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The Impact of Economic Policy Uncertainty on Green Technology Innovation of New Energy Vehicle Enterprises in China

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Abstract: Against the backdrop of increasingly serious global carbon emissions and environmental challenges, new energy vehicles (NEVs), as important low-carbon means of transport, play a crucial role in reducing carbon emissions, enhancing energy efficiency, and promoting sustainable development. However, green technological innovation is under considerable pressure from economic policy uncertainty (EPU), and the exact effects are not well understood. Using panel data on listed companies' green technological innovation from 2012 to 2022, this study examines the relationship between EPU and green technological innovation in Chinese NEV enterprises. The findings reveal that rising EPU has a significant negative impact on green technological innovation in these companies; however, company ESG performance and government financial subsidies can effectively mitigate this negative impact. Notably, in provinces where public environmental concerns are high, the moderating effect of government subsidies is weaker; while facing EPU, NEV manufacturers rely more on government subsidies for green technological innovation than do parts manufacturers. These findings provide critical insights for guiding NEV enterprises in coping with EPU, advancing green technological innovation, and offering appropriate support and incentives to policymakers.

Keywords: green technology innovation; economic policy uncertainty (EPU); new energy vehicles (NEVs); corporate ESG; government subsidies; sustainable development

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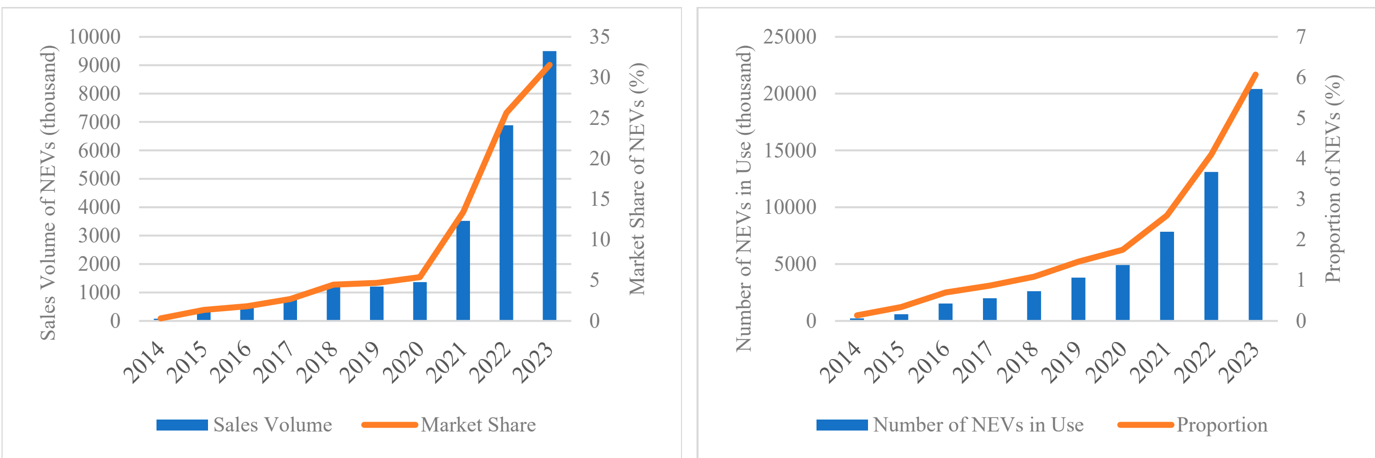
1. Introduction

The global surge in CO_2 emissions contributes to severe environmental and economic challenges, including global warming, rising sea levels, species depletion, and extreme weather events. The transportation sector, particularly road transportation, is a significant source of global CO_2 emissions [1–3] and faces the greatest pressure to reduce these emissions. Therefore, new energy vehicles (NEVs) with low-carbon and environmentally friendly characteristics have become a key strategy for alleviating global CO_2 emissions and environmental issues. In March 2024, the International Energy Agency (IEA) indicated in its "CO_2 Emissions in 2023" report that carbon emissions from the transport sector experienced the most pronounced growth, surging by nearly 240 Mt globally in 2023 [4] (p. 19). Without the growing deployment of five key clean energy technologies, including NEVs, since 2019, the rise in global CO_2 emissions would have been three times higher [4] (p. 6). Simulative studies have shown that deploying 1% more electric vehicles can reduce carbon emissions by 0.5–0.9% [5–7]. In this context, promoting NEVs and related industries to replace traditional fossil fuels has a profound impact on optimizing global energy structures and reducing carbon emissions [8,9].

Green technological innovation in the NEV industry is considered to be the core driving force for CO_2 emissions reduction and achieving stable, sustainable development [10–12]. Green technological innovation refers to the innovation of technological capabilities that reduce carbon emissions and improve energy utilization efficiency in a company's core operations [13–16]. This includes initiatives in energy savings, curbing pollution, reprocessing waste, designing eco-friendly products, and managing environmental impacts. Furthermore, green technological innovation competes with traditional technological innovation, which prioritizes economic benefits in the short term but promotes development alongside technological advancement in the long term. Green technological innovation can accelerate industry restructuring, extend the value of industrial chains, and improve labor productivity through the integration of multistage innovative knowledge and capabilities, contributing to the sustainability of the entire industry. Therefore, with the aid of green technological innovation, the NEV industry is expected to further enhance energy utilization efficiency and reduce carbon emissions in the production, transmission, and consumption processes of the entire supply chain, thereby achieving both environmental and economic benefits.

However, green technological innovation is currently facing unprecedented challenges due to economic policy uncertainty (EPU) [17–20]. In recent years, owing to the impact of a sluggish international market, trade protectionism, anti-globalization economic trends, and public health security concerns, governments worldwide have intervened in the market by formulating and implementing a series of economic stimulus policies [21,22]. While these policies prevented a sharp economic downturn, the frequent adjustment of macro-policy environments led to ambiguous and unpredictable government policy directions, resulting in significant EPU [23,24]. In China, the annual average value of the EPU index in 2020 was 13.39 times that in 2000 [25], leading to increased risks in market operations, exacerbated capital outflows, and economic turbulence [26]. Such factors affect enterprises' sensitivity to economic policies and influence their technological innovation activities. This influence is particularly evident in the NEV industry, which is heavily reliant on government support, where the impact of EPU on green technological innovation becomes pronounced. China, as the world's largest carbon emitter, actively promotes its domestic NEV industry through strategies such as financial subsidies and tax incentives [27,28]. According to data from the China Automotive Industry Association, NEV production volume in China amounted to 9.442 million units in 2023 [29]. As shown in Figure 1, the market share of NEVs in China has steadily increased year by year, reaching 31.55% in 2023, with NEVs accounting for 6.07% of the total vehicle stock. This surge in NEV consumption contributed to a global reduction of approximately 50 million tons of carbon emissions [30], significantly aiding emissions mitigation within the transportation sector. In this context, studying the impact of EPU on green technological innovation in Chinese NEV enterprises holds practical significance.



(**a**) (**b**)

Figure 1. (**a**) Sales volume and market share of NEVs in China; (**b**) total vehicle stock and the proportion of NEVs in China.

