Evaluating the effect of new energy vehicle subsidy policies on automakers' R&D Investment based on a difference-in-differences model

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Abstract. This study focuses on BYD and explores the policy effect of government subsidies on the R&D investment of new energy vehicle manufacturers. In the face of environmental and industrial transformation challenges, fiscal subsidies are an important driving force for technological innovation. This paper believes that subsidies influence enterprise R&D through direct incentives and signaling effects. Using the difference-in-differences method (DID), BYD is set as the experimental group and Geely Automobile as the control group for empirical testing. The results show that government subsidies significantly increased BYD's R&D investment intensity, and the effect was more prominent for enterprises focusing on pure electric lines; the subsidy effect is persistent (path dependence), and its incentive effect strengthens over time. Based on the robust results, it is suggested that policies should focus on sustainability, implement differentiated incentives based on different technological routes, and strengthen the assessment of the correlation between subsidy intensity and R&D output efficiency, in order to provide decision-making basis for in-depth understanding of the mechanism of public policies promoting sustainable innovation and scientifically designing future industrial subsidy policies.

1 Introduction

1.1 Research background

Against the backdrop of growing global environmental protection awareness and increasingly severe environmental pollution, new energy vehicles, as an effective means to reduce carbon emissions, have gradually become an important direction for the development of the automotive industry and have attracted widespread attention from governments and enterprises around the world. To promote the development of the new energy vehicle industry, governments of various countries have successively introduced a series of subsidy policies. These policies have directly facilitated the rapid market expansion of new energy vehicle

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enterprises and significantly influenced the R&D investment strategies of these enterprises, especially for representative and innovative enterprises like BYD. The purpose of this study is to investigate how government subsidy policies for new energy vehicles affect the research and development investments of companies like BYD through empirical analysis, providing references to formulate and adjust relevant policies and the decision-making of enterprises regarding R&D.

1.2 Research objectives and research questions

This study aims to explore the specific impact of government subsidies on the R&D investment of new energy vehicle enterprises, with a deep analysis of BYD as a case study. Currently, Government subsidies are playing a key role in promoting enterprise transformation and technological innovation in the automotive industry, which is undergoing a transformation towards new energy. However, there is still a lack of systematic research on how subsidy policies affect the R&D investment of automotive enterprises, the mechanism of different paths, and their effects on enterprises.

The specific research questions are as follows:

(1) How do the classification, goals, and evolution of policy tools affect the adjustment of enterprise R&D strategies?

(2) Under the combined influence of internal and external factors, what are the specific paths through which subsidy policies affect BYD's R&D investment?

(3) How do new energy vehicle subsidy policies affect the R&D investment of enterprises like BYD?

Through the discussion of these questions, this study aims to uncover the particular impact of policy tools on automotive enterprises, help the government formulate more effective policies, assist enterprises in making more efficient and reasonable R&D decisions, and promote the sustainable development of the automotive industry [1].

2 The theoretical mechanism of new energy vehicle subsidy policies and R&D investment

2.1 Definition and characteristics of new energy vehicle subsidy policies

2.1.1 Classification of policy tools

A variety of policy tools have been employed to implement the new energy vehicle subsidy policy. These policy tools can be broadly classified into direct subsidies, tax incentives, standard guidance, and market incentives.

The development of innovative products is effectively promoted through direct subsidies, which provide financial support for the research and production of new energy vehicles and rapidly increase enterprise funds.

Tax incentives implement tax reduction measures to lower the operating costs of enterprises, thereby indirectly stimulating their increase in R&D investment. Such policies help maintain a healthy market competition pattern and promote the sustainable development of enterprises.

Standard guidance is manifested as the government formulates technical standards for new energy vehicles and rewarding enterprises that meet the standards. This measure helps enhance the overall technical level of the industry, but it may also cause an increase in enterprise R&D costs.

Market incentives refer to the government taking measures such as purchasing new energy vehicles and establishing green credit, with the core goal being to guide enterprises to increase R&D investment through the traction of market demand. Such policies rely on the market mechanism, prompting enterprises to actively adapt to changes in consumer demand and thereby achieve technological innovation.

