (1) we allow for a different time trend in East and West Germany. In column (2) we include only counties with at least 20 transactions in a current year. In column (3) and (4) we control for the neighboring land price. In column (3) we do not instrument the neighbor land price, in column (4) the neighboring land price is instrumented. All columns show IV regressions for our main variable of interest using the interaction between the average wind strength and a reform indicator that is one for the years after 1999 as excluded instrument. In column (4) we additionally include the average wind strength in neighboring counties interacted with the reform dummy. Each regression includes a full set of county and time dummies (not reported). Robust standard errors, clustered at the county level, in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2004, Statistik Lokal and Regional 1997-2004, and Statistical Offices of the Laender 1997-2004.

Table A.7: Descriptive Statistics Taxable Agricultural Income

Variable in thd. euro	N	Mean	P25	P50	P75	SD
Taxable agricultural income	890	30,122	13,501	26,009	41,250	21,130
Lease payments due to WT (18%)	890	225	0	12	156	573
Capital gains due to WT (18%)	890	801	94	298	801	1,477
Additional taxable income due to WT (18%)	890	912	92	300	929	1,732

Notes: Sample includes all counties in West Germany in 1998, 2001, 2004 and 2007 that are included in the main analysis. WT stands for wind turbines.
Source: Authors' calculation based on data from German Weather Service, Operator Database 1990-2007, income tax statistic 1998, 2001, 2004, 2007, and Statistik Lokal and Regional 1998-2007.

Appendix B. Theoretical Framework

In this Appendix, we propose a theoretical model following Titman (1985) to formalize the assumption of the empirical analysis that the expected price of each field of land increases due to the introduction of the REA, independent of whether or not a turbine has been built on a field during our sample period. We show this by comparing the price of vacant land in period 1 with the price an investor pays to a landowner in period 1 to build a wind turbine on that land.

Suppose, there are two types of agents - landowners and investors - operating across three time periods. Each landowner owns one field at the beginning of period 1. All fields are of equal size and quality, differing only with respect to the wind strength on the field. Thus, the agricultural value of land is the same for each piece of land and it is for simplicity set to zero.[34] Further, we assume that landowners do not build wind turbines on their own land and that wind turbines do not affect the agricultural return of land. In total there exist K fields.

There are N $(> K)$ investors, each endowed with one unit of capital at the beginning of period 1. The investors differ in their degree of risk aversion. They maximize their wealth and can choose whether to invest in a one-year private capital market investment, yielding return r, or in wind turbines. The wind turbine investment is a two-year investment and yields a net-of-costs return π (due to the subsidy) at the end of the investment period. Investment costs are 1. As there are only three periods, wind turbines can only be built in the first two periods. The wind turbine investment is risky in period 1 as wind turbines are a new technology. In the second period, all problems related to the new technology are solved with probability s_H, making the wind turbine investment as certain as the private capital market investment. With probability $s_L = (1 - s_H)$, problems still exist and the uncertainty remains. Due to difference in the degree of risk aversion, in period 1 only N_1 $(< K)$ sufficiently risk-loving investors enter the market. If all problems are solved in period 2, either all remaining investors enter the market (N_2) causing excess demand for land or the number of investors stays the same.

If landowners and investors bargain with each other, landowners' bargai-

[34] This assumption is not crucial for the analysis, it only means that the price of land is solely determined by wind turbine profits. The assumption allows us to keep the analysis as simple as possible at the cost of land and capital having different returns.

ning strength is represented by β, which is mainly determined by market conditions. In the case of excess supply of land, β is zero as investors can easily find another suitable piece of land on which to build a wind turbine. In the case of excess demand, β is one due to the low substitution elasticity.

