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Inequality of renewable energy technology innovation in China

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ABSTRACT

This paper focuses on the major driving forces of the inequality in renewable energy technology innovation. We employ Gini coefficient and Shapley decomposition with semi-log regression model to examine the inequality in renewable energy technology innovation and contribution level of major driving factors in China during 2008-2017. The results show that the Gini coefficient of technology innovation with ultimately around 0.53 is obviously imbalanced in China, yet the unequal distribution display a decrease trend. The factors including R&D subsidy (33.7%), GDP per capital (19.87%), fixed industrial investment (9.13%) and officials' age (1.98%) are the most driving forces of the inequality in photovoltaic energy technology innovation, while the factors such as feed-in tariffs and officials' tenure have a negative effect. Meanwhile, the factors including R&D subsidy (30.72%), GDP per capital (23.09%), feed-in tariffs (8.45%) and fixed industrial investment (5.85%) are the largest source of the inequality in wind energy technology innovation in China, while officials' tenure and background produced passive effect.

Keyword: Renewable energy, Technology innovation, Gini coefficient, Inequality, Decomposition

1. INTRODUCTION

With the paramount challenges of climate change and energy concern, the renewable energies primarily in the form of photovoltaic (PV) and wind energy have apparently increasing dissemination [1,2]. Fig.1 depicts an increasing of electricity generated from PV and wind energy (approximately 766-fold for PV and 22-fold for wind) during 2008-2017 in China. As a major power engine in the diffusion process in renewable energy, technology innovation has received close attention during this period (Lindman et al., 2016; Costantini et al., 2017). The number of patents has rapidly grown at the

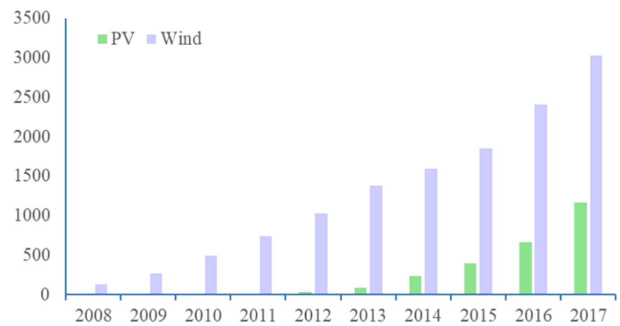

Fig 1 Electricity generated from PV and wind energy in China during 2008-2017.

rate with a about 11.7-time increase in renewable energy on average. However, technology innovation has distinct provincial heterogeneous characteristics and obvious spatial distribution feature in China, and lead to extreme inequality on energy consumption as well as carbon emission [3]. In fact, technology innovation is affected by diversity consequent factors in the form of natural resources, climate change, policy subsidy and personal behavior preference at the same time [4]

Against this background, the inequality of technology innovation in which entire renewable energy such as PV and wind change fundamentally have received increasing attention [5]. From a policy perspective, policies enact long-term sustainability goals, request emission reduction, provide renewable use funding or R&D subsidies for new technologies [6,7]. In practice, the inequality of technology innovation is affected by policies and many different local officials at the same time [8]. From a socio-technical system perspective, changes in policies, or local officials and inequality in local resource endowment system are highly correlated. The local officials can formulate

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policies to support and protect niche innovations such as feed-in tariffs and R&D programs or constrain incumbent technologies. The resulting advance in the local socio-technical system will in turn lead to amendments in the policies and adjust officials' promotion pressure critical. As some researchers said that technology innovation not only commonly depends on the officials and policies, but also shaped by local resource endowment involved the region economic development with natural conditions and resources [1].

This paper surveys the politics and regional characteristics of technology innovation inequality and takes a particular interest in how policies and actors, and what local resource influence the distribution of renewable technologies. The political dimension is about whether policies or officials are more or less ambitious in the stimulation of technology innovation, and whether these factors cut down more or less imbalanced technical system change. This dimension reveals struggles over values and is distinctly at the key of technology innovation. The second dimension reveals material struggles over regional innovative competence, assets and infrastructure etc. Therefore, this paper does not only gain insights into what is the distribution of technology innovation for PV/wind energy in China but also understand the innovation process, i.e. who prefer to support which existing policies based on regional resource endowment. Moreover, we acknowledge which factors make more or less contribution to technology innovation.

This paper contributes in three ways. Firstly, we measure the unequal distribution of technology innovation for PV/wind energy in the provincial level by Gini coefficient. It helps us to understand the basic distribution of technology innovation for PV/wind energy in China. Moreover, we screen out the attribution of technology innovation inequality with a study of the policies, actors and resource endowment to understand the contribution ratio of different factors. It will help us to identify whether policies, local official preferences and resource endowment overlap or conflict lines by our concentration on politics and located resource analysis. At last, we shed light on the similar and different effects of main factors between PV and wind energy. We can understand common interests and diverge among different renewable technologies such as PV, wind energy to further decreases the uncertainty of technology innovation to better narrow the imbalance gaps and to ensure the future strategic direction for renewable energy.

