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Are Firms More Willing to Seek Green Technology Innovation in the Context of Economic Policy Uncertainty? —Evidence from China

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Abstract: Frequent shifts in economic policies not only inject uncertainty into the economic landscape but also pose significant challenges to corporate endeavors in green technological innovation. Drawing on a dataset of Chinese A-share listed companies spanning 2008 to 2020, this research delves into the repercussions of economic policy uncertainty on the green technological pursuits of manufacturing firms and elucidates the underlying dynamics at play. The empirical evidence underscores a marked reluctance among companies to champion green technological innovation in the face of economic policy ambiguity, a stance that holds water even after rigorous robustness checks. Delving into the mechanisms, the study pinpoints heightened financial constraints and a diminishing risk appetite within the managerial ranks as pivotal deterrents steering firms away from green innovation projects amidst such uncertainty. Intriguingly, the adverse interplay between economic policy uncertainty and green innovation is especially accentuated in firms marked by tenuous government–business affiliations, pronounced monopolistic inclinations, lax intellectual property safeguards, minimal pollution footprints, and a skewed labor-to-capital composition. This investigation augments the scholarly discourse on the nexus between economic policy volatility and corporate green innovation, shedding light on strategic imperatives for emerging economies as they chart out future environmental blueprints and cultivate a conducive milieu for green innovation.

Keywords: economic policy uncertainty; green technology innovation; financing constraints; management risk appetite; green transition

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1. Introduction

With the growing focus on ecological and environmental governance, enterprises face significant pressure from consumers' green preferences and government regulations. Thus, they must choose between green transformation and traditional production [1]. Failure to make a timely green transition will lead companies to suffer reputational damage and lose market opportunities from increased green preferences among consumers and investors [2]. To avoid losing competitive advantage, green technology innovation is now a strategic choice for companies to ease transformation burdens and boost competitiveness [3]. Green technology innovation integrates technological innovation with ecological principles, offering social value through carbon and pollution reduction, meeting market demand with product improvement, and bringing economic value [4]. Green technology innovation involves high-cost, long-term investment. Its success requires rigorous R&D, conversion, and packaging by various departments, making it a systematic and complex project [5].

Scholars identify enterprise management, financial status, and external environmental constraints as the main factors affecting green technological innovation [6–8]. The predictability of government macro policies is crucial for firms' decisions on green technological innovation [9]. Real options theory suggests that when macroeconomic policies become unpredictable, corporate managers may adopt a "wait and see" approach, putting risk-taking investments such as innovation on hold [10]. The current economic policy uncertainty is at an all-time high due to numerous fiscal, environmental, and trade policies addressing local debts, ecological pollution, and economic recovery. The impact of increased economic policy uncertainty on firms' transformation, upgrading, and green innovation, and its potential impediment to China's goals of "peak carbon" and "carbon neutrality," has become a central concern for scholars. Existing studies have explored economic policy uncertainty's relationship with corporate innovation and investment [11–13]. However, green technological innovation, as an "ecological window" for transformation and value creation, has received little attention, and this issue is the focus of this paper.

Enterprises, fundamental to microeconomics, are influenced by the macro environment in their planning and activities. While a theoretical framework on economic policy uncertainty and enterprise behavior exists, there are inadequate studies verifying the relationship between green technological innovation and this framework. Green innovation, characterized by a long investment time, high costs, and a low success rate, is a high-risk, high-reward strategy [14]. Green innovation can create social value through energy savings and emission reductions [15], and expand the market by meeting consumers' green preferences [16]. As green innovation is a long-term strategy, external environmental stability is crucial [17]. Real options theory suggests that increased economic policy uncertainty leads corporate managers to postpone innovation investments and financial institutions to be cautious in lending to reduce "sunk costs" [8,18]. Firms' decision makers often adopt a "wait-and-see" approach in the face of policy uncertainty, supported by evidence that it leads to reduced innovation [19,20]. Thus, policy uncertainty likely increases the probability of firms delaying innovation activities. Unlike the "wait-and-see" approach amid economic policy uncertainty, enterprises' investment in green innovation is a proactive strategy. Studies show that although short-term compensation for green innovation investments may be delayed, long-term benefits include increased innovation returns through competitive advantages and financial gains through market reputation and consumer support [21,22]. The theoretical framework of green innovation within economic policy uncertainty involves balancing long-term returns against short-term costs and resource allocation. In practice, firms are motivated to pursue green innovation due to economic policy uncertainty, an effect linked to the enforced "wait-and-see" strategy. Since 2013, stricter regulations have forced Chinese firms to face higher environmental costs, leading to a choice between green innovation, compliant equipment purchase, or bearing pollution costs directly—a double loss financially and reputation-wise [23]. Consequently, firms are more inclined to invest in green equipment and technological innovations. Under high economic policy uncertainty, the "wait-and-see" approach entails a waiting cost. Relying on outsourcing or mergers will not allow access to core technology; hence, enterprises increase investment in green innovation to develop in-house capabilities [24].