Limited research has been dedicated to exploring the effect of EPU on green technological innovation in NEV enterprises. Current scholarly works primarily focus on the relationship between green technological innovation and EPU, but no consensus has been reached [17,18,24,31], reflecting the profound complexity of this field. Compared to general industries, the NEV industry is in a rapid development stage with competitive market incentives and high policy environment dependence [10,11,32]. Moreover, compared to general technological innovation, green technological innovation involves large amounts of R&D resources, has long investment cycles, and bears higher risks [33–35], typically generating direct economic benefits over the long term. This implies greater uncertainty and more externalities for businesses. These characteristics create a clear distinction between the green technological innovation of NEV enterprises and that of general industries or typical technological innovation activities, necessitating further study. However, no study has specifically focused on the activities related to green technological innovation of NEV enterprises under EPU.

Therefore, this study examines the relationship between EPU and green technological innovation in Chinese NEV enterprises using panel data on green technological innovations of listed companies between 2012 and 2022. In addition, considering the constraints of internal resources and the external institutional environment on corporate innovation, we also analyzed the moderating effects of corporate ESG performance and government subsidies on this relationship.

The potential marginal contributions of this study are as follows: First, by focusing on the impact of EPU on green technological innovation in NEV enterprises, this study broadens the scope of existing research on NEV enterprises. Existing literature primarily focuses on aspects such as market demand, technological advancement, and the policy impact of NEVs [27,28,36,37]. Through an EPU examination, this study further uncovers the influence of the policy environment on green technology innovation in NEV enterprises, which is important for understanding how businesses innovate in uncertain environments.

Second, by exploring the moderating roles of corporate ESG performance and government subsidies from the perspective of internal corporate resources and external government policy incentives, this study enriches and expands the boundary conditions under which EPU affects green technological innovation in the NEV industry. Existing research indicates that corporate green technological innovation is a complex systemic issue constrained by the external institutional environment and internal resource conditions [33–35,38]. Thus, this study clarifies the role of corporate ESG performance and government subsidies in mitigating the effects of EPU on green technological innovation while providing a new perspective for understanding and guiding green technological innovation.

Finally, in further analysis, this study considers factors such as regional public environmental concern [39] and NEV company types (whole vehicle manufacturers versus parts producers) [40] and their roles in the relationship between EPU and corporate green technological innovation. The findings suggest that the social environments in different regions and types of businesses may have varying impacts on the relationship between NEV enterprises' EPU and green innovation.

The rest of this article is structured as follows: The second section reviews relevant previous research, the third section proposes the research hypotheses of the study, the fourth section describes the methodology, the fifth section presents the results of the empirical tests, and the sixth section concludes the study.

2. Literature Review

2.1. Research on the Relationship between EPU and Green Technology Innovation

EPU refers to the ambiguity regarding the future direction and intensity of government policies, particularly economic policies related to socioeconomic conditions and enterprise operations. EPU reflects a lack of transparency in economic decisions, inconsistency in the implementation of economic policies, and difficulty in predicting future policies [31]. Frequent adjustments in economic policies aim to impact overall economic operations and guide economic development. However, during the policy formulation stage, companies often cannot accurately predict future policy content; after the policy implementation phase, enforcement intensity and outcomes come with various possibilities, causing enterprises to face uncertainty in economic policymaking [41]. When economic entities, such as companies, cannot accurately predict whether, when, or how the government will change current economic policies, the high degree of uncertainty in the economic policy environment can negatively affect the overall economy and business activities [42–44].

Many scholars have studied the impact of EPU on corporate technological innovation, but the existing studies have not reached unanimous conclusions. Some scholars believe that an increase in EPU raises companies' capital costs, thereby hindering their technological innovation activities [21–24,26]. Others propose that EPU is positively correlated with corporate technological innovation. Although EPU brings risks to companies, it also creates opportunities, and companies can consolidate their market positions through increased strategic investments in innovation [24]. Some scholars found that EPU's impact on corporate technological innovation is related to industry and company characteristics. Corporate innovation can be categorized into exploitative and exploratory [31] or green and non-green [14]. In the short term, both types compete but complement each other in the long term [45]. Non-green innovation prioritizes economic benefits, while green innovation focuses on environmental gains. With limited R&D resources, they compete, but in the long run, they mutually benefit, enhancing both economic and environmental outcomes. Green innovation boosts R&D efficiency, aids industrial restructuring, and improves labor productivity. However, it requires more resources, has longer cycles, and has higher risks compared to non-green innovation. This shapes EPU's impact because, while it drives general innovation, its effect on green innovation may be limited [46].

These studies reflect the deep and complex relationship between EPU and corporate green technological innovation. Overlooking company industry characteristics and the multidimensional attributes of technological innovation are pivotal factors contributing to the disparate outcomes of previous research.

2.2. Research on the Relationship between Corporate ESG and Innovation Decisions

Corporate ESG involves a comprehensive assessment of a company's environmental responsibility (E), social responsibility (S), and internal governance performance (G). Corporate ESG moves beyond the traditional single mode of information disclosure, emphasizing the comprehensive development of companies and reflecting on their efficiency and effectiveness in resource utilization, green investment, fulfilling social responsibilities, and corporate governance [47,48].

Numerous studies indicate that strong ESG performance not only enhances a company's market reputation and investor confidence but also fosters an innovation culture. For instance, Broadstock et al. suggest that companies with higher ESG scores often exhibit greater innovation capabilities [49]. This phenomenon stems from their ability to effectively attract and utilize talent and capital invested in sustainability initiatives. Moreover, Lee et al. suggest a positive correlation between environmental performance, as part of ESG assessment, and firms' R&D investments [50], indicating that investing in environmental technologies and products can yield broader social and economic returns. Thus, superior ESG performance drives companies to adopt forward-thinking and higher-risk innovation strategies, which are crucial for long-term sustainability.

In environments characterized by high EPU, firms face increased risks and uncertainties, wherein the positive impact of ESG performance on corporate innovation strategies becomes particularly pronounced. Zhang et al. indicate that companies with high ESG scores are more inclined to maintain or increase R&D expenditures when confronted with macroeconomic and policy uncertainties [51]. This underscores how effective ESG management provides firms with internal stability, facilitating sustained innovation investments amidst uncertainty. Similarly, Vural-Yavaş suggests that firms with outstanding ESG performance are more likely to invest in innovation projects related to societal and environmental issues during periods of uncertainty [52], as these companies have already internalized sustainability principles into their organizational structures and strategic planning. Such a strategy not only helps mitigate the direct impacts of external uncertainty but also creates new business opportunities during crises. Therefore, corporate ESG performance stands as a key factor in maintaining momentum for sustained innovation in the face of EPU.

2.3. Research on the Relationship between Government Subsidies and Innovation Decisions

Government subsidies serve as a pivotal mechanism for fostering green technological innovation, particularly within industries such as the NEV sector, with their positive impact well-documented across various studies. By alleviating the economic burden associated with high-risk green technology R&D, governmental financial support incentivizes firms to engage in more innovation activities. Bai et al. indicate that subsidies directed towards environmentally friendly products and processes significantly boost firms' R&D expenditures and innovation in green products [53]. Similarly, Sun et al. reveal that government R&D subsidies, particularly in the realm of green technologies, notably increase firms' innovation investments and patent outputs, particularly among small and medium-sized enterprises in China [54]. These studies underscore the pivotal role of government subsidies in promoting technological innovation, especially in environmentally relevant domains, demonstrating that policymakers can effectively drive the development and commercialization of green technologies through appropriate fiscal incentives.