The rest of this paper is structured as follows. Section 2 introduces the empirical model and Shapley decomposition method, main indicators and data source. Section 3 provides the specific empirical results and discussion. Section4 offers conclusions and policy implications.

2. METHODS AND DATA

2.1 Drivers of technology innovation for PV/wind energy

Policies are expected to have significant effect on renewable energy technology innovation. The higher the feed-in tariffs, the better the means for stimulating innovative activities [7]. In addition, a greater number of R&D investments tend to foster an increase in regional innovation performance, because of the positive environment for technology development [9]. Meanwhile, the factor of policy counts in renewable (PCR) is expected to better the means for transiting regional energy use and innovating technologies in a more efficient way for renewable energy [10].

Officials' personal characteristics are another important factor. Education level is a compelling indicator of a officials' quality and environmental performance, and thus education level is expected to high correlate to technology innovation [11]. The officials with energy and environmental background are expected to foster technology innovation, since they pay full attention on energy use and environmental protect [12]. The higher officials' age with operational capability and experience are more richness and thus have an intense environmental consciousness in their behavior preference [13]. The longer officials' tenure, the worse is the expected innovation performance derived from the higher promotive pressure [14].

In this case, *geographic features* are expected to positively associate with the renewable energy technology innovation. Technology innovation is highly correlated with the element of knowledge stock. As stressed on [6], knowledge stocks certainly influence renewable energy technology innovation, but that value of these patents will decrease marginally over time. There are also have some indirect effects: for instance, a considered index of GDP per capital and fixed industrial investment is expected to foster technology innovation [15,16].

2.2 Inequality measurement

Based on the previous works, this paper selects the classical Gini coefficient to assess the technology innovation inequality for PV/wind energy in the provincial level. Similarly, the Gini coefficient of PV/Wind technology innovation are calculated as follow:

$$Gini_t = \frac{1}{2n^2\overline{K_t}}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|K_{t,i} - K_{t,j}\right| \quad (1)$$

Here, $t = 2008, \cdots, 2017$ indexes time, n indexes the count of provinces; $K_{t,i}, K_{t,j}$ stand for the growth rate of renewable energy technology innovation in i, j province, respectively, and $i \neq j$, $i, j = 1, 2, \cdots, n$; $\overline{K_t}$ represents the average speed of growth for renewable energy technology innovation in t year in China, $\overline{K_t} = \frac{1}{n}\sum_{i=1}^{n} K_{t,i}$.

2.3 Decomposed the inequality in PV/wind energy technology innovation by determinants

Fields and Morduch firstly introduce a decomposition method based on regression model to analyze the determinants for inequality distribution [17,18]. Wan have advanced this decomposition method, named Shapley decomposition, because of some limitations on the equations and variables of previous researches [19]. Compared with the other methods, the Shapley decomposition are widely used in analyzed the contribution of income inequality and other welfare indicators, based on the decomposing inequality index [19]. In light of this, we use Shapley decomposition method to deconstruct the determinants the inequality of renewable energy technology innovation.

Moreover, technically, log-level auxiliary regression is commonly appropriate method t in the decomposed progress by using Shapley decomposition method [20]. In practice, we construct log-level regression model to identify the driving factors including policies, officials' personal characteristics and geographic feature. We test the unit root of all explanatory variables to escape spurious regression, and find the variables are stationary trend. We focus on the factors with significant and statistical role for PV/wind energy technology innovation, because the contribute rate of inequality depend on variable coefficient and significant estimate. The determined formulation of technology innovation is expressed in the following:

$$\log(Patent)_{i,t} = \beta_0 + \beta_1(\textbf{Policies})_{i,t} + \beta_2\textbf{(Officials' personal characteristics)}_{i,t} + \beta_3\textbf{(Gegraphic features)}_{i,t} + \varepsilon_i \quad (2)$$

Here, $Patent_{i,t}$ stand for the PV/wind energy technology innovation, $i = 1, \cdots, n$ represents provinces, $t = 2008, \cdots, 2017$ represents time. We set three groups of independent factors capturing: (i) the influence of ($\textbf{Policies}_{i,t}$) such as feed-in tariffs and R&D subsidy, PCR; (ii) the impact of $\textbf{(Officials' personal characteristics)}_{i,t}$ including education, background, age and tenure; (iii) the impact of $\textbf{(Gegraphic features)}_{i,t}$, such as knowledge stocks, GDP per capital and fixed industrial investment; and finally, ε_i are stochastic errors.