This paper revisits the issue from a Chinese perspective. The choice to research this issue is significant because China, transitioning from a planned to a market economy with fluctuating policies, offers a valuable research platform for studying economic policy uncertainty. Since 1990, China has become the world's largest carbon emitter within 15 years, reaching 12.46 billion tons in 2021, or nearly a quarter of global emissions. Hence, it is vital for China to pursue green technology innovation to reduce carbon emissions [25]. Green technology innovation is crucial for enterprise transformation, and designing tailored incentives is vital for China's "dual-carbon goal." This perspective emphasizes the importance of micro-level innovation and local adaptations. Green technology innovation is essential to developing countries for economic growth and environmental protection. China's experience can provide insights and lessons for other nations.

This paper empirically analyzes the influence of economic policy uncertainty on green technological innovation in manufacturing firms using China's A-share listed firms' data from 2008 to 2020. Methods include instrumental variables and clustered standard error regression. The study finds that firms hesitate to pursue green innovation under economic policy uncertainty. This conclusion holds after various tests, including altering green innovation indicators, econometric methods, and economic policy uncertainty indicators, and addressing issues related to two-way causal endogeneity, omitted variable endogeneity, and control error endogeneity. Mechanism analysis reveals that higher financing constraints and lower executive risk preferences lead firms to reduce green innovation under economic policy uncertainty. Heterogeneity analysis demonstrates that the negative relationship between economic policy uncertainty and green innovation is more pronounced in firms with factors such as weaker government connections, greater monopoly power, and less intellectual property protection. This information is standard in research papers and does not require any specific mention.

This paper's marginal contribution lies in exploring economic policy uncertainty in developing countries, a topic relatively rare in the literature. (1) Unlike existing studies focusing on developed countries' R&D investment, innovations, and mergers [26,27], this paper explores corporate green technology innovation in emerging markets like China. This study bridges the research gap by focusing on China's emerging market. (2) Existing research emphasizes positive incentives like government subsidies on green innovation [28], often overlooking economic policy uncertainty. This paper investigates this unexplored area, providing a comprehensive analysis of behavioral motivation in green innovation. (3) Many studies on economic policy uncertainty omit time-fixed effects, leading to conflicting conclusions [29]. This paper controls for macro variables like the purchasing manager index, allowing for a more nuanced analysis of enterprise green technology innovation. It concludes that increased economic policy uncertainty will inhibit green innovation, a finding consistent with Cui et al. (2023) [30]. (4) While most studies apply real options theory to analyze economic policy uncertainty's impact on green innovation, few empirically test its applicability to China. This paper verifies the real options theory as a suitable basis by exploring corporate financing constraints and managerial risk preferences. (5) Many studies on corporate green technological innovation focus primarily on manufacturing enterprises, overlooking sectors like agriculture and processing. This study, however, encompasses manufacturing, agriculture, and diverse processing sectors to enhance the generalizability of its findings.

The remainder of the paper is organized as follows: Section 2 presents the theoretical analysis and research hypotheses on economic policy uncertainty and firms' green technological innovation; Section 3 explains the econometric methodology, econometric model, variable definitions, and data sources used; Section 4 reports the estimation results; Section 5 discusses the similarities and differences between this paper and the existing literature in terms of the methodology and conclusions of this study; and Section 6 summarizes the main findings of this paper and suggests some policy implications for China and the emerging market countries at present.

2. Theoretical Analysis and Research Hypothesis

2.1. Economic Policy Uncertainty and Corporate Green Technological Innovation

Since Kenneth Galbraith's "The Age of Uncertainty" [31], the academic significance of economic policy uncertainty has grown. Scholars have studied economic policy uncertainty, linking it to macro-level effects like low growth [32] and micro-level effects like reduced investment intentions [33,34]. Domestic scholars have identified how macroeconomic factors affect firms in areas like innovation [29], financing costs [35], and digital transformation [36]. Existing studies commonly define "economic policy uncertainty" in a unified way. Economic policy uncertainty is defined, from a macro perspective, as market volatility stemming from fiscal, monetary, and regulatory regimes [37]. From a micro perspective, it is defined as firms' inability to predict changes in existing economic policies [38,39]. Although unified in their definitions, differences in research samples make replication studies in other countries challenging [40]. To address inconsistencies, Baker et al. developed a set of indices for measuring economic policy uncertainty [41]. Davis expanded this system to include 16 major economies [42]. The indices developed by Baker et al. and optimized by Davis have become standards in studies of economic uncertainty worldwide.