Based on these assumptions, we derive first the price of vacant land k, which is the expected price of land k in period 2 (Titman (1985)). The price of land k in period 2 ($A_{k,2}$) can be derived using a bargaining framework. The outside option of landowners is the agricultural return from land in periods 2 and 3, which is set to zero by assumption. The investors' outside option is to invest in the private capital market in periods 2 and 3, which has a discounted value of 1. The outcome of the bargaining process for the k field in period 2 is thus given by

$$A_{k,2} = arg\,max\,\Omega_{k,2} \tag{B.1}$$

with

$$\Omega_{k,2} = \beta_2 \ln(A_{k,2}) + (1-\beta_2)\ln(\frac{\pi_{k,2}}{(1+r)^2} - 1) \tag{B.2}$$

$$A_{k,2} = \beta_2 \frac{\pi_{k,2} - (1+r)^2}{(1+r)^2} \tag{B.3}$$

Rearranging the first order condition (equation (B.2)) shows that the price of land equals a share β_2 of the discounted wind turbine profits, after deducting the value of investors outside option ($(1+r)^2$). From the point of view in period 1, it is not clear whether all technical problems related to wind turbines will be solved in period 2 (with probability s_H) or not (1-s_H). If they are solved, β_2 is one as there will be excess supply due to the additional investors entering the market. If they are not solved, β_2 will be zero.

The price of vacant land in period 1 can thus be written as the value of land in the two states of nature in period 2, multiplied by the respective probabilities (see equation B.4). This is nothing other than the net present value of wind turbine profits after deducting investors' opportunity costs multiplied by the probability that there will be more investors than fields available in period 2 (s_H, see equation (B.5)). The whole expression is discounted by one period as it is the land price of tomorrow.

$$p^*_{k,1} = \frac{s_H * [\frac{\pi_{k,2}}{(1+r)^2} - 1] + (1-s_H) * \frac{0}{(1+r)^2}}{(1+r)} \tag{B.4}$$

$$p^*_{k,1} = s_H * \frac{\pi_{k,2} - (1+r)^2}{(1+r)^3} \tag{B.5}$$

In the next step, we show that this price is also paid by an investor to build a wind turbine in period 1. We derive this price using the bargaining framework again. In contrast to period 2, landowner's outside option in period 1 is to reject the offer by the investor and to receive the expected share of profits reaped in the next period, discounted by one period. Thus, this outside option value has the same value as the price of vacant land. If the investor buys the land today, he earns π in period 2, discounted by two periods, and pays today $A_{k,1}$. The investor's outside option is also to wait, invest in the capital market for one period, and to buy the land and to build a turbine in the next period while again investing the remaining capital in the private capital market again. Thus, the value of this outside option is the discounted capital market investment return for one year ($\frac{r}{(1+r)}$) and the expected net present value of profits of the wind turbine builds in period 2 on the same piece of land. From the period 1 point of view in period, the investor will receive with probability s_H in period 3 only the capital market return for a wind turbine investment in period 2, with probability $1 - s_H$ he receives the whole surplus of the wind turbine.

The outcome of the bargaining process for the k field in period 1 is given by

$$A_{k,1} = arg\, max\, \Omega_{k,1} \tag{B.6}$$

with

$$\begin{aligned} \Omega_{k,1} \quad = \quad & \beta_1 \ln(A_{k,1} - s_H[\frac{\pi_{k,2} - (1+r)^2}{(1+r)^3}) + (1-\beta_1)\ln(\frac{\pi_{k,1}}{(1+r)^2} \\ & -A_{k,1} - [\frac{r}{(1+r)} + (1-s_H)\frac{\pi_{k,2}}{(1+r)^3} + s_H\frac{(1+r)^2}{(1+r)^3}]) \end{aligned} \tag{B.7}$$

$$A_{k,1} = s_H \frac{\pi_{k,1} - (1+r)^2}{(1+r)^3} \tag{B.8}$$

The rearranged first order condition, using $\pi_{k,1} = \pi_{k,2}$ and $\beta_1 = 0$ due to excess supply of land, is given by equation (B.8). This is the same expression as derived for the price of vacant land in equation (B.5). Thus, the price of suitable land to build wind turbines increases independent of whether or not a turbine is built.

Appendix C. ONLINE APPENDIX

Appendix C.1. Microsimulation of the Net Present Value of Wind Turbine Profits

In the following, we describe the simulation of wind turbine profits. We explain the microsimulation for the case of simulating expected net present value of profits of wind turbines built, as this particular application is used to calibrate the model to fit aggregated values. The expected net present value of profits of wind turbines built is also used in the analysis of agricultural income.

