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Evaluating the economic impact of wind power development on local economies in China

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ABSTRACT

Given that wind power has received so much public financial support, it is important not only to understand its overall impact but also who receives the benefits and who bears the costs. One important aspect is to quantitatively evaluate the potential impact of wind power development on local economies. This study conducts an *ex post* econometric assessment of the effect of wind power installation on local economy in China, using a national county-level dataset between 2005 and 2011. We find that installed wind power capacity has a small and statistically significant positive effect on GDP but negatively affect local fiscal income. Based on our results, an additional 1 MW wind power installation (per capita) would bring 2246 RMB increase in GDP per capita over the year 2005 and 2011. The annual benefits is about 321 RMB ($45)increase in GDP per person, which is much lower than the estimates for U.S. case. We further explore why China's wind power development did not benefit local economy as much as the case of U.S.

1. Introduction

Many countries have increased efforts to promote deployment of renewable energy. Currently 164 countries have set national renewable energy development targets accompanied by favorable policies (International Renewable Energy Agency (IRENA), 2016a, 2016b). Even with declining costs and improved reliability (International Energy Agency (IEA), 2016), the rapid development of wind power is mostly driven by favorable governmental policies. The argument that renewable energy can stimulate economic growth and create jobs in addition to contributing to energy independence and mitigating climate change is often used to justify governmental support. For example, during the 2008 financial crisis, the U.S. government offered $21 billion in direct financial support for renewable energy, included in the economic stimulus package (Mundaca and Richter, 2015). Similarly, Yang et al. (2010) estimated that the Chinese government provided $14 billion in direct investment for alternative energy. These economic recovery packages are expected to stimulate green economic growth, create jobs or support low-carbon economies. IEA estimated that global renewable energies received $121 billion in a single year in 2013 (IEA, 2014).

Given that wind power has received so much public financial support, it is important not only to understand its overall impact but also who receives the benefits and who bears the costs, which can help policy makers make more informed and targeted decisions. One important aspect is to quantitatively evaluate the potential impact of wind power development on local economies. It is argued that wind power development not only directly benefits local economies through wind turbine production and wind farm construction, but also provides indirect benefits by increasing demand for supporting industries and inducing reinvestment and spending by direct and indirect beneficiaries. Studies estimating the potential direct, indirect, and induced impact of wind power often produce significantly positive benefits of wind power development.

However, most of these studies are *ex ante* analysis employing input-output methods and ignore the negative side of wind power development. In fact, wind power development can have both positive and negative effects on local economies. At least three negative effects exist. First, there may be economic losses associated with the displacement of other energy sources or land uses. Second, wind power investment can have a crowding-out effect on other industries, especially when the development is largely dependent on limited public funds. Third, there are concerns that wind farms may have a detrimental effect on local residential property prices. The opportunity costs of wind power development may be high enough to cancel out its positive effects on local economies. Therefore, the economic development potential of wind power needs to be carefully evaluated.

In this paper, we aim to examine whether and how wind power

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development affects local economies in the case of China. China is representative because its installed capacity reached 145 GW in 2015 and now ranks first in the world, representing more than one-third of the world's total installed capacity. The Chinese government has a target of further expanding the installed capacity to 200 GW by 2020 (State Council, 2014). Building on existing studies and employing a method similar to that used by Brown et al. (2012), we first econometrically assess the effect of wind power installation on local GDP and fiscal income in China, using county-level data. Interestingly, in contrast with the U.S. experience, which shows that wind power development can generate significant contributions in terms of GDP growth and fiscal income to local economies (Brown et al., 2012; De Silva et al., 2016), we find that in China wind power development has a much lower impact on local GDP and negatively affect the local fiscal income. We further explore the possible reasons why wind power development in China does not benefit local economies as much as the case of U.S.

Our work makes several contributions to the existing literature. First, it helps the public discussion of renewable energy supporting policies by evaluating the economic impact to local residents, who are important stakeholders and directly affected by the deployment of wind farms. Second, as far as we know, it is the first study evaluating the local economic impact of wind power development in China, which is the largest developing country and the country with the most wind power installation. Third, although it may need more evidence, our research results show that the resource curse phenomenon may not only happen with conventional energy but also with renewable energy.

The paper is organized as follows. Section 2 reviews previous studies measuring the local economic impact of wind power development, as well as the characteristics of China's wind power development. Section 3 presents the methods and data used in this study and the estimation results; Section 4 compares our estimate with previous studies focusing on U.S.; and Section 5 provides a summary of conclusions and a discussion of policy implications.

2. Literature review

2.1. Measuring the economic impact of wind power deployment

The argument that renewable energy can stimulate economic growth and create jobs is often used to justify governmental support. There have been many studies estimating the economic impact of increased renewable energy use at various geographical scales. IRENA (2016a, 2016b) employs a macro-econometric model (E3ME) to simulate a scenario which doubles the share of renewables in the final global energy mix in 2030 and finds that it leads to an increase of global GDP of between 0.6% and 1.1%. Positive effects on economies are also found for countries and regions, including the U.S. (ICF International, 2015), European Union (European Commission, 2014), Germany, OECD countries, etc. (Lehr et al., 2012; Blazejczak et al., 2014; Böhringer et al., 2013; Inglesi-Lotz, 2016).