Building on the understanding of economic policy uncertainty, research indicates that firms cannot accurately predict when government policies will be enacted or assess changes in outcomes related to policy shifts. This unpredictability leads to increased decision-making costs, encouraging firms to delay investments [38,43]. Real options theory explains this behavior as a comparison between "wait-and-see" and "execute" options due to irreversible investment costs [44]. Given the irreversible nature of green innovation, enterprises may face significant losses if the innovation fails. Thus, rising economic policy uncertainty makes it optimal to delay green innovation investments without effective angel funding or predictable returns. This leads to the paper's first hypothesis(H1):

H1: *Firms are reluctant to seek green technology innovations under economic policy uncertainty.*

2.2. External Financing Constraint Mechanism

Green technological innovation is a capital-intensive endeavor requiring both substantial and continuous financial investment. Financial disruptions during crucial phases can jeopardize green innovation activities [45]. In the initial phases of green R&D, foundational innovation often necessitates multiple failures as a foundation. Due to the prolonged commercialization process and lower short-term returns, businesses may lack motivation for green innovation without adequate "angel round" funding [46].

A significant aspect of this financial challenge is the management of green technological innovation. In the context of green technological innovation process management, large enterprises struggle with the "complexity" of managing "collaborative" innovation due to the intricate nature of green innovation activities. Conversely, SMEs face a dearth of in-house R&D expertise. As a result, corporations favor hiring external R&D and management professionals for their green innovation needs. However, the limited availability of management and green R&D experts compels businesses to provide competitive compensation to attract the right talent. Insufficient funding for talent acquisition can hinder the momentum for green innovation [47].

In terms of commercializing green technological innovations, a pressing concern is whether consumers are prepared to shoulder the added "green purchase cost" attributed to the "green premium" commonly linked with eco-friendly products. A viable solution is to run market pilots in select cities targeting specific consumer demographics, necessitating significant financial support.

Further emphasizing the consumer aspect, Zhou and Yang (2021) investigated the limited adoption of electric vehicles, a quintessential green innovation, in China. Their findings emphasized that consumer acceptance is pivotal for the success of electric vehicles, underscoring the tangible challenges in transitioning to green innovations [48].

Unlike developed regions such as Europe and the US, where financing mainly comes from instruments like stocks and options, China predominantly depends on bank loans and fiscal subsidies for financing [49]. Consequently, local governments and state-affiliated banks are the main financiers for green innovation in Chinese enterprises. Xiang et al. (2022) supported this view, noting that Chinese listed companies mainly derive their green innovation funding from local fiscal subsidies, with minimal contributions from stock markets or debt instruments [50]. Considering the tight governmental oversight on financing, Chinese enterprises must align their green innovations with both consumer market trends and policy makers' inclinations. This difference is a key distinction between China and other developed nations.

Recent economic disturbances from political, financial, and trade sectors have heightened China's economic policy uncertainty. This unstable policy landscape, combined with China's unique financing model, presents businesses with unpredictable market outlooks. Consequently, businesses adopt a conservative stance in predicting innovation returns and prefer holding liquid assets to mitigate risks [51,52]. This challenges their financing abilities.

Amid increased financing needs due to uncertainty, banks and similar institutions, keen to avert bad debts, restrict liquidity, tighten lending, and elevate borrowing criteria (Bofondi et al., 2013) [53]. This further constrains financing for business investments. Makosa et al. (2021) also found that long-term economic policy uncertainty intensifies financing constraints for businesses, influencing their investment choices [54]. Considering green innovation's inherent need for significant, ongoing funding, the declining internal cash flow and increased external financing restrictions from economic policy uncertainty make businesses re-evaluate the potential costs of unsuccessful green initiatives. Consequently, green innovation projects may face delays or even cancelation. Building on this, we propose the second hypothesis of this study: (H2):

H2: *Economic policy uncertainty affects firms' green technology innovation activities through external financing constraint mechanisms.*

2.3. Management Risk Preference Mechanism

In 1947, economist Von-Neumann pioneered the study of risk preference using the VN-M utility function, based on the premise of an "absolutely rational person". He posited that risk preference embodies the psychological attitudes of decision makers, integrating their personal perspectives [55]. Risk preference can be categorized into three types: risk-loving, risk-neutral, and risk-averse. Given the influence of emotions and other irrational factors in human behavior, Hambrick and Mason's (1984) concept of "bounded rationality" is more widely accepted in academic circles than absolute rationality [56]. This concept later became foundational to the upper echelons theory. The upper echelons theory posits that variations in gender, experience, knowledge, and personal history influence how corporate leaders approach similar issues. Specifically, a management team's attitude towards risk can significantly influence the risk orientation of pivotal corporate decisions.

