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The Effectiveness of the Government Subsidies on the Photovoltaic Industry--Spatial Econometric Analysis Based on China's Provincial Panel Data（2011-2018）

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Abstract
Energy resources are important sources of social and economic development, human survival and security. However, energy resources are objective and scarce, especially the fossil energy, such as coal, oil, natural gas, etc. Human survival environment is increasingly damaged, and the condition of energy is also gradually becoming deficient, so it is necessary to develop new energy resources to meet the increasing demand of material civilization. Solar energy can meet the needs of human development in the future as a kind of clean resource and it has been concerned by all countries in the world. We analyzed the effectiveness of subsidies to the PV industry of both the price and R&D by the spatial econometric model. In some region, the production capacity of photovoltaic industry has shown a significant spatial agglomeration situation in China since 2012. At the same time, benchmarking price and R&D subsidies played a positive incentive to the photovoltaic industry production capacity. It is a certain degree of inverse correlation between the scale of policy subsidies and the resource endowment of solar resources. Therefore, the countermeasures should be considered from the aspects of institutions, industry, technology and public financial policies.
Keywords: emerging energy, photovoltaic industry, subsidies

1. Background

Energy resources are important sources of social and economic development, human survival and security. However, energy resources are objective and scarce , especially the fossil energy, such as coal, oil, natural gas, etc. Human survival environment is increasingly damaged, and the condition of energy is also gradually becoming deficient, so it is necessary to develop new energy resources to meet the increasing demand of material civilization. As a kind of clean resource with wide distribution, huge amount, unlimited development and utilization potential, solar energy can meet the needs of human development in the future and it has been concerned by all countries in the world. So far, solar energy is the only source of energy that can guarantee the future of mankind. Based on the current technology level, the potential scale of solar energy can reach 120000TW, while the actual recoverable resource is 600TW. What's more, solar energy is safe, universal and clean. At present, the way of using solar energy to generate electricity is mainly represented by photovoltaic power generation, that is, solar energy can directly convert light energy into electric energy by using photogenic volt effect of semiconductor interface. Photovoltaic power mainly reflects three aspects. First, it can provide power for occasions without electricity. Second, solar energy can produce daily electronic products. Third, photovoltaic power can be used in grid-connected systems.

Because of its characteristics, photovoltaic power generation has developed rapidly and it has become an indispensable part of the industrial development. Due to the high cost of photovoltaic power generation and the long cycle of return on investment, the industry will face a large development bottleneck in the initial period without relevant subsidies for photovoltaic power generation.

In recent years, as the world's fastest-growing economy with large energy consumption, China has been looking for alternative energy resources. Data shows that China's total energy use reached 4.64 billion tons in 2018, ranking first in the world, of which coal resources accounted for 59% of total energy consumption. At the same time, the consumption of natural gas, hydropower, nuclear power, wind power and other clean energy accounted for 22.1%. Relevant Chinese authorities have paid more attention to the transformation of energy resources development and utilization. In 1995, the State Economic and Trade Commission, the State Science and Technology Commission and the State Planning Commission formulated ''Outline of Development for New and Renewable Energy". And the government issued the "Renewable Energy Law of the People's Republic of China" in 2005, which defined the strategic position of renewable energy by legislation, including solar energy resources. At the same time, it marks that exploitation and utilization of renewable energy such as solar energy resources has entered a new stage of development [1]. Most of the regions with abundant solar energy resources in China are concentrated in Xinjiang, Gansu and other provinces in the west. Developing photovoltaic industry in these regions is also conducive to promoting economic and social development in backward areas and achieving photovoltaic poverty alleviation. Since the 18th National Congress of the Communist Party of China, the importance of developing and utilizing new clean energy has been increasing year by year. The report of the 19th National Congress further pointed out that "the development of clean energy is an important task for improving energy structure, ensuring energy security and promoting the construction of ecological civilization". It can be predicted that the future development trend and path of photovoltaic industry will become clearer. We made an empirical analysis on the policy subsidies and other related issues in the development of China's photovoltaic industry at this stage. And finally we proposed relevant countermeasures to further promote the development of photovoltaic industry.

The significance of this paper to study the implementation effect of photovoltaic power generation industry policy is as follows: studying photovoltaic policies has a positive effect on the healthy development of the photovoltaic industry. China's photovoltaic industry has only one dozen years of development history. It has a late start, little experience, and has not yet formed a sound industrial chain. Compared with developed countries, the photovoltaic industry development time is short, and experience is lacking. At the same time, the policy implementation model needs to be optimized and improved. Through empirical research, this paper drew the results of different types of financial subsidy policies on the photovoltaic industry, and we finally gave corresponding suggestions on the direction of policy development, providing a new perspective for industrial policy reform.

