Does a small difference make a difference? Impact of feed-in tariff on renewable power generation in China

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Does a Small Difference Make a Difference? Impact of Feed-in Tariff on Renewable Power Generation in China

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Abstract

This study investigates the effectiveness of regionally differentiated feed-in tariffs (FIT) for the development of renewable energy in China. By using a spatial regression discontinuity design, we estimate the impacts of regionally differentiated FITs on the outcome indicators of wind and solar power generation, such as utilization rate, installed capacity, power generation, and hours of operation. Our findings show that FIT implementation plays an important role in promoting renewable energy development. A small difference in the tariff rate leads to statistically significant differences in outcome indicators among regions. Our results suggest that regionally differentiated FITs might help mitigate the overproduction of wind electricity in regions with abundant wind resources but low electricity demand. In addition, we conclude that enlarged tariff gap among regions can lead to greater impact on increasing installations of renewable power generation facilities in resource-poor regions.

Keywords: Feed-in Tariff; Renewable Energy; Renewable Curtailment; Spatial Regression Discontinuity Design

JEL classification: Q42, Q48

1 Introduction

Wind and solar power generation in China have achieved tremendous growth. In 2016, the cumulative wind and solar capacity reached approximately 150 GW and 77 GW, respectively, which was the largest worldwide (China National Renewable Energy Center, 2017). However, since 2010, renewable energy industries in China have faced the issue of oversupply, leading to the curtailment of renewable power. The country's renewable curtailment is the worst in the world, with a total of 56,200 GWh of renewables curtailed in 2016 – the national average curtailment rate was as high as 17% and 10% for wind and solar energies, respectively (China Electricity Council, 2018). The high curtailment rate is partly due to the dramatic regional disparity of China's renewable energy development. Because of the uneven distribution of renewable energy resources, over 70% of China's large-scale wind and solar farms have been built in resource-rich regions where electricity demand and export capacity are low. Oversupply is particularly significant in Inner Mongolia, with 75 GW of available capacity versus only 20 GW of peak demand in 2016 (Bloomberg New Energy Finance, 2017). The imbalance between resource abundance and low electricity demand has led to overcapacity and high rates of curtailment.

In 2009, the feed-in tariff (FIT) scheme for on-grid wind power replaced the concession bidding system to promote the generation of renewable power. The tariff was regionally differentiated to mitigate the imbalanced spatial distribution of renewable energy projects. Similarly, the regionally differentiated policy for on-grid solar energy was announced in 2013. Several studies explore the weakness of the FIT policy with a national uniform tariff rate and claim that regional differentiation of tariffs can optimize the investment of renewable energy power plants. For instance, Obermüller (2017) points out that a uniform FIT policy would incentivize unfavorable wind capacity allocations. By investigating the discrepancy between economically optimal wind locations under a uniform wind tariff and system optimal wind locations in Germany, Obermüller (2017) finds that the uniform FIT attains the highest regional revenues in locations with rich wind resources but independent of electricity demand.

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Using an empirical optimization model, Schmidt et al. (2013) compare investment behavior under fixed and premium FITs for the case of Austria. As a result, they find that the premium FIT scheme promotes the location diversification of wind turbines.

The main objective of this study is to estimate whether the implementation of regional differentiation of tariffs has a positive impact on mitigating uneven regional distribution and overproduction of renewable energy in China. Assuming that counties located just south of the FIT boundary do not differ systematically from those located north of the boundary on relevant covariates, we estimate the effect of the difference in wind and solar tariffs across the boundary using the spatial regression discontinuity design (RDD). In addition, to investigate the effects of regionally differentiated FITs on subsequent dynamics, we adopt an approach that combines the multiple-period difference-in-differences (DID) model with spatial RDD.

This study makes the following contributions to the literature on the economics of renewable energy policy. First, we examine the impact of regional tariff policy on reduction in the overcapacity of renewable energy projects through a quasi-experimental design. Existing empirical studies show inconclusive results regarding the FIT's impact on the renewable energy industries in China. Xia and Song (2017b) empirically investigated the driving factors of the regional disparity of China's wind power development. Their findings show that the FITs are most effective in wind resource-rich regions and have little impact on other regions. The results indicate that one driving force of the uneven development of wind power in China is the regional differentiation of on-grid wind tariffs. On the contrary, Zhao et al. (2016) empirically analyzed the impacts of regionally differentiated FITs on the increase in installed wind capacity and concluded that the FIT was more effective in areas with poor wind resources. Wei et al. (2019) employed a dynamic computable general equilibrium model to evaluate the impact of FIT on real GDP, employment, and emission reductions in China. They concluded that a sustained higher tariff rate could help abate greenhouse gas emissions while stimulating both real GDP and employment during the early policy period. However, this will not be conducive to growth over time due to an increasing tax burden. Second,

while previous studies use installed capacity and power generation as indicators to capture wind power development, this study uses alternative measures of indicators. For instance, Menz and Vachon (2006) estimated the effects of the state renewable energy policy on wind power capacity and generation in the United States. Hitaj and Löschel (2019) estimated the impact of FIT on installed wind-power capacity in Germany. Their findings indicated that a 1 euro cent/kWh increase in the FIT rate would increase additions to capacity by 796 MW on average each year from 1996 to 2010. In addition to these indicators, we use the utilization rate and operation hour of wind turbines in our analysis. These alternative measures allow us to capture the degree of effective utilization of the installed wind turbines. Third, while previous empirical studies on the impact of FIT mainly focus on wind power development, our study investigates the impact of regional differentiation of tariffs on the solar energy industry as well. Our findings on solar energy deployment are in line with the finding of Wang et al. (2016) that the FIT policy significantly mitigates the overcapacity of China's solar power industry. To the contrary, Ouyang and Lin (2014a) calculated the levelized cost of electricity for solar photovoltaic (PV) power in China, finding that the FIT should be improved and dynamically adjusted to provide better support. Ye et al. (2017) similarly concluded that the tariff levels of the FIT for solar PV power in China should be adjusted more frequently to keep the internal rate of return.

This study's results suggest that regionally differentiated FITs have promoted the development of both the wind and solar energy industries in China. Specifically, our findings show that wind facilities' utilization rate has improved in regions with relatively poor wind resources through adoption of higher tariff rates. To explore this impact of the FIT, we use the actual amount of power generation and installed power capacity to calculate the utilization rate, which is used as a major production indicator of wind facilities. In addition, we find that the implementation of regional tariffs relieved the uneven distribution of renewable power facilities by attracting more projects to resource-poor regions. Interestingly, our findings show that the regionally differentiated FIT had the greatest impact in the year the tariff

cuts were enforced. This result indicates an acute impact of the regional tariff gap, which incentivizes renewable energy developers to locate the projects in resource-poor regions.

The remainder of this paper is organized as follows: Section 2 introduces the policy of regionally differentiated FIT to promote the wind power and solar power industries in China, and selection of study area. Section 3 describes the data and analysis framework, including a description of the spatial RDD approach and regression discontinuity (RD) polynomial. Estimation results and discussions are provided in Section 4. Finally, Section 5 presents our conclusions and discusses the research implications.

2 Regionally differentiated FIT in China

To mitigate the uneven distribution of renewable energy industries, the tariff rate is differentiated regionally under the FIT regime in China. The regionally differentiated FIT policy for on-shore wind power was first introduced by the National Development and Reform Commission (NDRC) in August 2009. As illustrated in Figure 1, the FIT policy divided the regions of China into four zones, each with a different tariff rate according to onshore wind resources and construction conditions. Regions with the richest wind resources in the north and west were given the lowest tariff of 0.51 yuan/kWh, reflecting lower production costs resulting from resource endowments. Regions with modest wind resources have tariffs of 0.54 yuan/kWh or 0.58 yuan/kWh. Regions with comparatively poor wind resources and construction conditions in the central area and coastline of China were given the highest tariff of 0.61 yuan/kWh.

[Figure 1]

Compared with the rapid growth of the wind power sector, the growth of solar power industries in China lagged until the cost of the technology declined sharply since 2009. In response to the introduction of a nationally uniform FIT policy for on-grid solar in 2011, installation of solar power plants in China reached a record high of 2.5 GW, accounting for

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9.12% of the world total that year (Zhang and He, 2013).[1] Because the uniform tariff rate leads to concentration of solar energy projects in mainly the western regions with rich solar resources in China, the NDRC issued a new FIT scheme in 2013 that applied different tariff rates based on the cost of electricity generation. Figure 2 illustrates the division of China into three resource zones under the regionally differentiated FIT policy. The tariff rates applied for each resource zone range from 0.90 to 1.00 yuan/kWh.

[Figure 2]

As production and construction costs of solar power continue to fall, the NDRC announced that it will cut the FIT offered to solar power to reflect the new market conditions in 2016 (NDRC, 2015). The tariff rates have reduced by as much as 11%, that is, by 0.02 to 0.1 yuan/kWh for on-grid solar farms. In addition, solar energy developers announced in December 2016 that the solar tariff will be cut further by as much as 19% in 2017. Therefore, some argue that this series of tariff cut announcements led to a rush in solar power installation ahead of the start of tariff cuts in June 2016 and January 2017 (Daiwa Capital Markets, 2015). Table 1 represents changes in tariff rates for on-grid wind and solar projects. It shows that the regionally differentiated FIT policy was firstly implemented for wind power in 2009. After that, tariff rates for wind resource Zone I II and III were cut by 0.02 yuan/kWh in 2013 and 2016. Tariff rates provided for wind projects in Zone IV, the resource-poor region, remained the same at 0.61 yuan/kWh in 2013 and cut by 0.01 yuan/kWh in 2016. On the other hand, the national uniform tariff rate for solar power was applied in 2011. The tariff has been regionally differentiated since 2013, creating a gap of 0.1 yuan/kWh at the largest. Subsequently, the tariff gap between the highest and lowest areas increased to 0.18 yuan/kWh in 2016.

[Table 1]

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[1]According to the uniform solar FIT, projects approved prior to July 1, 2011, that have completed construction and achieved commercial operation prior to December 31, 2011, are entitled to a tariff of 1.15 yuan/kWh; projects approved after July 1, 2011, or approved prior to that date but not completed before the end of 2011 are entitled to a tariff of 1 yuan/kWh.

Figure 3 shows the spatial distribution of the counties comprising this study's research area. The FIT boundary divides the study location into southern and northern areas. Wind-power developers in northern counties receive the lowest tariff rates in China. By contrast, southern counties receive the highest tariff rates. There was a 0.1 yuan/kWh difference in the on-grid wind tariff rate between counties south and north of the FIT boundary in 2009.[2] This part of the country was selected for study because it is the only location where regions with the highest and lowest wind tariff rates share the same border. Focusing on this area (which contains the regions with the most abundant renewable resources) enabled us to investigate how the different tariff rates most affected renewable energy development. Similarly, the 2013 tariff rate provided for electricity generated by on-grid solar panels was 0.05 yuan/kWh higher in the south than in the north.[3] Under the RDD, border cities near the FIT boundary provide a good basis of comparison because the observable differences in renewable resources, land-use, and population characteristics tend to be smaller. Likewise, since the RD design validity required that all relevant factors (besides treatments) varied smoothly at the cutoff, we could exclusively focus on the counties located in these border cities.[4]

[Figure 3]

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[2]As shown in Table 1, due to the announced tariff cuts, the differences in wind tariff rates between the southern (Zone IV) and northern (Zone I) areas of study were increased to 0.12 yuan/kWh in 2013 and 0.13 yuan/kWh in 2016.