Understanding the risk preferences of senior executives is crucial when considering their influence on corporate green innovation activities. Senior executives, central to major corporate decisions, hold significant discretion over these activities [57]. Their risk attitude directly influences the allocation and efficiency of resources for green innovation, shaping the company's green technology initiatives.

Economic policy uncertainty also plays a pivotal role in shaping corporate green technology innovation. Roper and Tapinos (2016) highlighted that risks to this innovation primarily stem from external factors, with economic policy uncertainty destabilizing this environment [58]. Thus, there is a close link between economic policy uncertainty and the risks associated with corporate green innovation. Ivanov and Dolgui (2022) demonstrated that uncertain trade policies can escalate raw material costs or cause supply shortages, increasing the cost of transitioning to green innovation [59]. Gholipour (2022) found that economic policy uncertainty can dampen consumer confidence and spending, impacting corporate product profitability [60]. Krol (2014) noted that this uncertainty can cause exchange rate volatility, jeopardizing corporate exports [61]. Economic policy uncertainty introduces unpredictability to corporate green technology innovation, potentially resulting in companies incurring sunk costs [62].

The concept of sunk costs encompasses the dual notions of "danger" and "opportunity". Specifically, managers with a risk-loving disposition often view economic policy uncertainty as an "opportunity". Frequent policy changes, leading to economic policy uncertainty, can make bank investors wary and prompt consumers to curtail non-essential spending to ensure future consumption, potentially causing a market downturn. In such scenarios, leveraging corporate reputation and social responsibility to gain consumer trust becomes crucial for businesses to capitalize on opportunities amidst policy uncertainties. Green technology innovation, a key reflection of corporate social responsibility that enhances reputation, is viewed by risk-loving managers as a pivotal strategy. Such managers are inclined to consistently invest in it, aiming for long-term benefits, innovation success, and a bolstered company reputation. Zhang and Ye (2021) supported this assertion [63]. Their empirical study on Chinese pharmaceutical firms indicated that a management's risk preference aids companies in navigating post-innovation uncertainties and steers them toward successful innovation outcomes.

Unlike risk-loving managers, those who are risk-averse typically perceive economic policy uncertainty as a "danger". Risk-averse managers believe that in the face of economic policy uncertainty, companies struggle to predict government policy timelines and assess the implications of policy shifts. Consequently, the cost of strategic decision making becomes significantly high. Green technology innovation requires considerable time and investment and is intricately linked to government policies and market acceptance. Given this, risk-averse managers, amidst economic policy uncertainties, tend to align with current trends, curb their risk-taking tendencies, prioritize resource allocation to guaranteed-return activities, and often shy away from green innovation initiatives. In essence, while risk-loving managers lean towards high-risk, high-return green technology innovations, risk-averse managers tend to be more cautious. Building on this, we propose the third hypothesis of this study (H3, H3a, H3b):

H3: *Economic policy uncertainty affects firms' green technology innovation activities through the risk appetite mechanism of firms' management.*

H3a: *Economic policy uncertainty increases the level of risk appetite of firm management and thus, firms are more likely to seek green technological innovations.*

H3b: *Economic policy uncertainty reduces the level of risk appetite of firms' management and thus, firms are reluctant to seek green technological innovations.*

3. Research Design and Data Sources

3.1. Sample Selection, Data Processing, and Data Sources

This paper utilizes annual data from China's A-share listed non-financial insurance companies from 2008 to 2020 as the research sample. The initial sample was refined using the following process, inspired by Zhang et al. [64]: (1) Adhering to the CSRC's "Guidelines for the Industry Classification of Listed Companies (2012 Guidelines)", enterprises in the financial and insurance industries were excluded. (2) ST, *ST, and insolvent enterprises were excluded. (3) Samples with glaringly unreasonable or substantially missing data from 2008 to 2020 were excluded, and all continuous variables were Winsorized at the 1% and 99% quantiles to mitigate outliers. (4) A small number of missing values were filled using the index interpolation method, and the GDP deflator and fixed assets deflator were applied to the input and output indicators. This process resulted in 13,625 balanced panel observations.