Amidst heightened EPU, government subsidies play a critical buffering role in shaping corporate innovation decisions, particularly in green technology innovation. During periods of policy and market ambiguity, subsidies provide a safety net, assisting firms in sustaining their R&D investments. Aristei et al. suggest that firms across EU countries receiving government subsidies are better positioned to maintain their R&D activities during economic crises compared to those without subsidies [55], indicating that subsidies help mitigate the adverse effects of external economic fluctuations on firms' innovation activities. Moreover, Tajaddini and Gholipour lend further support to this notion, revealing that government subsidies not only increase firms' R&D expenditures but also enhance their ability to continue investing in innovation during periods of high uncertainty [56]. These studies collectively highlight that government subsidies, particularly in uncertain economic environments, effectively support firms in undertaking necessary technological upgrades and green innovations, thereby reducing the negative impact of uncertainty on firms' innovation strategies.

3. Research Hypotheses

3.1. EPU and Green Technology Innovation in NEVs

Owing to the dual impact of industry characteristics and innovation features, green technology innovation in the NEV industry is particularly sensitive to EPU. First, the unstable policy environment caused by EPU affects NEV enterprises' future expectations regarding external government incentives for green technological innovation. The pace and direction of the NEV industry's development are often contingent on policy changes. As EPU increases, companies' expectations may become vague, making them more cautious about making long-term investment decisions in R&D and technological innovation [45,57]. As an emerging industry, NEV projects typically entail a lengthy process, from conception to R&D and market launch, and the projects themselves are highly uncertain [5]. Green technological innovation requires substantial upfront investment and a longer development cycle, making it difficult to realize short-term economic benefits. Under conditions of increased EPU, NEV enterprises might choose to reduce their resource investment in green technological innovation to avoid risk.

Second, the resource constraints caused by EPU can decrease NEV enterprises' internal motivation to engage in green technological innovation. The NEV industry faces fierce market competition and a rapid pace of core technology updates. Against the backdrop of increasing environmental pollution and greenhouse effects, more and more countries and regions, such as Europe, have introduced plans to restrict or prohibit the sale of fossil-fueled vehicles [58]. China is actively promoting NEVs and supporting the development of related industries. These policies provide a vast market space for the development of the NEV industry. Traditional car manufacturers, such as BYD and FAW, are transforming, and many new forces in car-making, such as Li Auto, NIO, and Xpeng, have emerged, resulting in intense market competition. Competitive pressure forces NEV enterprises to continuously innovate core technologies, especially in areas that consumers care about, such as vehicle range, electronic systems, and control systems, to gain a competitive market advantage. However, EPU can influence the market context for companies and limit the R&D resources they can access and use. For instance, EPU-induced market volatility may amplify the instability of firms' cash flows, thereby increasing the costs of external financing for companies [17,22,31]. In this situation, NEV enterprises may prefer to allocate limited R&D resources to innovation projects that can bring direct economic benefits in the short term rather than green technology innovations.

Based on the above analysis, we propose the following hypothesis:

H1. *As EPU increases, green technology innovation in NEV enterprises decreases.*

3.2. The Moderating Role of Corporate ESG

Internal resource constraints are crucial factors affecting green technological innovation in NEV enterprises. However, NEV enterprises with different ESG performances exhibit significant differences in obtaining government and societal resources and in the efficiency of resource utilization, which can alter the impact of EPU on green technological innovation [47,48].

First, proactive ESG performance can reduce information asymmetry among enterprises, the government, and the public, enabling NEV enterprises to secure resources to address R&D constraints imposed by EPU. If NEV enterprises demonstrate environmental protection and voluntary fulfillment of social responsibilities, they are likely to reduce the risk of environmental penalties and receive more policy subsidies and incentives. Furthermore, favorable ESG performance can reduce information asymmetry in the market and help enterprises solve their financing difficulties. This support can alleviate the issue of resource scarcity for NEV firms in an economically uncertain environment, thereby increasing the company's R&D investment in green technological innovation.

Second, an ESG-oriented strategy can boost internal operational efficiency, enabling NEV enterprises to integrate internal resources better and improve resource utilization efficiency. Enhancing the capability to optimize the allocation of internal resources can also alleviate the resource constraint pressure generated by EPU, and strengthening internal governance allows NEV enterprises to make more rational decisions in the face of EPU, leading them to favor green technological innovations that can enhance sustainable development capabilities when weighing traditional technological innovation against green technological innovation. Therefore, an ESG strategy may mitigate the negative effect of EPU on green technological innovation in NEV enterprises.

Based on the above analysis, we propose the following hypothesis:

H2. *The higher the ESG of NEV enterprises, the weaker the negative impact of EPU on green technological innovation.*

3.3. The Moderating Role of Government Subsidies

Industrial development and corporate green transformation require strong fiscal support [32,33,59]. To create competitive advantages for NEVs and ensure environmental sustainability, the NEV industry has been supported by various subsidy policies from the central and local governments since 2010, including research and development subsidies, consumer subsidies, and government procurement [28,36,37]. The government aims to adjust the distribution of benefits through these policies to encourage independent innovation and enhance the industrial development capacity, thus accelerating the development of

NEV enterprises [60,61]. Against the backdrop of rising EPU, strong government subsidies can significantly improve the external input incentives and internal innovation resource constraints faced by NEV enterprises, thereby influencing the relationship between EPU and green technological innovation.

First, government subsidies reduce enterprises' concerns regarding the instability of government policies and enhance their confidence in green technological innovations. The introduction and continuous implementation of subsidy policies demonstrate the government's long-term willingness and commitment to the NEV industry [62]. The stability and predictability of such policies are favorable for enterprises to plan and implement long-term green technological innovation strategies, thereby mitigating the negative impact of EPU.

Second, government subsidies can increase the cash flow of NEV enterprises, easing the deficiency in R&D investment caused by EPU [63] and promoting the progress of green technology innovation. Additionally, the guiding nature of government subsidies encourages NEV enterprises to prioritize their environmental responsibilities during production and operations, thus strengthening their preference for investing in green technological innovation to accelerate sustainable development. Moreover, for the external market, government subsidies have a phenomenon known as the "signaling effect" [64,65], which can help NEV enterprises attract more external investment, thereby easing external financing constraints brought by EPU and enhancing their green technology innovation capability.

Based on the above analysis, we propose the following hypothesis:

H3. *The more government subsidies NEV enterprises receive, the weaker the negative impact of EPU on their green technological innovation.*

The theoretical framework of this study is shown in Figure 2.