The impact of wind power development on local economies is particularly interesting given that wind resources are often abundant in economically less-developed regions, such as the central U.S. and Northwestern China (De Silva et al., 2016). The idea of generating electricity with wind and stimulating local economies at the same time seems to create a win-win scenario. However, as we argued above, whether the deployment of wind power can contribute to local economies needs to be carefully evaluated.

Three methods have been used to evaluate the local economic impact of wind power development. The first is a project-level assessment of a particular project (e.g., Pedden, 2006). It is essentially a case study method, which suffers from many problems, such as lack of representativeness, underestimates of the impact by only including the direct benefits and costs, or sensitivity to the parameters.

Another commonly used method is the input-output method, which classifies these impact as direct, indirect, and induced impact. Direct impact include the increased income and employment resulting from spending on development, construction, and operation of wind farms. Spending on wind projects also has indirect impact through multiplier effect that are driven by the increase in demand for goods and services from direct beneficiaries. Finally, induced impact result from reinvestment and spending by direct and indirect beneficiaries. For example, Lantz (2008) estimated that the construction and operation of 1000 MW of wind power in Nebraska could create 300–600 job opportunities and $900–1700 million in economic impact, including economic output, land leases and tax payments. Similar positive benefits are found by Torgerson et al. (2006), Lantz and Tegen (2008, 2009), Reategui and Hendrickson (2011) and Reategui and Tegen (2008).

However, wind power development can affect local economies in both positive and negative ways. The input-output method adopted by many studies usually accounts for only positive impact and ignores the opportunity costs of wind power development. As we argued above, at least two types of opportunity costs should be taken into account: the costs associated with the displacement of other energy sources or land uses and the costs of public funds invested in wind power development instead of other industries. An *ex post* econometric analysis can serve as a better approach because both the local economic costs and benefits of wind power development are likely to be reflected in measured changes in outcomes such as employment and income (Brown et al., 2012). Not only the positive impact measured in input-out models but also any substitution and displacement effects can affect overall economic performance.

There are very few existing studies evaluating the overall economic effects using *ex post* econometric analysis. Two notable studies are Brown et al. (2012) and De Silva et al. (2016). Brown et al. (2012) investigate the partial effects of wind power development on local economic outcomes measured by personal income and employment, using a county-level dataset in the large, wind-rich Great Plains region of the U.S. They find an aggregate increase in county-level personal income and employment of approximately $11,000 and 0.5 jobs per megawatt of wind power capacity installed over the sample period of 2000–2008. De Silva et al. (2016) expand the study to more economic outcomes, including employment, personal income, tax and public goods. They focus on Texas and also find evidence of significant positive benefits, except for employment.

2.2. China's wind power development

As we review above, most studies estimating the impact of wind power development on local economies focus on the U.S. or Europe, with few studies focusing on China, the largest developing country and

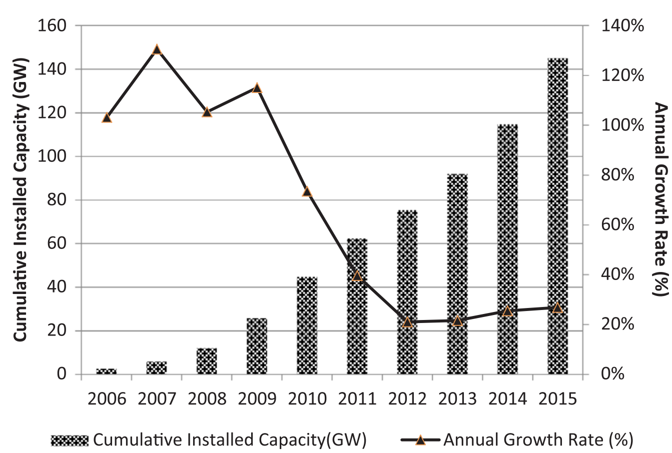

Fig. 1. Annual cumulative installed capacity and growth rate of wind power (2006–2015).