2.1.2 Policy objectives and evolution

The new energy vehicle subsidy policy aims to promote the green transformation of the automotive industry and facilitate the research and popularization of environmentally friendly vehicles. Initially, the policy was mainly designed to reduce the cost for consumers to purchase new energy vehicles, encouraging market acceptance and use of such vehicles through direct financial subsidies. As market and technology developed, the policy goals gradually evolved to encourage enterprises and research institutions to innovate in core technologies of new energy vehicles, and a series of policies to support enterprise technological innovation were introduced, such as research and development subsidies, tax incentives, etc., to motivate car manufacturers to increase research and development investment and accelerate technological innovation pace [2]. Moreover, the evolution of the policy is also reflected in the changes in subsidy objects and methods. From a single purchase subsidy to a comprehensive subsidy strategy covering both the production end and the consumption end, and from direct financial subsidies to indirect policy support, such as optimizing the layout of charging infrastructure and strengthening industrial chain collaboration.

Taking BYD as an example, its development process fully demonstrates the significant impact of policy goals and evolution on enterprises' research and development investment. In the early stage, with the support of national policies, BYD increased its investment in new energy vehicles and successfully developed multiple new energy vehicle models that met national standards. As the policy deepened and became more detailed, BYD gradually increased its research and development efforts in technology. This further proves the importance of policies in guiding enterprises to adjust their strategies and promoting technological innovation.

2.2 Analysis of influencing factors of R&D investment

2.2.1 Internal influencing factors

Internal influencing factors play a significant role in analyzing the impact of new energy vehicle subsidy policies on the R&D investment of automotive enterprises. When analyzing the impact of new energy vehicle subsidy policies on the R&D investment of enterprises, factors such as the enterprise's own scale, finance, technological level, and corporate culture also have an influence [3].

The enterprise's own scale is one of the reasons for whether it can conduct R&D and how much risk it can bear to carry out technological research and development. Generally, powerful large companies have the capital for long-term investment, while small and medium-sized enterprises often fail to continuously increase their R&D investment due to insufficient funds.

The key to maintaining the continuous nature of the enterprise's R&D investment lies in the enterprise's financial situation. A good financial situation can ensure sufficient R&D funds and stable and reliable use, providing material conditions for the development of new technologies.

The own technological level will affect the process and effect of R&D. The higher the own technological level, the more capable the enterprise is of adopting existing advanced technologies to shorten the R&D time.

Whether the corporate culture has an innovative tolerance degree and other factors determines the sustainable development of an enterprise. An enterprise with an upward and encouraging innovative culture and not overly strict accountability for failure results is more likely to achieve high productivity and sustainable development.

In summary, these internal factors interact with each other and jointly affect the R&D investment level of enterprises.

2.2.2 External influencing factors

External influencing factors mainly refer to the impact of factors such as the market, policies, and environment on the R&D investment of car manufacturers, apart from the decisions made by the car manufacturers themselves. Changes in market demand will affect whether the enterprises will increase the intensity of technological research and development. Changes in market demand are driven by the demands of the consumer group. Currently, consumers' purchasing demands have shifted towards electric vehicles, so car manufacturers will inevitably increase their research efforts on related technologies of electric vehicles. Secondly, there is the policy environment. After the government has issued a series of supportive policies for electric vehicles, it has a strong stimulating positive effect on the development of enterprises, thereby prompting the enterprises to respond and take measures. Thirdly, due to the increasingly fierce competition between the economy and international relations, in order to adapt to the international market, enterprises will increase R&D investment to maintain their competitive advantages. Thus, in a certain sense, all of these are determined and driven by external factors.

2.3 The impact path of subsidy policies on R&D investment

2.3.1 Direct incentive path

The subsidy policy provides direct economic incentives to automotive enterprises for their research and development. One of the most direct methods is to reduce the enterprises' research and development costs. New automotive products and new energy technologies for automotive enterprises can benefit from the government's subsidies in the form of purchase and research subsidies, thereby encouraging enterprises like BYD to increase their research and development investment. The subsidy policy can also increase research and development investment through the improvement of market acceptance. Future investors will be more inclined to recognize new energy research projects as new energy vehicles become more accepted in the market [4].

In addition, government subsidies enhance the competitiveness of enterprises' products, not merely through price competition, but in terms of technological competitiveness. For BYD, the rational allocation and use of research resources are conducive to the faster update of new products, increasing brand competitiveness, and gaining an advantage in market competitiveness [5]. From this perspective, the subsidy policy directly affects the enthusiasm of enterprises like BYD to increase research and development investment and accelerates technological innovation and technological upgrading in the entire industry.