The main application of the model is to compute the expected net present value of profits of a county and year representative wind turbine that is used for the estimation of the incidence share. The main difference to the calculation of the expected net present value of profits of a particular wind turbine built is that we used year median-technology characteristics for the representative wind turbine and that there is a representative wind turbine in each county and year, regardless whether or not a turbine has been built in that county and year.

The inputs used for the calculation of the net present value of built wind turbine profits are i) information on the average wind strength at 10 and 80 meters above ground, available in a 1 square kilometer raster for the whole of Germany; ii) the location and the technological details of each wind power plant in Germany; and iii) the feed-in tariff.

Since we only observe the county in which a turbine is located, we map the wind strength data to the county level. More precisely, we map the wind data to the German municipality level and then weight the wind strength on the municipality level with the share of agricultural land in the municipalities to the county level.

The energy produced by a wind turbine depends on the wind strength at the hub height and the technological details of the turbine. For a given roughness parameter (z_o), which accounts for the impact of the shape of the landscape and a given wind strength in one height, the wind strength in every other height can be calculated (see equation (C.1)). Since the average wind strength at 10 and 80 meters above ground is given, the roughness parameter is calculated first and then the average wind strength at the hub height.

$$ws_i = ws_j * \frac{ln(\frac{height_i}{z_0})}{ln(\frac{height_j}{z_0})} \tag{C.1}$$

$$R_R = \eta * 0.5 * AD * \frac{\pi}{4} * RD_i^2 * \sum P_k WS_{k,R,h_i}^3 \tag{C.2}$$

With the wind strength at the hub height and the technological information of a turbine, the amount of produced energy can be derived using equation (C.2). The efficiency factor of the power plant is given by η and set to 36%[35] such that the overall produced energy in 2002 equals the reported produced energy published by the electricity network operators.[36] AD is the air density at the hub height. It amounts roughly to 1.2 $\frac{kg}{m}$. RD is the rotor diameter. Finally, WS stands for the wind strength. Since wind strength affects the return of the wind turbine to the power of three, we approximate the wind strength distribution using the mean wind strength and a Rayleigh distribution, which is a good approximation for the wind strength distribution in Western Europe. In a first step the probability to observe a wind strength of 1, 2, ... , 30 m/s is calculated, which is shown for an average wind strength of 5, 7 and 9 m/s in Figure C.1. Since wind turbines usually do not operate when wind strength is very low or very high, we set the probabilities to zero if the wind strength is below 4m/s or above 27m/s. Based on the distribution of wind strength in a particular county, the amount of electricity produced for each wind turbine is calculated. We further multiply the value per hour with 365 (days) and 24 (hours) to derive the amount per year. With the wind strength at the hub height and the technological information of a turbine, the amount of produced energy can be derived using equation (C.2). The efficiency factor of the power plant is

[35] In a robustness check we use the wind strength at the 80th percentile and ended up with an efficiency factor of 0.33. This suggests that our microsimulation is quite accurate as the efficiency factor of wind power plants is between 0.2 and 0.4. The efficiency factor includes the potential breakdown of the plant. Further, it accounts for the fact that plants might not be built at a location with the average wind strength in a county but with a better one. The reader should note that the efficiency factor is different from the capacity factor (ratio of produced to installed capacity) discussed in literature (e.g. Boccard (2009)). The capacity factor in our study equals the one that can be derived from official publications as our simulation only replicates the aggregated numbers. The efficiency factor we use to calibrate the model is an indicator of how much energy is produced by a particular turbine in relation to the overall kinetic energy available and, thus, for a given wind strength distribution at a particular location.

