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Industrial Policy and Technological Innovation of New Energy Vehicle Industry in China

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Abstract: Promoting the development of new energy vehicles is one of the important measures to ensure energy security and deal with global warming. Technological innovation is an inexhaustible driving force for the development of the new energy vehicle industry. This study considered listed enterprises in China's new energy vehicle industry as research samples and used the fixed effect model to study the impact of government subsidies on the quantity and quality of technological innovation in the new energy vehicle industry. The empirical results show that government subsidies have a significant positive impact on the quantity of technological innovation in the new energy vehicle industry; however, government subsidies have no significant impact on the quality of technological innovation. Government subsidies increase the quantity of technological innovation in the new energy vehicle industry by increasing R&D investment, mitigating financing constraints, and improving the external attention of enterprises. Compared to downstream enterprises in the industrial chain, government subsidies have a better incentive effect on the technological innovation of upstream enterprises, which increases the number of patents and enhances the quality of utility model patents. Government subsidies have a better effect on promoting the quantity of technological innovation in large enterprises.

Keywords: new energy vehicle industry; technological innovation; industrial policy; government subsidy; innovation quality

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1. Introduction

The new energy vehicle industry is a strategic emerging industry that China focuses on developing. Over the past 40 years, China's economic development has progressed significantly. The Chinese government has constantly adjusted economic policies to achieve coordinated development between the economy and environment. Developing strategic emerging industries is the key to achieving high-quality development in China. The new energy vehicle industry has been listed as one of the seven key strategic emerging industries in the file issued by the State Council named *Decision on Speeding up the Cultivation and Development of Strategic Emerging Industry* in 2010. Today, the development of the new energy vehicle industry can ensure China's energy security and is an important means of low-carbon consumption under carbon peaking and carbon neutrality goals (China aims to reach a CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060 to accelerate the world's transition to green and low-carbon development).

Developing a new energy vehicle industry is vitally important to energy security for China, since it has relatively insufficient oil resources and a low crude oil reserve, but has a very high demand on oil consumption as China has become the world's second largest oil consumer in recent years due to economic growth. The country depends significantly on imported oil from foreign countries, and China's dependence on imported oil has been rising from 5% in the early 1990s to as high as 70% by 2020. The increasing dependence on imported oil reflects the great risk of China's energy security. New energy vehicles use electricity and clean energy fuels as driving forces that can reduce China's demand on oil resources, and further ensure China's energy security.

Developing the new energy vehicle industry can help China achieve carbon peaking and carbon neutrality goals. In September 2020, the Chinese government proposed the goals of reaching peak carbon emissions in 2030 and carbon neutrality in 2060. China's transportation, thermal power generation, and steel industries are the most important industries for carbon dioxide emission. Automobile carbon emissions account for up to three-quarters of the total carbon emissions in the field of transportation [1]. The use of new energy vehicles has enormous advantages in reducing carbon emissions. The well-to-wheel greenhouse gas emission intensities of battery electric vehicles (BEVs) is 22–293 g CO_2eq/km, while that of gasoline internal combustion engine vehicles (ICEVs) is 227–245 g CO_2eq/km [2]. Developing new energy vehicles is a fast and effective way to achieve the goal of carbon peaking and carbon neutrality in China.

The development of a new energy vehicle industry cannot do without technological innovation. Many studies have shown that to promote industry development and achieve low-carbon transformation, it is necessary to gradually shift from factor driven to innovation driven. Zhao et al. [3] analyzed the R&D incentive mechanism of China's photovoltaic industry based on the system dynamics model, and believed that technological progress in the photovoltaic industry could reduce carbon emissions. Wu et al. [4] studied the listed companies of new energy vehicles in China as a sample, and found that the firm's technological capability is an important factor to promote industrial development and increase R&D investment. These studies all show that technological innovation is a driving force for industrial development.

The new energy vehicle industry and its technological innovation have strong positive externalities. Technological innovation has a long cycle and causes great uncertainty. At the same time, the benefits generated by innovation are difficult to be fully owned by private individuals [5], which is prone to "free riding" behavior, thus inhibiting the R&D momentum of micro subjects [6]. Therefore, the Chinese government has paid much attention to the guidance of industrial policies in the new energy vehicle industry and its technological innovation.

The Chinese government has started to provide policy guidance for the new energy vehicle industry since the beginning of the 21st century. Before 2009, there were few supporting policies for China's new energy vehicle industry, and these mainly focused on planning from the production-side. From 2009–2015, China's new energy industry policy has focused on consumption. Meanwhile, the central government and local governments have launched industrial policies intensively to stimulate the technical breakthrough of key links such as new energy vehicle drive systems, battery management systems, and vehicle integration, and also began to encourage the construction of new energy vehicle supporting facilities. Since 2015, the government's industrial policy has begun to attach importance to the combination of promising governments and effective markets. *The Notice on the Financial Support Policy for the Promotion and Application of New Energy Vehicles from 2016–2020* in 2015 indicated that the subsidy would gradually decline after 2016. "The dual credit policy" issued in 2017 represents the industrial policy's impact on leading the new energy vehicle industry transit from being policy driven to market driven, the gradual withdrawal of subsidy policy, and the function of the market mechanism (In September 2017, the Ministry of Industry and Information Technology and other five departments jointly issued *the measures for the parallel management of average fuel consumption and new energy vehicle credits of passenger vehicle enterprises* (hereinafter referred to as *"the double credits policy"*), which was implemented on 1 April 2018. "The double credits policy" set up two credits for the average fuel consumption of automobile manufacturers and new energy vehicles, and established a credit trading mechanism. "The double credits policy" is an assessment system. The assessment indicators are the average fuel consumption credits and new energy vehicle credits. The purpose is to promote enterprises to develop new energy vehicles to alleviate the energy and environmental pressure.) The subsidy policy for energy vehicles after 2018 has increasingly higher standards for key technical indicators such as the energy density of power battery systems, vehicle energy consumption, and endurance to stimulate the innovation vitality of enterprises and improve the product quality [7].