[3]As shown in Table 1, due to the announced tariff cuts, the differences in solar tariff rates between the southern (Zone II) and northern (Zone I) counties increased to 0.08 yuan/kWh in 2016.

[4]The counties in our sample are located in border cities of the FIT boundary, including Yulin, Xinzhou, Shuozhou, Datong, Ordos, Huhhot, and Ulanqab. Yulin is a prefecture-level city located in Shaanxi Province. Xinzhou, Shuozhou, and Datong are cities in Shanxi Province. These cities border Ordos, Huhhot, and Ulanqab in Inner Mongolia to the north.

3 Empirical strategy

3.1 Data

Our data consist of a panel of 71 counties located in Inner Mongolia, Shanxi Province, and Shaanxi Province. These are unbalanced yearly panel data[5] from 2009 to 2012 for simple RDD wind power-related regression, from 2009 to 2016 for multiple time period wind regression, and from 2011 to 2016 for multiple time period solar regression.[6]

Installed power capacity and wind power generation are typically used by previous studies to measure wind power development. In addition to these two indicators, we adopt the utilization rate and operation hour to capture the effectiveness of wind power facilities. The utilization rate is calculated by the percentage of time a turbine can be used during the 8,760 hours of the year (Welch and Venkateswaran, 2009).[7] Due to data availability, only installed capacity of power generation facilities can be used as the indicator of wind and solar power development in the multiple time period regressions.[8] Production indicators of renewable power plants are obtained from the Compilation of Power Industry Statistics collected by the China Electricity Council. This dataset contains information on the production status of electric power plants of over 6,000 kW, which represent over 85% of total capacity in China.

As a treatment indicator for the regionally differentiated tariffs, we adopted a dummy variable that equals one if the county in the study area is located in the south of the FIT boundary and zero otherwise. During the study period, the tariff applied for wind power developers in counties south of the FIT boundary is 0.61 yuan/kWh generated electricity, while that for developers in northern counties is 0.51 yuan/kWh. In the case of solar energy,

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[5]Information on the mean area slope and agricultural land area of two counties was missing for 2012, resulting in an unbalanced dataset. We interpolated this missing data by calculating the average slope and agricultural land area of neighboring counties.

[6]Sample period starts from 2009 for wind power-related regression and 2011 for solar regression, since there were no renewable power generation facilities located in counties south to the FIT boundary in the study area before these years.

[7]The calculation formula of utilization rate can be described as follows: utilization rate (%)= power generation (GWh) / capacity (GW) × (24 × 365) (h).

[8]Information on production indicators of facilities other than installed capacity are not avaliable after 2012.

the tariff provided for on-grid solar energy facilities located in southern counties under the regionally differentiated FIT is 0.95 yuan/kWh, while that for facilities in counties north of the FIT boundary is 0.90 yuan/kWh.[9] Thus, the south dummy captures the higher tariff rate applied in counties south of the boundary under the FIT regime.

To control for counties' demographic and geographic characteristics, we use data on population density, agricultural land area, and secondary industry output of each county from the Statistical Yearbook of Shanxi Province, Shaanxi Province, and the Inner Mongolia Autonomous Region. Information used to capture the endowment of renewable energy resources, such as annual average wind speed measured at 70 meters height above the ground level and annual average solar radiation, are obtained from the China Meteorological Data Service Center. ArcGIS 10.1 is used to calculate the mean area slope and weighted elevation of each county. The elevation data, namely digital elevation models, are produced by the NASA Shuttle Radar Topography Mission database.

To capture the impact of conventional energy on the deployment of renewable energy, we use the installed capacity of thermal power plants provided by the Compilation of Power Industry Statistics. The database contains thermal power plants whose capacity is larger than 300 MW. By including information on thermal power plants, we can consider the substitution between renewable and traditional energy sources. Although efforts have been made to diversify the primary sources for power generation, China will continue to rely on coal for power generation in the near future (Ma, 2011). At present, power grid companies are obligated to pay a part of the tariff to renewable energy developers, that is, 0.4 yuan/kWh, while the average thermal power price ranges from 0.2 to 0.3 yuan/kWh in China. This makes the price of renewable power higher than that of coal-fired power. Thus, renewable electricity appears less attractive to power companies (Xia and Song, 2017a). In addition, subsidies for fossil fuels in China are far larger than those for renewable energy, which may

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[9]More precisely, as presented in Table 1, the tariff rate for solar energy projects in southern counties under the regionally differentiated FIT is cut to 0.88 yuan/kWh, and that for solar projects in northern counties is 0.80 yuan/kWh in 2016.

discourage renewable energy production and investment (Ouyang and Lin, 2014b).

The summary statistics for wind and solar power regressions are presented in panel A and B of Table 2, respectively. Table 2 shows that there are an average of 20 MW wind turbines per county in the south of the FIT boundary, and 89 MW in the north. Thus, counties in the north seem to have more power capacity. However, as the comparison does not consider that observations further from the boundary are different in many respects from those that are closer, we cannot draw any credible causal inferences from them (MacDonald et al., 2016).

[Table 2]

The two-tailed t-tests show that there are statistically significant differences in the mean values of demographic and geographic characteristics between counties south and north of the boundary. A visual inspection of the data is more informative. Figures 4 and 5 plot county characteristics other than renewable energy development at the county level based on distance to the FIT boundary. Using the ArcGIS 10.1, we calculate the Euclidean distance from each county's government office to the FIT boundary. Counties located south (north) of the boundary are assigned a positive (negative) distance value. We find that there exist significant discrete changes in county characteristics such as agricultural land area, annual average wind speed, solar radiation, and elevation at the FIT boundary. Therefore, these county geographic and demographic characteristics are included as covariates in our estimation model. Besides, whereas some counties north of the boundary have relatively high wind speed and solar radiation, this pattern dissipates for counties that are close to the FIT boundary. Thus, we test our estimate's robustness by limiting the sample within 80 km and 50 km from the boundary as well. Table 3 represents summary statistics for the sample within 80 km of the FIT boundary. The t-test results denote that the differences in geographic characteristics such as agricultural land area, elevation, and slope are statistically insignificant between the treatment and control groups when we restrict the sample to those

close to the boundary.[10] The total number of counties in study area decrease from 71 to 43 after we limit the sample to fall within 80 km of the FIT boundary, which is nearly half of the full sample.[11]

[Figure 4]

[Figure 5]

[Table 3]

3.2 Model

Our empirical analysis aims to measure the impact of the regionally differentiated FITs on the development of renewable energies in China. The spatial RDD approach exploits the discontinuous changes in tariff rates that drive variations in wind power development between the south and north of the FIT boundary. The general form of the spatial RDD model is as follows:

$$W_{it} = \alpha + \beta south_i + \gamma X_{it} + f(geographic\ location_i) + \lambda_b + \theta_t + \epsilon_{it}, \tag{1}$$

where W_{it} refers to the production indicators of wind power generation facilities in county i and year t. The wind power indicators include utilization rate, installed capacity, power generation, and operation hour of power plants. $south_i$ is a dummy variable for counties south of the resource zone boundary. Our coefficient of interest, β, measures the discontinuous changes in W_{it} just south of the policy boundary. The time-varying county characteristics are captured by X_{it}, which include the demographic and geographic characteristics such as population density, secondary industry output, agricultural land area, annual average wind speed, annual average solar radiation, installed capacity of thermal power plants, and

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[10]Results of two-tailed t-tests are shown in column (4) of Tables 2 and 3.
[11]The number of counties in study area decrease to 29 in the case of limiting sample to fall within 50 km of the FIT boundary.

mean area weighted elevation and slope for county i in year t. $f(geographic\ location_i)$ denotes the regression discontinuity polynomial, which controls for smooth functions of the geographic location. Recent studies suggest that the local linear polynomial should be run with kernel weights that assign more weights on observations near the cutoff (Imbens and Kalyanaraman, 2012; Calonico et al., 2014). Therefore, our main results are estimated with a local linear regression with triangular kernel weights. We also estimate regressions with quadratic and quartic polynomials for checking the robustness of the main results. λ_b represents the boundary segment fixed effects that denote which of the five equal-length segments of the boundary is the closest to the county's government offices. Finally, the year dummy θ_t is used to capture external events that commonly affect the development of the wind power and solar power industries, such as changes in policies and regulations at the national level.

In general, spatial RDD provides estimates of local-average treatment effects around policy boundaries where treatment and control units are most similar. It requires that there are no observable differences or clear discontinuities in any other characteristics of observations at the boundary. However, since the counties to the south and north of the FIT boundaries examined in this study belong to different provinces, systematic differences may exist between observations of the treatment and control groups. For instance, counties belonging to Inner Mongolia have relatively favorable conditions for the construction of renewable power facilities (e.g., higher and steadier wind flow and solar radiation, more flatlands, and less population density). As such, these geographic and demographic characteristics were included in the estimation model to isolate the effect of our main focus. Further, although Inner Mongolia was the first province to issue a comprehensive set of provincial policies to supplement the national renewable power policy framework (Liu and Kokko, 2010), these were either regulations designed to facilitate development planning, investigations, and feasibility studies for projects or were provisions of administrative processes aimed at project development. We assume that these non-price policy instruments do not directly change the profitability

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of renewable energy projects and may have little impact on developer incentives.[12]

Simultaneously, to examine whether these systematic differences significantly affect the estimated impact of FIT policy, we adopted counties located in the Eastern Inner Mongolia region as another sample area in this study. The regression is estimated using the same method as our main regression, and the sample period is from 2009 to 2012. All counties are located in the same administrative region and, thus, have the same local policies except for the tariff level.[13] As shown in Figure 6, the FIT boundary divides the Eastern Inner Mongolia region into eastern and western areas. Developers in the eastern area receive higher tariff rates for wind power generation. The difference in the 2009 wind tariff rates between east and west is 0.03 yuan/kWh.[14]

[Figure 6]

In addition, to investigate the effects of regionally differentiated FITs on the subsequent dynamics of solar power development, we adopt an approach that combines the multi-period DID model with the spatial RDD:

$$S_{it} = \alpha + \beta_0 south_i + \sum_{t=-2}^{3} \beta_t south_i \times \theta_t + \gamma X_{it} + f(geographic\ location_i) + \lambda_b + \theta_t + \epsilon_{it},\ (2)$$

where S_{it} denotes the indicator of solar power development. Compared with the wind power regressions, only the cumulative installed capacity of on-grid solar power generation facilities in county i in year t has been adopted due to data availability. $south_i \times \theta_t$ are interaction terms between the treatment indicator $south_i$ and year dummy θ_t. The excluded time category is 2012 ($t = -1$) such that the effects are measured relative to the year prior to the

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[12]Although China introduced tax incentives that provide 50% refunds of the value-added tax imposed on enterprises utilizing wind (The Notice on the Taxation of the Comprehensive Utilization of Resources and Other Value-added Tax in 2008) and solar power (The Notice on Value-added Tax of the Solar PV in 2013), these are part of national policies that equally apply to all provinces.