2. Literature Review

Objectively speaking, the theoretical and policy research on photovoltaic industry in foreign countries is earlier than that in China. Some literatures have systematically combed this. Joel West [2] divided the history of American photovoltaic producers in California into

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three stages, namely the niche market in the 1950s and 1960s, short-term policy-guided photovoltaic power generation in the 1980s, and the Photovoltaic Renaissance driven by venture capital from Silicon Valley in the 21st century. Federica Cucchiella and Idiano D 'adamo [3] pointed out that photovoltaic power generation is developing at an amazing speed in the global scale, with the generating capacity increasing from 24GW in 2009 to 138GW in 2013. And it is becoming a strategic industry in various countries around the world.

In recent years, some literatures on the development of China's photovoltaic industry have focused on in-depth analysis of the problems arising from the development of the photovoltaic industry, especially the problem of overcapacity, and they mainly put forward some views based on the theory of market failure and information asymmetry. Wang Hui and Zhang Yueyou [4] consider that the overcapacity in the photovoltaic industry is mainly composed of institutional overcapacity and structural overcapacity. What's more, they think that developing emerging industries with the ideas of traditional industries, excessive investment, imbalance of structure supply and demand directly lead to overcapacity in the photovoltaic industry. Yu Donghua and Lu Yinan [5] put forward the "Government Improper Intervention Theory" to explain why China's strategic emerging industries emerged overcapacity. Xu Feng and Li Yunlong [6] used the SCP paradigm in the theory of industrial organization to analyze the market performance, market behavior, and the market structure of the photovoltaic industry, and summarized the problems facing the development of the photovoltaic industry, which urgently need to be solved by the government. Xiong Yongqing et al. [7] consider that at this stage, strategic emerging industries should focus on developing the domestic market, and it is necessary to shift from external demand to domestic demand, which is a choice based on the realistic environment and actual contribution. Zhu Xiangdong et al. [8] consider that government should pay attention to the characteristics of the green industry, trade environment and conditions in different regions in guiding the photovoltaic industry. Some scholars have pointed out the plight of the development of the photovoltaic industry and proposed corresponding solutions, such as stimulating the domestic market demand for photovoltaic and defining the boundaries of the government's regulatory power. Wang Wenxiang and Shi Yanxin [9] pointed out that the government's economic regulation of the industry should be strictly limited to the fields of information asymmetry and natural monopoly in order to avoid the generalization of regulation and the boundless expansion of government regulatory power.

Domestic and foreign researchers have studied the policy guidance and subsidy of photovoltaic industry from different perspectives. Domestic scholars focus on starting from the demand side and they analyzed the necessity of solar photovoltaic subsidy policies leaning towards the demand side. Shi Zulin and Dai Yixin [10] analyzed the advantages and disadvantages of domestic photovoltaic system in market competition. Guo Benhai et al. [11] indicated that while the coordination degree of photovoltaic industry policy was increasing. At the same time, the intensity of policy was decreasing, so we should take the road of "core technology breakthrough". Yu Lihong and Yu Yihong [12] established the policy system framework based on the balanced development of the industrial chain as the basis for future policy adjustments. Chen Jian and Liu Hong [1] introduced dynamic evolution analytical framework of policy changes by combining with the multiple-streams theory. And they analyzed the long-term constraints, problem drivers and evolutionary path of gradual modification in photovoltaic industry policy changes in China. Su Jun and Zhang Fang [13] indicated that the future development of photovoltaic industry in China depends more on a more rational and prudent policy mix structure. Wang Sicong [14] thought that the new policy of photovoltaic power general subsidy will help reduce "solar abandonment" and it can accelerate the energy transformation. Zhou Dequn et al. [15] constructed evolutionary game model with the government and photovoltaic power generation enterprises as the main players to analyze the influence of technological changes to the equilibrium strategy of both sides of the game. Xiong Yongqing et al. [16] compared the demand side and the supply side. What's more, they analyzed the feasibility and necessity of the financial subsidy moderately

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biased towards the demand side. Lv Dongdong et al. [17] proposed some industrial policy optimization paths, including improving the top-level design, reconstructing the subsidy system and attaching importance to the construction of supporting the policy system. Other scholars studied the performance of photovoltaic industrial policy from a micro perspective. Ye Feiyang and Jia Fansheng [18] examined the policy effect from the perspective of researching the market performance of company stocks before and after the policy was introduced by using the event method. On the other hand, foreign scholars have studied the effect of subsidy policies of renewable energy from a relatively broad perspective. Federica Cucchiella and Idiano D'Adamo [3] evaluated the efficiency of renewable energy power generation policies (such as on-grid tariffs and tax deductions), and they compared the benefits of residential photovoltaic facilities between 2012 and 2014. Finally they concluded that the cost of investment and the incentive mechanism had an effect on returns. Weidong Chen and Huan Song [19] studied the optimal subsidy level of distributed photovoltaic power generation from the perspective of maximizing policy benefits by applying the principal-agent theory. It shows that the policy benefits are directly affected by investor preferences. In addition, they emphasized that the government played an important role in improving the preference level of investors, eliminating asymmetric information and reducing subsidy costs in order to develop distributed photovoltaic power generation. Teresa Grijó and Isabel Soares [20] explored the relationship between technologies of renewable energy (solar photovoltaic) and GDP. They used a fixed-effect panel data model to analyze samples from 18 EU countries. And they found that solar installed capacity increased by 1%, and GDP increased by 0.0248%. The renewable energy power generation increased by 1%, and GDP increased by 0.0061%. At the same time, greenhouse gas emissions increased by 1%, and GDP increased by 0.3106%. Based on the findings of this study, the fixed effects were estimated to be most significant in the Germany, France, Italy, United States and the United Kingdom.