[36] The information is included in the REA statements (https://www.netztransparenz.de). 2002 is chosen randomly; results are similar when using other years to calibrate the simulation.

given by η and set to 36%[37] such that the overall produced energy in 2002 equals the reported produced energy published by the electricity network operators.[38] AD is the air density at the hub height. It amounts roughly to 1.2 $\frac{kg}{m}$. RD is the rotor diameter. Finally, WS stands for the wind strength. Since wind strength affects the return of the wind turbine to the power of three, we approximate the wind strength distribution using the mean wind strength and a Rayleigh distribution, which is a good approximation for the wind strength distribution in Western Europe. In a first step the probability to observe a wind strength of 1, 2, ... , 30 m/s is calculated, which is shown for an average wind strength of 5, 7 and 9 m/s in Figure C.1. Since wind turbines usually do not operate when wind strength is very low or very high, we set the probabilities to zero if the wind strength is below 4m/s or above 27m/s. Based on the distribution of wind strength in a particular county, the amount of electricity produced for each wind turbine is calculated. We further multiply the value per hour with 365 (days) and 24 (hours) to derive the amount per year.

Figure C.2 reports the electricity generated by wind turbines according to our simulation and as published by the network operators for 2000 to 2008.[39] Overall, the model matches the published data fairly well: up to 2006 the two lines almost overlap, onwards there are temporary differences.

To derive the stream of revenue for each wind turbine, we determine the feed-in tariff that applies for the year of the connection to the grid.[40] The feed-in tariff for wind electricity introduced with the REA over the lifetime

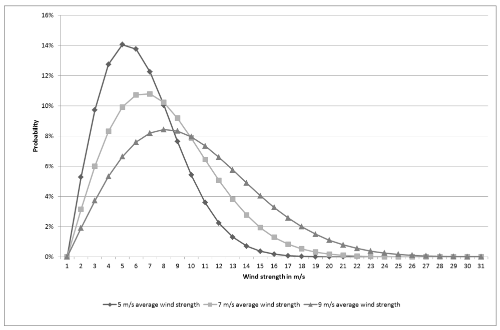
[37]In a robustness check we use the wind strength at the 80th percentile and ended up with an efficiency factor of 0.33. This suggests that our microsimulation is quite accurate as the efficiency factor of wind power plants is between 0.2 and 0.4. The efficiency factor includes the potential breakdown of the plant. Further, it accounts for the fact that plants might not be built at a location with the average wind strength in a county but with a better one. The reader should note that the efficiency factor is different from the capacity factor (ratio of produced to installed capacity) discussed in literature (e.g. Boccard (2009)). The capacity factor in our study equals the one that can be derived from official publications as our simulation only replicates the aggregated numbers. The efficiency factor we use to calibrate the model is an indicator of how much energy is produced by a particular turbine in relation to the overall kinetic energy available and, thus, for a given wind strength distribution at a particular location.

[38]The information is included in the REA statements. 2002 is chosen randomly; results are similar when using other years to calibrate the simulation.

[39]In the year of construction we assumed that half of the annual energy is feed-in.

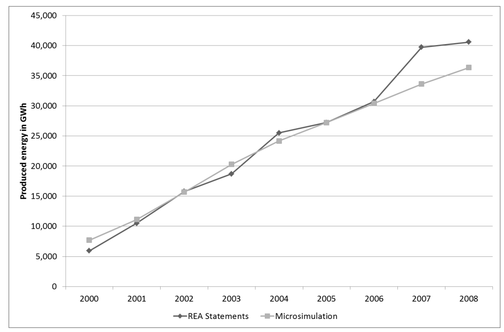
[40]We assume that the year of connection to the grid equals the construction year.

Figure C.1: Wind Strength Distribution for Different Means



Source: Authors' calculations using Rayleigh distribution.

Figure C.2: Energy Produced by Wind Turbines



Notes: Produced energy by wind turbines based on REA statements published by the network operators and based on the simulation model are depicted. *Source:* REA statements and authors' calculations based on data from German Weather Service and Operator Database 1990-2008.

of a plant is related to three parameters, two tariffs (high and low) and a parameter that determines the duration of the high tariff. The length of the first feed-in tariff is at least 5 years and is extended by two months for each 0.75 percent (0.85 for the years 2005 to 2008) that the produced energy is below 150% of the return of a hypothetical reference wind power plant defined in the law.