[13]The eastern counties in the Eastern Inner Mongolia Sample are located in cities including Xing'an, Tongliao, and Chifeng. These cities border Xilinguole to the west.

[14]As shown in Table 1, the differences in wind tariff rates between eastern (Zone II) and western area (Zone I) had not been changed after the tariff cuts announced in 2013 and 2016.

implementation of the solar FIT policy in 2013. β_t is the coefficient on the tth lead or lag of the policy implementation year. These coefficients of $south_i \times \theta_t$ capture the effects of a discontinuous change in the solar tariff rate between the southern and northern counties on the installation of solar power generation facilities in each year during the research period.

4   Results and discussions

4.1   Impact on wind power industries

We estimate the effects of regionally differentiated tariffs on renewable energy development using the spatial RDD model. Table 4 reports the regression results regarding the FIT's impact on the production indicators of wind power facilities, including the annual utilization rate, installed capacity, power generation, and operation hours. Panels A and B in Table 4 report the specification that includes a single-dimensional RD approach. Particularly, the linear polynomial in distance from the county government to the FIT boundary with kernel weights in panel A allows us to assign more weights on observations near the boundary. We also report alternative specifications that use multiple dimensional discontinuities in the longitude-latitude space in panels C and D of the table. It provides useful checks on the regression results estimated by the model with the single-dimensional RD polynomial. All regressions include controls for boundary segment fixed effects and year fixed effects. Controls for demographic and geographic conditions as well as conventional energy sources are adopted in all regressions as well. The full set of estimation results including control variables are reported in Table A1 in the Appendix..

[Table 4]

Our estimates imply that regional differentiation of tariffs has positively affected the development of the wind power industry in China. According to the results in column (1) in panel A of Table 4, a 0.1 yuan difference in the tariff rate will result in approximately an

8.26% increase in annual utilization rates of wind facilities. This implies that the adoption of regionally differentiated FIT increases the utilization rate by 1.45 times of the total utilization rate per year.[15] In column (2), the coefficient of *South* is positive and statistically significant. The result suggests that the regionally differentiated tariff encourages the installation of wind power plants of nearly 77.8 MW in regions with higher tariff rates. This implies that the regional FIT has attracted more plants to resource-poor regions. In addition, according to the results in columns (3) and (4), implementation of the regionally differentiated tariffs is related positively to the annual total power generation and operation hours of wind facilities. The annual increase in power generation of wind turbines caused by the difference in tariff rate is approximately 153.1 GWh. Moreover, due to the FIT, the annual operation hours have increased to 151,800 hours, which is about 1.45 times the annual average.[16] These results indicate that the implementation of regional FITs might help mitigate the overproduction of wind electricity in regions with rich wind resources but lower electricity demand. Panels B, C, and D in Table 4 examine the robustness of the main results through two alternative specifications of the RD polynomial. The effects of regionally differentiated FIT on wind deployment are statistically significant across all specifications.

[Table 5]

Table 5 limits the sample to counties located within 80 km of the FIT boundary. The specification reported in panel A of Table 5 suggests a statistically significant and positive effect of the tariff at around 12.8%, as compared with the mean utilization rate of 2.41% throughout the north counties located within 80 km of the FIT boundary, which again is statistically significant in panels B, C, and D. We find that the regression results are broadly robust to the choice of average distances to the boundary, that is, for counties located within 80 km from the boundary, counties located within 50 km from the boundary (see Table A2

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[15]According to the summary statistics in Table 2, the average utilization rate of wind facilities in the control group is around 5.69%.

[16]According to the summary statistics in Table 2, the average operation hours of wind facilities in the control group are around 104,800 hours.

in Appendix), or all counties. Our estimation results are consistent with the findings of Zhao et al. (2016), showing that the FIT policy had a strong impact on the promotion of wind power in areas with fewer wind resources, namely the southern counties, than in areas with rich wind resources in China.

On the other hand, in order to estimate whether the tariff cuts implemented in 2013 and 2016 have affected effectiveness of the FIT on wind power development, we also adopted the approach of multiple time period analysis for wind power related regression. Estimating the evolution of the coefficients of South in each year between 2009 and 2016, we find that compared to the year that the FIT was firstly implemented, the observed FIT effect showed in 2016 due to the announcement of tariff cuts.[17] As shown in Table A3 in Appendix, the impact of FIT was statistically significant and robust across all the regressions in 2016, which is when the tariff provided for wind power were cut further. The wind-tariff gap between the southern and northern areas increased to 0.13 yuan/kWh in 2016.[18] According to the coefficients of $South \times 2016$ in column (1) of Table A3, the wind-installed capacity in the South area was increased by 198.9 MW in 2016. Estimated results by the sample limited to counties located within 80 km and 50 km of the boundary are represented in Tables A4 and A5 in Appendix and are consistent with the above findings. By comparing with the main results, which indicate that regional differentiation of tariffs has significantly promoted the wind power development in China, results of the multiple period estimation show that tariff cuts announced afterwards have further improved effectiveness of the FIT. These results illustrate that the enlarged tariff gap will result in greater positive impact of the regionally differentiated FIT on wind capacity installations in the resource-poor region.

Moreover, to confirm that the estimated impact of FIT is not biased by the systematic

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[17]The general form of the multiple time-period model for the wind-power related regression can be written as follows: $w_{it} = \alpha + \sum_{t=1}^{7} \beta_t south_i \times \theta_t + \gamma X_{it} + \text{f(geographic location}_i) + \lambda_b + \theta_t + \epsilon_{it}$. The regionally differentiated FIT policy was first implemented for wind-power generation technologies in 2009. This was set as the baseline year in the regression.

[18]As represented in Table 1, the tariff gap between the highest and lowest tariff areas of wind power was 0.1 yuan/kWh in 2009, this gap was increased to 0.12 yuan/kWh and 0.13 yuan/kWh in 2013 and 2016, respectively.

variances of the different administrative locations in the south and north areas, the Eastern Inner Mongolia sample is used for additional analysis in this study. Table A6 reports the summary statistics of the Eastern Inner Mongolia sample. As shown in Table A7, we find a positive impact of FIT policy on promoting wind power development within the same administrative region. According to the estimated coefficient, the increase in installed wind capacity in the resource-poor area is approximately 738.5 MW per year. Moreover, the annual utilization rate of wind facilities in the resource-poor area can be increased by 2.57% with the adoption of regionally differentiated FIT. The strong impact of the FIT policy compared to our main results suggest the power of a slight difference in incentives within the same province."

4.2   Impact on solar power industries

This section investigates the effect of the regionally differentiated FIT on the development of solar energy, with a focus on location choices of the solar power industries. The installed power capacity of solar power is adopted as the dependent variable in the regression model. The sample period of the solar power-related regression can be divided into two sub-periods: pre-FIT period from 2011 to 2012 and post-FIT period from 2013 to 2016.[19] The approach of spatial RDD combined with the multiple time-period DID model allows us to estimate the evolution of the coefficients of *South* over time.

[Table 6]

Table 6 illustrates the regression results on the impact of the regional differentiation of tariffs on the installed capacity of solar energy facilities. Similar to the wind power regression, specifications that include a single-dimensional location polynomial are reported in columns (1) and (2) of Table 6. Particularly, the location polynomial used in column (1) is a linear polynomial in the distance to the FIT boundary with kernel weights. In addition,

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[19]The year of 2012 was set as baseline year of the solar power-related regression.

specifications that use multiple dimensional location polynomials are reported in columns (3) and (4). As represented by the coefficients of $South \times 2011$ in Table 6, solar capacity additions caused by the implementation of the FIT is insignificant in the pre-treatment period. The result indicates that the observed FIT effect is not driven by the fact that counties just south and north of the FIT boundary are affected differently based on geographic and demographic conditions. On the other hand, we find that the estimated coefficients are negative and significant in 2013, the year in which regionally differentiated FIT had been adopted. This result may be because the announcement about the implementation of the on-grid solar FIT was made in the last quarter of the year and investments from developers were suspended until then. After that, the FIT's impact was insignificant until 2016, which is when the tariff cut of on-grid solar power was announced. This result indicates that the difference in tariff rate between resource regions when the on-grid solar FIT was first adopted in 2013 was not enough to incentivize developers to locate the power plants in resource-poor regions.[20] When the tariff rate cuts for solar power were announced in 2016, the difference in tariff rates between resource-poor and rich regions became larger. A large gap in tariffs helps to incentivize solar energy developers to invest in regions with relatively poor resources and location conditions.[21] The coefficient of $South \times 2016$ in column (1) of Table 6 suggests that the solar installed capacity increased by 99.6 MW due to the 0.08-yuan/kWh difference in solar tariff. This result shows that the annual capacity addition of solar facilities caused by the FIT in 2016 is approximately 4.1 times the average solar power installed capacity in each county.[22] Our results suggest that the regionally differentiated FIT was not effective until new tariffs with higher differences in tariff rates among regions were announced.

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[20]In our case, the difference in on-grid solar tariff rates between the southern and northern counties was 0.05 yuan/kWh before the tariff cut had been announced in 2016.

[21]Because the tariff cut occurred in early 2016, the difference in solar tariff rates between the treatment and control groups in our study increased from 0.05 yuan/kWh to 0.08 yuan/kWh. In other words, after the tariff cut, tariff provided for per kWh electricity generated by on-grid solar projects located in the southern counties is 0.08 yuan higher than that for solar projects located in the north. More details can be found in Table 1.

[22]According to the summary statistics in Table 2, the mean solar capacity in the control group is 24.3 MW.

[Figure 7]

Figure 7 illustrates the same results as Table 6 but in a more intuitive way. The interaction coefficient was positive and statistically significant in 2016. This result suggests that, only in the year when the new tariff rates of on-grid solar power were announced, the installed capacity of solar power plants increased in the southern counties compared with counties located in the north of the FIT boundary.

[Table 7]

Similar to the wind power regression, Table 7 limits the sample to counties located within 80 km of the FIT boundary. In addition, the regression results estimated by the sample limited to the counties located within 50 km of the FIT boundary are reported in Table A8 in Appendix. We find that the regression results are robust to the choice of average distances to the boundary. The coefficients of $South\times2016$ in the first column of Table 7 suggest a statistically significant and positive effect of the solar tariff at around 146.7 MW in 2016.

5   Conclusions

By focusing on the wind and solar power industry in China, this study estimates whether the implementation of regionally differentiated FIT mitigated the uneven development of renewable energy. The spatial RDD approach allows us to examine the impact of differentiated FIT across the resource zone boundary through a quasi-experimental design. In addition, the multiple time period model helps us to consider how the estimated impact changes over time.