To sum up, from the perspective of the photovoltaic energy and its industrial development, domestic and foreign scholars mainly focus on the development and efficiency of the photovoltaic industry, innovative policies, performance evaluation of the renewable energy and other aspects of in-depth research. In terms of literature research, it can be seen that there is relatively little literature on the impact of subsidies on the photovoltaic industry in the process of policy support for the industry. What's more, the research on the spatial impact of subsidies on the photovoltaic industry is still at its early stages. Therefore, we selected the panel data of 31 provincial administrative units in China from 2011 to 2018 as the research object. And we analyzed the current production capacity and the output efficiency of the photovoltaic industry by constructing a spatial econometric analysis model. In addition, we focused on the analysis of price subsidies of photovoltaic grid benchmarking and R&D subsidies. And on this basis, we put forward some countermeasures and suggestions to further promote the development of photovoltaic industry in China.

3. Research Method

3.1. Research Hypotheses

The research hypotheses proposed in this paper are:

Hypothesis 1: The price subsidy of grid benchmark is conducive to the development of the photovoltaic industry. The benchmark electricity price is based on the country's electricity price during the operating period, and the government implements a uniform pricing policy for new power generation projects based on the average regional cost. The policy basis is to follow the long-term expected reform path of market-based electricity price. The government can adjust the investment structure of electricity, in addition, the government can promote the optimal allocation of resources and the rational flow of capital by formulating and adjusting benchmark electricity prices. The price subsidy of grid benchmark is conducive to the development of the photovoltaic industry. Based on the experience of developed countries, the PV "one machine, one price" pricing method has been changed, and photovoltaics have been incorporated into the construction of laws and regulations for renewable energy generation such as wind, water and biomass. The government gives certain subsidies to promote the optimization of resource allocation and the healthy development of the photovoltaic industry in various regions in China. In order to promote the development of the photovoltaic industry, China has adjusted the benchmark electricity price subsidies on the grid. On August 1st, 2011, the National Development and Reform Commission announced the nationwide unified solar photovoltaic power grid benchmarking electricity price for the first time, stipulating solar photovoltaic power generation projects approved after July 1st, 2011 and approved before July 1st, 2011, but as of 2011 projects that have not been completed and put into operation on 31st December , except for Tibet 1.15 yuan / kW·h, the remaining provinces are 1 yuan / kW·h; 2013-2015 benchmark electricity prices for photovoltaic power generation on the grid are based on subsidies of three types of resource areas, of which, type Ⅰ resource areas including Gansu, Ningxia and other provinces, the online benchmark electricity price is 0.9 yuan / kW·h. The type II resource area mainly includes Beijing, Tianjin, Hebei and other provinces. The on-grid benchmark electricity price is 0.95 yuan/kW·h. The type III resource area mainly includes Shanghai, Jiangsu, Zhejiang and other provinces and the on-grid benchmark electricity prices are 1 yuan / kW·h; in the year of 2016, the on-grid benchmark electricity prices for photovoltaic power generation were adjusted on the basis of 2013. On-grid benchmark electricity prices in type I resource areas were 0.8 yuan / kW·h, 0.88 yuan / kW·h in type II resource areas , and 0.98 yuan / kW·h in the type III resource areas. In 2017, the on-grid benchmark electricity prices of the above-mentioned type I, II, and III resource areas were 0.65 yuan / kW·h, 0.75 yuan / kW·h and 0.85 yuan / kW·h, respectively. In 2018, the above-mentioned benchmark electricity prices for the above-mentioned type I, II, and III resource areas were adjusted to 0.55 yuan / kW·h, 0.65 yuan / kW·h, and 0.75 yuan/ kW·h, respectively. However, how efficient is the subsidy? Has it promoted the mid-long term development of the photovoltaic industry? Will it help the photovoltaic industry to achieve equilibrium across regions? The existing literature does not give a clear answer. This paper intends to make a judgment based on quantitative analysis from this point.

Hypothesis 2： The R&D subsidies of photovoltaic industry play a positive role in promoting the development of the industry. Krugman believes that if there are foreign and domestic manufacturers in an industry, both parties are committed to investing in technology to occupy market leadership. However, technological development is spillovers, and new products developed by one manufacturer will benefit another. Therefore, the government is motivated to adopt protectionist policies to support high-tech research and development. Lotzeller and others have the same view, pointing out that policy support for strategic industries is necessary, because technological innovation is essentially risky, and there is an asymmetry between the cost of failure from technological innovation and the dividend of success. In order to make up for this asymmetry, government provides research and development subsidies can effectively play an incentive role. Technology itself belongs to the public products, so it is difficult to trade according to the market principle. When companies invest in the photovoltaic industry, the rate of return of a single company is usually less than the overall rate of return of the society, so companies lack investment motivation. In view of this, in the technology innovation process of the photovoltaic industry, R&D subsidies are a necessary condition to ensure technological progress at least in the early stages of the development for this type of enterprise. In the following part of this paper, we also make a judgment based on quantitative analysis.