Government subsidies are the most common industrial policy tool in China's new energy vehicle industry. However, industrial policies such as government R&D subsidies may lead to distortions in resource allocation and incentives, resulting in negative effects [8]. Therefore, the policy's impact on technological innovation remains controversial. Some scholars have shown that government subsidies have a positive impact on the technological innovation of enterprises. Hottenrott and Lopes-Bento [9] used the Belgian Community Innovation Survey data and found that public R&D support had a significant incentive effect on enterprise innovation output. Huergo and Moreno [10] used Spanish company data and found that obtaining any type of direct assistance significantly increased the possibility of carrying out R&D activities. However, some believe that government subsidies have had a negative impact on the enterprises' technological innovation. Wallsten [11] found that the Small Business Innovation Research (SBIR) program funding in the United States had a significant negative effect on enterprise R&D expenditure. Link and Scott [12] also found that the commercialization probability of the R&D achievements funded by the SBIR program was very low, while other studies have shown that the impact of government subsidy on technological innovation is uncertain. Marino et al. [13] used the data of French companies from 1993 to 2009, and based on the DID model, found that public subsidies had neither an incentive effect nor crowding out effect on private R&D expenditure. Montmartin and Herrera [14] used a database of 25 OECD countries and found that there was a nonlinear relationship between R&D subsidiaries and financial investments implemented within a country and private R&D.

The effects of government subsidies on the new energy vehicle industry are also controversial. Some scholars hold a positive attitude toward the effect of government subsidies on the new energy vehicle industry. Using data from 32 European countries, Münzel et al. [15] found a significant positive correlation between financial incentives and plug-in electric vehicle (PEV) adoption. Xing et al. [16] found that federal income tax credits from the United States could increase the sales of electric vehicles. Breetz and Salon [17] found that government subsidies could significantly improve the cost competitiveness of new energy vehicles by studying 14 cities in the United States. Jiao et al. [18] and Wang and Li [19] believe that government subsidies could significantly promote the expansion of China's new energy vehicle market. Gao and Hu [20] found that the subsidy policy for new energy vehicles played a significant role in promoting enterprise performance through two mechanisms: enterprise size and patent behavior. Some scholars also hold a negative attitude toward the implementation effect of government subsidies for the new energy vehicle industry. Zhang et al. [21] found that in Beijing, the license plate lottery policy was better than the subsidy policy in promoting electric vehicles. Sheldon and Dua [22,23] explored the impact and cost-effectiveness of electric vehicle subsidies by using the data of U.S. new car buyers and Chinese new vehicle consumers. Both research results showed that the cost of the subsidies was too high and the subsidy target should be determined according to the policy objectives.

Reviewing the existing studies, scholars have used data from various countries to conduct extensive research on the impact of industrial policies on energy vehicles and their technological innovation. Relevant research includes the impact of industrial policies on the use and diffusion of new energy vehicles [24], the new energy vehicle industrial policies on environmental pollution [25], and industrial policies on the R&D and development strategies of new energy vehicle enterprises [26]. Only a few studies have examined the impact of industrial policies on technological innovation in the new energy vehicle industry [27,28]. So far, whether the existing industrial policies have really improved the technological innovation level of the new energy vehicle industry is open to debate.

Furthermore, the impact of government industrial policies on the quantity and quality of technological innovation in the new energy vehicle industry has not been compared and analyzed yet. This study examined the impact of government subsidies on technological innovation in the new energy vehicle industry from the dimensions of the quantity and quality of technological innovation and explored how government subsidies impact the effect of policies to enrich the research in related fields.

The marginal contributions of this study are as follows. First, the different effects of government subsidies on the quantity and quality of technological innovation in the new energy vehicle industry were investigated; it was found that government subsidies could significantly promote the quantity of technological innovation but could not improve the quality of technological innovation. Second, it was found through empirical study that the industrial policy could increase the number of innovations in the new energy vehicle industry through three mechanisms: improving the attention of enterprises, increasing the R&D investment, and mitigating the financing constraints. Third, we examined the differences in the impact of industrial policies on technological innovation in different links of the industrial chain, which provides valuable insights for industrial policies to promote technological innovation in the new energy vehicle industry.

The rest of this paper is organized as follows. Section 2 introduces the empirical method and data. Section 3 presents the benchmark regression and robustness test results. Section 4 discusses the mechanism test and a series of heterogeneity analyses. Section 5 concludes the study and puts forward policy implications.