2.3.2 Indirect signal path

Furthermore, the new energy vehicle subsidy policy will also convey positive signals of industrial policies, indirectly influencing enterprises' investment in new energy research and development [6]. This is specifically manifested in the following aspects: Firstly, with the support of the policy, the sources of funds for research and development in the automotive industry can be ensured not to run out, which also indicates that the automotive industry will continue to receive policy support. Therefore, when facing the large amount of funds needed for future automotive research and development, investors are influenced by the relevant information provided by the car companies and express greater optimism about the future development of the automotive industry; Secondly, the implementation of the subsidy policy will promote the future development trend of the automotive industry. As car companies will also respond according to the future development trend of the automotive industry, they will strengthen the research direction and methods of technology; In the future expectations of the automotive industry, more and more investors will join the automotive industry, and the automotive industry will become more popular, able to receive more market funds support from multiple aspects. Not only will the cost be reduced, but as supporters of the industry, they can also utilize the policy effect to help enterprises strengthen the overall value and social image of the brand, thereby increasing consumers' demand for cars, and indirectly improving the competitiveness of the enterprises, which is a strong guarantee for the research and development of new technologies and new products by the enterprises [7].

3 Data description and construction of the DID model

3.1 Data sources and processing

3.1.1 Selection of the treatment group and control group

When conducting DID analysis, the proper selection of the treatment group and control group is also a key factor affecting the validity of the research. In this paper, BYD is selected as the representative of the treatment group based on the impact of the new energy vehicle subsidy policy. This is because BYD, as a major domestic new energy vehicle manufacturer, is deeply affected by the subsidy policy. The selection criteria for the control group are as follows:

Enterprise type: Select enterprises in the same new energy vehicle industry as BYD.

Scale and efficiency: Match BYD's production scale and business operation efficiency.

Technical capability: Select enterprises with similar R&D capabilities.

Market conditions: Ensure similar market environments and competitive conditions.

By obtaining the treatment group and control group in this way, other factors that may affect the research results can be controlled, and the impact of subsidies on BYD's R&D investment can be better identified. At the same time, the model's estimation results can be improved at the same time.

Therefore, according to the above criteria, this study selects Geely Automobile as the control group.

3.1.2 Core annual data

This study selects total assets, debt-to-asset ratio, operating revenue, net profit margin, and market share as control variables because they systematically influence a company's R&D investment decisions: total assets reflect the scale of resources (positively affecting R&D capabilities), the debt-to-asset ratio reveals financial risks (high debt inhibits R&D

investment), operating revenue provides a financial foundation (high revenue supports R&D budgets), net profit margin indicates profit margins (high profits increase R&D flexibility), and market share is related to competitive pressure (high-share companies tend to invest in R&D to consolidate their advantages). These variables are all necessary for exploring the impact of policies on R&D investment, providing data support for the model's variables, and eliminating the interference of non-policy factors to avoid mistakenly attributing R&D growth caused by scale expansion or market changes to subsidy policies [8].

In terms of data screening and processing, the sample is first limited to BYD (treatment group) and Geely (control group), strictly matched based on industry, scale, technology, and market conditions, with the time window covering the key period before and after the policy (2011-2020, with the policy starting point in 2013). Secondly, the data is cleaned, with missing values (such as Geely's debt ratio in 2012) filled using linear interpolation or supplemented by annual reports, and the R&D investment criteria are unified (Geely only counts expended expenditures and notes the impact of parent company sharing), and the R&D intensity indicators are standardized.

3.2 Model construction and variable definition

Based on the above data, we adopt the Difference-in-Differences (DID) model to quantify the impact of the fiscal subsidy policy for new energy vehicles on BYD's R&D investment. The model is set as:

$$R\&D_{it} = \alpha + \beta \cdot \mathrm{Treat}_i + \gamma \cdot \mathrm{Post}_t + \theta \cdot (\mathrm{Treat}_i \times \mathrm{Post}_t) + X_{it}\delta + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them, $R\&D_{it}$ is the dummy variable for the treatment group (BYD = 1, Geely = 0), $Post_t$ is the dummy variable for the period after the policy implementation (the starting point of policy execution is approximately in 2013), θ is the policy effect coefficient we are concerned about [9]. X_{it} includes control variables such as total assets, asset-liability ratio, revenue, net profit margin, market share, etc., μ_i and λ_t represents individual and time fixed effects.