According to the estimation results, the adoption of regional differentiation of tariffs effectively enhanced location diversification of renewable projects, at least for a limited distance around the FIT boundary. In the case of wind power industry, we find that a higher tariff rate leads to an increase in the utilization rate of wind turbines in counties located

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in resource-poor regions by approximately 8.26%, as compared with the mean wind facility utilization rate of 5.69% throughout the northern counties. In addition, when considering the FIT's effect on the installation of wind power plants, we find that the annual wind capacity additions caused by FIT adoption are about 77.8 MW. Besides, the results indicate that enlarged tariff gap will result in greater positive impact of the regionally differentiated FIT on wind capacity installations in the resource-poor region. The effect of regionally differentiated FIT is also found in the case of solar energy. The annual increase in cumulative installed capacity of solar power plants through adoption of the FIT is estimated at about 99.6 MW in 2016, the year when the significant cut in solar tariff was proposed. Before that, the FIT for on-grid solar power did not have a significant effect on promoting the location diversification of the solar power industry.

Our results suggest that the regional differentiation of tariffs has mitigated the uneven regional distribution of both the wind power and solar power industries in China. This finding is in line with those in the existing literature, which indicate that cost-based tariffs can incentivize renewable energy developers to diversify the locations of wind turbines (Schmidt et al., 2013; Zhao et al., 2016). In addition, we also find that the regionally differentiated FIT mitigates overproduction in wind-rich yet remote regions, by improving the utilization rate of wind turbines in resource-poor regions. Lastly, our results indicate that the tariffs significantly encouraged installations of both wind and solar power generation facilities in the year that new tariff rates with a higher regional gap were enforced. This result indicates that even a small increase in the tariff rate can provide a strong incentive for the development of renewable power.

The endowment of renewable energy is regionally diverse. Therefore, the renewable curtailment issue arising from geographical concentration of the renewable project and the limited transmission grid is a challenge for many countries in the world. For instance, Kyushu Electric Power Co. in Japan restricted third-party solar power supplies four times during October 2018. With rich endowment of solar radiation, there has been massive investment

in solar power in Kyushu area, particularly after the FIT policy's introduction in 2012. The capacity of solar power in Kyushu area is 8.07 GW, which accounts for more than 80% of the electricity demand when demand is low.[23] Moreover, in the case of Germany, wind power projects are concentrated in the northern area with abundant wind resources, while most solar projects are located in the southern areas rich in solar radiation (Obermüller, 2017). In these countries, the unified nationwide tariff policy for on-grid renewable electricity has been implemented, instead of the regionally differentiated one. The findings from this study provide a policy implication for countries throughout the world facing the challenge of overproduction of renewable energy, which is caused by the increasing capacity installation and shortage of the transmission grid.

Despite our effort to use a spatial RDD to estimate the casual effect of the regionally differentiated FIT policy on renewable-energy development at the boundary of the tariff zone, this study had several limitations. Although we adopted several covariates to capture the impacts of observably different county characteristics at the boundary, it is still possible that other unobserved factors were present. Secondly, interregional connections between the southern and northern area is not considered in this study, as the current status of interregional connections among these regions are underdeveloped.[24] We thus assumed that electricity transactions may not have significantly impacted power generation among renewable facilities in the study area at the current stage. However, expanded interconnections should eventually mitigate the issue of overproduction in Inner Mongolia. Further, findings may depend on our choice of study area. Future studies should thus expand the geographical scope to test the external validity of our results.

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[23] *The Nikkei* newspaper, 13 October 2018.

[24] Approximately 6,669 GWh of electricity (about 3.71% of total electric power consumption in Shanxi) was transmitted from Inner Mongolia to the Shanxi province in 2016. Similarly, approximately 1,523 GWh (1.12% of all electricity consumption in Shaanxi) was transmitted from Inner Mongolia to the Shaanxi province in the same year.

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Acknowledgements

Table 1: Tariff Rates for On-grid Wind and Solar Projects in China (yuan/kWh)

Wind			
	2009	2013	2016
Zone I	0.51	0.49	0.47
Zone II	0.54	0.52	0.50
Zone III	0.58	0.56	0.54
Zone IV	0.61	0.61	0.60
Solar			
	2011	2013	2016
Zone I	1.15/1.00	0.90	0.80
Zone II	1.15/1.00	0.95	0.88
Zone III	1.15/1.00	1.00	0.98

Source: Notice on Adjustments to FITs for Onshore Wind and Solar Power, The National Development and Reform Commission.

Table 2: Descriptive Statistics
(Full Sample)

Panel A: Wind

	Unit	Control groups (south=0)			Treatment groups (south=1)		
		Obs	Mean	Std.dev.	Obs	Mean	Std.dev.
Wind facility production indicators							
Utilization rate	%	112	5.690	8.946	172	3.574	7.912
Wind capacity	MW	112	89.25	185.4	172	20.17	50.44
Power generation	GWh	112	149.5	345.1	172	33.76	98.02
Operation hour	10 hour	112	104.8	287.1	172	47.97	155.6
County characteristics							
Population density	1,000 person/km^2	112	0.192 **	0.315	172	0.664	2.520
Secondary industry output	billion yuan	112	9.760***	11.71	172	5.255	9.506
Agricultural land area	10^5 ha	112	0.371*	0.241	172	0.336	0.186
Wind speed	m/s	112	5.862***	1.027	172	5.456	0.773
Weighted average elevation	100 m	112	13.53***	1.719	172	12.75	2.047
Slope	degree	112	4.098***	2.728	172	8335	3.480
Thermal capacity	GW	112	0.763***	1.379	172	0.398	0.934

Panel B: Solar

	Unit	Control groups (south=0)			Treatment groups (south=1)		
		Obs	Mean	Std.dev.	Obs	Mean	Std.dev.
Solar facility production indicators							
Solar capacity	MW	168	24.30	55.41	258	27.16	90.51
County characteristics							
Secondary industry output	billion yuan	168	12.58***	14.80	258	7.010	12.18
Weighted average elevation	100 m	168	13.53***	1.716	258	12.75	2.045
Slope	degree	168	4.098***	2.724	258	8.242	3.642
Solar radiation	100 kWh/m^2	168	16.26***	0.258	258	15.30	0.448

Note: Mean value of variables differ with statistical significance in a two-tailed t-test between the treatment and control groups, and they are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3: Descriptive Statistics
(Sample Falling within ≤ 80 km of the Boundary)

Panel A: Wind

		Control groups (south=0)			Treatment groups (south=1)		
	Unit	Obs	Mean	Std.dev.	Obs	Mean	Std.dev.
Wind facility production indicators							
Utilization rate	%	64	2.410	5.956	108	4.593	8.860
Wind capacity	MW	64	23.46	63.42	108	26.62	59.16
Power generation	GWh	64	28.10	83.14	108	46.66	118.4
Operation hour	1,000 hour	64	23.30	81.49	108	63.28	185.8
County characteristics							
Population density	1,000 person/km^2	64	0.207*	0.306	108	0.970	3.146
Secondary industry output	billion yuan	64	12.15**	13.40	108	7.533	11.37
Agricultural land area	10^5 ha	64	0.301	0.184	108	0.346	0.188
Wind speed	m/s	64	5.646	0.748	108	5.665	0.757
Elevation	100 m	64	13.41	1.489	108	13.08	1.846
Slope	degree	64	3.890***	2.571	108	6.602	2.890
Thermal capacity	GW	64	0.928*	1.503	108	0.621	1.115

Panel B: Solar

		Control groups (south=0)			Treatment groups (south=1)		
	Unit	Obs	Mean	Std.dev.	Obs	Mean	Std.dev.
Solar facility production indicators							
Solar capacity	MW	96	14.17	30.77	162	41.72	110.93
County characteristics							
Secondary industry output	billion yuan	96	15.72**	16.90	162	10.12	14.46
Elevation	100 m	96	1341	148.5	162	1308	184.4
Slope	degree	96	3.890***	2.564	162	6.453	3.112
Radiation	100 kWh/m^2	96	16.12***	0.179	162	15.52	0.296

Note: Mean value of variables differ with statistical significance in a two-tailed t test between the treatment and control groups, and they are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 4. Effect of FIT on Wind Power Development
(Full Sample, 2009–2012)

	Utilization rate	Wind capacity	Power generation	Operation hour
	(1)	(2)	(3)	(4)
Panel A: Linear Polynomial in Distance with Kernel Weights				
South	8.259***	77.82***	153.1***	151.8***
	(1.781)	(17.70)	(31.59)	(35.77)
Adj. R^2	0.412	0.499	0.471	0.349
Panel B: Quadratic Polynomial in Distance				
South	8.104***	68.77***	134.4***	149.1***
	(1.738)	(20.04)	(35.66)	(37.36)
Adj.R^2	0.453	0.523	0.492	0.368
Panel C: Linear Polynomial in Longitude and Latitude				
South	6.259***	7.307	25.27	87.79**
	(1.723)	(21.14)	(39.16)	(39.04)
Adj.R^2	0.473	0.508	0.469	0.354
Panel D: Quadratic Polynomial in Longitude and Latitude				
South	8.198***	52.22**	107.6***	145.0***
	(1.794)	(21.94)	(39.27)	(40.37)
Adj.R^2	0.493	0.583	0.533	0.379
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	284	284	284	284

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes the geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 5. Effect of FIT on Wind Power Development
(Sample Falling within $\leq$ 80 km of the Boundary, 2009–2012)

	Utilization rate	Wind capacity	Power generation	Operation hour
	(1)	(2)	(3)	(4)
Panel A: Linear Polynomial in Distance with Kernel Weights				
South	12.80***	83.19***	156.2***	177.1***
	(2.463)	(19.80)	(34.42)	(53.20)
Adj.R^2	0.393	0.341	0.319	0.277
Panel B: Quadratic Polynomial in Distance				
South	12.84***	81.10***	154.2***	178.2***
	(2.481)	(19.67)	(33.99)	(53.28)
Adj.R^2	0.399	0.350	0.327	0.278
Panel C: Linear Polynomial in Longitude and Latitude				
South	12.11***	72.66***	145.6***	169.5***
	(2.543)	(21.91)	(43.27)	(62.62)
Adj.R^2	0.378	0.349	0.320	0.277
Panel D: Quadratic Polynomial in Longitude and Latitude				
South	9.810***	61.78***	128.6***	150.7**
	(2.566)	(21.76)	(40.87)	(60.80)
Adj.R^2	0.406	0.356	0.324	0.265
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	172	172	172	172

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 6. Effect of FIT on Solar Power Development
(Full Sample, 2011–2016)

	Explanatory variable: solar capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
South	45.67***	35.69***	59.24***	67.82***
	(14.75)	(12.78)	(16.10)	(19.79)
South×2011	0.278	1.605	1.688	1.580
	(1.253)	(2.276)	(2.269)	(2.290)
South×2013	-7.284*	-9.950**	-10.12**	-9.897**
	(4.071)	(4.282)	(4.289)	(4.313)
South×2014	-11.01	-18.38	-18.67	-18.29
	(13.30)	(14.11)	(14.12)	(14.19)
South×2015	1.865	-8.648	-9.151	-8.494
	(15.47)	(16.48)	(16.51)	(16.56)
South×2016	99.62***	68.75**	68.16**	68.92**
	(37.14)	(33.43)	(33.33)	(33.50)
Cons.	-16.90	-401.9	1778	-16451
	(349.1)	(274.9)	(1250)	(25012)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	426	426	426	426
Adj.R^2	0.234	0.185	0.200	0.207