3.2. Model and Variable

The development of the photovoltaic industry is affected by multiple factors such as the distribution of solar energy resources, photovoltaic technology, government industrial policies, and level of economic development. Based on this, the model established in this paper is as follows:

$$L\mathrm{nINSTALL}_{\mathrm{i,n}} = \alpha + \beta_1 RD_{i,n} + \beta_2 LnSUBSIDY_{i,n} + \Sigma\beta_{\mathrm{i}} \times Z_{\mathrm{i}} + \varepsilon_{i,n}$$

where i is each province in China, n=1, 2, 3……n is the year, β_1, β_2, β_i is the weight coefficient of each explanatory variable, $\varepsilon_{i,n}$ is the disturbance term. The explanation of the variables in the model is as follows:

(1) These are the explained variables. $INSTALL_{i,n}$ represents the n-th year installed photovoltaic capacity in province i. With reference to relevant literature on the evaluation of the photovoltaic industry policy by Wei Jiabao (2016) and Yang Rui (2014), they generally selected photovoltaic installed capacity or photovoltaic power generation increment as dependent variables. Considering the availability of data, we choose photovoltaic installed capacity as explained variable in order to measure the capacity of photovoltaic production [21].

(2) These are the explanatory variables. At present, China's photovoltaic industry is characterized by "two ends outside", that is, research and development of photovoltaic product (mainly referring to polysilicon materials) depends on imports, and the photovoltaic market demand is abroad. Zhang Meng (2015), Meral M E, and Dincer F (2011) believe that China has few core technologies in this field, so price subsidies on PV grid benchmark electricity and R&D subsidy policies are particularly important to reduce the cost of photovoltaic power generation. Therefore, on the basis of controlling other variables, we select price subsidies on PV grid benchmark electricity and R&D subsidies for above-scale industrial enterprises as variables. $RD_{i,n}$ represents the R&D expenditure of above-scale industrial enterprises in province i in the n-th year, $SUBSIDY_{i,n}$ represents the subsidies for the electricity benchmarking policy in province i in the n-th year.

(3) These are the control variables. Z_i represents a family of control variables, mainly including three cases. First, it is the future potential of the development of the photovoltaic industry. Literature shows that the more developed a region's economy is, the easier it to gather capital, technology, talents and other production factors. So it can drive the flow of factors in the surrounding areas to form an industrial pattern and scale. Therefore, we select the regional GDP (GDP), per capita regional GDP (AGDP), electricity consumption (ELECTRIC), local fiscal general budget income (FISCAL), and energy industry investment (ENERGY) as the potential index to describe the development of the photovoltaic industry. Second, the impact of the photovoltaic industry on economic efficiency is mainly reflected in the consumer and production sides of photovoltaic power generation. From the perspective of the consumer end of photovoltaic power generation, the lower the energy consumption per unit of GDP is, the higher the energy utilization rate is. From the perspective of the production end of photovoltaic power generation, photovoltaic power generation is greatly affected by the weather. The sunshine time and haze are main factors that affect photovoltaic power generation. And the main source of haze is smoke and dust emission. Therefore, we select the energy consumption per unit of GDP (GEC), the electricity consumption per unit of GDP (GPC), the sunshine hours of major cities (SUN), and the amount of smoke (powder) and dust emissions (SMOKE), etc. to measure the efficiency of photovoltaic industry. Third, it is about the policy conditions for developing the photovoltaic industry. The better the environmental quality of a region, the stronger the government 's awareness of environmental protection and responsibility, and the more it has the incentive to develop the photovoltaic industry. As the cost of photovoltaic power generation is much higher than traditional fossil energy sources such as coal, the market competitiveness of photovoltaic power generation will be greatly weakened at least in the short term if there is no policy support. Therefore, we select the local fiscal environmental protection expenditure (ENVIR), the completion investment on exhaust gas project (GAS), the proportion of thermal power generation (FIRE), the green coverage of built-up areas (GREEN), forest coverage (FOREST), sulfur dioxide emissions (SULFUR) and coal consumption (COAL) etc. as the policy conditions to characterize the development of the photovoltaic industry.

(4) After considering the external impacts of the economy, environment, and energy, we performed a logarithmic treatment for each variable in order to effectively eliminate possible fluctuations and heteroscedasticity.