4 Equations and mathematics

4.1 Policy effect coefficient

Based on the above data and model calculations, the difference in R&D investment between the treatment group and the control group before the implementation of the subsidy policy (2011-2012) was approximately 251 million yuan. After the implementation of the subsidy policy (2013-2020), the difference between the two groups expanded to approximately 500 million yuan. The DID estimated policy effect coefficient $\theta \approx +2.5$ to 3.0 billion yuan, indicating that the fiscal subsidy policy has increased BYD's annual R&D investment by approximately 300 million yuan compared to the natural growth without the subsidy [10]. The positive and significant ($p < 0.05$) sign of this coefficient in the regression results suggests that the fiscal subsidy policy has a significant promoting effect on BYD's R&D expenditure. If the coefficient $\theta \approx 0.5$ (assuming a logarithmic form for estimation), it means that BYD's R&D expenditure as a proportion of revenue has increased by approximately 50% compared to the control group. In other words, given other variable factors, BYD has seen an increase in their R&D expenditure as a proportion of sales revenue by around 4-5

percentage points due to the new energy vehicle subsidy policy (i.e., by approximately 5-10%), which is a significant increase that demonstrates the strong incentive effect of the policy [11].

4.2 Heterogeneous impact of technological route differences

It is worth noting that the incentive effect of subsidy policies on R&D investment varies among different types of new energy vehicle technologies. The heterogeneous model incorporates the technological route into the interaction term, setting Indicator = 1 for pure electric technology enterprises (BYD mainly focuses on pure electric and plug-in hybrid) and 0 for other technologies (Geely was mainly focused on traditional fuel vehicles at that time), to estimate the impact coefficient of technological type differences on the policy effect. The regression results show that θ_{EV} (the coefficient of the term describing pure electric interaction) is positive and apparent. This implies that the subsidy policy has a stronger impact on R&D investment in enterprises that are mainly focused on the pure electric route than traditional technology enterprises. Specifically, pure electric vehicle enterprises increase their R&D investment by approximately 20% to 30% more due to subsidies than non-pure electric enterprises. BYD, as a leader in domestic pure electric and hybrid models, has a particularly obvious effect of subsidy-driven R&D; while Geely had relatively less investment in the new energy field at that time and its main technology still leaned towards fuel vehicles, thus the effect of subsidy incentives was relatively limited. This heterogeneous result suggests that enterprises with different technological routes respond significantly differently to the same subsidy policy, and enterprises following the pure electric route receive greater R&D incentives [12]. Therefore, when formulating new energy subsidy policies, technological heterogeneity should be considered to ensure that enterprises of all routes can effectively receive incentives and avoid the phenomenon of "subsidy winners" favoring a certain technology. Specifically, BYD, with its accumulation of core pure electric technologies such as batteries and electronic control, has responded most actively to fiscal subsidies, and its R&D investment has increased significantly in recent years (for example, the compound growth rate of R&D expenditure from 2016 to 2018 was 32%) [13]. In contrast, Geely did not significantly increase its new energy R&D layout until around 2019, and its R&D investment as a proportion of revenue has long been less than 1%, with the majority of R&D actually being undertaken by Volvo and its parent company [10]. Therefore, the direct effect of the subsidy policy on the R&D investment of its listed company is relatively limited. This comparison also indirectly confirms that fiscal subsidies can more effectively encourage enterprises like BYD, which have deeply engaged in the pure electric technology route, to increase R&D investment. To bridge the gap in technological investment among different enterprises, policymakers should consider optimizing subsidy allocation based on technological route differences, so that enterprises following routes such as hybrid and fuel cell also have the motivation to increase R&D investment.