2. Method and Data

2.1. Model Design

This paper used the two-way fixed effect model for estimation, which can make the estimation result control some individual heterogeneity that will not change over time and is difficult to observe as well as reduce the problem of missing variables. The following is the benchmark model of this paper:

$$innov\_n_{it} = \beta_0 + \beta_1 sub_{it} + \beta_2 X_{it} + firm_i + year_t + \varepsilon_{it} \quad (1)$$

$$innov\_q_{it} = \beta_0 + \beta_1 sub_{it} + \beta_2 X_{it} + firm_i + year_t + \varepsilon_{it} \quad (2)$$

where $innov\_n$ represents the quantity of technological innovation including $tpatent$ (the number of total patents); $ipatent$ (invention patents); and $upatent$ (utility model patents). $innov\_q$ represents the quality of technological innovation including $width$ (patent quality); $iwidth$ (invention patent quality); and $uwidth$ (utility model patent quality). sub represents the government subsidy; X represents a series of control variables including capital structure (lev), profitability (roa), enterprise size ($size$), proportion of fixed assets (ppe), proportion of independent directors (dir), enterprise age (age), enterprise growth ability (gov), and enterprise human capital (hc). $firm$ is the enterprise fixed effect; $year$ is the year fixed effect; ε is the random disturbance term.

2.2. Definition of the Variable

(1) Quantity and quality of technological innovations

Patents are generally considered good indicators of technological innovation. Compared to utility model and design patents, invention patents have higher requirements and are more innovative and breakthrough. Utility model patents represent the improvement in existing technology by enterprises to a certain extent, but the improvement is relatively small. The patent does not contain any technological innovations. Therefore, this study selected the number of invention patent applications and utility model patent applications to measure the quantity of technological innovation.

This study used patent knowledge width to measure the quality of technological innovation. The patent knowledge width can measure the quality of patents based on the complexity and universality of the knowledge contained in patents. Therefore, this study used the practices of Zhang and Zheng [29] and Aghion et al. [30] to measure the quality of each patent using the knowledge width method, which can measure the complexity of knowledge contained in a patent. In this study, the formula for calculating the width of patent knowledge is $width = 1 - \sum x^2$; x is the proportion of each group of patent IPC classification numbers. We then added the patent knowledge width to the enterprise level according to the average value. The greater the knowledge width value of a patent, the wider the knowledge involved in the patent, and therefore the higher the quality of innovation.

(2) Government subsidies

In this study, the data of government subsidy were processed logarithmically.

(3) Control variables

In order to exclude the influence of other factors on the regression model and estimation results, referring to the research of Chen et al. [31], this study selected some variables related to the nature and capabilities of the enterprise for control including: capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and enterprise human capital (*hc*) (see Table 1 for the definition of variables).

Table 1. Definition of the variables.

Variable Classification	Variable	Symbol	Definition
Dependent variable	Quantity of technological innovation	*tpatent*	*ln*(Number of invention patent applications + number of utility model patent applications + 1)
		ipatent	*ln*(Number of invention patent applications + 1)
		upatent	*ln*(Number of utility model patent applications + 1)
	Quality of technological innovation	*width*	Quality of patent
		iwidth	Quality of invention patent
		uwidth	Quality of utility mode patent
Independent variable	Government subsidy	*sub*	*ln*(Government subsidy)
Control variable	Capital structure	*lev*	Asset liability ratio
	Profitability	*roa*	Net interest rate of total assets
	Enterprise size	*size*	*ln*(Number of employees)
	Proportion of fixed assets	*ppe*	Net fixed assets/total assets
	Proportion of independent directors	*dir*	Number of independent directors/numbers of board of directors
	Enterprise age	*age*	*ln*(Year—establishment year + 1)
	Enterprise growth ability	*gov*	Year on year growth rate of operating revenue
	Enterprise human capital	*hc*	Number of undergraduates/number of employees

2.3. Data

2.3.1. Data Source

This study used the listed enterprises in the field of new energy vehicle industry as the research object. China's support policies for the new energy vehicle industry began to grow rapidly after 2010. In this study, enterprises listed on energy vehicles from 2010 to 2019 were selected as the research samples, and the samples were processed as follows: (1) the samples with ST and ST* marks were excluded; and (2) eliminated samples with missing data. Finally, we obtained 242 new energy automobile enterprises, with a total of 1671 observations. To prevent interference from extreme values, all continuous variables were subjected to tailing reduction.

The patent data for this study came from the Incopat database. First, the name of each listed company and its subsidiaries was extracted from the Chinese Research Data Services (CNRDS) database. Then, the names of the listed companies and their subsidiaries were manually retrieved by patent applicants through the Incopat database, and the patent data of the listed companies and their affiliates were counted. Finally, the number and quality data of patents applied for by enterprises every year were obtained through sorting and statistics. Government subsidies and other financial data received by the enterprises were obtained from the Wind and CSMAR databases.

2.3.2. Descriptive Statistics

Table 2 presents the descriptive statistics for the main variables. The average number of enterprise patents (tpatent) was 3.559, the average number of invention patents (ipatent) was 2.628, and the average number of utility model patents (upatent) was 3.017. It can be seen that new energy vehicle enterprises apply for more utility model patents. The maximum values of the invention patents, utility model patents, and total patents were 6.443, 6.724, and 7.407, respectively. The standard deviation was also relatively large, which indicates that there is a large gap in the level of technological innovation between different enterprises. The average quality of patents (width) was 0.219, the average quality of invention patents (iwidth) was 0.245, and quality of utility model patents (uwidth) was 0.18. It can be seen that the average quality of the utility model patents was significantly lower than that of the invention patents. The maximum patent quality, invention patent quality, and utility model patent quality were 0.723, 0.75, and 0.57, respectively. The maximum value of the government subsidies was 20.88, the minimum value was 12.68, and the standard deviation was 1.537. It can be seen that there were certain differences in the government subsidies received by enterprises.