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 7. Effect of FIT on Solar Power Development
(Sample Falling within $\leq$ 80 km of the Boundary, 2011–2016)

	Explanatory variable: solar capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
South	31.89**	32.46**	30.30*	19.15
	(22.46)	(20.33)	(22.90)	(24.51)
South×2011	-0.693	-0.460	-0.434	-0.401
	(1.662)	(1.870)	(1.699)	(1.520)
South×2013	-2.093	-1.447	-1.639	-1.882
	(4.759)	(4.440)	(4.347)	(4.274)
South×2014	2.086	1.796	1.524	1.180
	(14.93)	(15.86)	(15.85)	(15.66)
South×2015	20.65	20.01	19.47	18.78
	(17.12)	(17.78)	(17.79)	(17.38)
South×2016	146.7***	143.3***	142.7***	141.9***
	(45.84)	(46.59)	(46.55)	(46.25)
Cons.	-468.6	-651.5	-7.192	-19659
	(562.5)	(498.6)	(1557)	(50567)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	258	258	258	258
Adj.R^2	0.292	0.282	0.278	0.281

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.
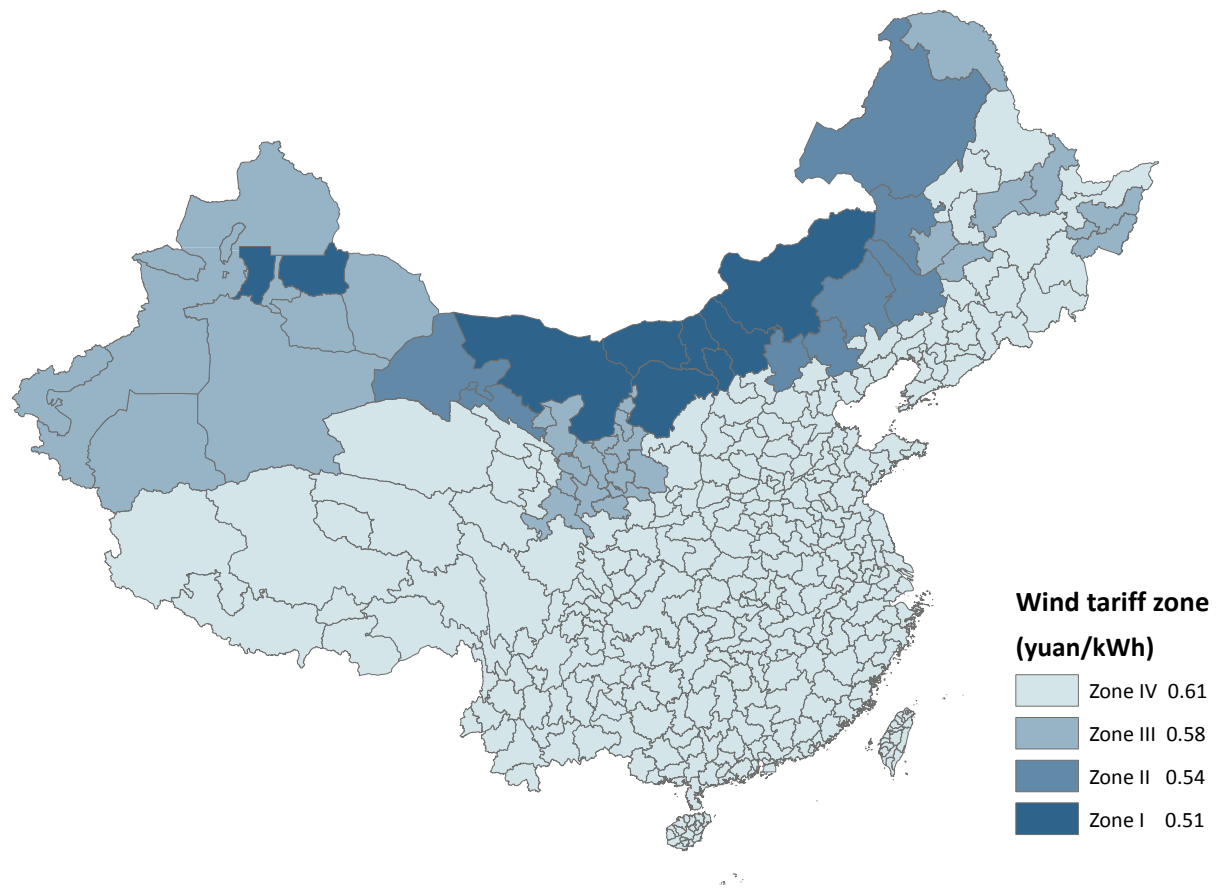
Figure 1: Distribution of wind resource zones and regionally differentiated on-grid wind tariffs in China.
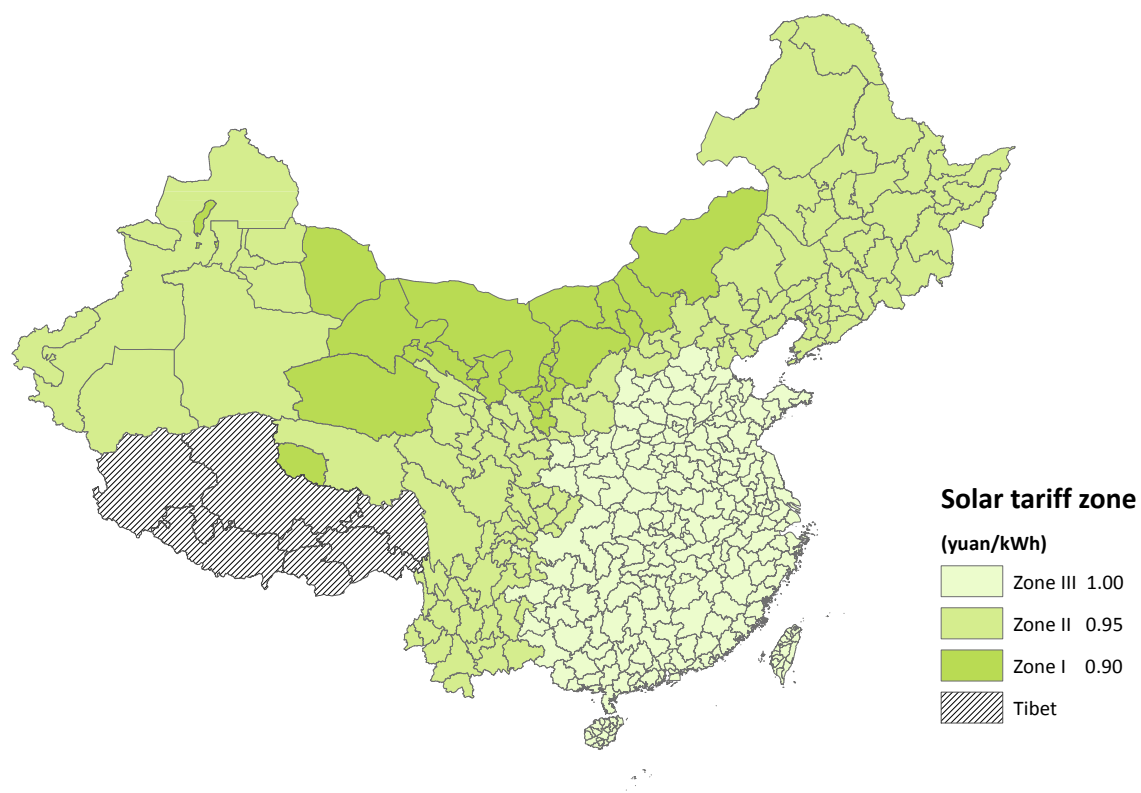
Figure 2: Distribution of solar resource zones and regionally differentiated on-grid solar tariffs in China.
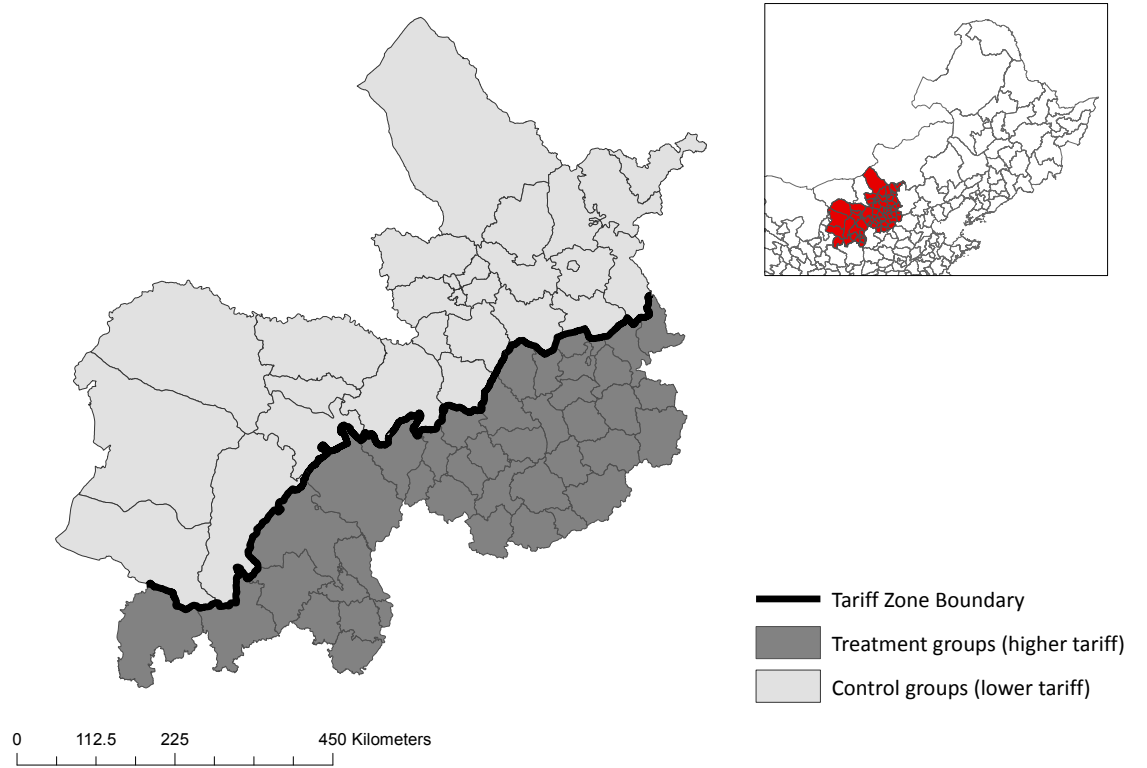