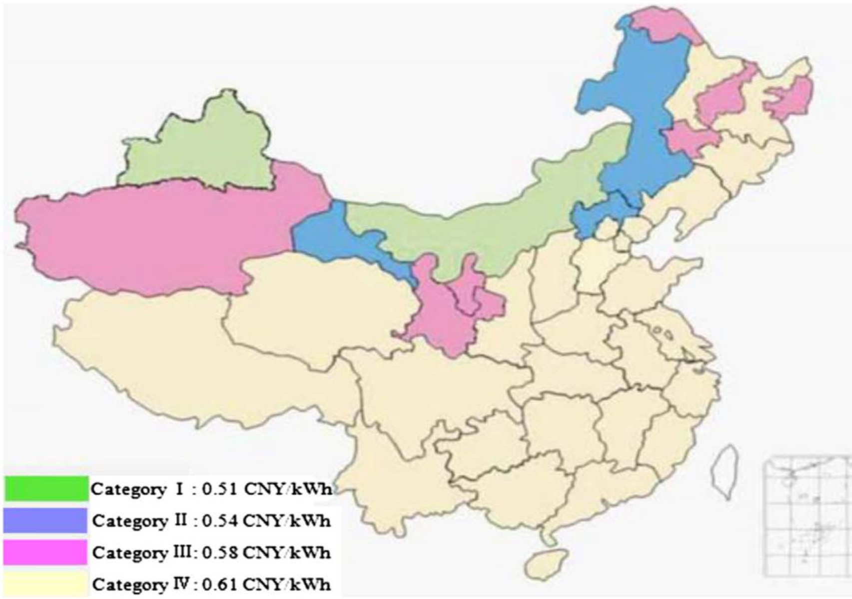

Fig. 2. Benchmark feed-in-tariffs for onshore wind power (Jiang et al., 2011).

the country with the most wind power installation. Wind power development in China began to enter a fast development stage during the 11th Five-Year Plan (2006–10). Installed capacity increased from 2.5 GW in 2006 to 14525 GW in 2015, with an annual growth rate reaching 50% (Fig. 1).

The fast growth of China's wind development is mostly driven by supporting policies. There have been many studies reviewing the supporting policies for China's renewable energy, including wind power (e.g., Liu and Kokko, 2010; Liu et al., 2013; Hu et al., 2013; Zhao et al., 2016); therefore, we briefly summarize here. The Renewable Energy Law approved in 2005 serves as the principal framework for development of renewable energy. Since the 11th Five Year Plan, the central government has set installed capacity of wind power as an obligatory target for every five-year period, accompanied by three major supporting policies. The first type of policy is the guarantee of full purchase. The Renewable Energy Law requires grid companies to purchase the full amount of renewable energy produced by registered producers. The second type of policy is the tax exemption, which we will discuss in more detail in Section 4. The third type of policy is the favorable on-grid price. Between 2006 and 2008, wind tariff rates had been mostly determined on the basis of bidding. In 2009, a fixed benchmark pricing policy was introduced. It divided China's onshore wind resource into four categories, each with a different benchmark tariff (Fig. 2). Regions with rich wind resources have the lowest benchmark price, reflecting lower production costs resulting from higher capacity factors.[1] Because the on-grid prices for wind power are higher than the prices for coal-fired power, the extra cost is subsidized from the Renewable Energy Development Fund, financed by an electricity surcharge.

Partly because of wind resources distribution, and partly because of the supporting policies (Xia and Song, 2016), wind power development in China is characterized by large-scale, centralized development and long-distance transmission. Wind resources in China are distributed very unevenly. He and Kammen (2014) estimate that wind capacity potential varies at the provincial level from less than 1 GW to nearly 600 GW, and that wind conditions are notably favorable over extensive regions of Northwestern China, where the economy is less developed and electricity consumption is low. Fig. 3 illustrates the provincial distribution of the cumulative installed wind power capacity in 2014. Six provinces (Inner Mongolia, Xinjiang, Hebei, Gansu, Liaoning and Heilongjiang) account for over half the wind power capacity. As we can observe in Fig. 4, installed wind capacity tends to concentrate in low-income provinces.

One of the major motivations to build and then manage large wind power farms in northern wind bases is to boost the local economy and increase local income (State Council, 2010). We examine in the next section whether this goal is fulfilled.

3. Identifying impact of wind power development on local economies

3.1. Empirical model

The basic hypothesis that wind power development would benefit local economic development is empirically tested by regressing the changes of the economic outcome variables on the change of installed wind power capacity over the study period with other determinants properly controlled. Thus the regression model is specified as following:

$$\Delta y = \Delta w\alpha + x'\beta + \epsilon \tag{1}$$

where y and w represent the economic outcome and wind power development, x is a vector of variables indicating other important determinants of the economic development, respectively, and Δ stands for the changes in these variables during sample period (2005–2011). The estimated coefficient α is of our main interest and measures the net benefit of wind power development on local economy, which captures its accumulative effects including both construction and operation impact over the sample period. The approach is in line with the more general literature on evaluating the long run impact of the natural resources on regional economy (e.g., Sachs and Warner, 1999; Papyrakis and Gerlagh, 2007) as well as the studies focusing on wind resources (Brown et al., 2012; De Silva et al., 2016).

Two variables common in economic literature – GDP and governmental revenue (both in per capita) – are employed to measure economic development outcomes. Wind power installation per capita is used to represent the wind power development over the sample period. The economic growth theory points out that input factors such as labor, capital and land are important determinants of economic development. We use population (pop) to represent labor as there is no good data on

[1] The capacity factor (CF) defines the fraction of the rated power potential of a turbine that is actually realized over the course of a year given expected variations in wind speed. For example, 20% of CF value for wind farms indicates that a 1.5-MW turbine installed in this region could potentially provide as much as 2.6 GW h of electricity over the course of a year.