Table 2. Descriptive statistics.

Variable	N	Mean	SD	Min	Max
tpatent	1671	3.559	1.582	0	7.407
ipatent	1671	2.628	1.498	0	6.443
upatent	1671	3.017	1.612	0	6.724
width	1671	0.219	0.133	0	0.723
iwidth	1671	0.245	0.164	0	0.75
uwidth	1671	0.18	0.12	0	0.57
sub	1671	16.53	1.537	12.68	20.88
lev	1671	0.417	0.187	0.0681	0.933
roa	1671	4.88	5.916	−22.11	18.1
size	1671	7.9	1.15	5.733	11.46
ppe	1671	0.204	0.104	0.0157	0.541
dir	1671	0.37	0.0486	0.333	0.556
age	1671	2.841	0.294	2.079	3.526
gov	1671	17.32	28.56	−41.29	130
hc	1446	18.45	13.02	3.16	73.28

In order to see the development of technological innovation in China's new energy vehicle industry in detail, Table 3 presents the annual mean value of the dependent variables. As shown in Table 3, from 2010 to 2019, the number of invention and utility model patents of the listed companies in the new energy vehicle industry maintained a steady upward trend. In 2010, the average annual number of patents of enterprises was 40.99, which nearly quadrupled to 159.32 in 2019, with an average annual growth rate of 16.28%. Overall, in 2010, the annual average patent quality of the listed companies in the new energy vehicle industry was 0.195, and the patent quality increased to 0.275 in 2019. The patent quality fluctuated from 2010 to 2015 and improved rapidly after 2015. In terms of the patent type, the quality of invention patents was significantly higher than that of the utility model patents.

Table 3. Descriptive statistics of the dependent variables by year (mean value).

Year	*Tpatent*	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
2010	40.99	13.61	27.38	0.194	0.194	0.151
2011	69.63	25.36	44.27	0.176	0.2	0.126
2012	76.98	29.05	47.94	0.191	0.207	0.148
2013	97.87	36.46	61.41	0.177	0.195	0.136
2014	106.7	40.99	65.71	0.187	0.213	0.159
2015	109.8	42.61	67.14	0.188	0.197	0.156
2016	132.6	55.37	77.28	0.228	0.248	0.174
2017	140.9	59.28	81.66	0.244	0.282	0.202
2018	160.6	71.1	89.45	0.247	0.29	0.206
2019	159.3	69.4	89.93	0.275	0.314	0.247

3. Empirical Results and Analysis

3.1. Analysis of Benchmark Regression Results

First, we discuss the impact of government subsidies on the number of new energy vehicle patents. It can be seen from columns (1)–(3) in Table 4 that the coefficients of government subsidies were significantly positive at the level of 1%, and the coefficients were 0.173, 0.147, and 0.162, respectively. The number of enterprise patent applications increased by 0.173%. The more subsidies the government gives to enterprises, the more invention patents and utility model patents the enterprises apply for.

Table 4. The regression results of government subsidies on the quantity and quality of technological innovation.

	(1)	(2)	(3)	(4)	(5)	(6)
	Tpatent	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
sub	0.173 ***	0.147 ***	0.162 ***	0.00003	−0.00295	0.00211
	(4.540)	(4.483)	(4.284)	(0.00791)	(−0.428)	(0.443)
Constant	−4.693 *	−6.205 **	−4.382	0.577 *	0.194	0.186
	(−1.849)	(−2.414)	(−1.632)	(1.958)	(0.564)	(0.749)
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES
N	1446	1446	1446	1446	1446	1446
R^2	0.465	0.425	0.443	0.120	0.133	0.138

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

Second, we discuss the impact of government subsidies on the NEV patent quality of new energy vehicles. As shown in columns (4)–(6) in Table 4, the coefficients of sub were relatively small and not significant, indicating that government subsidy had no significant impact on the quality of patents. The reason is that enterprises encouraged by industrial policies will significantly increase their patent applications in order to obtain more government subsidies. However, due to many uncertain risks in the process of early research and development, some enterprises prefer to carry out low-quality technological innovation with relatively short cycles and low investment than high-quality technological innovation to reduce the costs and risks [32–35].

3.2. Endogenous Test

Considering the endogeneity problem of reverse causality may exist between government subsidies and the amount of technological innovation of enterprises, that is, the higher the level of the technological innovation of enterprises, the easier it is for them to meet the standards for granting subsidies and obtain more government subsidies. This study selected the mean value of government subsidies in the new energy vehicle industry lagging behind the first phase and government subsidies lagging behind the second phase as instrumental variables for the two-stage least squares estimation [36]. Reasons for selecting tool variables are as follows. (1) When applying for government subsidies, enterprises are likely to refer to the subsidy amount applied by other enterprises in the same industry in the previous period to ensure that the maximum subsidy amount can be obtained on the basis of successful application; and (2) if the enterprise can obtain government support in the early stage, it may send a positive signal to the government, which is conducive to the enterprise applying again for government subsidies. Table 5 shows that government subsidies had a significant effect on the total number of patents, invention patents, and utility model patents at the 5% level. The impact of government subsidies on patent quality was still insignificant. These results are consistent with the benchmark regression results.

Table 5. Regression results of the endogenous test.