Figure 3: Distribution of the feed-in tariff (FIT) boundary and counties in the study area. Counties located in the south of the FIT boundary contributed to the treatment group and are colored in dark grey *(south=1)*.
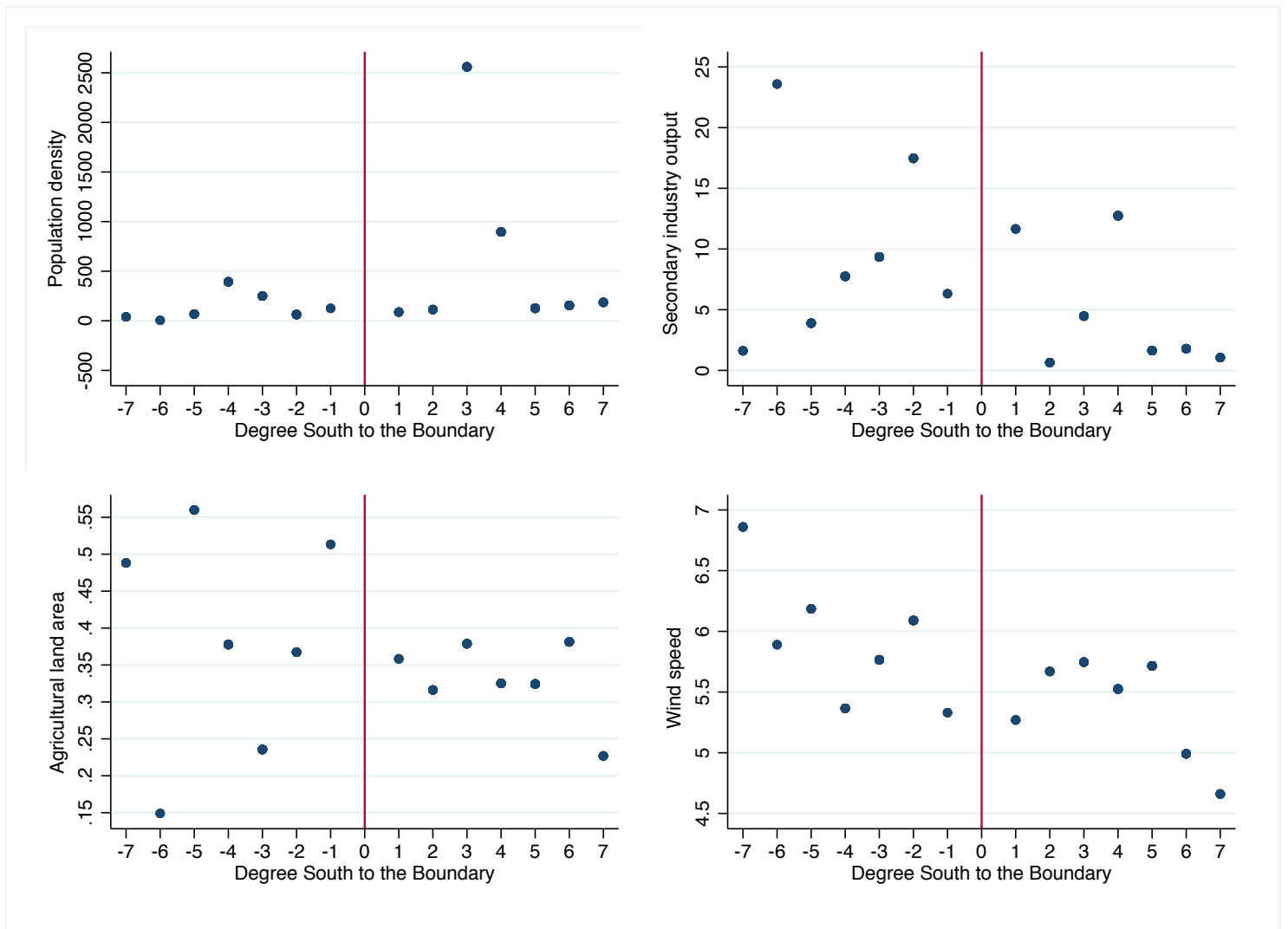
Figure 4(a): Local polynomial smoothing of characteristics by county relative to the distance from the feed-in tariff boundary (wind).
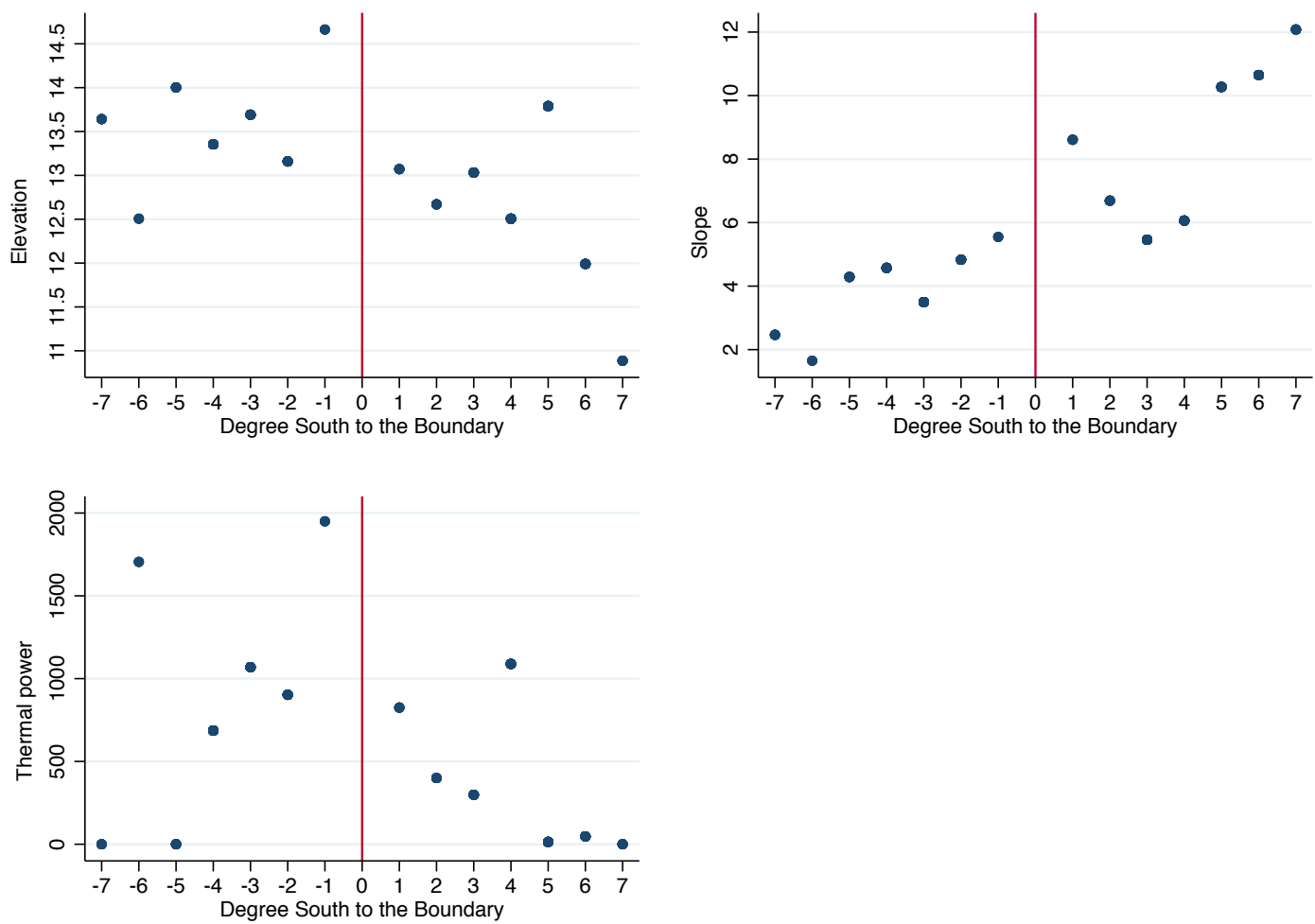
Figure 4(b): Local polynomial smoothing of characteristics by county relative to the distance from the feed-in tariff boundary (wind) - *Continued*
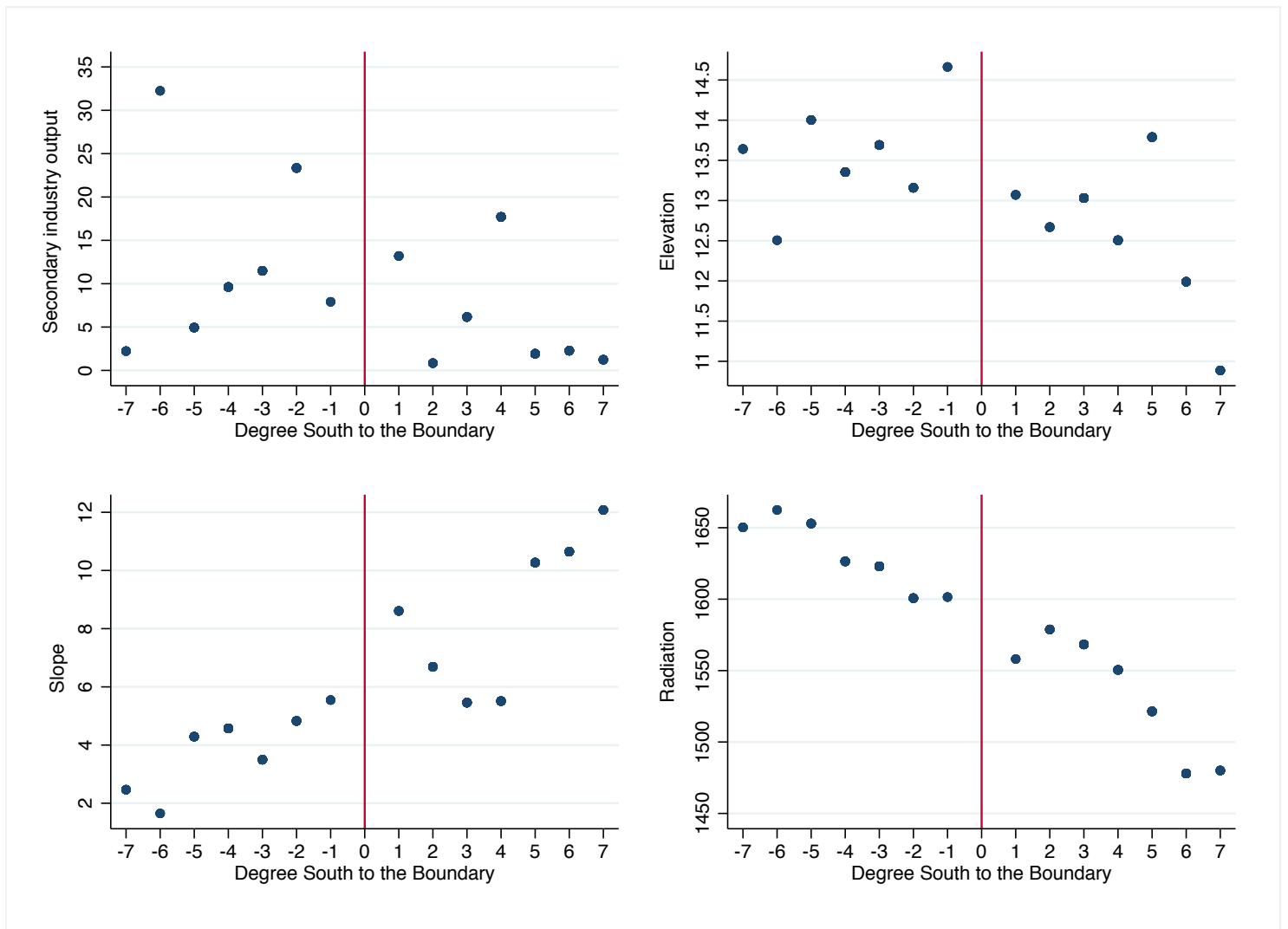
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Figure 5: Local polynomial smoothing of characteristics by county relative to the distance from the feed-in tariff boundary (solar).
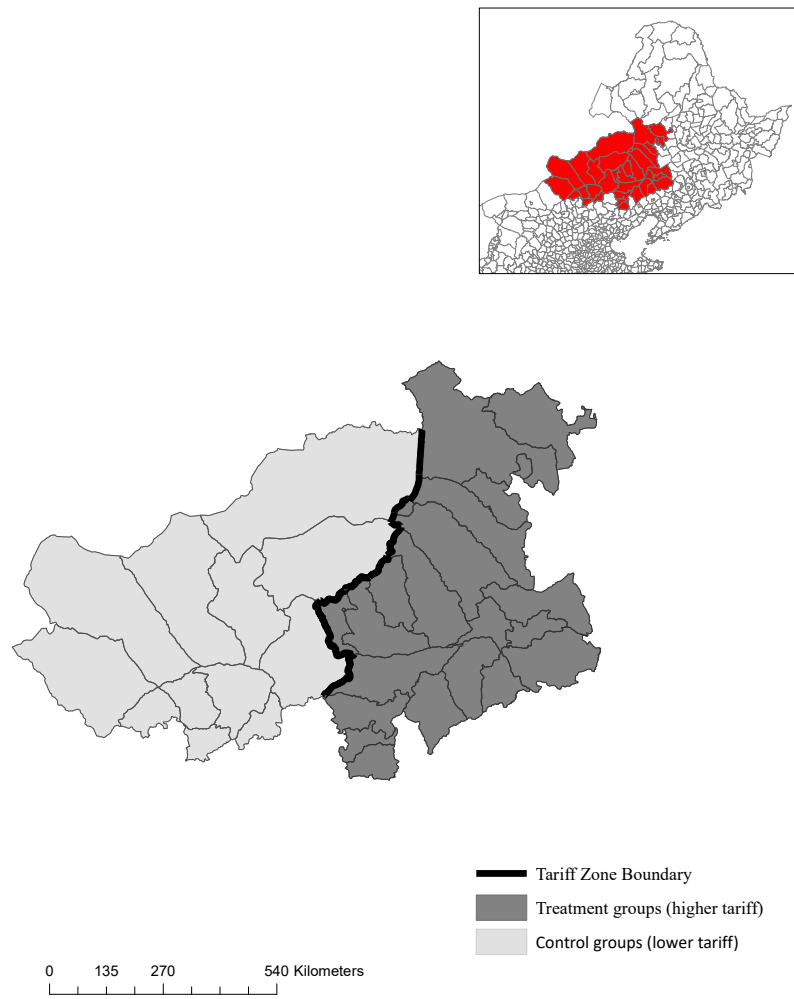
Figure 6: Distribution of the feed-in tariff (FIT) boundary and counties in the Eastern Inner Mongolia Sample. Counties located in the east of the FIT boundary contributed to the treatment group and are colored in dark grey *(east=1)*.
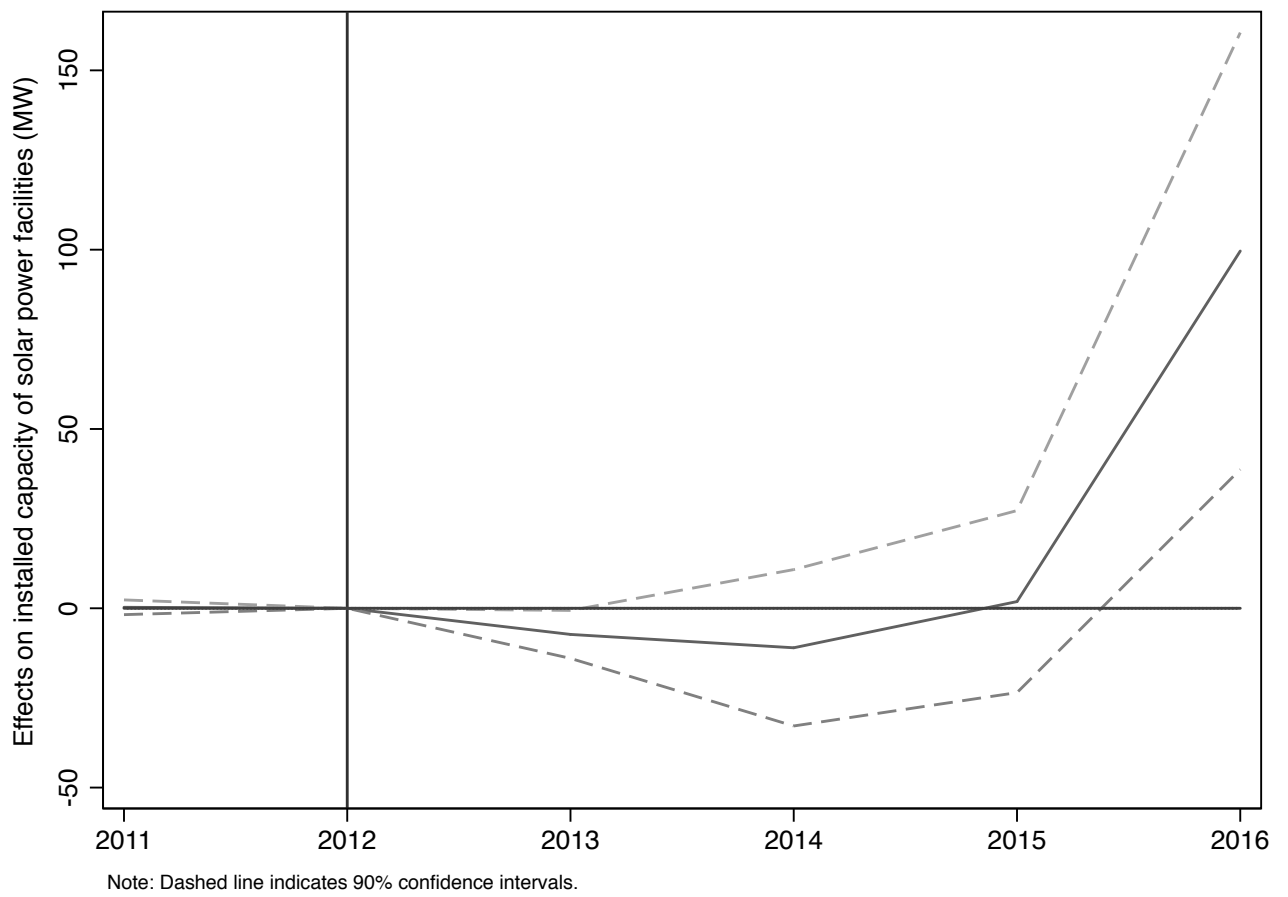
Figure 7: Annual effect of on-grid solar Feed-in Tariffs from the regression discontinuity design and multi difference-in-differences model.