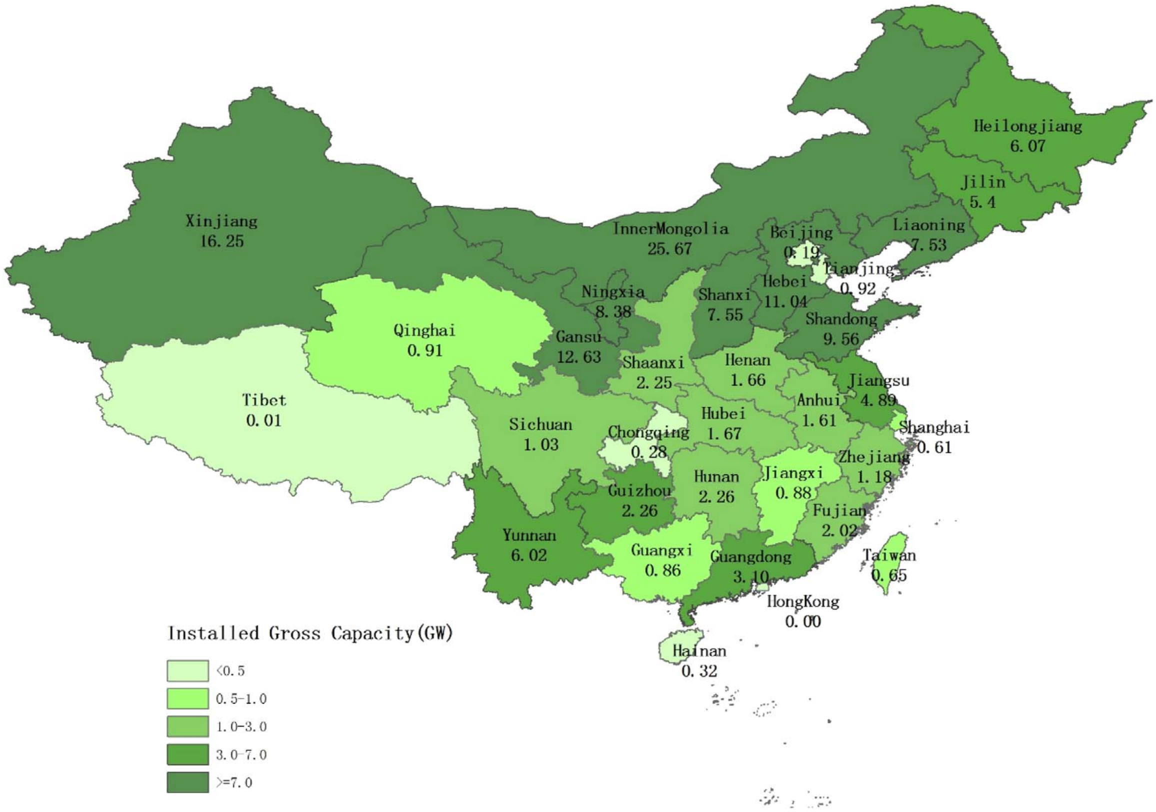

Fig. 3. Provincial installed capacity of wind power in 2015 (in GW).

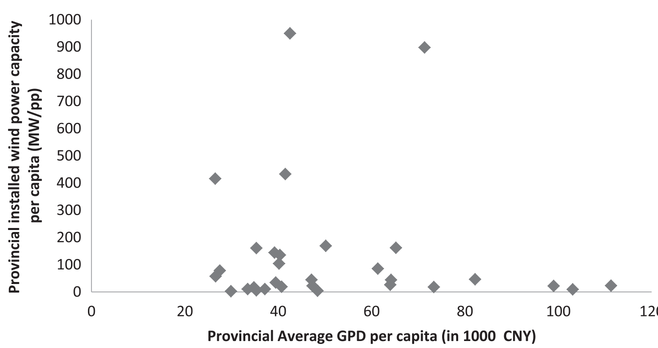

Fig. 4. Economic development and wind resources.

Table 1
Dependent variables and explanatory variables and their notations.

	Notation
Dependent variables	
Changes in GDP/capita between 2005 and 2011	Δy
Changes in fiscal income/capita between 2005 and 2011	Δf
Changes in value added by sectors /capita between 2005 and 2011	$\Delta y_1;\Delta y_2;\Delta y_3$ [a]
Independent variables	
Change in wind power installation /capita between 2005 and 2011	Δw
Change in labor between 2005 and 2011	Δl
Investment/capita between 2005 and 2011	Δk
Change in land/capita between 2005 and 2011	Δland
Change in share of agricultural land between 2005 and 2011	Δag
Change in wind power capacity/capita in neighboring counties between 2005 and 2011	Δnw
Distance to railway	d

[a] 1, 2, 3 stand for agricultural sector, industrial sector and service sector, respectively.