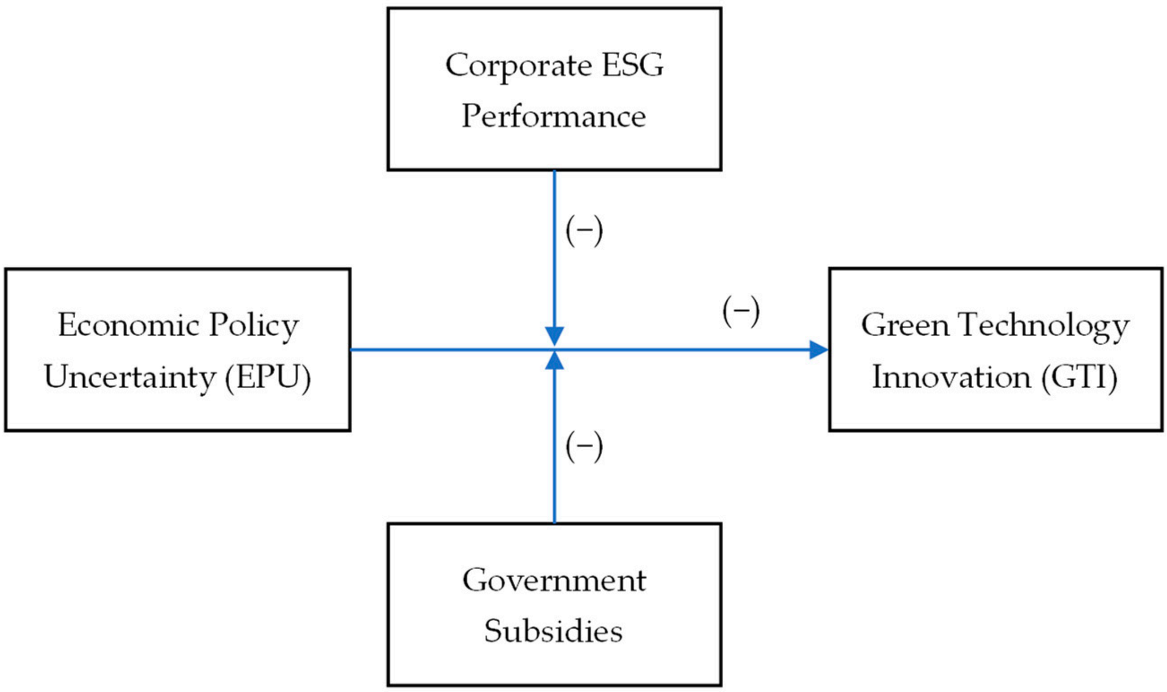


Figure 2. The theoretical framework.

4. Materials and Methods

4.1. Data

This study used data from listed companies and enterprises listed on the National Equities Exchange and Quotations (NEEQ) platform in the NEV industry from 2012 to 2022.

China implemented the "Energy-saving and New Energy Vehicle Industry Development Plan (2012–2020)" in 2012, after which the development of the NEV industry accelerated rapidly, so the year 2012 is considered the starting point for the data.

The selection of listed companies and NEEQ-listed enterprises in the NEV industry was based on the following considerations: First, listed companies and enterprises listed on the NEEQ have well-established organizational management systems that can represent the development of the main industry. Moreover, companies listed on the NEEQ are often high-quality enterprises in emerging industries, which aligns with the focus of this study: the NEV industry. Secondly, the NEV industry is an emerging industry with no clear definitions. However, some analytical indices have been formed for the capital market, such as the CSI NEVs Index, the Wind NEVs Index, and the Tonghuashun NEV Concept Stocks. The market has a basic understanding of which enterprises belong to the NEV industry. Appropriate corporate samples for this research can be selected from listed companies and NEEQ-listed enterprises. Third, data on government subsidies, green patents, and corporate financing are required for research purposes. Listed companies and NEEQ-listed enterprises have good disclosure mechanisms, and the necessary information for this research can be obtained from the Wind database, the CSMAR database, and the annual reports of listed companies.

Considering the inclusion of the NEV index and concept stocks, data relevant to listed and NEEQ-listed companies in the NEV industry from 2012 to 2022 were selected. Invalid and missing data were comprehensively assessed and subsequently excluded by combining the company's principal business, operating income, and other main constituent information. Ultimately, 62 NEV enterprises and their upstream and downstream industry chain-related enterprises were selected for a total of 682 observational data points.

4.2. Variables

(1) Dependent Variable: Green Technology Innovation (GTI). The number of green patent applications by enterprises is used as a proxy variable for green technology innovation [17,18,33].

(2) Core Explanatory Variable: Economic Policy Uncertainty (EPU). This was measured using Baker et al.'s [41] EPU index. The index is constructed based on the content of news reports from the South China Morning Post and is jointly released by Stanford University and the University of Chicago, which effectively reflects the level of EPU in China in different months. According to Li et al. and Peng et al. [19,20], the annual arithmetic average of the monthly data for each of the 12 months is used to calculate the annual EPU data.

(3) Moderating Variable: Corporate ESG (ESG). This was measured using the ratings of the China Securities ESG evaluation system. China Securities' ESG rating data are characterized by their relevance to the Chinese market, broad coverage, and high timeliness.

Government Subsidies (Gsub). This was measured as the log value of financial subsidies obtained by the enterprise in the current year. Government subsidies refer to monetary or non-monetary assets obtained by an enterprise from the government without compensation, and the enterprise should separately disclose the type, amount, and reported items of government grants in notes to the financial statements [66].

(4) Control Variables: Building upon previous research [32,40,67], this study selects factors that may influence green technology innovation in NEVs, including enterprise age (Age), measured by the number of years an enterprise has existed up to the current year; enterprise size (Size), measured by the log value of the total assets of the enterprise; enterprise profitability (ROA), measured by the return on total assets of the enterprise; ownership nature of the enterprise (SOE), a dummy variable, with state-owned enterprises assigned the value 1 and non-state-owned enterprises the value 0; and financial risk of the enterprise (Frisk), measured by the asset-liability ratio of the enterprise. Table 1 presents the variables included in the main regression analysis.

Table 1. Variables and data sources.

Variable	Abbreviation	Description	Source
Green technology innovation	GTI	Number of green patent applications	CNRDS database and firm annual reports
Economic policy uncertainty	EPU	EPR Index	Baker et al. [41]
Firm ESG Performance	ESG	China Securities ESG Index	Wind database
Government subsidies	Gsub	ln (government subsidies)	Firm annual reports
Firm age	Age	Years of firm establishment to the current year	Wind database and firm annual reports
Firm size	Size	ln (total assets)	Wind database
Firm profitability	ROA	(Total profit + financial expenses)/average total assets	Wind database
Firm ownership	SOE	If the controller is a state-owned enterprise, equals to 1; otherwise, 0	Wind database
Firm financial risk	Frisk	Asset-liability ratio	Wind database

4.3. Econometric Model

To test the impact of EPU on technological innovation in the NEV industry, the following regression model was constructed:

$$GTI_{it} = \beta_0 + \beta_1 EPU_t + \beta_2 EPU_t \times ESG_{it} + \beta_3 EPU_t \times Gsub_{it} + \sum Control_{it} + \mu_i + \varepsilon_{it}, \quad (1)$$

where i denotes the enterprise, t denotes the year, GTI_{it} represents the green technological innovation of the enterprise, EPU_t is the measure of economic policy uncertainty, ESG_{it} is the corporate ESG performance, $Gsub_{it}$ is the government subsidies received by the enterprise, and EPU×ESG and EPU×Gsub are interactive terms, aiming to investigate the moderating effects of corporate ESG performance and government subsidies [68]. $Control_{it}$ represents a series of control variables, β are the coefficients to be estimated, μ_i represents the enterprise-fixed effect, and ε_{it} is a random disturbance term. The regression analysis for this study was generated using Stata 15.0.