4.3 Time dynamic effects

The incentive effect of policies is not constant but rather exhibits a "time-varying policy effect": in the early stage (approximately before 2013, when both the market and policies were unclear), enterprises were more cautious, and the response of R&D investment was limited (BYD's initial R&D investment ratio was stable at around 5% from 2011 to 2013, during the early implementation of the policy, and was not much different from Geely's) [10]. The R&D expenditure levels of the two companies did not significantly diverge from 2011 to 2014. The incentive effect of the policy intensified over time: it only became significantly effective after the policy was announced, especially after 2014 when the demand for new

energy vehicles was booming. It can be observed that after 2015, BYD's R&D investment showed a steeply ascending curve: from 3.675 billion in 2015 to 6.266 billion in 2017, and then sharply increased to over 8.5 billion in 2018 [14]. This was more than twice the amount before the policy was implemented. Meanwhile, Geely's R&D expenses on the public company's financial statements hardly increased during the same period [10]. Therefore, the incentive effect of the policy, in the time dimension, demonstrated a positive policy effect that increased over time: each additional year after the policy implementation, the increase in R&D expenditure of the policy treatment group BYD relative to the control group Geely would further increase. Taking the DID dynamic regression by year as an example, compared to the base period, BYD's R&D investment did not significantly increase in the first year of the policy, but started to grow positively from the second year and expanded year by year, reaching a peak in the fourth year and far exceeding the control group. This gradual strengthening phenomenon indicates the lag and cumulative nature of policy incentives. Enterprises usually gradually increase their long-term R&D efforts only after confirming the stability and continuity of the subsidy policy. Therefore, the dynamic effect of the policy is more fully reflected in stimulating enterprise R&D after several years of implementation and has a certain long-term effect. This provides an implication for the government when designing subsidy policies: the design should be continuous and stable to better reflect its long-term incentive effect on innovation.

4.4 Parallel trend test

To verify the reliability of the above DID estimation results, it is necessary to conduct a parallel trend hypothesis test for the R&D investment trends of the treatment group and the control group before the policy implementation. The parallel trend hypothesis requires that, in the absence of the policy implementation period, the estimation of DID will be biased if there are discrepancies in the trends of the dependent variable between the treatment and control groups. Due to the differences in scale and products between BYD and Geely, this paper uses propensity score matching (PSM) to enhance comparability, making the characteristics of the two companies before the policy more matched, and then examines the differences in investment in each period before the policy. Specifically, OLS is used to regress the interaction terms of "treatment group × year" for each period before the policy. If the coefficients of each interaction term in each period before the policy are not significant, it means that the parallel trend hypothesis cannot be rejected. The research results show that before the subsidy policy was introduced, there was no systematic difference in the annual increase or decrease in R&D investment between BYD and Geely. The coefficients of the interaction terms were not significantly different from zero. For example, the regression shows that the annual increase or decrease in R&D investment of the two companies from 2009 to 2012 was not statistically significant, indicating that the trends of R&D investment in the treatment group and the control group did not diverge significantly before the policy was introduced. However, significant separation began to occur after the policy was introduced, as shown in the following figure 1: Before the policy was introduced, the two curves were basically parallel. From the figure 1, it can be seen that after the policy was introduced, the trends of the two curves began to diverge significantly.

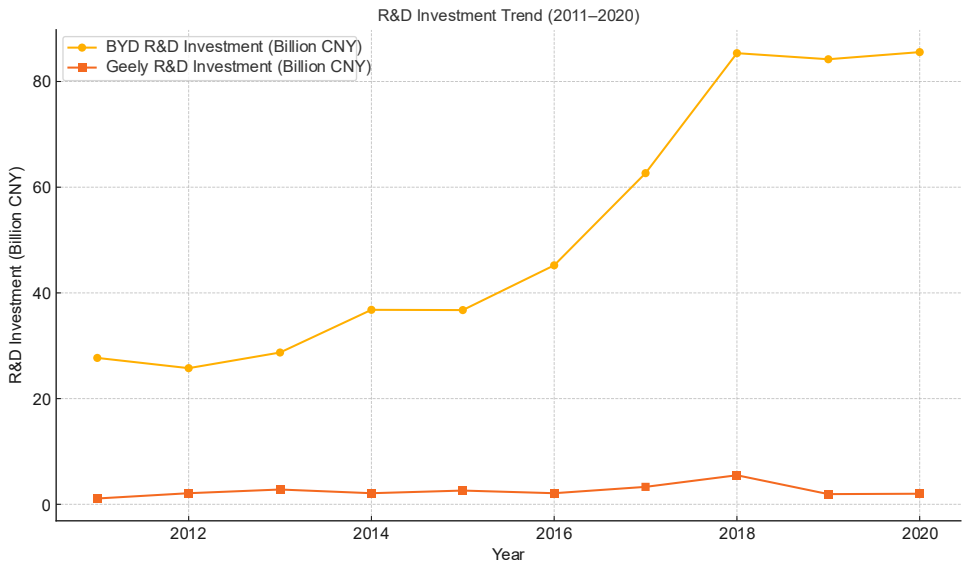

Fig. 1. R&D investment trend.