China's employment and labor force at the county level. Capital is represented by two variables, newly formed capital (investment) and the distance to railway (rail). The latter serves as a proxy measure of public infrastructure which is commonly viewed as a particularly important determinant of economic development. In addition, the theory of regional growth often assumes that the growth depends on the initial economic conditions (Carlino and Mills, 1987; Deller et al., 2001; Papyrakis and Gerlagh, 2007; Brown et al., 2012; De Silva et al., 2016), therefore the indicator of initial outcome variables are also included in the regression. Finally, Brown et al. (2012) show that wind power development may demonstrate a spatial effect, that is, a county's wind power development may affect its neighbor's economy. Because we also observe geographic clusters of counties with wind power installations, similar to the U.S, we estimate a spatial model using the weighted wind power installations in neighboring counties as an explanatory variable (*nw*). Neighboring counties are defined as counties within 250 km to guarantee that every county in our sample has at least one neighboring county. The dependent and independent variables are summarized in Table 1.

All variables were taken logarithm except the ones in percentage and monetary values were adjusted to in 2011 RMB value. The double-log specification of the model implies that we assume that the wind power installation shows a decreasing marginal benefit. It is a reasonable assumption because the newly added wind power farms may be less productive for several reasons. First, the later entrant may only take the less windy location due to the limited wind resources. In addition, the wake effect causes the wind passing through a wind turbine to slow down and be turbulent, which negatively affects the productivity of wind turbines behind (Crespo et al., 1999). Second, too many wind farms may cause congestion problem and negatively impact grid stability (Schmidt et al., 2013).

We further explore the channels through which wind power development affects the economy by evaluating the economic impact by sectors, which is measured by the value added increased in each sector as well as the governmental revenue measured by fiscal income over the sample period. As we discussed above, although wind power installation contributes directly to secondary sectors, it may have crowding-out effect on other sectors. In sum, we will estimate five models to evaluate the impact of wind power development on overall economy (represented by GDP), each sector (represented by valued added in each sector) and governmental income (represented by fiscal income).

3.2. Data and estimation strategy

We use county as the unit of analysis to investigate the economic impact of wind power development. There are no official data on wind power capacity at the county level. As an alternative, we aggregate the wind power capacity of wind plants over 6000 kW located in the same county, which is obtained from Electricity Statistics. This can represent over 85% of the country's total capacity. County information such as GDP, land area, population, and investment was obtained from publicly available statistics. Distance to railway is extracted from county and railway maps by calculating the distance between the county center and the nearest major railway. Counties that are in technically infeasible locations for wind power plants are excluded from the sample, such as counties with an average wind power class equal to 1, as well as counties with a population density greater than 1000 people per square kilometer. By doing this, our data include 963 counties and cover the years 2005–2011.

Descriptive statistics in Table 2 show on average a county's per capita GDP increased from 12,405 to 27,363 RMB between 2005 and 2011, with the primary sector, the secondary sector and the tertiary sector contributing about 32%, 45% and 23% of the increase, respectively. The annual fiscal income per capita increased from 547 to 1660 RMB, indicating a higher growth rate than that of GDP during the sample period. The county's average installed wind power capacity increased almost by 37 times, from about 1 MW to 41MW. Investment increased significantly from 1804 RMB per capita to 18,466 RMB per capita while the land hardly changed. The average distance to the nearest major railway is 82 km.

An ordinary least squares estimation (OLS) of Eq. (1) is not proper because it may suffer an endogeneity problem, i.e., the economic outcomes may affect wind power development. For example, people living in areas with rapid economic growth may be more interested in clean energy. Alternatively, wind power development is affected by unobserved factors that also affect changes in GDP or fiscal income. As we discuss above, China's wind power farms are more likely to locate in the Northwestern areas where the economy is less developed. The unobserved factors that hinder the economic development of these regions, such as poor infrastructure, less institutional openness or lack of entrepreneurial capacity may also be related to the development of wind power. Because estimates using OLS could be biased, we use an instrument variable (IV) estimation to address the endogeneity problem. The wind class is used to instrument wind power development because it is the most important determinant of wind farms' potential productivity but is unlikely to be directly related to economic outcomes.

The Kleibergen-PaapWalsrk (KP) test was conducted to determine whether the chosen IV suffers a weak instrument problem, that is, whether the wind class is sufficiently correlated with the wind power development. The KP F-statistics are between 31 and 34 which exceed the corresponding critical values for 10% maximal IV relative bias (16.38), implying that any bias from the two-stage least squares estimates using the instrument is less than 10% of the bias from the OLS regression, with a 5% significance level. In summary, the test results show that the IV has enough strength.