5. Results

5.1. Descriptive Statistics

Table 2 presents the descriptive statistics of the main variables. The mean value of GTI among Chinese NEVs was 12.379, with a standard deviation of 44.434, ranging from 0 to 526. This indicates significant differences in green technological innovation among Chinese NEV enterprises. Among the explanatory variables, the average value of EPU is 4.198, with a standard deviation of 2.374, ranging from 1.139 to 7.919, indicating some variability in China's EPU over different periods.

Table 2. Descriptive statistics.

Variable	N	Mean	Sd	Min	Max	VIF
GTI	682	12.739	44.434	0	526	
EPU	682	4.198	2.374	1.139	7.919	1.23
ESG	682	3.753	1.789	0	7	2.99
Gsub	682	7.355	3.553	0	13.06	3.33
Age	682	9.891	7.679	1	29	1.56
Size	682	20.479	7.437	0	27.621	4.17
ROA	682	0.033	0.096	−1.127	0.439	1.29
SOE	682	0.113	0.317	0	1	1.12
Frisk	682	0.504	0.215	0	1.698	1.50

Note: Mean VIF is 2.15.

Moreover, the multicollinearity test of the model showed that the average variance inflation factor (VIF) of the variables selected in this study was 2.15 (below the conventional threshold of 6), and the maximum VIF value was 4.17 (below the conventional threshold of 10). Therefore, multicollinearity was not a concern.

5.2. Cross-Sectional Dependence (CD) Test

Before proceeding with panel data analysis, it is essential to test for cross-sectional dependence. We employ two testing methods: the Baltagi–Pinnoi LM test and the Pesaran CD test [69,70]. The results, presented in Table 3, show that both tests reject the null hypothesis of "no cross-sectional dependence" at a 1% significance level. Therefore, it is necessary to consider the impact of cross-sectional dependence in the subsequent empirical analysis.

Table 3. Results of cross-sectional dependence tests.

Test	Statistics	Prob.
Baltagi–Pinnoi LM test	483.629 ***	0.000
Pesaran CD test	6.376 ***	0.002

Note: Null hypothesis is that no cross-sectional dependence exists within the panel data. *** $p < 0.01$.

5.3. Regression Analysis

The dependent variable in this study is the green technological innovation of Chinese NEV enterprises, as measured by the number of corporate green patent applications. For this count variable, Poisson and negative binomial regressions are appropriate econometric methods. However, a limitation of the Poisson regression is the Poisson distribution characteristic, in which the mean equals the variance, which does not conform to our actual data. The standard deviation of the dependent variable in this study was 44.434, with a mean of 12.739, making the variance more than a hundred times the mean. This indicates a potential overdispersion. Although the panel Poisson regression remains consistent even with overdispersion, a negative binomial regression may be more efficient. Hence, we used a panel negative binomial regression model for data analysis. In the robustness check, Poisson regression was used as an alternative testing method.

After selecting the panel negative binomial model, we conducted both the Likelihood Ratio (LR) test and the Hausman test to ascertain the appropriate model specification among mixed-effects, fixed-effects, or random-effects. The LR test significantly rejected the null hypothesis of mixed effects at the 1% significance level. Similarly, the Hausman test significantly rejected the null hypothesis of random effects at the 1% level, prompting us to adopt a fixed-effects model. The fixed-effects panel negative binomial regression offers the advantage of estimating the coefficients for variables that are invariant over time, showcasing a key benefit of this methodological approach.

Table 4 presents the results of the basic linear regression analysis. In Table 4, the first column includes only the control variables, and the second column adds EPU to the control variables. The regression results in the second column indicate that the coefficient for EPU is significantly negative at the 5% level, which implies that as EPU increases, green technological innovation in Chinese NEV enterprises decreases significantly, which validates H1.

Table 4. Regression results.

	(1)	(2)	(3)	(4)	(5)
EPU		−0.370 **	−0.350 ***	−0.240 *	−0.432 ***
		(−2.49)	(−4.41)	(−1.86)	(−3.44)
EPU×ESG			0.080 ***		0.073 ***
			(3.76)		(2.92)
EPU×Gsub				0.345 ***	0.271 ***
				(3.53)	(2.71)

Table 4. *Cont.*

	(1)	(2)	(3)	(4)	(5)
Age	−0.038	−0.040	−0.043	−0.041	−0.044
	(−1.29)	(−1.32)	(−1.60)	(−1.27)	(−1.56)
Size	0.790 ***	0.790 ***	0.738 ***	0.651 ***	0.690 ***
	(5.14)	(5.20)	(5.05)	(3.86)	(4.50)
ROA	3.893 **	4.216 **	3.217 *	4.111 **	3.217 *
	(1.97)	(2.06)	(1.86)	(2.01)	(1.85)
SOE	0.250	0.333	0.288	0.318	0.285
	(0.69)	(0.95)	(0.90)	(0.86)	(0.86)
Frisk	2.255 **	2.319 **	2.984 ***	2.361 **	2.928 ***
	(2.30)	(2.35)	(3.09)	(2.47)	(3.06)
_cons	−17.352 ***	−17.540 ***	−16.532 ***	−14.377 ***	−15.408 ***
	(−4.77)	(−5.21)	(−5.16)	(−3.78)	(−4.52)
N	682	682	682	682	682
pseudo R^2	0.079	0.079	0.085	0.081	0.086

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Columns 3 to 5 test the moderating roles of corporate ESG and government subsidies. Columns 3 and 4 include the interaction terms EPU×ESG and EPU×Gsub, respectively. Column 5 includes this information in the test model. The test results in Columns 3–5 show that the coefficient of the EPU×ESG interaction term is significantly positive, indicating that corporate ESG significantly mitigates the negative impact of EPU on green technological innovation in NEV enterprises. In other words, the higher the corporate ESG of NEV enterprises, the lower the negative impact of EPU on their green technology innovation, confirming H2; the coefficient of the EPU×Gsub is significantly positive, demonstrating that government subsidies significantly weaken the negative impact of EPU on green technology innovation in NEV enterprises. That is, the more government subsidies NEV enterprises receive, the less negative the impact of EPU on their green technological innovation, supporting H3.

5.4. Endogeneity and Robustness Tests

5.4.1. Discussion of Endogeneity Issue

Although EPU is an exogenous macroeconomic variable with a lower possibility of sample selection bias and causality issues, endogeneity can still be introduced by measurement errors. Therefore, we use the instrumental variable two-stage least squares (IV-2SLS) method to mitigate the issue of endogeneity. Building on the methodology of Zhong et al. [31], we selected U.S. EPU (IV-EPU) as the instrumental variable for China's EPU. The macroeconomic policies of China and the United States are highly correlated, satisfying the assumption of relevance for the instrumental variable; however, U.S. EPU does not directly affect the green technological innovation activities of Chinese NEV enterprises, meeting the exogeneity condition of the instrumental variable. Additionally, a weak instrument variable test revealed an F-value of 368.52 (far greater than 10) and a *p*-value of 0.000, suggesting that there was no weak instrument variable problem. Table 5 presents the regression model using the U.S. EPU index as an instrumental variable, which shows that after using the U.S. EPU index as an instrumental variable, EPU still had a significant negative impact on the green technological innovation of Chinese NEV enterprises, indicating that the baseline conclusions of this study remain valid even after addressing potential endogeneity issues.

Table 5. Regressions using U.S. EPU as an instrumental variable.