The data on green innovation patent applications were sourced from the China Research Data Service Platform (CNRDS). This platform offers more precise information on green patents filed by A-share listed companies by aligning it with the "International Green Patent Classification List" published by the World Intellectual Property Organization (WIPO). This article primarily centers on examining green inventions and green utility model patents within enterprise green patents. The primary source of economic policy uncertainty data is the Chinese economic policy uncertainty database, built by Huang and Luk [39] using a text mining method (the database can be accessed at https://economicpolicyuncertaintyinchina.weebly.com/. (accesed on 15 August 2023)). The data about enterprise microfinance originated from the Cathay Pacific (CSMAR) database. The data about local government support for industries were derived from the local five-year plans of previous years, while the PMI index data were sourced from the CEIC database.

3.2. Variable Definitions

(1) Dependent variable: Enterprise green technology innovation. Since patent application indicates that the corresponding technology has reached maturity and is ready for use, this paper employs the proportion of green patents applied by enterprises in the current year to all patents applied by enterprises in the current year (IPC) as

the primary measurement index of enterprises' green technology innovation level. In order to avoid the conclusion bias caused by measurement error, the robustness test presented in this paper uses both the number of enterprise green patent applications (GreenPat_1) and the number of enterprise green patent grants (GreenPat_2) to measure the level of enterprise green technology innovation. Considering that the patent data are missing, explicitly assigning the value of 0 would result in right-biased characteristics of the data; therefore, the missing value of the original data is assigned to 0 based on adding one and logarithmic processing.

(2) Explanatory variable: Economic policy uncertainty. Most existing studies use the economic policy uncertainty index calculated by Baker et al. (2016) using the South China Morning Post as the core explanatory variable [41]. Since the South China Morning Post is based in Hong Kong, and the index from a single newspaper is not sufficiently convincing, it has limitations. In contrast, the Chinese index by Huang and Luk (2020) compensates for the shortcomings of Baker et al. (2016). This paper measures economic policy uncertainty using the index calculated by Huang and Luk (2020), constructed by (1) selecting 10 newspapers such as Beijing Youth Daily, Guangzhou Daily, Jiefang Daily, People's Daily (Overseas Edition), Shanghai Morning Post, etc., which are circulated in major mainland China cities, as text-mining sources from the 114 newspapers in the Wisers' News database; (2) filtering and tagging keywords in news reports; (3) dividing the number of tagged articles by the total number of articles in the same month for the monthly index; (4) averaging monthly data to obtain yearly data, dividing by 100 for the final economic policy uncertainty index (See Table 1).

Table 1. A keyword screening system for economic policy uncertainty indices.

Form	English Keywords
Economic	Economic/Economy/Financial
Uncertainty	Uncertainty/Uncertain
	Volatile
	Unstable/Unclear
	Unpredictable
Policy	Policy/measures
	Politics
	Government/Authority
	President
	Prime minister
	Reform
	Regulation
	Fiscal
	Tax
	People's Bank of China/PBOC
	Deficit
	Interest rate

Figure 1 shows fluctuations from January 2000 to January 2020. Observing Figure 1, the time trend of the index aligns with China's key economic events over 20 years, indicating reliability. To avoid biased conclusions, the robustness test in this paper also uses the monthly economic policy uncertainty index (epu_robust) calculated by Huang and Luk (2020) after annual geometric mean treatment to measure economic uncertainty.