3.3. Results

The IV estimating results for the impact of wind power development on the overall economy (Model 1), each sector (Model 2–4) and fiscal income (Model 5) are presented in Table 3. The coefficient of the wind power installation in Model 1 is positive and significant, suggesting that on average a 1% increase in installed wind power brings a 0.017% increase in a county's GDP over the sample period (2005–2011). To understand the impact more intuitively we put the estimated coefficient into context using an average county with wind power installation increasing from 0.007 kW to 0.24 kW per capita over the sample period. The change of wind power capacity brings about 6% increase in GDP

Table 2
Descriptive statistics.

	2005 No. of Ob. 963		2011 No. of Ob. 963	
	Mean	**S.D.**	**Mean**	**S.D.**
GDP (10 thous. yuan)	406,304	483,280	876,196	1,008,099
GDP from primary sector (10 thous. yuan)	108,490	128,541	252,976	276,368
GDP from secondary industry (10 thous. yuan)	174,403	290,445	376,752	552,967
GDP from tertiary industry (10 thous. yuan)	123,411	148,000	246,468	321,270
Fiscal income (10 thous. yuan)	14,539	18,303	47,438	63,495
Installed power (KW)	1124	7958	41,115	193,452
Installed power for neighboring counties (KW)	918	3205	35,507	91,709
Population (thous.)	358	273	370	290
Administration area (sq. km)	5751	12,102	5745	12,278
Share of land area for agriculture	0.170	0.175	0.191	0.182
Investment (10 thous. yuan)	170,072	200,163	517,735	545,645
Distance to the nearest major railway (km)	82	133	82	133
Wind resource (class 2–11)	3.384	1.620	3.384	1.620
Per capita				
GDP (yuan)	12,405	11,130	27,363	31,540
GDP from primary sector (yuan)	3427	4396	8236	10,338
GDP from secondary industry (yuan)	5225	7075	11,968	19,866
GDP from tertiary industry (yuan)	3753	3940	7158	8421
Fiscal income (yuan)	547	908	1660	2573
Installed power (kW)	0.007	0.059	0.240	1.565
Installed power for neighboring counties (KW)	0.004	0.017	0.279	2.309
Administration area (sq. km)	0.074	0.382	0.065	0.335
Investment (yuan)	4804	6863	18,468	23,822

Note: Monetary values are adjusted to 2011 RMB.

Table 3
IV Estimation results.

	Model 1 Δy	**Model 2** Δy_1	**Model 3** Δy_2	**Model 4** Δy_3	Model 5 Δf
Δw	0.017**	0.024**	0.038***	− 0.010	− 0.024**
	(0.007)	(0.012)	(0.011)	(0.006)	(0.011)
Δl	− 0.874***	0.452**	0.787**	− 1.065***	− 0.792***
	(0.084)	(0.210)	(0.152)	(0.077)	(0.158)
Δland	− 0.033	− 0.033	− 0.023	− 0.013	− 0.210*
	(0.040)	(0.121)	(0.085)	(0.038)	(0.113)
Δag	− 0.018	0.596*	− 0.237	0.096	− 0.926***
	(0.170)	(0.322)	(0.257)	(0.171)	(0.331)
Δk	0.088***	0.061**	0.101**	0.045***	0.177***
	(0.014)	(0.024)	(0.024)	(0.014)	(0.028)
d	− 0.001*	0.038**	0.001	− 0.014**	0.003
	(0.006)	(0.010)	(0.010)	(0.006)	(0.010)
Δnw	− 0.000	0.006**	− 0.002	0.004***	− 0.006***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)
Initial controls	− 0.015	0.206**	0.112**	− 0.023	− 0.086***
	(0.024)	(0.030)	(0.024)	(0.026)	(0.024)
Constant	0.729***	2.362**	1.488**	0.875***	1.527***
	(0.225)	(0.244)	(0.206)	(0.210)	(0.156)
Observations	963	963	963	963	963
R-squared	0.141	0.073	0.163	0.178	0.096
First-stage for Δw					
Wind resource	1.039***	1.062**	1.076**	1.037***	1.029***
	(0.186)	(0.188)	(0.184)	(0.184)	(0.181)
KP Wald F statistic	31.262	31.844	34.128	31.893	32.416
Stock-Yogo: 10% maximal IV size	16.38	16.38	16.38	16.38	16.38

Note: Robust standard errors are reported in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

per capita, or equivalently 667 RMB increase in GDP per capita. During the same time, the average GDP per capita increased by 2.2 times and the contribution from wind power development is about 0.3%, which is rather small.

We expect the wind power development may have asymmetric impact on different economic sectors. Model 2–5 estimate the impact of wind development on the agriculture, industry, service sectors as well as the governmental income, respectively. Consistent with our expectation, it contributes to the industry sector most as a 1% increase brings a 0.038% increase in the value added in this sector. Possible through the land rental income, it also positively contributes to the agricultural sector. The impact on the service sector is insignificant. Interestingly, a 1% increase in installed power reduced a county government's fiscal income by 0.024%. We speculate it is because wind farms enjoyed favorable tax policies, which we will discuss in details in the next section.

