A Study on the Impact of New Energy Policies and Their Combinations on Corporate Innovation Performance: Evidence from Panel Data of 361 Chinese Listed Photovoltaic Firms

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Abstract. In this study, we empirically analyze the effect of new energy policies and their combinations on corporate innovation performance by using panel data from 361 Chinese listed photovoltaic firms between 2016 and 2021. We find that Chinese new energy policies and their combinations significantly incentivize corporate innovation performance. Furthermore, we also reveal that the demand-side new energy policy has a more pronounced effect on promoting firm innovation performance. Based on the findings, we suggest that China's government needs to improve its demand-side new energy policies and emphasize the integrated design of the new energy policy system to better play the synergy effect of the policy mix in corporate innovation.

Keywords: New energy policy, Policy mix, Innovation performance, Photovoltaic industry

1 Introduction

In the context of innovation-driven development strategy, China's R&D and experimental development investment has shown a rapid growth trend in recent years. In 2022, China's total R&D spending reached 3,087 billion yuan, which has achieved that of the level of medium-developed countries. As an active participant in technological innovation, the Chinese photovoltaic industry has developed rapidly with solid support from public policy over the last decade. Its installed capacity has realized a "blowout" development, ranking first worldwide for eight years. However, the rapid rise of the scale of the photovoltaic industry also presents some downsides like a long cultivation cycle, high R&D investment, R&D risk, and externality. In the face of this series of problems, photovoltaic enterprises are difficult to cross the start-up stage and compete with traditional energy enterprises[1]. Therefore, the development of photovoltaic companies urgently needs national policy support to boost their innovation, thus providing strategic support for China's development. Given these issues, an obvious question is to what extent existing new energy policies have influenced China's photovoltaic companies.

To provide an answer, we use the panel data of Chinese listed PV companies between 2016 and 2021, and employ the propensity-score matching (PSM) method to investigate the impact of

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Chinese new energy policies and their combinations on innovation performance. It also provides references for China's new energy policy-making and adjusting.

2 Literature review

2.1 Research on policy mix

The concept of policy mix first appeared in the study of the interaction between fiscal and monetary policy in the 60s of the last century. Then, it expanded to the study of innovation policy in the early twentieth century. Compared with a single policy, the interaction between policy instruments has a more profound impact on corporate innovation[2]. Although researchers and policymakers have widely recognized the importance of the policy mix in recent decades, there is still no consensus on its precise definition. The studies by Flanagan et al.[3] and Rogge et al.[4] provided a framework for innovation policy mix in terms of policy formulation, policy implementation, policy planning, policy instruments, and policy objectives. In the extant literature, the vertical dimension of the policy mix has also been the focus of analysis, which studies the interactions between policy instruments at different governance levels. Dragana et al.[5] argued that the combination of multilevel government subsidies favors an increase in firms' R&D investment, but its effect on firms' innovation performance is insignificant. Similarly, Huang[6] studied the role of the multilevel policy mix in promoting sustainability transitions and examined the interaction mechanism of the multilevel policy instruments. Ossenbrink et al.[7] provide a more general strategy to identify complex policy mix, including "top-down" and "bottom-up" paths.

2.2 Research on impact of policies and their combinations on corporate innovation performance

Considering externalities and high risks involved in innovation, the government, to some extent, has become an important force in promoting corporate innovation. In the literature on policy interactions, the focus of analysis has mainly been on the impact of the supply-side and demand-side policy instruments and their combinations on corporate innovation performance.

On the supply side, government subsidies, as a widely used policy instrument, have been adopted by multilevel governments to promote innovation. However, the debate over its effectiveness is still ongoing. Wei et al.[8] and Lee et al.[9] all agree that government subsidies have an incentive effect on corporate innovation performance by reducing the risk in innovation and enlarging the R&D input. While the study outlined by Lu et al.[10] suggests that government subsidies have a negative impact on corporate innovation input and output. As another important policy on the supply side, the effect of tax incentives has more consistent research results that it has a significant incentive effect on enterprise innovation. Mansfielde et al.[11] argue that tax incentives can reduce the cost of corporate innovation, increase the expected benefits of corporate innovation, and stimulate R&D investment, thus promoting the corporate innovation input, and also have a positive effect on corporate innovation performance.