3.3. Data

We selected the data of 31 provincial administrative units in China from 2011 to 2018 as analysis samples. What's more, the data on regional GDP, per capita GDP, electricity consumption, general fiscal revenue of local finances, hours of sunshine in major cities, green coverage in built-up areas, local fiscal environmental protection expenditures, and forest coverage data were from 2012- 2019 "China Statistical Yearbook", data on R&D expenditures of industrial enterprises above designated size were derived from the 2012-2019 "China Science and Technology Statistical Yearbook", energy industry investment, smoke (dust) emissions, coal consumption, and thermal power generation were all derived from the 2012-2019 "China Energy Statistical Yearbook". The thermal power generation amount is equal to the thermal power generation divided total power generation. And the data for the completion investment in treatment projects of waste gas and sulfur dioxide emissions were derived from the 2012-2019 "China Environmental Statistics Yearbook". The data of solar (photovoltaic) installed capacity came from the 2012-2019 "China Electric Power Yearbook ". The energy consumption per unit of GDP is equal to the total energy consumption divided regional GDP, and the electricity consumption per unit of GDP is equal to the whole society electricity consumption divided regional GDP. PV grid benchmark electricity price subsidy is equal to large-scale power station photovoltaic power generation times local subsidy standards. The missing data were smoothed using the geometric average growth rate in order to keep the overall trend.

4. Results

4.1. Descriptive Statistical Analysis

The statistical description of the variables is shown in Table 1.

Table 1. Descriptive Statistics.

Variables	Mean	Standard Deviation	Minimum	Max
Photovoltaic installed capacity （INSTALL）	135.570	231.169	0.0001	1052.000
Price subsidies PV grid benchmarking electricity （SUBSIDY）	10.174	18.962	0.000	88.200
R&D funds for industrial enterprises above designated size （RD）	293.727	384.119	0.164	1865.031
Gross domestic product（GDP）	21966.201	17587.766	605.830	89705.230
Per-capita gross domestic product （AGDP）	50238.991	23517.368	16413.000	128994.000
Electricity consumption （ELECTRIC）	1776.201	1308.160	23.770	5959.000
Local fiscal general budget revenue（FISCAL）	2397.346	1959.696	54.760	11320.350
Investment on energy industry （ENERGY）	925.866	639.905	64.000	3383.000
Energy consumption per unit of	0.813	0.434	0.255	2.584

GDP（GEC）				
Electricity consumption per unit of GDP（GPC）	992.006	653.263	369.232	3448.752
Hours of sunshine in major cities（SUN）	2036.118	573.011	598.400	3162.900
Smoke dust emissions（SMOKE）	40.915	32.666	0.660	179.770
Local fiscal expenditure for environmental protection（ENVIR）	121.571	74.392	16.050	458.440
Completed investment for wasting gas treatment project（GAS）	15.803	17.500	0.004	128.135
Proportion of thermal power generation（FIRE）	0.730	0.264	0.029	0.998
Coal consumption（COAL）	14355.340	10465.790	490.460	42942.290
Green coverage of built-up area（GREEN）	0.388	0.041	0.181	0.491
Forest cover rate（FOREST）	0.317	0.178	0.040	0.660
Sulfur dioxide emissions（SULFUR）	56.182	39.841	0.350	182.740

4.2. Spatial Correlation Test

4.2.1. Spatial Global Autocorrelation

The test of spatial correlation is usually expressed by Moran's I index, and its interval is usually -1≤Moran's I≤1. The larger the absolute value of Moran's I index is, the stronger the spatial correlation is. When Moran's I index is less than 0, it indicates that there is a spatial negative correlation. When Moran's I index is greater than 0, it indicates that there is a spatial positive correlation. When Moran's I index is equal to 0, it indicates that there is no spatial correlation. Table 2 shows the Moran 's I index of solar installed capacity of various provincial administrative units in China from 2011 to 2018.

Table 2. Moran 's I index of solar installed capacity of Chinese provincial administrative units (2011-2018)

Year	2011	2012	2013	2014	2015	2016	2017	2018
Moran's I	0.001	0.145	0.455	0.341	0.318	0.313	0.303	0.297
P value	0.250	0.029	0.004	0.003	0.006	0.005	0.003	0.01

According to Table 2, in 2011, the Moran'I value of solar installed capacity of various provincial administrative units in China was close to 0, and the P value was greater than 0.05. That is to say, it was not significant at the level of 0.05. So there was no spatial autocorrelation for the installed solar capacity of provinces and cities in China in 2011. However, during the period of 2012-2018, P value that based on the Moran's I of solar installation capacity for each provincial administrative unit was less than 0.05, indicating that there was spatial autocorrelation for the solar installation capacity of each provincial administrative unit in China at a 95% confidence level.

In addition, Figure 1 and Figure 2 are Moran scatter diagrams of the installed photovoltaic capacity (INSTALL) of provincial administrative units in 2011 and 2018, respectively. As shown in Figure 1, compared with the scatter plot in 2011, the Moran index of photovoltaic installed capacity in 2018 mainly fell in the first and third quadrants. This means that the more points that fall in the first and third quadrants, the stronger the spatial correlation are. What's more, the figures further verified the test results in Table 2.