Among the determinants of the economic growth and fiscal income, capital is the most important driver as shown by the significant coefficient of the two variables representing capital. A 1% increase in investment translated into growth of total GDP and fiscal income of 0.09% and 0.18%, respectively. The distance to the railway is a proxy variable of public infrastructure. It shows a negative effect on GDP as indicated by the negative and significant coefficient while it shows no effect on the fiscal income. The coefficient of land shows negative effects on GDP (not significant) and fiscal income. One possible reason is that infrastructure is not fully controlled for in our regressions, and larger administrative areas partially capture remote counties with limited access to infrastructure. The small change of the land area per capita over the sample period may also prohibit precisely estimate of the coefficient. As all the dependent variables are measured by per capita value, the negative coefficient of population indicates a decreasing economy of scale of the production function. There is little evidence of spillover effects of neighboring wind power development. Finally, the dependence of growth trajectory on the initial economic conditions is found for fiscal income.

4. Comparison with the U.S. case

We can compare our results of evaluating the impact of wind power development on local economy in China with the results of Brown et al. (2012) and De Silva et al. (2016) who studied U.S.'s cases. Using county level data of 12 states in the Great Plains over the year 2000–2008, Brown et al. (2012) found that an additional 1 MW wind power installation (per capita) would generate $11,000 increase in personal income over the sample period. De Silva et al. (2016) focused on Texas' counties during 2000 and 2011 and estimated that an additional 1 MW wind power installation (per capita) would bring $2658 increase in personal income over their sample period. It means that the annual benefits of wind power development for U.S.'s local economy range from $222 to $1222.

Different from Brown et al. (2012) and De Silva et al. (2016) who used personal income to measure the local economic benefits, we used GDP per capita which is a more comprehensive indicator of local economic development and can be considered as providing an upper limit for the change of personal income. Based on our results, an additional 1 MW wind power installation (per capita) would bring 2246 RMB increase in GDP per capita over the year 2005 and 2011. The annual benefits is about 321 RMB increase in GDP per person or $45 (converted using the averaging exchange rate at RMB7.18/$ between 2005 and 2011), which is much lower than the estimates for U.S. case.

Then it is interesting to explore why China's wind power development does not benefit local economy as much as U.S. The estimation results of Model (2)–(5) show that wind power development positively contribute to the agricultural and industrial sectors but negatively affect local fiscal income. The two most important taxes for local government are income tax and value added tax (VAT). Wind farms enjoy full exemption from income tax for the first three years of operation

Table 4
Wind power tax policy in China.
Source: Liu et al. (2015)

Types of tax	**Tax rate**	**Tax base**
Income tax	Full exemption for the first three operation years, and half exemption for the second three operation years, otherwise 15%	Taxable income
Value added tax	17% with 50% exemption	Deduction from annual income of intermediate costs and fixed assets investment
Property tax	1.2% with 30% exemption	Land and building assets (about 10% of total investment)
Land use tax (yuan/m^2)	2 yuan/m^2 for non-cultivated land; or 12 yuan/m^2 for cultivated land	Occupied area (lump sum)
Urban construction tax	0.05	Payable value added tax
Education surcharge (central government)	3%	Payable value added tax
Education surcharge (local government)	1%	Payable value added tax

(Table 4) and then half exemption for the second three years. The 2009 VAT reform allowed deduction of newly purchased equipment such as wind turbines. Given the high initial investment and low operation costs of wind power projects, the deduction of the VAT substantially decreased VAT payments from developers to local governments during the early years of operation. In addition, because most of the wind farms are invested in by large state-owned enterprises, which mostly do not register locally, local governments lack tax jurisdiction, causing tax collecting uncertainty.

In contrast, local governments in the U.S. can collect property tax payments from wind power operators and thus greatly increase their taxable property base, although counties may impose different tax rates. Both *ex ante* and *ex post* analysis show wind farms in the U.S. make important contributions to the local economy. For example, Lanz (2008) estimates that wind farm operators in Nebraska pay $3648/MW per year to local governments. Based on the tax records, Ferrell and Conaway (2015) estimate that wind farms in Oklahoma paid $134 million in ad valorem taxes to local governments over the period 2004–2014. De Silva et al. (2016) find that wind power development has positive and statistically significant contribution to local property tax revenues in Texas.

Another reason to explain why China's wind power development does not benefit local economy much compared to the United States may be related to the fact that China has a very high wind power curtailment rate while U.S. consistently has an edge in terms of utilization of its wind turbines. The national average curtailment rate reached 17% in 2012, and steadily dropped to 8% in 2014, but came back to 15% in 2015. As the installed capacity expands, a rough estimate of the unrealized potential revenue increases from 1408 million RMB to 17,289 million RMB.[2] Almost all under-utilization happens in North and West China. The curtailment rates in Gansu, Jilin and Xinjiang were as high as 39%, 32%, 32% in 2015, respectively, which can be translated to 4182, 1377 and 3570 million RMB revenue loss to local economies, respectively (Table 5).