On the demand side, public procurement has gained a series of studies abroad. Bakirtas et al.[12] believes it can stimulate demand and has a potent stimulus for corporate technological innovation. In China, the research on demand-side policy instruments is still in the stage of theoretical analysis, and the literature on empirical analysis is relatively scarce. Liu et al.[13] use the PSM method to study the impact of government procurement on enterprise R&D investment and conclude that government procurement can significantly increase the scale of R&D investment in SMEs.

As relevant research progressed, many scholars questioned single policy studies. They argued that estimating the effect of only a single policy instrument without controlling for other policy instruments may lead to potential bias. However, there remains a lack of conceptual and empirical research on the combination of supply-side and demand-side policy instruments. Guerzoni et al.[14] study the effects of government subsidies, tax incentives, and public procurement on corporate R&D activity and find that public procurement, the demand-side policy, promotes corporate innovation more significantly. Using a triple-difference approach, Kalcheva et al.[15] study the impact of supply-side environment and demand-side policy on innovation and show that the better the supply-side environment, the more significant the effect of demand-side policy on innovation. The study proves the interaction between supply- and demand-side policies and its superimposed effect on innovation.

3 Empirical analysis

3.1 An overview of new energy policy mix in China

China's new energy policy instruments can be categorized into two main categories: supply-side and demand-side. They all act directly on the innovation entities of the new energy industry and support these companies from the supply side and demand side. The supply-side policy provides guidance for R&D investment and path selection of new energy enterprises. Its policy instruments mainly include government subsidies and tax incentives. The demand-side policy, however, is mainly implemented by the public sector through bulk purchases or price subsidies for new products to reduce the risks faced by products at the early stage and to boost the confidence of these companies. Its policy instruments mainly include government procurement, trade control, and outsourcing. When carrying out the policy, the government usually selectively uses and combines the policy instruments according to the actual situation and stage of a specific industry so as to stimulate synergies between policies and have a more profound effect on new energy enterprises.

New energy policies and their combinations can affect corporate innovation performance in two ways: firstly, by directly affecting the innovation willingness and ability of new energy enterprises; and secondly, by indirectly affecting the corporate innovation performance through the influence on the innovation environment.

3.2 Data collection

Our data includes photovoltaic firms listed at two stock exchanges in mainland China between 2016 and 2021. In order to ensure a robust result, we exclude the following samples: 1) All ST, *ST firms; 2) Firms with serious missing data on government subsidies, tax incentives, government procurement and control variables; 3) Firms with discontinuous operations during the period; 4) Firms with abnormal data. And then, we winsorize all continuous variables at 1% and 99% levels to eliminate the influence of extreme values on the results.

The patent application data is hand-collected from the China National Intellectual Property Administration (CNIPA). The government procurement information is obtained from the disclosed data of the website of China Centralized Government Procurement (CCGP). Fundamental balance sheet data, government subsidies, and tax incentives information are obtained from the Chinese database iFinD and CSMAR.

3.3 Definition of variables

The dependent variable is corporate innovation performance. Referring to the study of Yan et al.[16], this paper uses patent applications to measure corporate innovation performance, and then takes the logarithm of patent applications to reduce data volatility.

The independent variables are new energy policies, including three supply- and demand-side policies and their combinations, totaling seven dummy variables. On the supply side, government subsidies refer to the government subsidy items included in the current profit and loss of the financial statements. Tax incentives refer to the tax returns and other incentives obtained by enterprises. On the demand side, government procurement refers to the policy provided by the central or local government as a consumer for new products and services. For all three supply- and demand-side policies, dummy variables are set to reflect whether photovoltaic firms are supported by policy.

Corporate innovation performance is not only affected by policy but also by the factors of enterprises. Concerning the research of Boeing (2016)[17], Dou et al. (2019)[18], and Zhang et al. (2021)[1], the following control variables are introduced: size, age, leverage, return on assets (ROA), and growth rate. Table 1 provides the definition of variables.

Table 1. Definition of variables.