Appendix

Table A1. Effect of FIT on Wind Power Development (Full Sample, 2009–2012)
– *with regression coefficients for control variables*

	Utilization rate	Wind capacity	Power generation	Operation hour
	(1)	(2)	(3)	(4)
Panel A: Linear Polynomial in Distance with Kernel Weights				
South	8.259***	77.82***	153.1***	151.8***
	(1.781)	(17.70)	(31.59)	(35.77)
Population density	-0.760***	-3.005**	-7.191**	-9.416**
	(0.196)	(1.474)	(3.146)	(4.480)
Secondary industry output	-0.122***	-1.496***	-2.840***	-2.040*
	(0.0420)	(0.480)	(0.936)	(1.127)
Agricultural land area	-0.927	22.12	19.44	4.718
	(1.939)	(23.03)	(45.53)	(58.66)
Wind speed	3.456***	65.33***	125.9***	74.43***
	(0.543)	(14.64)	(30.00)	(25.09)
Elevation	0.585**	5.472*	6.644	9.093
	(0.249)	(2.976)	(5.525)	(6.626)
Slope	-0.486***	-2.652*	-5.996**	-7.245**
	(0.144)	(1.365)	(2.566)	(3.095)
Thermal capacity	-0.352	-1.173	-0.838	-6.431
	(0.354)	(3.441)	(6.445)	(7.965)
Adj. R^2	0.412	0.499	0.471	0.349
Panel B: Quadratic Polynomial in Distance				
South	8.104***	68.77***	134.4***	149.1***
	(1.738)	(20.04)	(35.66)	(37.36)
Population density	-0.709***	-3.016**	-7.211**	-9.441**
	(0.183)	(1.505)	(3.282)	(4.612)
Secondary industry output	-0.128***	-1.614***	-3.063***	-2.229*
	(0.0422)	(0.525)	(1.013)	(1.152)
Agricultural land area	-0.180	19.62	16.51	0.557
	(1.788)	(24.77)	(51.67)	(67.31)
Wind speed	3.408***	68.92***	132.2***	75.02***
	(0.486)	(15.58)	(32.10)	(26.62)
Elevation	0.563**	6.571**	8.907	10.59
	(0.234)	(3.089)	(5.806)	(7.205)
Slope	-0.511***	-3.846***	-8.067***	-8.383***
	(0.131)	(1.364)	(2.618)	(3.068)
Thermal capacity	-0.284	-1.043	-0.638	-5.545
	(0.333)	(3.620)	(6.758)	(7.911)
Adj.R^2	0.453	0.523	0.492	0.368
Geographic location polynomial	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	284	284	284	284

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes the geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A1. Effect of FIT on Wind Power Development (Full Sample, 2009–2012)
– *with regression coefficients for control variables, continued*