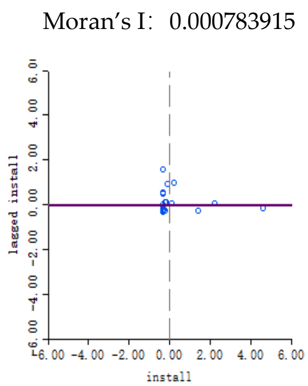

Figure 1. INSTALL Moran scatter plot in 2011

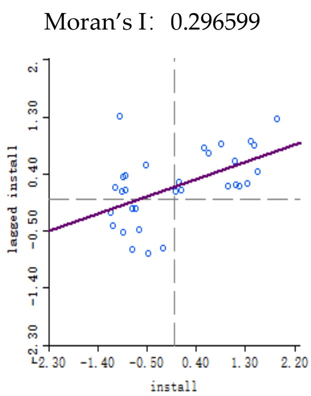

Figure 2. INSTALL Moran scatter plot in 2018

4.2.2. Spatial Local Autocorrelation

In view of the fact that the Moran's I index cannot determine whether the local correlation types and their agglomeration areas in each area are statistically significant, we used GeoDa software to draw the LISA agglomeration map, which is divided into four modes according to the agglomeration situation. Among them, the High-High mode indicates it is a region formed by a high level of spatial distribution of itself, and there are many provinces with high levels of distribution in the surrounding area. The Low-Low mode indicates that the spatial distribution level of itself is low, and some provinces with low levels of distribution are gathered together. The Low-High mode indicates that its own spatial distribution level is low, and some provinces with high levels of distribution are gathered together in the surrounding area. The High-Low mode indicates that its own spatial distribution level is high, and some provinces with low levels of distribution are gathered together in the surrounding area.

Table 3. Spatial distribution pattern of China's photovoltaic installed capacity (2011-2018)

Year	High-High mode	Low-Low mode	Low-High mode	High-Low mode
2011	Gansu	Guangdong and Jiangxi	Xinjiang	——
2012	Xinjiang and Gansu	Guangdong and Hunan	Tibet	——
2013	Xinjiang, Gansu, Qinghai and Ningxia	Guangdong and Chongqing	Tibet	——
2014	Xinjiang, Gansu, Qinghai and Ningxia	Guangdong, Guizhou, Yunnan and Chongqing	——	——

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2015	Xinjiang, Gansu, Qinghai and Ningxia	Guangdong and Hunan	Tibet	——
2016	Xinjiang, Gansu and Ningxia	Guangdong, Guizhou, Yunnan and Hunan	Tibet	——
2017	Gansu, Shandong, Shanxi, Henan, Anhui and Jiangsu	Guangdong, Guizhou, Yunnan	Shanghai	——
2018	Gansu, Shandong, Shanxi, Henan, Hebei Anhui and Jiangsu	Guangdong, Guizhou, Yunnan	——	——

Table 3 shows the spatial distribution of solar photovoltaic installed capacity in China's provincial administrative units from 2011 to 2018. The inspection results show that from a nationwide perspective, there are large regional differences in photovoltaic installed capacity. The installed photovoltaic capacity in Eastern and Northwestern China is relatively high, while the installed photovoltaic capacity in Southern and Southwestern China is relatively low. From the perspective of the spatial agglomeration from time series during the annual interval, most of the provinces included in the four models are relatively stable. Among them, the High-High mode is mainly concentrated in Northwestern China such as Xinjiang, Gansu, and Ningxia. The High-High mode further expanded to the East China after 2017, such as Shandong, Jiangsu, and so on. The Low-Low mode is concentrated in South and Southwest China, such as Guangdong, Hunan, Guizhou, and so on. The Low-High mode mainly refers to Tibet, which also shows that there are large differences in installed capacity between Tibet and surrounding areas. It is also worth mentioning that from 2012 to 2018, the spatial distribution status of High-High mode and Low-Low mode has shown a dynamic trend that gradually spreads to surrounding provinces using the original area as the "gathering point".

In summary, according to the results of the spatial global autocorrelation test, there was no spatial autocorrelation in China's photovoltaic installed capacity in 2011. However, there was a significant spatial autocorrelation during 2012-2018. From the results of the spatial local autocorrelation test, from 2012 to 2018, China's photovoltaic installed capacity showed a significant spatial concentration trend. What's more, the High-High mode is mainly concentrated in the Northwest and East China, while the Low-Low mode is concentrated in South and Southwest China.

4.3. Goodness-of-fit Test

The model selection of the fitting degree between the variables of the spatial econometric model is generally carried out through several criteria such as Log Likelihood, Schwarz Criterion, and Akaike Info Criterion in order to do the comprehensive judgment. In general, the larger the Log Likelihood value is, the better the model's fit. The smaller the values of the Schwartz criterion and the Akaike criterion are, the better the model's fit.