Varname	Definition
innoper	ln (Patent applications + 1)
sub	Dummy variable, 1 for receiving government subsidies; 0 otherwise.
tax	Dummy variable, 1 for receiving tax incentives; 0 otherwise.
pp	Dummy variable, 1 for receiving government procurement; 0 otherwise.
sub×tax	Dummy variable, 1 for receiving both government subsidies and tax incentives; 0 otherwise.
sub×pp	Dummy variable, 1 for receiving both government subsidies and government procurement; 0 otherwise.
tax×pp	Dummy variable, 1 for receiving both tax incentives and government procurement; 0 otherwise.
sub×tax×pp	Dummy variable, 1 for receiving government subsidies, tax incentive and government procurement at the same time; 0 otherwise.
size	ln (Total assets at the end of the period + 1)
age	ln (Years from business establishment to current year + 1)
lev	Total liabilities / Total assets
roa	Total profit / Total assets
growth	Growth in operating income / Total operating income of the previous year

3.4 Model

In order to analyze the effect of single policy and their combinations on corporate innovation performance, equation (1) is established:

$$Innoper = f\{sub, tax, pp, sub \times tax, sub \times \text{pp}, tax \times pp, sub \times \text{tax} \times \text{pp}\} + \beta_i \, controls + year_i + firm_i + \varepsilon \quad (1)$$

Where subscript i denotes year. $year_i$ and $firm_i$ denote time effect and individual effect, respectively, and ε is the random error term.

Considering the sample selection problem, PV firms that receive policy support are not random. There is a phenomenon of "picking winners" when the government decides whom to support, which means firm characteristics have a significant impact on the acquisition of government support[17]. Therefore, in order to overcome the impact of sample selection bias on the results, this paper uses the propensity score matching (PSM) method for analysis.

4 Empirical results

4.1 Descriptive statistics and correlation analysis

The maximum value of corporate innovation performance during the reporting period is 6.068, and the mean value is 1.897, indicating that PV firms have significant differences in innovation performance. To meet the model requirements, government subsidies, tax incentives, and government procurement are conceptualized as binary variables. The mean value of government subsidies, tax incentives, and government procurement is 0.559, 0.849, and 0.027, respectively. It indicates that the three policy varies in intensity when implemented. Tax incentives are more widely used and implemented, followed by government subsidies. However, the implementation of government procurement, the demand-side policy, needs to be further strengthened. The mean value of the policy combination of government subsidies and tax incentives is 0.481. In contrast, the mean value of the rest of the policy combinations is relatively small, and the mean value of the policy combinations of the three policies is 0.017. The maximum value of the seven new energy policies and their combinations is all 1, and the minimum is 0. All of these indicate that a considerable gap exists in the government subsidies, tax incentives, and government procurement received by PV enterprises. In addition, the descriptive statistics of firm size, leverage, age, profitability, and growth rate all present a large gap between Chinese listed PV companies. Table 2 provides descriptive statistics.

Table 2. Descriptive statistics.

VarName	Obs.	Mean.	Std. dev.	Min.	Max.
innoper	2,166	1.897	1.649	0	6.068
sub	2,166	0.559	0.497	0	1
tax	2,166	0.849	0.359	0	1
pp	2,166	0.027	0.163	0	1
sub×tax	2,166	0.481	0.500	0	1
sub×pp	2,166	0.018	0.135	0	1
tax×pp	2,166	0.026	0.159	0	1
sub×tax×pp	2,166	0.017	0.130	0	1
size	2,166	22.248	1.433	19.203	26.000
lev	2,166	0.455	0.181	0.079	0.849
age	2,166	2.991	0.280	2.303	3.611

roa	2,166	6.121	6.995	-18.766	28.134
growth	2,166	18.853	33.144	-49.258	172.420

Subsequently, the effects of new energy policies and their combinations on corporate innovation performance are tested separately through correlation analysis. According to the results, except for government subsidies, which show a negative (but statistically insignificant) correlation with corporate innovation performance, the other six types of policies and their combinations all have a significant positive correlation with corporate innovation performance.

4.2 Matching balance test

By selecting the firm size, leverage, age, roa and growth rate as covariates, we apply the logit regression model to estimate the propensity score, perform three nearest neighbor matching method and match every treated observation with the most similar three control observations from the pool of potential control observations, and judge whether the matching effect is effective, i.e., matching balance test.

The matching balance test requires no significant differences in the matching variables between the treatment and control groups. It is usually measured by standardized deviation, which generally requires at most 10%, or the desired result will not be achieved. If the standardized deviation is less than 5%, the matching results are considered to match the treatment and control groups better. Table 3 provides the balance test results. The standardized deviations of new energy policies and their combinations do not exceed 10%, indicating they are well-matched. pseudo-R2, an indicator representing the degree of the sample that is explained by the relevant covariates, requires that the matched values are lower than the unmatched values. The indicator psedo-R2 reflects the extent to which the covariate explains the sample. Matched values are usually required to be lower than the unmatched values. The results in Table 4 show a significant decrease after matching compared to the unmatched. Therefore, we agree that the matching results of all seven types of policies and their combinations align with the matching balance assumption, and the desired results are achieved.