The high and the low tariff decreased relatively steadily from 9.1 and 6.19 cent per kWh in 2000 to 8.02 and 5.02 cent per kWh in 2008 mainly due to relative reductions per year included in the law (see Table C.1). Despite the reduction in the generosity of the feed-in tariff, the return of newly built wind power plants increased over time due to the technological development of wind turbines. The average installed capacity of a single wind turbine almost tripled between 1998 and 2008, mainly related to larger plant size and larger rotor calibers (see Figure C.3).[41]

For wind turbines built before the REA was introduced we assume that investors expect to receive the guaranteed price of 90% of the end-consumer price as guaranteed by the EFA for three years after the installation of the

[41]For an empirical analysis on the impact of RES support schemes on technological development see Johnstone et al. (2010).

plant; these investors are then assumed to expect the average market price for electricity of 3 cent per kWh.

Table C.1: Feed-in Tariff Wind Energy and Evolution Wind Turbine Profitability

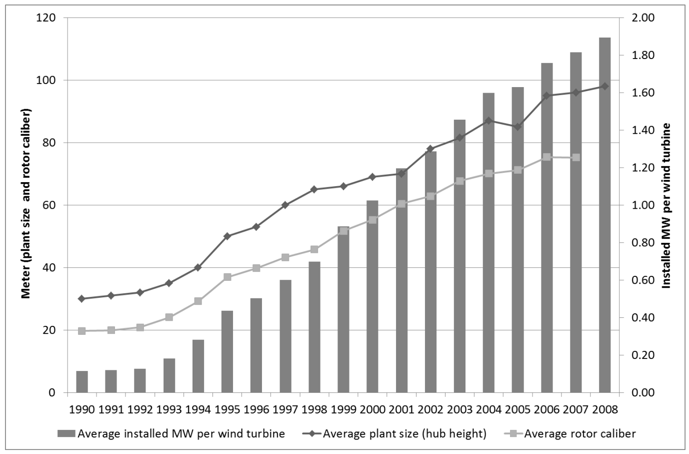
	Feed-in Tariff				Wind Turbine Profitability	
Year	Tariff 1	Factor for time period calculation for tariff 1	Tariff 2	Guaranteed time period in years	Technology 2000	Latest
1991-1999	90% of the consumer electricity price			none	3.92	3.92
2000	9.10	0.75	6.19	20	6.98	6.98
2001	9.10	0.75	6.19	20	6.98	7.08
2002	8.96	0.75	6.10	20	6.90	7.16
2003	8.83	0.75	6.01	20	6.82	7.28
2004	8.70	0.75	5.92	20	6.74	7.41
2005	8.53	0.85	5.39	20	6.63	7.33
2006	8.36	0.85	5.28	20	6.52	7.31
2007	8.19	0.85	5.07	20	6.42	7.22
2008	8.02	0.85	5.02	20	6.31	7.53

Note: Tariff 1 is paid for at least five years. The time period is extended if the wind turbine has a lower productivity than the reference plant as defined in the law. Evolution of expected wind turbine profitability for median wind strength are shown. The expected profitability in a current year is calculated as expected income over costs. The latest available technology is based on the median technology of wind turbines built in a current year.
Source: REA 2000, 2005 and authors' calculations based on data from German Weather Service and Operator Database 1999-2008.

Since the length of the first part of the feed-in tariff under the REA depends on the ratio of the return of the plant to the return of a reference plant defined in the law, we calculated the return of the reference plant using the steps outlined above. The hypothetical reference wind power plant is defined as the same plant at a location with 5.5 m/s average wind strength at a height of 30 meters above ground and a roughness parameter of 0.1. Based on the reference plant return, we calculate the years and months that the higher first feed-in tariff is paid. After deriving the expected income streams, we simulate the net present value of the future income streams using a discount rate of 3% and a life span of 20 years.