	Utilization rate (1)	Wind capacity (2)	Power generation (3)	Operation hour (4)
Panel C: Linear Polynomial in Longitude and Latitude				
South	6.259***	7.307	25.27	87.79**
	(1.723)	(21.14)	(39.16)	(39.04)
Population density	-0.806***	-4.945***	-10.41***	-11.26**
	(0.186)	(1.750)	(3.753)	(4.860)
Secondary industry output	-0.0984**	-1.301**	-2.646**	-1.997
	(0.0417)	(0.564)	(1.077)	(1.220)
Agricultural land area	1.088	49.90*	69.86	33.83
	(1.738)	(25.61)	(52.88)	(69.78)
Wind speed	2.395***	52.73***	105.7***	58.26**
	(0.559)	(14.70)	(30.29)	(25.44)
Elevation	0.793***	9.580***	13.06**	12.52*
	(0.258)	(3.402)	(6.162)	(7.250)
Slope	-0.322**	-0.901	-2.725	-4.103
	(0.136)	(1.380)	(2.656)	(3.122)
Thermal capacity	-0.924**	-13.08**	-21.11**	-18.54*
	(0.369)	(5.329)	(9.704)	(9.500)
Adj.R^2	0.473	0.508	0.469	0.354
Panel D: Quadratic Polynomial in Longitude and Latitude				
South	8.198***	52.22**	107.6***	145.0***
	(1.794)	(21.94)	(39.27)	(40.37)
Population density	-0.841***	-7.002***	-13.68***	-12.84**
	(0.188)	(1.964)	(4.159)	(5.198)
Secondary industry output	-0.0749*	-0.570	-1.380	-1.216
	(0.0430)	(0.492)	(0.978)	(1.266)
Agricultural land area	-0.333	5.351	-7.544	-14.55
	(1.760)	(26.39)	(55.47)	(70.27)
Wind speed	2.483***	49.20***	101.1***	57.25**
	(0.549)	(13.41)	(27.99)	(24.58)
Elevation	0.877***	9.536***	13.95**	14.60*
	(0.256)	(3.404)	(6.467)	(8.379)
Slope	-0.412***	-1.884	-5.078*	-6.579*
	(0.143)	(1.539)	(2.994)	(3.576)
Thermal capacity	-0.748**	-9.913**	-14.76*	-13.20
	(0.358)	(4.565)	(8.520)	(9.296)
Adj.R^2	0.493	0.583	0.533	0.379
Geographic location polynomial	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	284	284	284	284

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes the geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A2. Effect of FIT on Wind Power Development
(Sample Falling within ≤ 50 km of the Boundary, 2009–2012)

	Utilization rate	Wind capacity	Power generation	Operation hour
	(1)	(2)	(3)	(4)
Panel A. Linear Polynomial in Distance with Kernel Weights				
South	11.82***	60.35***	104.3***	109.1**
	(3.619)	(22.71)	(35.63)	(51.22)
Adj.R^2	0.367	0.287	0.256	0.242
Panel B. Quadratic Polynomial in Distance				
South	10.51***	51.31**	88.00**	93.30*
	(3.880)	(23.97)	(34.36)	(49.98)
Adj.R^2	0.374	0.284	0.257	0.241
Panel C. Linear Polynomial in Longitude and Latitude				
South	9.996**	39.43	84.48*	105.2*
	(3.815)	(23.92)	(42.83)	(59.65)
Adj.R^2	0.367	0.283	0.249	0.243
Panel D. Quadratic Polynomial in Longitude and Latitude				
South	10.90***	43.63**	77.20**	95.23*
	(3.507)	(20.02)	(35.84)	(54.28)
Adj.R^2	0.493	0.374	0.316	0.244
Geographic location polynomial	yes	yes	yes	yes
Controls	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	116	116	116	116

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance from the county's government office to the tariff zone boundary, x denotes the longitude, and y denotes the latitude of the county, the linear polynomial in distance is $z + z \times south$, the quadratic polynomial in distance is $z + z^2$, the linear polynomial in longitude and latitude is $x + y$, and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

	Explanatory variable: wind capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
South×2010	84.43***	34.24	35.86	71.73**
	(29.04)	(25.90)	(29.36)	(30.07)
South×2011	76.12**	18.07	19.84	55.37*
	(31.94)	(30.01)	(33.28)	(31.87)
South×2012	86.86***	26.87	28.22	64.32**
	(31.24)	(27.49)	(30.31)	(29.86)
South×2013	84.15**	19.67	21.00	56.85
	(40.64)	(34.82)	(39.37)	(38.57)
South×2014	116.6***	44.83	47.77	84.22**
	(43.82)	(37.23)	(41.93)	(40.65)
South×2015	130.1***	57.27	60.96	96.98**
	(47.81)	(44.27)	(48.40)	(46.85)
South×2016	198.9***	122.3**	126.1**	161.9***
	(59.43)	(53.88)	(59.83)	(57.41)
Cons.	-838.1***	-862.9***	-10834.6***	141750.2***
	(87.79)	(92.30)	(1796.7)	(41773.4)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	568	568	568	568
Adj.R^2	0.427	0.472	0.494	0.526

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A4. Effect of FIT on Wind Power Development
(Sample Falling within ≤ 80 km of the Boundary, 2009–2016)

	Explanatory variable: wind capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
South×2010	-1.802	57.42*	123.5**	14.00
	(44.77)	(31.49)	(52.08)	(42.58)
South×2011	15.88	73.85**	140.1***	30.04
	(44.62)	(31.34)	(52.08)	(41.07)
South×2012	13.42	72.22**	138.9***	28.45
	(46.88)	(33.32)	(53.23)	(40.04)
South×2013	24.26	79.89*	145.2**	34.70
	(55.57)	(42.68)	(60.95)	(46.96)
South×2014	74.40	130.7***	197.1***	86.70*
	(59.98)	(47.89)	(63.52)	(49.60)
South×2015	83.25	144.9**	212.2***	101.6*
	(68.35)	(62.65)	(77.62)	(58.87)
South×2016	160.6**	220.9**	288.2***	177.7**
	(80.57)	(88.14)	(102.1)	(80.81)
Cons.	-677.5***	-750.0***	-9887.8	-331375.6
	(128.2)	(154.1)	(7314.4)	(229940.0)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	240	240	240	240
Adj.R^2	0.315	0.310	0.339	0.393

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A5. Effect of FIT on Wind Power Development
(Sample Falling within $\leq$ 50 km of the Boundary, 2009–2016)

	Explanatory variable: wind capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
South×2010	28.56	231.2**	262.9**	-9.955
	(64.47)	(111.1)	(106.3)	(65.05)
South×2011	61.15	262.2**	293.4***	15.08
	(63.73)	(112.6)	(105.0)	(63.26)
South×2012	115.9*	312.6***	338.4***	50.69
	(67.83)	(117.2)	(109.9)	(66.68)
South×2013	138.0**	335.2***	367.6***	80.82
	(67.69)	(118.0)	(107.6)	(65.49)
South×2014	162.7**	359.7***	391.8***	109.3
	(72.52)	(120.3)	(109.4)	(73.06)
South×2015	129.3	328.5**	361.9***	81.11
	(80.52)	(132.7)	(121.8)	(73.04)
South×2016	196.2**	392.6***	425.4***	143.0*
	(80.76)	(131.6)	(117.2)	(76.39)
Cons.	-1278.1***	-848.8**	15998.2	3522406.1***
	(321.7)	(351.1)	(11161.6)	(885112.2)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	128	128	128	128
Adj.R^2	0.456	0.402	0.418	0.517

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A6. Descriptive Statistics
(Eastern Inner Mongolia Sample)

	Unit	Control groups (east=0)			Treatment groups (east=1)		
		Obs	Mean	Std.dev.	Obs	Mean	Std.dev.
Wind facility production indicators							
Utilization rate	%	48	1.345	1.171	104	0.670	0.944
Wind capacity	MW	48	143.4	249.2	104	168.1	302.6
Power generation	GWh	48	228.5	360.1	104	279.0	541.0
Operation hour	10 hour	48	344.0	440.7	104	226.2	376.7
County characteristics							
Population density	1,000 person/km^2	48	0.012***	0.016	104	0.104	0.146
Secondary industry output	billion yuan	48	35.43**	28.87	104	59.75	67.57
Agricultural land area	10^5 ha	48	0.193***	0.254	104	1.310	0.913
Wind speed	m/s	48	3.683***	0.710	104	3.050	0.628
Weighted average elevation	100 m	48	11.81***	1.537	104	5.938	3.191
Slope	degree	48	2.173***	0.768	104	4.501	2.651
Thermal capacity	GW	48	382.9	898.3	104	250.1	628.1

Note: Mean value of variables differ with statistical significance in a two-tailed t-test between the treatment and control groups, and they are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A7. Effect of FIT on Wind Power Development
(Eastern Inner Mongolia Sample, 2009 - 2012)

	Utilization rate	Wind capacity	Power generation	Operation hour
	(1)	(2)	(3)	(4)
Panel A: Linear Polynomial in Distance with Kernel Weights				
East	2.570***	738.5***	1463.9***	800.0***
	(0.623)	(146.5)	(307.3)	(222.9)
Adj. R^2	0.348	0.292	0.314	0.273
Panel B: Quadratic Polynomial in Distance				
East	2.412***	682.3***	1382.9***	747.1***
	(0.577)	(152.6)	(318.9)	(199.5)
Adj.R^2	0.373	0.256	0.275	0.275
Panel C: Linear Polynomial in Longitude and Latitude				
East	2.856***	718.6***	1473.3***	845.4***
	(0.615)	(177.1)	(356.3)	(229.4)
Adj.R^2)	0.381	0.269	0.292	0.291
Panel D: Quadratic Polynomial in Longitude and Latitude				
East	2.571***	695.5***	1471.5***	806.1***
	(0.569)	(180.7)	(365.1)	(234.1)
Adj.R^2	0.433	0.299	0.315	0.321
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
City fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	152	152	152	152

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes the geometric distance to the tariff zone boundary, the linear polynomial in distance is $z + z \times south$ and the quadratic polynomial in distance is $z + z^2$. If x denotes the longitude and y denotes the latitude of each county, the linear polynomial in longitude and latitude is $x + y$ and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table A8. Effect of FIT on Solar Power Development
(Sample Falling within $\leq$ 50 km of the Boundary, 2011–2016)

	Explanatory variable: solar capacity (MW)			
	Single-dimensional RDD		Multi-dimensional RDD	
	Linear	Quadratic	Linear	Quadratic
	(1)	(2)	(3)	(4)
south	38.19*	17.50	23.32	20.12
	(21.42)	(18.86)	(27.22)	(23.98)
South×2011	-1.797	-1.668	-1.745	-1.685
	(1.738)	(1.669)	(1.781)	(1.804)
South×2013	-3.378	-3.127	-3.077	-3.116
	(6.133)	(5.858)	(5.882)	(5.940)
South×2014	2.280	1.688	1.782	1.709
	(14.28)	(14.03)	(14.10)	(14.22)
South×2015	21.87	20.67	20.88	20.72
	(17.38)	(17.00)	(17.10)	(17.27)
South×2016	146.4***	145.1***	145.4***	145.2***
	(52.65)	(53.55)	(53.85)	(54.28)
Cons.	-782.1	-897.2	-1709	-22978
	(556.8)	(577.3)	(1901)	(44733)
Geographic location polynomial	yes	yes	yes	yes
Control	yes	yes	yes	yes
Segment fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	174	174	174	174
Adj.R^2	0.339	0.332	0.328	0.320

Note: Robust standard errors, adjusted for clustering by county, are in parentheses. If z denotes geometric distance from the county's government office to the tariff zone boundary, x denotes the longitude, and y denotes the latitude of the county, the linear polynomial in distance is $z + z \times south$, the quadratic polynomial in distance is $z + z^2$, the linear polynomial in longitude and latitude is $x + y$, and the quadratic polynomial in longitude and latitude is $x + y + x^2 + y^2 + xy$. Coefficients that are significantly different from zero are denoted by * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$