Table 4. Goodness-of-fit Test

Year	Model Type	Log Likelihood	Akaike info Criterion	Schwarz Criterion
2012	Spatial Lag Model	-0.060	40.120	70.648
	Spatial Error Model	3.352	31.295	60.296
2013	Spatial Lag Model	-15.623	71.246	101.773
	Spatial Error Model	-7.857	53.714	82.714
2014	Spatial Lag Model	-9.915	59.831	90.358

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	Spatial Error Model	-7.796	53.591	82.592
2015	Spatial Lag Model	-3.247	46.495	77.022
	Spatial Error Model	1.997	34.006	63.007
2016	Spatial Lag Model	-15.727	71.454	101.981
	Spatial Error Model	-7.242	52.483	81.484
2017	Spatial Lag Model	39.853	-39.706	-9.179
	Spatial Error Model	45.099	-52.198	-23.197
2018	Spatial Lag Model	27.24	-18.23	-12.11
	Spatial Error Model	36.27	-21.43	-25.89

Table 4 shows the fit test of the model according to the above criteria. The test results show that compared with the spatial lag model, the maximum likelihood estimate of the spatial error model is larger. At the same time, the estimates obtained by the Schwartz criterion and the Aike criterion is smaller. It can be seen that the fitting degree of the spatial error model is relatively better, so we focused on the analysis of selecting the spatial error model.

4.4. Results of Estimation

Based on the above tests, Table 5 lists the model estimation results of China's installed photovoltaic capacity according to provincial (municipal) administrative divisions and various variables.

Table 5. Estimated results

Variables	Result 1	Result 2	Result 3
Constant	0.0032 (-0.001)	0.0045 (-0.711)	0.0010 (-0.226)
*Ln*SUBSIDY	0.816*** (21.324)	0.813*** (32.213)	0.826*** (32.703)
*Ln*RD	0.327*** (4.480)	0.348*** (6.642)	0.314*** (6.553)
*Ln*GDP	1.469*** (4.462)	1.461*** (6.768)	1.671*** (7.945)
*Ln*AGDP	-0.532*** (-4.127)	-0.538*** (-6.353)	-0.536*** (-6.547)
*Ln*ELECTRIC	-0.844*** (-3.769)	-0.864*** (-5.836)	-0.865*** (-5.934)
*Ln*FISCAL	-0.431* (-2.041)	-0.439*** (-3.167)	-0.518*** (-3.606)
*Ln*ENERGY	-0.225* (-2.092)	-0.221*** (-3.132)	-0.275*** (-3.872)
*Ln*GEC	0.599** (2.573)	0.595*** (3.897)	0.708*** (4.671)
*Ln*GPC	0.896*** (4.287)	0.916*** (6.614)	0.872*** (6.344)
*Ln*SUN	-0.011 (-0.075)	-0.007 (-0.073)	-0.029 (-0.288)
*Ln*SMOKE	-0.303** (-2.601)	-0.293*** (-3.798)	-0.319*** (-4.274)

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*Ln*ENVIR	-0.069 (-0.967)	-0.062 (-1.313)	-0.098** (-1.999)
*Ln*GAS	-0.148* (-1.856)	-0.143*** (-2.731)	-0.150*** (-2.852)
*Ln*FIRE	0.329*** (5.864)	0.328*** (8.896)	0.340*** (8.856)
*Ln*GREEN	0.163 (0.275)	0.139 (0.358)	0.324 (0.795)
*Ln*FOREST	0.079 (1.489)	0.071** (2.016)	0.072** (2.169)
*Ln*SULFUR	0.118 (1.452)	0.116** (2.165)	0.129** (2.307)
*Ln*COAL	-0.006 (-0.060)	-0.009 (-0.150)	-0.018 (-0.303)
R^2	0.798	0.623	0.679

***, **, and * indicate that the statistical level of 1%, 5%, and 10% are significant, respectively, and the t value is located in the parentheses.

Table 5 showed the conclusion obtained based on least square method, spatial lag model and spatial error model. According to the estimation results, the two research hypotheses were well verified after considering the condition of other control variables.

First of all, subsidy policy for the grid benchmark is conducive to the balanced development of photovoltaic industry on the whole. According to the estimation result 3 in Table 5, the subsidy for the grid benchmark passed the significance test at the level of 1%, which showed that the spatial impact of subsidy for grid benchmark on the installed photovoltaic capacity is significant. The correlation coefficient between the grid benchmark and the installed photovoltaic capacity was positive. In other words, the installed photovoltaic capacity increased along with more subsidies. The spatial correlation test also showed that the increasing tendency of the installed photovoltaic capacity slowed down from 2012 to 2018. However, subsidies for the grid benchmark at the regions which are short of solar energy resources were more than those for the regions rich in solar energy resources according to the variation tendency of subsidy policy for the grid benchmark. This is because such policy helps promoting inter-regional coordinated development from the perspective of policy support. As known to all, long duration of sunshine, open area and abundant energy reserves in Western China are in favor of the development of the photovoltaic industry, such as Xinjiang and Ningxia. But the energy consumption of these regions are low because of low population density. The improved capacity of production for photovoltaic industry driven by policy support can lead to overcapacity if we only consider the regional conditions. The subsidy will lead to the waste of resources and equipment if transmission equipment fails to match the generated power. On the other hand, inadequate resources in some regions can hardly prove the efficiency of photovoltaic industry. However, the national government offers some subsidies for these regions in order to promote the balanced development of the industry. As a result, it is difficult to reflect that subsidy helps local develop in a sustainable and balanced manner at least in the short run. What's worse, it increases the financial burden to some extent. Furthermore, the subsides for the regions with better conditions to develop photovoltaic industry are less. Therefore, how to evaluate the contribution of subsidy policy to the development of photovoltaic industry objectively, and how to set up corresponding inter-regional incentive compatibility mechanism that is conducive to the balanced development of local economy and promoting the upgrade of the photovoltaic industry should be the key points that policy makers focus on in the next step.