The causes of wind power curtailment in China are manifold. A detailed discussion of the root causes of the curtailment is outside the scope of our paper, but is the focus of several studies (Zhao et al., 2012, 2016; Xiong et al., 2016), to which interested readers can refer. There exists a geographic mismatch between wind power demand and supply. The imbalance in the distribution of wind power installation and power load centers means that local load demand usually does not align with local wind generation capacity, and the wind power needs to be transmitted to Eastern China in order to be utilized. As a result, the use of vast amounts of electricity generated from wind depends on wind power transmission across provinces or regions (Zhao et al., 2012), which in turn faces two major obstacles. First, the transmission across regions is constrained by both lack of physical transmission lines and lack of incentives for inter-province/region trade. Second, grid construction lagged far behind the rapid growth of wind power capacity due to coordination problems between grid companies and wind farms. Meantime, the current regulatory structure creates obstacles for power trade between provinces (and between regions). Although around 90% of electricity transmission is provided by two state-owned companies, the provincial grid company is the major entity for power operations and dispatching. Most dispatch decisions are made on the basis of balancing production and consumption within a single province; thus, a province usually prioritizes utilizing the power generation capacity inside its border. Moreover, the feed-in-tariff for wind power is much higher than for conventional power sources, which creates little incentive for grid companies to source wind power outside of the province (Zhao et al., 2012).

[2] We assume an electricity rate of 0.51 RMB/KWH, which equals the feed-in-tariff for wind power in the type I wind resource area.

Table 5
National wind power generation loss in selected regions, 2009 and 2015.

	Generation loss (GW h)		Share of generation loss as % of wind generation		Unrealized potential Revenue (Million RMB)	
	2009	2015	2009	2015	2009	2015
Xin Jiang	0	7000	0%	32%	0	3570
Jilin	194	2700	9%	32%	99	1377
Gansu	181	8200	14%	39%	92	4182
Heilongjiang	113	1900	7%	21%	58	969
Liaoning	23	1200	1%	10%	12	612
Hebei	264	1900	10%	10%	135	969
Inner Mongolia	1986	9100	19%	18%	1013	4641
National	2761	33,900	10%	15%	1408	17,289

5. Conclusion and policy implications

Globally, great efforts have been made to transition to a low-carbon economy. It is optimistically forecast that wind power could reach a total installed global capacity of 2000 GW by 2030, supplying up to 19% of global electricity (Global Wind Energy Council, 2016). While the dramatic development of wind power is fundamentally driven by ambitious energy transition goals and requirements of serving national energy strategies, an important question is how wind power development can contribute to local economies. While many analyses exist for developed countries such as the U.S, there are surprisingly few studies focusing on developing countries.

The aim of this paper is to empirically estimate the expected economic impact of wind power development in China, which is the largest developing country and is experiencing dramatic growth in the utilization of wind resources. We examine the effect of installed wind power capacity on economic growth and fiscal revenue between 2005 and 2011, using a national county-level dataset. We find that installed wind power capacity has a small and statistically significant positive effect on GDP. The distribution of the benefits differentiate by sectors as we expected. Specifically, wind power development positively affects agricultural and industrial sectors but negatively affects the fiscal income.

The idea that utilization of renewable energy can achieve double dividends (environmental benefits and local economic benefits) is very tempting because many renewable resources are located in less-developed regions. Both the U.S. experience and China's experience shows that the wind power development can achieve the co-benefits in reality. In addition, due to China's serious underutilization of installed wind power, there exists large potential to enhance the contribution of wind power development to local economy.

It is also worth noting that the distribution of the benefits may also affect local acceptance of renewable energy. It has been reported that in late 2015 local authorities in Xinjiang, Gansu and Yunnan took actions against wind power, including squeezing their production quotas and cutting prices.[3] Social conflict around wind farms is not unique to China; it also has been found in the U.K. and Germany (Toke, 2002; Cowell et al., 2011). To enhance the social acceptance of wind power development or renewable resource development more generally, public policies should be designed to increase benefit flows to local residents. In China's case, we suggest changing tax policies and leaving more tax revenue with local governments. As wind turbine costs

[3] In December, authorities in Xinjiang squeezed production quotas of wind, solar and hydro power producers; levied an extra fee on them; and used the revenue to subsidize coal-fired power plants, the CWEA said. The Gansu government cut the price paid by the state-run operator of the local grid when buying 1 W of electricity from a wind power generator by 40–75%. In November, authorities in Yunnan tried to slap an extra surcharge on wind and hydro power producers and to use the revenue to subsidize underperforming coal-fired plants.

continue to drop, tax exemptions for newly constructed wind farms can be removed. In the long run, renewable energy, including wind power, should be encouraged to participate in the generation market with competitive pricing. Because the marginal cost of wind power is close to zero, it can provide lower electricity costs to load users. This may help attract energy-intensive sectors to relocate to these less-developed regions and may stimulate the local economy.

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