Moreover, this paper uses Shapley decomposition method to investigate the determinants' contributions to technology innovation inequality, since it is a reasonable method to resolve the above issues in analyzing initial allocation.

2.4 Data

This paper firstly collects patent counts for PV/wind during 2008-2017 from the State Intellectual Property Office of China (SIPO) and then aggregated these patents to build a pooled panel. In terms of the feed-in tariffs, information on the policy proxy is available from the National Development and Reform Commission (NDRC). Besides, the indicators of officials' personal characteristics, refer to provincial secretary, also be concerned and are collected from several databases. As for the name and tenure of provincial secretary are gained from Zecheng Net (http : // www. hotelaah.com /liren/index.html). Based on the name of the provincial secretary, all provincial official's yearly resumes are obtained from Baidu (www.baidu.com), and thus gain education level, professional background, tenure and age. On the contrary, it was calculated from next year. Finally, the indicators of geographic features are concerned, such as R&D subsidy, GDP per capital, fixed industrial investment. As for the collecting data for GDP per capital and fixed industrial investment, we obtain from CSTSY.

3. RESULTS AND DISCUSSION

3.1 The inequality in PV/wind energy technology innovation: some comparative analysis

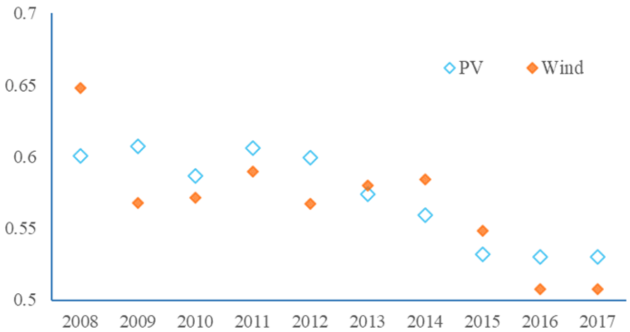

Fig 2 The Gini coefficient of technology innovation for renewable energy and PV/wind.

This paper documents the Gini coefficient of technology innovation for renewable energies such as PV and wind energy (see, Fig.2). The Gini coefficients for PV/wind energy technology innovation in China are 0.65 and 0.62 respectively. As for PV technology innovation, we document the Gini coefficient in China is between 0.53 and 0.61 from 2008 to 2017. Meanwhile, the Gini coefficient of technology innovation for wind energy is between 0.5 and 0.65 during 2008-2017. We can acknowledge that the Gini coefficients in this paper are more than the standard for inequality i.e., 0.4. Taking together, the significant inequality is in technology innovation for PV/wind energy in the provincial level, while this difference is continuously declined. compared with the inequality of technology innovation, we find that the inequality for PV is higher than wind energy, but the decreasing trend is lower than wind energy.

3.2 Determinants of the inequality in PV/wind energy technology innovation

In the model 1 on the determinants of PV, R&D subsidy appear to be significant in technology innovation, but the element of feed-in tariffs has a negative correlation. R&D program, s a scientific special project, can spur the creative enthusiasm from firms, the while the policy of feed-in tariffs will lead to an excessive reliance for continuous subsidy, and thus slack to original technology innovation. In addition, this result shows that officials' personal characteristics are significantly associated with PV technology innovation. Officials' age is positive associate with PV technology innovation, while officials' tenure has a negative effect. One possible interpretation of this uncertain finding is that regional officials with the increasing age place emphasis on green awareness and environmental pressure. However, the officials' promotion pressure is increasing as higher age

Table 1
Results from OLS-regressions on PV/wind energy technology innovation.

Factors	PV Model 1	Wind Model 2
FiT	-1.9807*** (-4.10)	2.4894*** (5.12)
R&D	0.0020*** （5.91）	0.0009*** (3.80)
PCR	-0.3358 （-1.20）	0.0289 (1.14)
Edu	-0.0290 (-0.51)	-0.0602 (-1.13)
Bg	-0.1706 (-1.57)	-0.1962* (-1.79)
Age	0.0443*** (3.25)	0.0102 (0.70)
Tenure	-0.0852*** (-3.43)	-0.0455** (-1.97)
Knstock	-0.0001 （-0.57）	0.0013* (1.91)
GDP	0.1067*** （3.43）	0.1582*** (6.14)
Fix	0.0006*** （3.51）	0.0005*** (3.27)
Cons	2.9780 (2.73)	0.0087 (0.01)
R-squared	0.7062	0.6567
Mean VIF	2.49	2.08
N	305	285

Note: Robust standard errors are shown in parentheses.

and longer tenure. Some officials ultimately prefer to invest project with small investment and rapid economic return to stimulate regional economic growth, instead of contributing to long-term sustainable development. Besides, geographic features have significant and positive correlate on PV technology innovation, in particular GDP per capital and fixed industrial investment.