	(1)	(2)	(3)	(4)	(5)	(6)
	Tpatent	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
sub	0.257 *	0.226 **	0.290 *	−0.0187	−0.000443	−0.0105
	(1.819)	(2.033)	(1.886)	(−1.057)	(−0.0175)	(−0.573)
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES
Hansen-J P	0.8786	0.5249	0.9651	0.4827	0.9791	0.5214
N	1117	1117	1117	1117	1117	1117
R^2	0.408	0.376	0.378	0.127	0.145	0.130

Note: z-statistics are given in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

3.3. Robustness Test

3.3.1. Replace Dependent Variables

This study replaced the quantitative index of technological innovation with the number of patent applications provided by the CNRDS database (*cpt*, *cpi*, *cpu*). The patent quality index was replaced by the number of cited patents (*cited*) and patent claims (*claim*). The regression results are presented in Table 6. It can be seen that after replacing the measurement indicators, the regression results are consistent with the benchmark regression results.

Table 6. Robustness test: Replace the dependent variables.

	(1)	(2)	(3)	(4)	(5)
	cpt	*cpi*	*cpu*	*Cited*	*Claim*
sub	0.159 ***	0.122 ***	0.149 ***	0.0476	0.0894
	(5.151)	(3.969)	(4.631)	(0.734)	(1.383)
Constant	−4.182 *	−5.951 **	−3.090	4.525	2.781
	(−1.693)	(−2.327)	(−1.208)	(0.922)	(0.720)
CONTROLS	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES
N	1446	1446	1446	1374	1374
R^2	0.410	0.335	0.455	0.467	0.281

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

3.3.2. Subsample Regression

Considering that some enterprises may enter the new energy vehicle industry in a certain period, this paper verified the time when each enterprise entered the industry by consulting the annual report of the enterprise, and then selected the sub-sample after the enterprise entered the new energy vehicle industry for regression. The regression results are shown in Table 7. We can see that the regression results are consistent with the benchmark regression results.

Table 7. Robustness test: Subsample.

	(1)	(2)	(3)	(4)	(5)	(6)
	Tpatent	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
sub	0.154 ***	0.131 ***	0.145 ***	0.00142	−0.00320	0.00405
	(4.187)	(4.081)	(3.855)	(0.275)	(−0.433)	(0.804)
Constant	−4.157	−4.821 **	−4.354	0.667 **	0.269	0.195
	(−1.592)	(−2.012)	(−1.527)	(2.050)	(0.729)	(0.683)
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES
N	1350	1350	1350	1350	1350	1350
R^2	0.443	0.407	0.420	0.120	0.130	0.141

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

3.3.3. Panel Tobit Model

Because the patent quantity and quality data were non-negative, and had the characteristics of truncated data [37], this study used the panel Tobit model to estimate, and the results are shown in Table 8. The results show that the coefficients of sub on the quantity of technological innovation were all significantly positive, and the coefficients on the quality of technological innovation were still not significant, which is consistent with the benchmark regression results.

Table 8. Robustness test: Panel Tobit model.

	(1)	(2)	(3)	(4)	(5)	(6)
	Tpatent	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
sub	0.211 ***	0.199 ***	0.193 ***	0.00253	−0.000928	0.00443
	(7.950)	(7.220)	(6.744)	(0.685)	(−0.189)	(1.187)
Constant	−4.646 ***	−5.863 ***	−4.945 ***	0.338 **	0.383 **	0.151
	(−4.532)	(−5.595)	(−4.450)	(2.448)	(2.103)	(1.086)
sigma_u	0.867 ***	0.869 ***	0.969 ***	0.0866 ***	0.112 ***	0.0658 ***
	(18.44)	(18.07)	(18.44)	(15.83)	(15.29)	(12.83)
sigma_e	0.711 ***	0.730 ***	0.761 ***	0.104 ***	0.137 ***	0.110 ***
	(47.61)	(46.60)	(46.24)	(46.31)	(44.77)	(44.48)
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES
N	1446	1446	1446	1446	1446	1446

Note: z-statistics are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

3.3.4. System-GMM Model

Considering that the level of technological innovation in the previous period may have an impact on the level of technological innovation in the current period, this paper introduced the independent variable lagging behind the first phase and used the system-GMM model to estimate. As shown in Table 9, it was found that the quantity and quality of technological innovation in the previous period had a significant positive impact on the quantity and quality of technological innovation in the current period. The government subsidies had a significant positive impact on the quantity of technological innovation, but had no significant impact on the quality of technological innovation, which is consistent with the benchmark regression results.

Table 9. Robustness test: System-GMM model.

	(1)	(2)	(3)	(4)	(5)	(6)
	Tpatent	*Ipatent*	*Upatent*	*Width*	*Iwidth*	*Uwidth*
L.tpatent	0.549 *** (7.313)					
L.ipatent		0.507 *** (8.150)				
L.upatent			0.529 *** (6.411)			
L.width				0.205 *** (3.511)		
L.iwidth					0.224 *** (4.103)	
L.uwidth						0.113 ** (2.110)
sub	0.183 ** (2.374)	0.238 *** (4.138)	0.156 * (1.846)	0.000848 (0.112)	−0.0117 (−1.116)	0.000674 (0.0719)
Constant	−4.646 *** (−4.532)	−5.863 *** (−5.595)	−4.945 *** (−4.450)	0.338 ** (2.448)	0.383 ** (2.103)	0.151 (1.086)
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.259	0.228	0.133	0.546	0.785	0.142
Hansen *p* value	0.264	0.460	0.321	0.676	0.675	0.255
N	1446	1446	1446	1446	1446	1446