	The First Stage EPU	The Second Stage GTI
IV-EPU	1.156 ***	
	(8.21)	
EPU		−22.40 2**
		(−2.23)

Table 5. *Cont.*

	The First Stage EPU	The Second Stage GTI
EPU×ESG		1.529 **
		(1.97)
EPU×Gsub		1.417 **
		(2.40)
Age	0.045 ***	−0.605 *
	(3.52)	(−1.96)
Size	0.075 ***	−0.676
	(6.00)	(−1.09)
ROA	−2.264 **	−39.013
	(−2.48)	(−1.28)
SOE	−1.146 ***	0.934
	(−4.41)	(0.19)
Frisk	0.187	22.769 ***
	(0.42)	(2.67)
_cons	0.453	42.808 *
	(1.33)	(1.74)
N	682	682
adj. R^2	0.243	.

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. F value = 368.52.

5.4.2. Robustness Tests

To assess the robustness of the main findings, we replaced the dependent variable with both the test model and measurement indicators. First, a mixed Poisson regression was used as an alternative method for robustness testing. The test results in Table 6 are consistent with those in Table 4, further verifying the core findings' robustness.

Table 6. Poisson regression results.

	(1)	(2)	(3)	(4)	(5)
EPU		−0.108 **	−0.328 ***	−0.543 *	−0.634 **
		(−2.30)	(−2.81)	(−1.76)	(−2.19)
EPU×ESG			0.041 **		0.235 **
			(2.12)		(2.31)
EPU×Gsub				0.522 ***	0.510 ***
				(3.31)	(3.11)
Age	−0.061 *	−0.056	−0.057	−0.055	−0.056
	(−1.69)	(−1.61)	(−1.62)	(−1.63)	(−1.64)
Size	0.738 ***	0.773 ***	0.71 2***	0.590 ***	0.575 ***
	(5.54)	(5.46)	(4.83)	(4.37)	(4.22)
ROA	−0.054	−0.494	−1.100	−0.421	−0.868
	(−0.05)	(−0.42)	(−0.94)	(−0.33)	(−0.68)
SOE	0.185	−0.012	0.019	−0.017	0.010
	(0.53)	(−0.04)	(0.06)	(−0.05)	(0.03)
Frisk	1.931 **	1.935 **	2.138 ***	2.003 **	2.173 ***
	(2.16)	(2.16)	(2.68)	(2.32)	(2.84)
_cons	−15.461 ***	−15.829 ***	−14.336 ***	−11.348 ***	−11.007 ***
	(−5.03)	(−4.95)	(−4.31)	(−3.66)	(−3.55)
N	682	682	682	682	682
pseudo R^2	0.438	0.451	0.461	0.464	0.469

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 presents a pseudo R^2 of approximately 0.45, while Table 4 reports a notably lower pseudo R^2 of about 8%. The significant difference in pseudo R^2 between the mixed Poisson regression and the fixed effects negative binomial regression could be attributed to the following reasons: (1) As previously mentioned, the dependent variable exhibits overdispersion. The mixed Poisson regression, by incorporating random effects, may partially account for unobservable heterogeneity, which could inflate the model's R^2. However, this model may not fully account for the overdispersion present in the data. (2) The fixed effects negative binomial regression is equipped to handle overdispersion in panel data and controls for unobserved individual-specific invariant characteristics through fixed effects. However, if there is a correlation between individual effects and explanatory variables, the fixed effects model might absorb some of this explanatory power, leading to a lower R^2.

Second, green invention patent applications (GTI2) and green utility model patent applications (GTI3) are used as alternative measurement indicators for the explained variable of green technology innovation. According to the application standards, green patents are classified into categories encompassing inventive patents, utility models, and design patents [17,18,46]. The endorsement process for inventive green patents is notably more intricate and protracted compared to that for green utility model patents. In robustness testing, further dividing the number of green patent filings into counts of invention and utility model patents allows for further investigation of the effects of EPU on sustainable innovation within NEV corporations. The regression results in Tables 7 and 8 show that after replacing the measurement indicators for the explained variables, and despite minor differences in the coefficients for EPU, the coefficients of EPU×ESG and EPU×Gsub remain consistent with those in Table 4, supporting our findings.

Table 7. Regression results using the number of green invention patent applications.

	(1) **GTI2**	**(2)** **GTI2**	**(3)** **GTI2**	**(4)** **GTI2**	**(5)** **GTI2**
EPU		−0.302 **	−0.371 ***	−0.277 **	−0.427 **
		(−2.20)	(−4.00)	(−2.15)	(−2.54)
EPU×ESG			0.087 ***		0.083 ***
			(3.66)		(2.88)
EPU×Gsub				0.317 ***	0.226 *
				(3.13)	(1.93)
Age	−0.023	−0.027	−0.029	−0.026	−0.030
	(−0.68)	(−0.77)	(−0.95)	(−0.72)	(−0.93)
Size	0.814 ***	0.812 ***	0.756 ***	0.683 ***	0.724 ***
	(5.04)	(5.14)	(5.06)	(4.00)	(4.49)
ROA	3.763 *	4.167 *	3.304 *	4.078 *	3.300 *
	(1.73)	(1.86)	(1.76)	(1.81)	(1.75)
SOE	0.041	0.156	0.143	0.125	0.135
	(0.11)	(0.44)	(0.45)	(0.34)	(0.42)
Frisk	1.954 *	2.040 **	2.746 ***	2.073 **	2.705 ***
	(1.90)	(1.97)	(2.78)	(2.03)	(2.75)
_cons	−18.378 ***	−18.601 ***	−17.526 ***	−15.628 ***	−16.768 ***
	(−4.71)	(−5.27)	(−5.31)	(−4.05)	(−4.64)
N	682	682	682	682	682
pseudo R^2	0.086	0.087	0.096	0.089	0.096

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8. Regression results using the number of green utility model patent applications.

	(1) **GTI3**	**(2)** **GTI3**	**(3)** **GTI3**	**(4)** **GTI3**	**(5)** **GTI3**
EPU		−0.283 *	−0.307 ***	−0.309 *	−0.467 ***
		(−1.67)	(−2.67)	(−1.75)	(−2.65)
EPU×ESG			0.059 **		0.052 *
			(2.32)		(1.94)
EPU×Gsub				0.455 ***	0.418 ***
				(4.06)	(3.97)
Age	(−2.36)	(−2.28)	(−2.50)	(−2.35)	(−2.53)
	0.770 ***	0.771 ***	0.715 ***	0.621 ***	0.624 ***
Size	(5.26)	(5.20)	(4.72)	(3.33)	(3.60)
	3.408	3.159	2.365	3.097	2.362

Table 8. *Cont.*

	(1) GTI3	(2) GTI3	(3) GTI3	(4) GTI3	(5) GTI3
ROA	(1.59)	(1.54)	(1.28)	(1.46)	(1.24)
	0.571	0.515	0.465	0.519	0.469
SOE	(1.50)	(1.36)	(1.30)	(1.34)	(1.27)
	2.615 **	2.561 **	3.061 ***	2.635 ***	3.037 ***
Frisk	(2.53)	(2.56)	(3.01)	(2.76)	(3.10)
	(−2.36)	(−2.28)	(−2.50)	(−2.35)	(−2.53)
_cons	−17.822 ***	−17.701 ***	−16.556 ***	−14.265 ***	−14.429 ***
	(−5.26)	(−5.33)	(−4.98)	(−3.38)	(−3.73)
N	682	682	682	682	682
pseudo R^2	0.092	0.092	0.097	0.095	0.098

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.5. Heterogeneity Analysis

Given the differences in public environmental awareness across provinces and among types of NEV enterprises (vehicle manufacturers or parts producers), the impact of EPU on green technological innovation, as well as the moderating effects of corporate ESG and policy subsidies, may vary significantly.