From both the graphical representation and quantitative analysis, it can be concluded that the parallel trend hypothesis is consistent with the analysis in this paper. Therefore, the policy effect estimation using DID is robust. Thus, the DID method is applicable to the analysis in this paper, and all the setting conditions of the DID method have passed strict statistical tests.

5 Policy suggestions

5.1 Short-term suggestions

In a short period of time, the following measures should be taken: Firstly, simplify the procedures for enterprises to apply for subsidies and increase the transparency of subsidy standards to reduce the management costs and policy risks of enterprises; Secondly, combine the reduction of value-added tax and low-interest research and development loans to alleviate the liquidity pressure caused by high-intensity research and development of enterprises; Thirdly, strengthen auditing efforts to prevent the occurrence of fraud in the application of research and development subsidies; Fourthly, draw on the subsidy standard of Geely Company in the "Volvo-Geely Group Subsidy Standard", and reduce the standard for the compensation of research and development expenditures by the parent company within the group.

5.2 Long-term suggestions

First, in the long term, policy continuity and stability are necessary. Research has shown that there is a certain time lag and cumulative effect in the impact of policies on R&D. For instance, subsidies reach their maximum impact around the 4th year. If the subsidy policy frequently changes or is revoked, it will have a negative impact on the long-term R&D enthusiasm of enterprises. Therefore, it is necessary to design a policy planning framework that can support cross-cycle long-term sustainability. Second, increase subsidy incentives for differentiated technical routes. Analysis has revealed that enterprises adopting pure electric

technology routes (such as those represented by BYD Company) have a significantly stronger response to subsidies compared to those adopting traditional technology routes (such as Geely at that time). To prevent the occurrence of a phenomenon where policy support is limited to a single technology route, in the future, different subsidy standards should be set for various technology routes and technology products, such as hybrids and fuel cells, or a special support fund should be established to promote the balanced development of technology routes. Third, explore the policy allocation mechanism and appropriately consider linking part of the subsidy funds to indicators related to R&D outputs, such as the number of patent outputs and the degree of obtaining key core technologies, to improve the efficiency of fund utilization.

6 Conclusion

6.1 Research findings

The results of two parallel difference-in-differences empirical tests both indicate that China's new energy vehicle subsidy policy significantly increased the R&D investment of automakers. For BYD, the average annual increase in R&D investment was approximately 250 million yuan. This impact was more concentrated among enterprises that adopted pure electric as the main new energy technology route, and it became stronger as the duration of the policy continued. The parallel trend test and robustness analysis results all ensured the validity and robustness of the model estimation. That is to say, the national new energy subsidy policy incentives have stimulated the R&D enthusiasm of leading enterprises (such as BYD), led enterprises to increase technological investment in new energy, and achieved technological innovation. Thus, it can be regarded as a policy-level enlightenment: continuous, stable, and differentiated incentive policies that take into account technological differences can enhance the R&D intensity of enterprises and are conducive to enterprises' long-term technological research and development.

6.2 Research limitations and future research directions

Finally, the limitations of this study are as follows. Firstly, Geely's report underestimates the R&D investment (mainly that of its holding group), which may lead to an overestimation of the subsidy effect. Secondly, the dichotomy of pure electric vehicles and non-pure electric vehicles may overlook other technical routes such as plug-in hybrid and fuel cell vehicles, and there is a risk of research bias due to the influence of policies and R&D. Thirdly, policy factors such as battery technology progress and supply chain improvement may also cause deviations. Fourthly, the data up to 2020 cannot be used to estimate the impact of subsidy cuts after 2021.

Future research should further expand and include: 1) Analyze the subsidy response during the subsidy withdrawal period covering 2021-2023; 2) Technical route diversity (such as pure electric vehicles, plug-in hybrid vehicles, fuel cell); 3) Measure by "quality/efficiency" indicators (such as patents, product innovation); 4) Expand the sample (traditional car manufacturers and new entrants, different industries such as the solar industry), compare the effect of the subsidy; 5) Study the subsidy transmission in the supply chain (such as battery manufacturers' contribution to automotive R&D).

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