The costs of each wind power plant are assumed to be 690 euro per installed kW capacity based on survey data by Gasch and Twele (2011). They suggest installation costs to be around 570 euro (between 614 and 530) per kW and around 20% other investment costs, e.g. connection to the grid and the baseplate. The investment and related costs are considered by

Figure C.3: Technological Development Wind Turbines



Notes: Averages are based on all wind turbines built in Germany in a current year.
Source: Authors' calculations based on data from Operator Database 1990-2008.

assuming geometric depreciation allowances with a life span of 16 years.[42] Further, we assume a ratio of debt financing of 80% with an interest rate of 4.5%. The bank loan is paid back over 8 years. All these parameter choices are based on descriptive statistics of balance sheet and profit and loss statements of wind turbine firms in the database DAFNE (see Appendix D). The equity rate of return is assumed to be 3%.

Appendix C.2. Descriptive Statistics for Wind Turbine Firms in DAFNE

The information on wind turbine firms' depreciation allowances and finance structure are based on descriptive statistics from the DAFNE database. The DAFNE database contains financial statements (mainly balance sheet but for a few firms also income statements) for German firms with a limited liability for 2004 to 2012. Since wind turbines at one location are often in single companies and have in most cases limited liability, financial statements are observed for some wind turbine firms. We identify wind turbine firms as follows. First, all firms with *wind* in their company name are identified. From these firms, those with *operator*, *real estate*, *administration*, or *development* in their company name are excluded. To derive an even finer sample, firms with fixed assets of less than 100,000 euro and firms with a

[42]This is the life span assumed by the tax authorities.

standard deviation of depreciation allowances above 0.1 are excluded. The first requirement is used as very small wind turbines with only 133 kWh installed capacity already have assets valued at 100,000 euro. The second requirement ensures that only "one time wind turbines (parks)" are included, but not wind turbine parks where single wind turbines are added in different years, as we are unable to identify the rate of depreciation allowance for these firms.

From roughly 30,000 firms with *wind* in their company name 7,473 are left in the final sample. The number of firms for which the variables of interest are available differ due to data availability. The statistics are shown in Table C.2. They suggest that the rate of depreciation is between 10 and 14% for about 90% of all firms in the sample. This is in line with a geometric depreciation with twice the rate of linear depreciation method rate and a life span of 16 years, which was allowed in Germany for tax purposes between 2001 and 2005. Before and after it was three times the linear depreciation method rate.

Regarding firms' financing behavior, the overall debt ratio (observed for all firms) as well as the ratio of bank liabilities to total assets (available for a subsample of firms) is reported. The reader should note that due to a different life span of fixed asset and the maturity of loans as well as firms' payout policy, the level of debt financing can only be calculated in the first year. The descriptive statistics suggest a range from 77% to 100% for the overall debt ratio and from 63% to 89% for bank liabilities to total assets. The maturity of debt is similar using overall debt or only bank liabilities and is around 8.5 years. It is calculated using the repayment rates of debt and bank liabilities, respectively. Finally, the interest rate, calculated as interest payments divided by overall debt and bank liabilities, respectively, is shown in the last four columns. Regardless of whether payments are scaled by current or lagged values, the median interest rate is around 4.5%.

Table C.2: Descriptive Statistics Wind Turbine Firms

	N	p10	p25	p50	p75	p90
Rate of depreciation allowances in %	5,825	0.06	0.10	0.12	0.14	0.21
Debt ratio (DR)	7,473	0.48	0.74	0.91	0.99	1.00
DR year of incorporation	84	0.59	0.77	0.95	1.00	1.00
Bank liabilities to total assets (BL)	1,318	0.49	0.70	0.87	0.96	0.98
BL year of incorporation	18	0.32	0.63	0.81	0.89	0.92
Maturity DR in years	5,849	1.54	5.14	8.41	12.19	19.96
Maturity BL in years	703	3.37	5.98	8.78	11.49	15.98
Interest to debt in %	347	1.38	3.48	4.31	5.06	5.60
Interest to L.debt in %	244	1.46	3.15	3.86	4.56	5.02
Interest to BL in %	287	3.55	4.30	4.92	5.69	8.74
Interest to to L.BC in %	173	3.35	3.84	4.44	5.19	9.27

Notes: L stands for last year values. For further information see text.
Source: Authors' calculation based on data from DAFNE database, 2004-2012.