In addition, Model 2 shows a clear and robust result, whereby the policies including feed-in tariffs and R&D subsidy are more effect on technology innovation for wind energy. These policies provided from both feed-in tariffs and R&D encourage tremendously innovative enthusiasm from both research institutes and firms to advance local wind energy technology. Moreover, local officials' personal characteristics such as background and tenure significantly and negatively influence on technology innovation for wind energy. This finding may be explained that officials' background relating to energy and environment can pay more attentions to regional energy development. However, their experience mostly associates with fossil energy such as coal petroleum, instead of emerging energy such as wind energy. Therefore, the officials' behavior preference tends to their specialized experience advantage and leads to adverse effect on wind energy technology innovation. In parallel, geographic features including knowledge stocks, GDP per capital and fixed industrial investment are found to be significantly and positively associated with innovation performance for wind energy.

3.3 Contribution of the inequality in PV/wind energy technology innovation

Table 2
Shapley decomposition of contributions of PV/wind energy technology innovation in China.

Factors	PV	Wind
Policies	42.66%	39.17%
FiT	8.96%	8.45%
R&D	33.70%	30.72%
PCR	--	--
Officials' Personal Characteristics	4.70%	2.08%
Edu	--	--
Bg	--	1.26%
Age	1.98%	---
Tenure	2.72%	0.82%
Geographic Features	29.00%	57.26%
Knstock	--	26.17%
GDP	19.87%	25.24%
Fix	9.13%	5.85%
Others	23.64%	1.49%
All factors present	100%	100%

Following the contribution of grouping variables, we now turn to investigate separate factor of technology innovation inequality for PV/wind energy from 3 sides including policies, officials' personal characteristics and geographic features (see., Table 2). Firstly, Table 2 shows the inequality determinants of PV technology innovation. The R&D program is the strongest contributor to the inequality of technology innovation, as its contribution to the inequality reaches 33.7%. Moreover, the GDP per capital has the second great explanatory power on technology innovation inequality. The next crucial element is indirected factor for PV, contributing 9.13% to technology innovation inequality, is fixed industrial investment. On one hand, the PV technology innovation are distributed in the developed provinces. These provinces more focus on optimizing the service efficiency of PV technology and further decrease regional carbon emission. On the other hand, these provinces possess the financial capacity to improve the innovative enthusiasm of enterprise and further to support regional technology innovation. Above all, these factors provide more power to explain the inequality of PV technology innovation. Meanwhile, the factor of feed-in tariffs contributes about 8.95% to the inequality of technology innovation, while this policy has a negative effect. First, this policy aims at broadening the generation production ratio of renewable energy, and thus obviously stimulate numerous of patenting activities in the early phase. However, with the maturing technology and decreasing subsidies, the policy makes some adverse effect on the inequality of technology innovation. In addition, officials' personal characteristics have an effect of 4.7% including age with 1.98% and tenure with 2.72%. However, local officials' age negatively influence on technology innovation inequality for PV although it has only a trivial effect.

We also pay attention to wind energy technology innovation inequality. The R&D program with 30.72% is the most important single factor contributing to inequality (as well as to PV technology innovation, which is not a surprising coincidence). About 26.17% of the knowledge stocks, the second strongest contributor, engaged in the inequality of wind energy technology innovation. The more knowledge stocks for wind energy, the better chain reaction in the constantly updated utilization. Meanwhile, GDP per capital with 25.24% is strong predictor to technology innovation inequality. we know that the wide distinction of economic growth also explains to the inequality distribution of technology innovation. The following greatest contributors to the inequality of technology innovation are feed-in tariffs with 8.45% and fixed industrial investment with 5.85%, which increase the dependence of advanced technology. At last, about 2.08% of the local officials' characteristics including background with 1.26% and tenure with 0.82% engaged in raising the inequality of wind energy technology innovation.

4. CONCLUSIONS

This paper is deepening observed the study of renewable energy technology innovation trend, the crucial drivers of technology innovation inequality, and the contribution of different factors in China during 2008-2017. As for the inequality of PV technology innovation, the R&D subsidy with 33.7% is the major contributor and the geographic features with 29% including GDP per capital (19.87%) and fixed industrial investment (9.13%) make the second most contribution. As for wind energy, policies including feed-in tariffs (8.45%) and R&D subsidies (30.72%) contribute more than 39% to the inequality of technology innovation among the pertinent component. Moreover, the geographic features including knowledge stocks, GDP per capital and fixed industrial investment are the most important factors with a contribution of 57.26%. Therefore, in the developing progress of PV technology innovation, local officials should take local economic and social conditions such as GDP per capital and fixed industrial investment into account to steadily advance regional innovative vitality. In the developing progress of technology innovation for wind energy, increasing more R&D subsidy and fixed industrial investment are best choice for provincial planners to balance the inequality distribution of technology innovation.

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