First, environmental awareness represents the public's environmental preferences in each province, which significantly influences the social resource support that NEV enterprises can obtain for green technological innovation. The literature indicates that profit-maximizing companies often lack motivation for active environmental engagement, necessitating government policy intervention [59,71]. However, market-based and informal regulatory oversight at the public level has not yet been effective [72]. To further explore the potential impact of public environmental preferences, we used the Baidu Smog Search Index to analyze the effects of environmental attention in different regions.

The Baidu Smog Search Index was chosen to represent public environmental attention for the following reasons:

(1) Baidu, as the largest Chinese search engine, has wide coverage and data accessibility, thus allowing for data analysis in all regions of China based on search frequency and location.
(2) Compared to other environmental issue keywords, such as "environmental pollution", smog weather offers higher environmental perceptibility, enabling the public to gauge its severity through air visibility.

The term "smog" attracts significant public attention, reflecting widespread environmental concern. The Baidu Index is categorized into three types: overall search index, PC search index, and mobile search index, where the overall search index is the weighted sum of the PC and mobile search indices. This study chose the keyword "smog" not only because smog weather has strong environmental perceptibility but also because the correlation coefficient between PM2.5, pollution concentration, and the Air Quality Index (AQI) is as high as 0.9267, making smog pollution a good indicator of air quality [39].

This study classified Chinese provinces into areas with high and low public environmental awareness based on the average Baidu Smog Search Index, conducting subsample tests according to company registration locations. Columns 1–2 in Table 9 present the regression results. The results show no significant differences in the impact of EPU or the moderating role of corporate ESG on green technological innovation in NEV enterprises between provinces with varying degrees of public environmental awareness. However, significant heterogeneity exists in the moderating effects of policy subsidies. In provinces with higher public environmental awareness, the moderating effect of government subsidies on the EPU-green technological innovation relationship in NEV enterprises is weaker compared to provinces with lower awareness, suggesting that social resource support and government subsidies can substitute for each other to a certain extent when facing resource constraints caused by EPU. In provinces with high public environmental awareness, NEV enterprises' green technological innovation activities receive more social resource support, which helps reduce their dependence on government subsidies.

Table 9. Regression results for public environmental awareness and company type.

	Low Awareness	High Awareness	Vehicle Manufacturers	Parts Producers
EPU	−0.398 ***	−0.734 **	−0.524 **	−0.272 ***
	(−3.24)	(−2.40)	(−2.18)	(−4.21)
EPU×ESG	0.088 ***	0.093 *	0.083 **	0.049 *
	(2.69)	(1.91)	(2.05)	(1.80)
EPU×Gsub	0.327 **	0.164	0.323 **	0.229
	(2.53)	(1.25)	(2.37)	(1.24)
Age	−0.035	−0.085 *	−0.060	−0.151 ***
	(−1.03)	(−1.73)	(−1.58)	(−4.53)
Size	0.822 ***	0.457 ***	0.723 ***	0.329 ***
	(4.99)	(2.59)	(2.64)	(3.55)
ROA	3.167 *	1.906	7.490 **	1.242
	(1.65)	(0.45)	(2.45)	(0.68)
SOE	−0.067	0.376	0.107	−1.126 *
	(−0.11)	(1.15)	(0.32)	(−1.87)
Frisk	0.904	5.804 ***	4.057 **	1.354
	(0.90)	(2.81)	(2.14)	(1.20)
_cons	−17.367 ***	−11.381 ***	−16.550 ***	−6.591 ***
	(−4.76)	(−2.97)	(−2.60)	(−3.28)
N	518	164	253	429
pseudo R^2	0.093	0.082	0.061	0.094

Note: t statistics are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Second, vehicle manufacturers and parts producers differ in their positions within the industry chain and the roles they play in green technological innovation within the industry [40,67], and the relationship between EPU and green technological innovation may vary accordingly. Columns 3–4 in Table 9 show the regression results from the subsample testing based on vehicle manufacturers and NEV parts producers. The results show that, although there is no significant difference in the impact of EPU and the moderating role of corporate ESG on green technological innovation for both types of companies, there is clear heterogeneity in the moderating role of government subsidies. Specifically, compared to that of parts producers, government subsidies have a more pronounced moderating effect on green technological innovation for vehicle manufacturers, which may be related to the core position of vehicle manufacturers in the industry chain. Vehicle manufacturers not only assemble vehicles but also work with suppliers, dealers, and service providers to jointly promote the industry's green transformation, which requires large-scale funding. Therefore, when faced with the EPU, green technological innovation among NEV manufacturers relies more on government subsidies.

6. Discussion

This paper aims to explore the impact of EPU on green technological innovation within NEV companies. As EPU has risen significantly worldwide, scholars such as Zhong et al. and Guan et al. [24,31] have dedicated considerable time and effort to investigating its effects on corporate innovation. However, most existing research has concentrated on the overall innovation activities of companies rather than specifically on the green technological innovation of NEV companies, and no consensus has yet been reached. We delve into the unique characteristics of the NEV industry and differentiate between green technological innovation and general corporate innovation activities, offering more nuanced theoretical insights into the relationship between EPU and corporate innovation. The NEV sector is rapidly evolving and heavily reliant on government policy support, distinguishing it from more established industries. Green technological innovation demands more extensive R&D investments, longer development cycles, and entails greater risks than traditional technological advances. Thus, it is particularly susceptible to EPU. EPU's increase may significantly reduce NEV companies' expectations of future government incentives and exacerbate challenges in acquiring and leveraging R&D resources in the market. Consequently, NEV companies may opt to direct their limited R&D resources towards projects with immediate economic returns, as opposed to long-term green technological innovations. Our findings indicate a significant decrease in green technological innovation within NEV companies with the escalation of EPU, an observation with significant implications for how governments and businesses can counteract the adverse effects of EPU and foster green technological development in the NEV sector.

Additionally, we examine the moderating role of corporate ESG performance and government subsidies on the relationship between EPU and green technological innovation in NEV companies, considering both the internal resource conditions of the company and external policy incentives from the government. ESG performance, as extensively analyzed in the literature [47], is a critical indicator of a company's capabilities for green development. We propose that robust ESG performance can alleviate the detrimental effects of EPU on green technological innovation in NEV firms. A strong ESG record may decrease information asymmetry between companies, the government, and the public, thus enabling NEV companies to secure resource support more effectively, which in turn mitigates the resource limitations imposed by EPU. Furthermore, a proactive ESG strategy can enhance a company's internal operational efficiency, allowing for better integration and utilization of resources. Therefore, the higher the ESG rating of a NEV company, the less pronounced the negative impact of EPU on its green technology innovation endeavors.