Note: z-statistics are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

4. Mechanism Test and Heterogeneity Analysis

4.1. Mechanism Test

In order to empirically test the mechanism of government subsidies affecting the amount of technological innovation of new energy vehicle enterprises, this paper designed the following mechanism test econometric models:

$$attention_{it} = \beta_0 + \beta_1 sub_{it} + \beta_2 X_{it} + firm_i + year_t + \varepsilon_{it} \tag{3}$$

$$R\&D_{it} = \beta_0 + \beta_1 sub_{it} + \beta_2 X_{it} + firm_i + year_t + \varepsilon_{it} \tag{4}$$

$$fund_{it} = \beta_0 + \beta_1 sub_{it} + \beta_2 X_{it} + firm_i + year_t + \varepsilon_{it} \tag{5}$$

where $attention$ represents the degree of external attention of an enterprise; $R\&D$ represents an enterprise's R&D capital investments; $fund$ represents the external financing of an enterprise. The other symbols have the same meaning as in Models (1) and (2).

In this paper, the logarithm of the number of analysts who make profit forecasts for enterprises every year was taken as the proxy variable that enterprises are concerned by the outside world [38]. The logarithm of an enterprise's annual R&D expenditure was used to measure $R\&D$. $fund$ was measured by the ratio of net cash flow from financing activities to total assets [39].

4.1.1. Improving the External Attention of Enterprises

Table 10 presents the regression results of the mechanistic tests. It can be seen from column (1) that government subsidies can significantly improve the number of analysts who pay attention to the subsidized enterprises. The more government subsidies the enterprises receive, the more attention they will receive from the outside world, which will increase the possibility of enterprises integrating various external innovation resources [38]. Therefore, government subsidies can promote technological innovation by increasing the attention of the enterprises.

Table 10. Mechanism test.

	(1)	(2)	(3)
	Attention	***R&D***	***Fund***
sub	0.162 ***	0.0688 **	0.00962 *
	(2.910)	(2.306)	(1.775)
Constant	−6.235 *	10.94 ***	0.195
	(−1.727)	(5.637)	(0.757)
CONTROLS	YES	YES	YES
COMPANY FE	YES	YES	YES
YEAR FE	YES	YES	YES
N	1138	1412	1446
R^2	0.190	0.662	0.072

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

4.1.2. Increasing R&D Capital Investment

Column (2) in Table 10 indicates that the coefficient of sub was 0.0688, which was significant at the 5% level, indicating that government subsidies play an important role in promoting the enterprises' R&D capital investment. Many studies have proven that R&D capital investment can significantly improve the enterprises' innovation output [40]. Therefore, government subsidies promote technological innovation by increasing enterprise R&D capital investment.

4.1.3. Mitigating Financing Constraints

Column (3) in Table 10 shows that the coefficient of sub was 0.00962, which was significant at the 10% level, indicating that government subsidies are conducive to enterprises obtaining more external financing. This alleviates enterprise financing constraints and promotes an increase in the quantity of technological innovation [41].

In general, these three mechanisms were significant. In comparison, the role of improving the attention of enterprises was greater, while the role of alleviating financing was relatively small.

4.2. Heterogeneity Analysis

4.2.1. Industrial Chain Perspective

This study divided enterprises into upstream, midstream, and downstream industries according to the industrial chain. Table 11 shows the regression results of the impact of government subsidies on the quantity of the enterprises' technological innovation in all links of the industrial chain. The results show that increasing government subsidies can increase the technological innovation across the entire industrial chain.

To test whether there was a difference in the significant impact of government subsidies on upstream, midstream, and downstream enterprises, we conducted an inter-group coefficient difference test. First, we set the dummy variables *chain*1, *chain*2, and *chain*3. The dummy variable *chain*1 is 1 when the enterprise belongs to the upstream, otherwise it is 0. The dummy variable *chain*2 is 1 when the enterprise belongs to the midstream, otherwise it is 0. The dummy variable *chain*3 is 1 when the enterprise belongs downstream, otherwise it is 0. Second, we multiplied the three dummy variables with the main independent variable (*sub*) to form the interactive terms *sub_chain*1, *sub_chain*2, and *sub_chain*3. Third, we set the three interactive terms in Model (1) for regression. The results are presented in Table 12. When government subsidies increased, Panel A shows that upstream enterprises applied for more utility model patents than the other links. Panel B shows that although the quantity of technological innovation in midstream enterprises increased, it was significantly less than the upstream and downstream enterprises. Panel C shows that compared to other links, downstream enterprises applied for more invention patents. Overall, government subsidies can promote technological innovation across the entire industrial chain. The number of invention patents of downstream enterprises increased the most, while the number of utility model patents of the upstream enterprises increased the most.

Table 11. Heterogeneity analysis: Industrial chain perspective (quantity of technological innovation).