Table 3. Matching balance test.

		PsR2	LRchi2	Pchi2	MeanBias	MedBias
sub	Unmatched	0.022	64.37	0.000	8.4	3.8
	Matched	0.000	0.39	0.996	0.7	0.7
tax	Unmatched	0.043	78.95	0.000	15.4	8.5
	Matched	0.001	6.31	0.277	2.4	1.4
pp	Unmatched	0.067	36.34	0.000	36.3	45.2
	Matched	0.009	1.48	0.915	7.9	10.1
sub×tax	Unmatched	0.028	85.05	0.000	8.5	2.4
	Matched	0.000	0.76	0.979	0.9	0.6
sub×pp	Unmatched	0.060	24.07	0.000	36.2	30.7
	Matched	0.009	1.04	0.959	6.6	5.8
tax×pp	Unmatched	0.067	34.93	0.000	36.0	42.3
	Matched	0.012	1.81	0.875	7.3	5.9
sub×tax×pp	Unmatched	0.122	43.99	0	52.1	55.3
	Matched	0.017	1.62	0.951	9.6	9.3

In addition, the probability distribution plots of the propensity scores show a significant difference between the treatment and control groups of all seven types before matching. This suggests that the difference in corporate innovation performance between the two samples does not entirely come from the policy impacts but from multiple factors. However, this difference narrows significantly after matching, indicating that the difference between PV firms in the treatment and control groups is extensively corrected in propensity score matching, and the matching effect is desirable.

4.3 Effectiveness on corporate innovation performance

We perform PSM after passing the matching balance test. After that, we can estimate the impact of policies and their combinations on corporate innovation performance. Since panel data is chosen for this study, time and individual fixed effects are considered during the empirical analysis. The results are shown in Table 4.

Table 4. PSM estimation.

		Treated	Controls	ATT	S.E.	T-stat
sub	Unmatched	1.886	1.910	-0.023	0.071	-0.33
	Matched	1.872	1.980	-0.108	0.084	-1.29
tax	Unmatched	1.992	1.361	0.631***	0.098	6.45
	Matched	1.928	1.329	0.598***	0.098	6.13
pp	Unmatched	3.160	1.861	1.299***	0.216	6.01
	Matched	3.124	1.958	1.166***	0.316	3.69
sub×tax	Unmatched	1.974	1.825	0.149**	0.071	2.10
	Matched	1.955	1.976	-0.021	0.084	-0.25
sub×pp	Unmatched	3.083	1.874	1.209***	0.262	4.61
	Matched	3.083	1.895	1.188***	0.398	2.98
tax×pp	Unmatched	3.276	1.860	1.416***	0.221	6.40
	Matched	3.276	2.040	1.236***	0.315	3.92
sub×tax×pp	Unmatched	3.252	1.873	1.379***	0.272	5.07
	Matched	3.252	1.728	1.524***	0.419	3.64

Notes: ***, ** indicate statistical significance at the 1 and 5 percent levels.

On the single policy, the average treatment effect of government subsidies, tax incentives, and government procurement on innovation performance is -0.108, 0.598, and 1.166, respectively. The effect of tax incentives and government procurement passes the test at the 1% significance level, while that of government subsidies does not pass the test. This may be due to the lack of relevant regulatory mechanisms. Direct subsidies to PV enterprises will distort the factor price, thus weakening the firms' motivation for R&D investment and stimulating "rent-seeking behavior". These result in that firms tend to spend more of their disposable funds on routine investment and rent-seeking activities, thus failing to achieve the desired incentive effect. In conclusion, tax incentives and government procurement can significantly improve corporate innovation performance.

On the combinations of two policies, the average treatment effect of government subsidies ×tax incentives, government subsidies×government procurement, and tax incentives× government procurement on corporate innovation performance is -0.021, 1.188, and 1.236, respectively. The latter two policy combinations all pass the significance test at the 1% level, and the effects are significantly positive, suggesting these two policy mixes can significantly promote innovation performance. However, the impact of the combination of government subsidies and tax incentives does not pass the test.