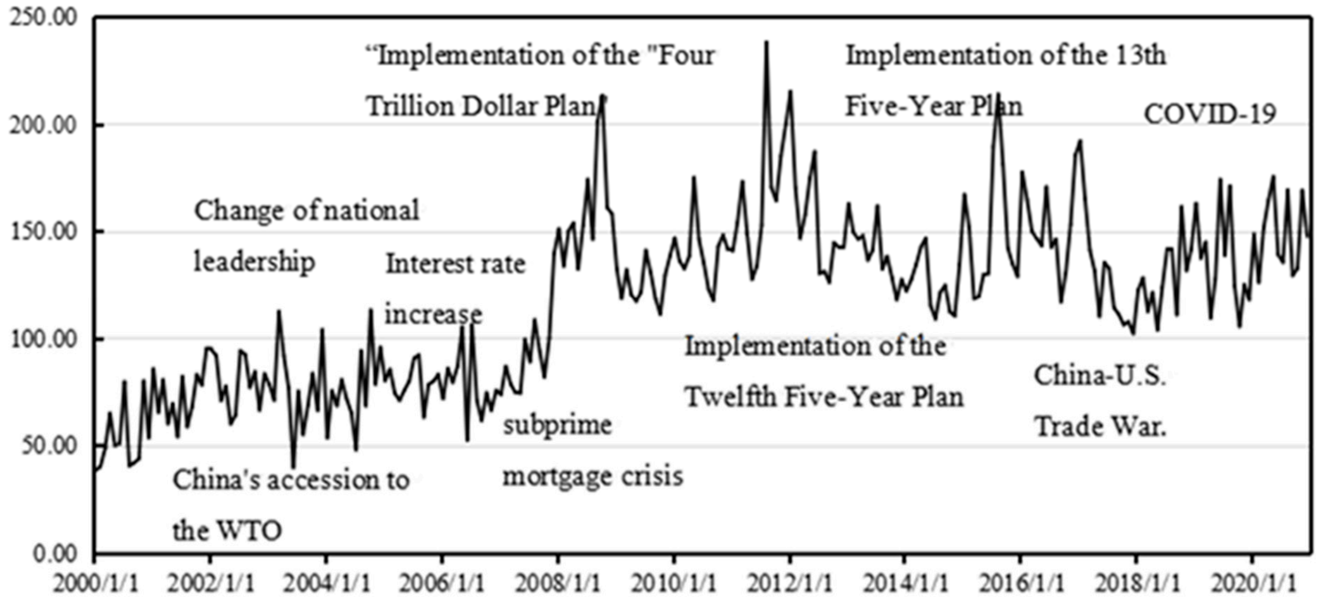

Figure 1. Trend of China's economic policy uncertainty index.

(3) Control variables. This study selects control variables from the micro-enterprise, meso industry, and macro-national levels, drawing on the relevant literature on economic policy uncertainty. At the micro-firm level, the control variables include the following: (1) firm size: firms with substantial assets usually have sufficient capital and social resources for green innovation projects [22]; (2) gearing ratio (lev): firms with higher financial leverage usually exhibit excellent environmental performance [65]; (3) operating income growth rate (growth): firms with better operating income growth prospects typically demonstrate superior environmental performance [66]; (4) equity concentration (top5): higher firm equity concentration is more likely to weaken firms' innovation capabilities [67]; (5) return on assets (Roa): firms with more substantial return on assets are more likely to engage in green innovation activities; (6) board size (Board): a higher proportion of board members helps cultivate CSR [68]; (7) fixed asset investment completion (fixed): the cost of machinery and equipment purchased by firms can usually be deducted from the sales of final products, which can increase the incentives for firms to purchase green equipment [69]; (8) corporate cash flow (Cash): corporate cash flow supports firms' green innovation activities [70]. The industry-level control variable is local government industrial support (gov): with sufficient local government support, firms can obtain more resources for technological innovation [71]. The macro-level control variable is the purchasing managers' index (PMI): the PMI is closely related to firms' inventory investment fluctuation, which to some extent affects firms' innovation behavioral decisions [72]. All variables are defined in Table 2.

3.3. Sample Selection, Data Processing, and Data Sources

To examine the influence of economic policy uncertainty on the creation of green technology in firms, we have developed the following foundational econometric model:

$$IPC_{it} = \beta_0 + \alpha_1 epu_t + \alpha_2 Controls\_firm_{it} + \alpha_3 Controls\_other_{it} + \mu_i + \theta_j + \delta_t + \varepsilon_{it} \quad (1)$$

The subscript i represents an individual firm, and t represents the observation year. IPC_{it} denotes the level of green technology innovation of firm i in year t, while epu_t denotes the level of economic uncertainty in year t. $Controls\_firm_{it}$ is a control variable selected from the firm level, and $Controls\_other_{it}$ is a control variable selected from the other level. u_i represents the firm-individual fixed effect to account for inter-firm differences that do not change over time, and θ_j denotes industry and city individual fixed effects to control for industry and city differences that do not change over time. ε_{it} is a random error term. To address potential heteroskedasticity and serial correlation issues, this paper introduces firm clustering standard errors to improve the robustness of the estimation results. Since the economic uncertainty index is time-series data, introducing time-fixed effects may cause multicollinearity. To mitigate the potential impact of the omitted variable problem, this paper includes the time-trend term (δ_t) following Bonaime et al. (2018) [73]. This paper focuses on the economic policy uncertainty variable coefficient α_1 and predicts a significantly negative sign for α_1.

Table 2. Definition and calculation of variables.