	(1)	(2)	(3)
	Tpatent	*Ipatent*	*Upatent*
Panel A: upstream			
sub	0.210 **	0.161 **	0.241 ***
	(2.650)	(2.360)	(3.034)
Constant	−10.64 *	−11.17 **	−13.15 *
	(−1.857)	(−2.225)	(−1.910)
N	247	247	247
R^2	0.539	0.474	0.543
Panel B: midstream			
sub	0.109 **	0.0805 *	0.107 **
	(2.360)	(1.786)	(2.189)
Constant	−1.281	−4.747	0.0820
	(−0.452)	(−1.581)	(0.0287)
N	877	877	877
R^2	0.477	0.424	0.456
Panel C: downstream			
sub	0.233 ***	0.226 ***	0.203 ***
	(3.051)	(3.528)	(2.795)
Constant	−7.045	−5.189	−7.213
	(−1.429)	(−0.983)	(−1.379)
N	322	322	322
R^2	0.509	0.526	0.441
CONTROLS	YES	YES	YES
COMPANY FE	YES	YES	YES
YEAR FE	YES	YES	YES

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

Table 12. Heterogeneity analysis: Comparison of inter-group coefficients of the industrial chain perspective (quantity of technological innovation).

	(1)	(2)	(3)
	Tpatent	*Ipatent*	*Upatent*
Panel A			
sub	0.161 ***	0.149 ***	0.134 ***
	(3.854)	(3.988)	(3.256)
sub_chain1	0.0609	−0.00870	0.146 *
	(0.663)	(−0.116)	(1.709)
Constant	−4.674 *	−6.208 **	−4.335
	(−1.850)	(−2.409)	(−1.640)
N	1446	1446	1446
R^2	0.465	0.425	0.446
Panel B			
sub	0.235 ***	0.209 ***	0.222 ***
	(4.136)	(4.450)	(4.219)
sub_chain2	−0.128 *	−0.128 **	−0.125 *
	(−1.753)	(−1.992)	(−1.769)
Constant	−4.423 *	−5.936 **	−4.118
	(−1.737)	(−2.302)	(−1.531)
N	1446	1446	1446
R^2	0.468	0.429	0.447
Panel C			
sub	0.136 ***	0.0930 **	0.147 ***
	(3.229)	(2.553)	(3.327)
sub_chain3	0.116	0.169 **	0.0461
	(1.322)	(2.299)	(0.559)
Constant	−4.486 *	−5.903 **	−4.299
	(−1.752)	(−2.286)	(−1.589)
N	1446	1446	1446
R^2	0.467	0.430	0.443
CONTROLS	YES	YES	YES
COMPANY FE	YES	YES	YES
YEAR FE	YES	YES	YES

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

Table 13 shows the impact of government subsidies on the quality of the enterprises' technological innovation in all links of the industrial chain. The results showed that government subsidies had a significant positive impact only on the quality of the utility model patents of upstream enterprises. This shows that government subsidies can improve the quality of the technological innovation of upstream enterprises, but are limited in terms of the quality of utility model patents, and have no impact on the quality of invention patents.

Table 13. Heterogeneity analysis: Industrial chain perspective (quality of technological innovation).

	(1)	(2)	(3)
	Width	*Iwidth*	*Uwidth*
Panel A: upstream			
sub	0.00522	0.00176	0.0205 **
	(0.713)	(0.261)	(2.045)
Constant	0.778	−0.351	−1.651 **
	(0.598)	(−0.296)	(−2.299)
N	247	247	247
R^2	0.130	0.161	0.228
Panel B: midstream			
sub	−0.00179	−0.00815	−0.00340
	(−0.298)	(−0.908)	(−0.502)
Constant	0.332	−0.0793	0.495 *
	(0.957)	(−0.177)	(1.804)
N	877	877	877
R^2	0.117	0.131	0.125
Panel C: downstream			
sub	−0.00355	−0.00545	−0.00108
	(−0.352)	(−0.370)	(−0.140)
Constant	0.685	0.715	0.403
	(1.580)	(1.400)	(0.829)
N	322	322	322
R^2	0.247	0.220	0.233
CONTROLS	YES	YES	YES
COMPANY FE	YES	YES	YES
YEAR FE	YES	YES	YES

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS includes capital structure (*lev*), profitability (*roa*), enterprise size (*size*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and human capital (*hc*).

4.2.2. Enterprise Size Perspective

Enterprises are divided into large and small enterprises according to their scale. Table 14 shows the impact of government subsidies on the technological innovation of enterprises of different sizes. Panels A and B show the regression results for large and small enterprises. The results show that an increase in government subsidies had a significantly positive impact on the quantity of technological innovation in large and small enterprises. To further analyze the difference between the two significant effects, an intergroup coefficient test was conducted. We set the dummy variable *size*1. When the enterprise is large-scale, it is 1; otherwise, it is 0. Then, the dummy variable *size*1 was multiplied by the main independent variable (*sub*) to form the interaction term *sub_size*1, and Model (1) was added for regression (see Panel C for the results). The results show that compared to small enterprises, large enterprises can apply for more invention patents after receiving government subsidies. There are two possible reasons for this finding. First, large enterprises have a wider and better internal division of labor and a stronger ability to use R&D networks and knowledge spillovers, which is more conducive to technological innovation. Second, from the perspective of enterprise strategic objectives, large enterprises pay more attention to long-term returns, so they have a stronger willingness to engage in technological innovation activities.

Table 15 shows the impact of government subsidies on the technological innovation quality of enterprises of different sizes. The results show that government subsidies had no significant impact on the quality of the technological innovation of enterprises of different sizes. This proves that the result of benchmark regression is robust. Overall, increasing government subsidies is significantly effective in increasing the technological innovation of large and small enterprises, especially for large-scale enterprises. However, the enterprise size heterogeneity does not significantly affect the effect of government subsidies on the technological innovation quality.