Secondly, the government R&D subsidy plays a positive role in promoting the development of the photovoltaic industry. Based on the estimation results, R&D subsidy

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passed the significance test. Objectively speaking, China lags behind developed countries in terms of the development of the photovoltaic industry. We have neither core competitiveness for sustainable development nor a thorough and detailed plan for the overall development of new energy [22]. In particular, we fail to overcome some technical barriers in the photovoltaic industry. At present, innovation by Chinese in the photovoltaic industry is far from enough. For instance, the key technology of polycrystalline silicon is still dominated by a few developed countries. There is a large technology gap between China and developed countries in terms of advanced technology, leading to less profit, more cost and technical bottleneck in the structural upgrade of the photovoltaic industry. R&D subsidy from government granted to the photovoltaic enterprises promotes technological advances and independent innovation. In addition, subsidy can reduce research and development costs of photovoltaic corporations. Thus, it can promote the technological progress of the photovoltaic industry. And it's good for the collaborative innovation of the photovoltaic industry chain from upstream (acquisition, processing and manufacturing for the raw material of crystalline silicon), midstream (manufacturing of photovoltaic cells and photovoltaic cell components) to downstream (integration and operation of photovoltaic power station system). It is independent from the path of traditional energy industry, thus it can solve the technical bottlenecks encountered in the development and utilization of new energy including photovoltaic industry.

Thirdly, most control variables passed the significance test. It is worth mentioning that in the estimation results of the spatial error model, sunshine duration of major cities, vegetation coverage rate of built-up areas and consumption quantity of coal failed to pass the significance test. This is probably because there is no necessary endogenous relationship among some variables. According to the policy conditions for the development of the photovoltaic industry, it is difficult to achieve actual effect only through policy support and subsidies. The incentive function of market may be more effective. At least from the policy level, a long-term stable industry planning or a similar mechanism is required for the further improvement.

5. Conclusions and Policy Implications

We used related data of the photovoltaic industry released by provincial administrative institutions in China from 2011 to 2018 as samples. With controlling other variables unchanged, we analyzed the policy performance of subsidy for subsidy of the grid benchmark and R&D subsidy on the development of the photovoltaic industry based on spatial econometric model. The main conclusions are as follows:

(1) The production capacity of the photovoltaic industry in some regions of China presents obvious spatial agglomeration state since 2012, especially in Southeastern and Eastern China. Nevertheless, it was not obvious in Southern and Southwestern China.

(2) Generally speaking, subsidy is conducive to the development of the photovoltaic industry. Particularly, the subsidy for photovoltaic grid benchmark and R&D subsidy plays a positive role for the production capacity of the photovoltaic industry to some degrees.

(3) However, the scale of subsidy was in inverse correlation with the resource endowment of solar energy resources in some regions. There was less subsidy for regions with better natural conditions. It is rather difficult to show that subsidy contributed to the sustainable development of the economy, and it even increased the financial burden of government at all levels, leading to economic distortions.

Therefore, we proposed countermeasures and suggestions from the following four aspects. First of all, from the perspective of institution, mid-and-long term strategic development plan for national energy, new energy industry should be formulated in order to provide renewable clean energy for the economy to develop in sustainable and high-quality manner. Secondly, from the aspect of industrial structure, emerging new energy should be promoted, especially the continuing ability of photovoltaic industry in the strategic transformation of energy development. So it is essential to optimize the energy structure and improve the quality of energy utilization. Additionally, the independent R&D capability in the photovoltaic industry should be improved from the perspective of technology. In other words, we should develop the core competitiveness of the emerging new energy including photovoltaic industry efficiently. Besides, from the perspective of the subsidy, we should match and coordinate the photovoltaic industry and subsidy for different regions. In other words, it's necessary to increase subsidies for photovoltaic system in Northwest China, and the government can continuously improve the corresponding mechanism in order to consume the excess capacity. Furthermore, the incentive mechanism should be built to promote regional government in Eastern, Southwest China and other regions to develop related industries according to their natural conditions.

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Author Contributions

The supervisor is X.S. ; This paper was written by X.S. and T.F.; The major data and key elements of the models were written by T.F. and X.S.; The first draft was written by T.F.

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Availability of data and materials

All relevant data is contained within the manuscript. In addition, raw data from processed data will be made available by the authors, without undue reservation, to any qualified researcher on request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All participants consented the confidential publication of their contributions in this study.

Competing interests

The authors declare that they have no competing interests.

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