Type	Symbols	Variable Name	Measurement Methods
Dependent variable	IPC	Green technology innovation	Proportion of green patents applied for by enterprises in the same year to all patents applied for by enterprises in the same year
Independent variable	epu	Economic policy uncertainty	Ten representative newspapers in mainland China are selected as texts to calculate monthly economic policy uncertainty, and the arithmetic mean of the monthly economic policy uncertainty index is converted into an annual index and divided by 100
Control variables	Roa	Return on equity	(Net profit of the enterprise for the year + interest expense + income tax) divided by average total assets
	lev	Debt-to-Asset Ratio	Total liabilities of the enterprise at the end of the year divided by total assets of the enterprise at the end of the year
	growth	Revenue growth rate	Current year's operating income divided by last year's operating income-1
	Top5	Equity concentration	Proportion of shares held by the top five shareholders of the enterprise at the end of the year
	Cash	Corporate cash flow	Cash flows from operating activities of the enterprise for the year divided by total assets of the enterprise
	Size	Company size	Total assets of the enterprise at the end of the year in natural logarithms
	Board	Board size	Number of people on the board of directors of the company
	fixed	Fixed Asset Investment Completion	Total company purchases of machinery and equipment, computer equipment, land, utilities, and repairs
	gov	Local government industry support	If the industry in which the enterprise is engaged is a key support industry in the local five-year plan, the value will be assigned as 1; otherwise, it will be defined as 0
	pmi	purchasing managers' index	Conversion of the arithmetic average of monthly PMI indices published by the National Bureau of Statistics into annual values

4. Empirical Analysis

4.1. Descriptive Statistical Analysis and Correlation Analysis

Descriptive statistics for each variable are presented in Table 3. The average corporate green technology innovation (IPC) is 4.7%, ranging from 0 to 1, with a standard deviation of 0.142. The overall level of corporate green technology innovation is relatively low, with notable disparities among companies. The average economic policy uncertainty (epu) is 1.430, ranging from 1.25 to 1.657, with a standard deviation of 0.142, suggesting high volatility. At the corporate level, both company size (Size) and board size (Board) have notable standard deviations, highlighting significant differences among sampled companies. For industry and macro-level control variables, local government industrial support (Gov) has a significant standard deviation, pointing to varied local industrial policies across regions. Among the samples, 5523 received local government industrial support, while 8102 did not. Other control variable characteristics align with the current literature.

Table 3. Descriptive statistics of variables.

VarName	Obs	Mean	SD	Min	Median	Max
IPC	13,625	0.047	0.142	0.000	0.000	1.000
epu	13,625	1.430	0.131	1.250	1.409	1.657
Size	13,625	22.448	1.406	19.226	22.309	27.784
Roa	13,625	0.036	0.060	−0.263	0.031	0.226
Cash	13,625	0.047	0.074	−0.213	0.047	0.256
Board	13,625	8.997	1.834	5.000	9.000	15.000
fixed	13,625	0.249	0.186	0.000	0.211	0.971
Growth	13,625	0.002	0.006	−0.007	0.001	0.049
top5	13,625	0.501	0.154	0.008	0.498	0.959
lev	13,625	0.500	0.203	0.007	0.509	2.529
gov	13,625	0.405	0.491	0.000	0.000	1.000
pmi	13,625	0.509	0.013	0.495	0.508	0.536
FC	13,625	3.805	0.258	2.344	3.816	4.83
Risk_Preference	13,625	0.109	0.577	−2.467	0.124	3.199

The results of the Spearman correlation analysis are presented in Table 4. The analysis reveals a statistically significant negative correlation (−0.026 at the 1% level) between economic policy uncertainty (epu) and the number of firms' green technological innovations (IPC). The correlation coefficients among the control variables are relatively low, suggesting a partial control of potential multicollinearity issues.

Table 4. Variable correlation analysis.

	IPC	epu	Size	Roa	Cash	Board	fixed	Growth	top5	lev	gov	pmi
IPC	1											
epu	−0.026 ***	1										
Size	0.071 ***	−0.080 ***	1									
Roa	0.005	0.0110	0.070 ***	1								
Cash	0.01	−0.019 **	0.049 ***	0.371 ***	1							
Board	0.046 ***	0.033 ***	0.246 ***	0.028 ***	0.073 ***	1						
fixed	0.035 ***	0.022 **	0.032 ***	−0.101 ***	0.259 ***	0.158 ***	1					
Growth	−0.009	0.006	0.050 ***	0.165 ***	0.0110	−0.021 **	−0.063 ***	1				
top5	−0.012	0.002	0.322 ***	0.158 ***	0.108 ***	0.126 ***	0.077 ***	0.094 ***	1			
lev	0.036 ***	0.006	0.378 ***	−0.373 ***	−0.178 ***	0.109 ***	0.01	0.045 ***	0.059 ***	1		
gov	0.064 ***	0.033 ***	−0.033 ***	0.046 ***	0.047 ***	0.035 ***	0.146 ***	−0.011	−0.0120	−0.099 ***	1	
pmi	0.002	−0.415 ***	−0.141 ***	0.095 ***	0.009	0.038 ***	0.035 ***	0.075 ***	−0.002	0.017 **	−0.037 ***	1

Note: *** and ** indicate significance at the 1% and 5% levels.