Table 14. Heterogeneity analysis: Enterprise size perspective (quantity of technological innovation).

	(1)	(2)	(3)
	Tpatent	***Ipatent***	***Upatent***
Patent A: large			
sub	0.225 ***	0.193 ***	0.218 ***
	(4.098)	(3.340)	(4.028)
Constant	−2.016	−5.175	−0.399
	(−0.551)	(−1.280)	(−0.108)
N	728	728	728
R^2	0.393	0.373	0.357
Panel B: small			
sub	0.136 ***	0.117 ***	0.136 ***
	(3.286)	(3.347)	(3.316)
Constant	−1.325	−1.843	−3.152
	(−0.383)	(−0.552)	(−0.791)
N	718	718	718
R^2	0.353	0.268	0.359
Panel C: coefficient compare			
sub	0.198 ***	0.134 ***	0.206 ***
	(4.297)	(3.548)	(4.555)
sub_size1	0.0374	0.118 **	−0.000342
	(0.642)	(2.360)	(−0.00581)
Constant	−2.098	−3.057	−2.145
	(−0.880)	(−1.238)	(−0.847)
N	1446	1446	1446
R^2	0.447	0.403	0.426
CONTROLS	YES	YES	YES
COMPANY FE	YES	YES	YES
YEAR FE	YES	YES	YES

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS in all models includes capital structure (*lev*), profitability (*roa*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and enterprise human capital (*hc*).

Table 15. Heterogeneity analysis: Enterprise size perspective (quality of technological innovation).

	(1)	(2)	(3)	(4)	(5)	(6)
	Large			**Small**		
	Width	***Iwidth***	***Uwidth***	***Width***	***Iwidth***	***Uwidth***
sub	−0.000816	2.47×10^{-5}	−0.000319	−0.00354	−0.00888	0.00372
	(−0.169)	(0.00346)	(−0.0574)	(−0.437)	(−0.800)	(0.491)
Constant	0.146	0.0563	0.409	1.027 **	0.668	0.281
	(0.614)	(0.133)	(1.645)	(2.125)	(1.376)	(0.620)
N	728	728	728	718	718	718
R^2	0.218	0.149	0.186	0.094	0.148	0.133
CONTROLS	YES	YES	YES	YES	YES	YES
COMPANY FE	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are given in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CONTROLS in all models includes capital structure (*lev*), profitability (*roa*), proportion of fixed assets (*ppe*), proportion of independent directors (*dir*), enterprise age (*age*), enterprise growth ability (*gov*), and enterprise human capital (*hc*).

5. Conclusions and Policy Implications

Against the background of carbon peaking and carbon neutrality goals, the new energy vehicle industry is a strategic emerging industry with huge social and economic benefits, and needs reasonable guidance through industrial policies. Technological innovation is the fundamental driving force to promote the high-quality development of the new energy vehicle industry and is an important way to advance the low-carbon transformation of energy. Taking the listed enterprises in the new energy vehicle industry from 2010 to 2019 as the research sample, this study compared the patent data of the Incopat database with the financial data of enterprises in the Wind and CSMAR databases. The quantity of technological innovation was measured by the number of patents, and the quality of technological innovation was measured by the width of patent knowledge. The fixed effects model was used to empirically test the impact of government subsidies on the quantity and quality of technological innovation and the internal impact mechanism.

The conclusions are as follows. (1) The government subsidy only encouraged the quantity of technological innovation in the new energy vehicle industry, but had no incentive effect on the quality of technological innovation. (2) There are three mechanisms for government subsidies to promote the quantity of technological innovations in the new energy automobile industry. First, as an approval from the government, the government subsidy can increase the enterprises' credibility in the market. Second, government subsidies can encourage enterprises to increase their R&D capital investment. Third, government subsidies can mitigate the financing constraints in technological innovation. (3) Government subsidies can only materially improve the quality of the utility model patents of upstream enterprises.

The policy implications of this study are as follows. (1) Optimizing the government subsidy policy system for the new energy vehicle industry. First, the selection mechanism for subsidy objects should be improved. We should strengthen the fairness and openness of the selection of subsidy objects and provide a competitive environment for enterprises. Second, the subsidy effect evaluation mechanism should be improved, the traditional innovation evaluation system based on the number of innovations should be abandoned, and the inspection of enterprise innovation quality should be strengthened. (2) Formulating differentiated subsidy incentive policies. When the government grants subsidies, it is necessary to fully consider the heterogeneity factors such as the location of the industrial chain and the size of enterprises. The government should promote differentiated incentive policies according to local conditions and improve the allocation efficiency of government subsidy funds. The government should further improve the incentive effect of technological innovation for midstream and downstream enterprises in the new energy vehicle industry chain. For upstream enterprises of the new energy vehicle industrial chain, the incentives of invention patents and high-quality innovation should be emphasized. At the same time, the government should enhance the incentive effect of industrial policies on the technological innovation output of small- and medium-sized enterprises.

There are still some limitations in this study. As above-mentioned, the purpose, object and strength of the industrial policies of the new energy vehicle industry are different. This study failed to distinguish the heterogeneity of the effects of the supply and demand side on subsidy policies. There are many kinds of government subsidies related to China's new energy vehicle industry, but it is difficult to obtain the details of each subsidy received by enterprises from the financial data of listed companies. This is the difficulty and direction of future research.

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