On the combination of all three policies, its treatment effect on innovation performance is 1.524, and it passes the test at the 1% level. The result proves that the interaction exists between supply- and demand-side policies and the policy mix can expose a superimposed effect on corporate innovation performance.

4.4 Robustness test

We conduct the robustness test to scrutinize the quality of the matching. We investigate whether our result is affected by matching methods by re-estimating the treatment effects with two other matching methods, the radius caliper matching and the kernel matching method. Table 5 provides the result of the robustness test. The comparison of treatment effects of policies and their combinations shows no significant differences between different matching methods, which indicates that the results are robust.

Table 5. Robustness test.

	Nearest neighbor matching	Radius caliper matching	Kernel matching
	Corporate innovation performance		
sub	-0.108 (-1.29)	-0.091 (-0.91)	-0.155 (-2.12)
tax	0.598*** (6.13)	0.405*** (3.09)	0.616*** (6.73)
pp	1.166*** (3.69)	0.697* (1.90)	1.268*** (4.57)
sub×tax	-0.021 (-0.25)	-0.055 (-0.54)	-0.005 (-0.06)
sub×pp	1.188*** (2.98)	1.279*** (2.78)	1.209*** (3.35)
tax×pp	1.236*** (3.92)	1.440*** (3.64)	1.386*** (4.94)
sub×tax×pp	1.524*** (3.64)	1.402*** (2.97)	1.377*** (3.71)

Notes: (1)***, **,* indicate statistical significance at the 1, 5 and 10 percent levels. (2) t-value are (in parenthesis).

5 Conclusions and recommendations

5.1 Conclusions

This study investigates the impact of new energy policies and their combinations on corporate innovation performance for Chinese listed photovoltaic firms between 2016 and 2021. For a single policy, tax incentives and government procurement have a significant promotion effect on the innovation performance of PV firms. The result also reveals that government procurement, as a demand-side policy, can boost innovation performance more significantly. As a bilateral economic behavior from the supply side to the demand side, government procurement policy, which requests enterprises to satisfy the public sector's demand, stimulates them to invest more in innovation and improve their willingness to be involved in innovation activity. For policy mix, in addition to the combination of government subsidies and tax incentives, the other three policy combinations positively impact the innovation performance. It reveals that the combination of demand-side policies and other policy instruments can significantly promote the innovation performance of PV firms.

5.2 Recommendations on policy-making

Based on the above results, combined with the current policy development actuality in the Chinese photovoltaic industry, a full-side policy system is needed. Specific recommendations on policy making are as follows:

On the one hand, build a demand-side support policy system and give full play to its role in promoting PV firms' innovation performance. Nowadays, there is still an imbalance in the policies for various production links of the PV industry. The productive incentives for upstream and midstream industries that manufacture polysilicon and solar photovoltaic cells are relatively adequate. In contrast, the downstream problems like applications are not well resolved, which leads to an increasing rate of light abandonment and a severe waste of energy[19]. Government procurement can effectively reduce the cost of innovation and sales prices of new products, guide the market to accept the new products quickly, help enterprises to recoup funds, and finally further expand the investment in R&D, thus forming a virtuous circle and can constantly promote innovation in the whole photovoltaic industry. Therefore, financial funds at provincial, municipal, and district levels should be further increased for procuring new technologies and products of photovoltaic enterprises. The government must strictly implement the full guaranteed purchase system and quota system for renewable energy. By continuously establishing and optimizing the demand-side policy system, we can cultivate a market environment conducive to the R&D of photovoltaic technologies and products, expand the actual market demand for photovoltaic creations, and pull the innovation supply of China's photovoltaic firms from the demand side.

On the other hand, improve the PV industry's full-side policy system with a holistic design and focus on compatibility. The empirical results show that the innovation performance of PV firms is differentially affected by supply-side and demand-side policies, which suggests that new energy policies and their combinations present structural characteristics. As the most widely-used policy, tax incentives incentivize all enterprises engaged in innovation activity across the PV industry. The policy encourages companies to innovate, eases the pressure of future financing constraints, and is characterized by universality and fairness, which make it a "health factor" in promoting innovation. Government procurement and other policies have a significant impact on innovation performance, which makes them "motivation factors" in promoting corporate innovation. Therefore, the government needs to optimize the existing policies according to the role and interaction of new energy policies in enterprise innovation. And then, the government should formulate a more diversified support policy system from both the supply and demand sides to maximize the synergy effect generated by the new energy policy mix, and to play out the best effect of the policy mix.

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