In contemporary research on NEV enterprises, it is widely held among scholars that the NEV industry's growth is significantly influenced by government policy support, especially financial subsidies [5,11]. Our findings align with these scholarly perspectives, showing that amidst escalating EPU, substantial government subsidies are crucial in mitigating the challenges NEV enterprises face, such as the lack of external investment incentives and constraints on internal innovation resources, during their green technological innovation endeavors. These government subsidies not only diminish apprehensions regarding policy volatility but also bolster the confidence of NEV enterprises to pursue green technological innovations. Furthermore, such subsidies provide a cushion against the financing strains that arise from heightened EPU. Therefore, it is evident that the extent of government subsidies received by NEV enterprises inversely correlates with the adverse effects of EPU on their green technological innovation efforts.

Our heterogeneity analysis delves into the influence of public environmental concern and the categorization of NEV enterprises—whether they are whole vehicle manufacturers or parts producers—on the interplay between EPU and the green technological innovation within these enterprises. Public environmental concern, as a reflection of societal environmental preferences across various provinces, plays a pivotal role. Echoing Porter's hypothesis, we posit that environmental regulations compel firms to innovate, thereby neutralizing the costs associated with environmental compliance. He et al.'s [73] investigation into the Dual Credit Policy (DCP) underscores this, highlighting its significant influence on the Total Factor Productivity (TFP) of NEV enterprises. Our study further suggests that societal environmental preferences directly impact the green technological initiatives of NEV enterprises. In regions marked by heightened public environmental concern, these enterprises gain increased support from social resources for their green innovation activities, diminishing their reliance on government subsidies. In contrast, in areas with strong public environmental awareness, the moderating role of government subsidies on the nexus between EPU and green technological innovation is comparatively less pronounced.

Additionally, our analysis reveals that government subsidies exert a more substantial moderating effect on the green technological innovation of whole vehicle manufacturers than on parts producers. Our findings diverge from those of Wu et al. and Ren and Liu [40,67], who focus on the stimulating effects of government subsidies on R&D innovation within NEV enterprises from an industrial chain perspective. Focusing more acutely on green technological innovation, our study acknowledges that such innovation is resource-intensive, with a protracted investment horizon and elevated risks. Whole vehicle manufacturers, in contrast to parts producers, are tasked not only with vehicle assembly but also with fostering collaboration among parts suppliers, dealers, service providers, and other stakeholders to spearhead the industry's green transition. Consequently, the reliance of whole-vehicle NEV enterprises on government subsidies has intensified in response to rising EPU, underscoring the subsidies' role in supporting sustainable industry innovation.

The negative impact of EPU on green technological innovation within NEV enterprises in China is evident. Reducing the negative effects of EPU is crucial for achieving China's "3060 Goals" and "Made in China 2025" strategy. Green technology innovation in NEV enterprises not only promotes the transformation and upgrading of China's automotive industry but also has a profound and positive impact on the modernization, intelligence, and greening of the entire manufacturing industry. This supports the achievement of both the "Made in China 2025" strategy and the goals of carbon peak and carbon neutrality. Firstly, the development of the NEV industry, being a technology-intensive field, necessitates continual research and innovation. Upgrading core technologies such as power batteries, motors, and electronic controls can advance the technological progress of the entire automotive manufacturing industry, aligning with the "Made in China 2025" emphasis on high-end manufacturing and innovation capabilities. By developing batteries with higher energy density, longer life, and greater recyclability and adopting more efficient electric drive systems and energy recovery technologies, the carbon footprint of NEVs can be reduced. Secondly, NEV enterprises can implement green manufacturing processes and build efficient, green, and transparent supply chain systems. This not only reduces costs but also ensures the environmental friendliness and sustainability of the entire production process, which is an important aspect of the green development goals outlined in "Made in China 2025." Thirdly, through green innovation, NEV enterprises can establish environmentally friendly brand images and accelerate the popularization of NEVs. This can lead to the large-scale replacement of traditional fuel vehicles, thereby reducing overall greenhouse gas emissions. This aligns with the brand-building strategies outlined in "Made in China 2025".

7. Conclusions

7.1. Main Conclusions

NEVs are now a crucial strategy for reducing global CO_2 emissions due to their low-carbon and environmentally friendly characteristics. Green technological innovation is an important route through which NEVs can effectively reduce carbon emissions, enhance energy use efficiency, and promote sustainable economic development. However, green technological innovation activities face EPU challenges. To address this issue, this study, based on panel data on green technology innovation from Chinese-listed NEV enterprises from 2012 to 2022, thoroughly discusses the impact of EPU on green technology innovation in these companies. This study finds the following points:

(1) EPU significantly hampers green technological innovation in Chinese NEV enterprises, while corporate ESG performance and government subsidies mitigate this negative impact. External investment incentives and internal resource constraints are the main pathways that influence corporate green technological innovation. Positive ESG performance can help NEV enterprises obtain more external resource support and improve the efficiency of internal resource utilization, which can effectively reduce companies' concerns about the stability of external policy incentives. The resulting increase in cash flow can also effectively alleviate research and development resource constraints. Therefore, they can effectively counteract the negative effects of EPU on green technological innovation.

(2) Further analysis reveals that in provinces with lower public environmental awareness and NEV manufacturers, the moderating effect of government subsidies on the relationship between EPU and NEV enterprises' green technological innovation is stronger. When NEV enterprises face resource constraints caused by EPU, social public resource support and government subsidies can substitute for each other to a certain extent, and higher public environmental awareness can reduce the dependence of green innovation activities on government subsidies. All vehicle manufacturers must collaborate with upstream and downstream enterprises in the industry chain during the green transition, which requires substantial financial resources, increasing their dependency on government subsidies.

7.2. Policy Implications

The conclusions of this study provide valuable insights for understanding how NEV enterprises respond to EPU and serve as a reference for the formulation of relevant economic and subsidy policies.

(1) Attention to the adverse impacts of EPU on green technological innovation in NEV enterprises. Governments should develop and refine economic policies to minimize EPU and foster a stable environment that enhances green technological innovation among NEV enterprises.
(2) Enhance corporate ESG performance. Companies should actively improve their ESG metrics to boost their brand image, secure more external resources, enhance competitiveness, and mitigate the adverse impacts of EPU. For instance, companies can enhance their environmental performance by adopting more environmentally friendly production processes and effective energy utilization plans; improve their social responsibility performance by actively participating in public welfare activities; and enhance their governance performance by improving corporate governance levels.
(3) Increase government funding for NEV enterprises. Governments can establish special funds to subsidize areas such as R&D investments, production facility transformations, and employee skill training for NEV enterprises, helping relieve the pressures brought about by EPU and thus facilitating green technology innovation. Particularly for vehicle manufacturers, fiscal subsidies are crucial in promoting green technological innovation and industry-wide green transformation.
(4) Improve public environmental awareness. Governments and all sectors of society should vigorously promote environmental protection and increase public environmental awareness to provide NEV enterprises with more social resource support and reduce their dependency on government subsidies. Governments can raise public environmental consciousness and NEV recognition through media campaigns, public service advertisements, and educational training.

This study has some limitations. Our models may not adequately capture complex nonlinear relationships, such as the nonlinear migration of EPU mentioned in Wu et al. [74] or the potential threshold effects of performance and government subsidies. Additionally, the models might not fully reflect the dynamic nature of innovation activities, which can vary with changing market conditions, policy frameworks, and technological progress. Future research could incorporate advanced nonlinear models, such as threshold regression or dynamic panel data models, to enhance our understanding and support of green technological innovation in this sector.

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