4.2. Benchmark Regression Estimation Results

Table 5 illustrates the results of the benchmark regression, estimating the effects of economic policy uncertainty (epu) on green technological innovation in firms. The regression, based on model (1), controls for firm clustering robustness error and fixed effects at the firm, industry, and city levels. Columns (1)–(3) present the results without control variables, while columns (4)–(6) show results after gradually adding firm-, industry-, and macro-level control variables. The coefficients for epu are all significantly negative at the 1% level, demonstrating robustness to the added controls. The R^2 fit coefficient increases from 0.06 to 0.38, indicating firms' reluctance to pursue green technological innovation under economic policy uncertainty. These findings align with Cui et al. (2023) [30], supporting this paper's hypothesis H1.

The results for control variables reveal that equity concentration (Top5), firm size (Size), and firm cash flow (Cash) significantly relate to green technology innovation in firms, aligning with the established literature [65,74]. Conversely, variables such as local government industrial support (gov), gearing ratio (lev), operating income growth rate (growth), purchasing managers' index (pmi), fixed asset investment completion (fixed), and return on assets (Roa) are statistically insignificant. The insignificance may arise from two scenarios: (1) control variables may be tied to unobserved variables, making marginal effects insignificant causally [75], and (2) the main effect of these variables may be overshadowed by the impact of economic policy uncertainty (epu) on green innovation. Since control variables primarily serve to reduce the interference of confounding variables, they do not disrupt the estimation of the main explanatory variable, i.e., the effect of economic policy uncertainty (epu) on green technological innovation.

Table 5. Benchmark regression results.

Variables	(1) IPC	(2) IPC	(3) IPC	(4) IPC	(5) IPC	(6) IPC
epu	−0.028 *** (−3.700)	−0.031 *** (−4.112)	−0.030 *** (−3.922)	−0.025 *** (−3.417)	−0.025 *** (−3.496)	−0.027 *** (−2.680)
Size				0.007 *** (3.123)	0.007 *** (3.139)	0.006 *** (2.969)
Roa				−0.002 (−0.082)	−0.003 (−0.120)	−0.002 (−0.066)
Cash				−0.029 * (−1.797)	−0.029 * (−1.783)	−0.030 * (−1.805)
Board				0.001 (0.963)	0.001 (0.929)	0.001 (0.954)
fixed				0.019 (1.170)	0.019 (1.128)	0.019 (1.135)
Growth				−0.020 (−0.166)	−0.021 (−0.169)	−0.016 (−0.127)
top5				−0.040 ** (−2.115)	−0.040 ** (−2.091)	−0.040 ** (−2.084)
lev				−0.003 (−0.242)	−0.002 (−0.232)	−0.002 (−0.182)
gov					0.005 (1.267)	0.005 (1.251)
pmi						−0.029 (−0.247)
_cons	0.087 *** (7.739)	0.091 *** (8.446)	0.089 *** (8.225)	−0.056 (−1.123)	−0.058 (−1.159)	−0.036 (−0.382)
Firm fixed effect	No	YES	YES	YES	YES	YES
Industry fixed effect	YES	YES	YES	YES	YES	YES
Urban fixed effect	No	No	YES	YES	YES	YES
Time Trend Control	YES	YES	YES	YES	YES	YES
N	13,625	13,625	13,625	13,625	13,625	13,625
Adjust R^2	0.0665	0.3851	0.3879	0.3891	0.3892	0.3892

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively, and in () are *t*-test statistics adjusted for firm clustering.

4.3. Endogeneity Treatment and Robustness Tests

To evaluate the robustness of the benchmark regression results and address potential endogeneity issues, we apply various robustness methods. These include substituting firms' green technology innovation indicators, altering economic policy uncertainty indicators, changing the econometric estimation method, incorporating lagged explanatory and control variables, and utilizing the 2sls instrumental variable method. These steps are taken to mitigate two-way causal endogeneity problems and to include control variables that handle omitted variable endogeneity issues.

4.3.1. Robustness Tests

(1) **Replacement of firms' green technology innovation indicators.** Although the benchmark regression indicates a reluctance among firms to pursue green technological innovation under economic policy uncertainty, the drop in the ratio-type green innovation indicator (IPC) might stem from an increase in current-year patent applications rather than a decrease in green patents filed. To alleviate the potential bias in measuring firms' green innovation, this study draws on Popp's methodology (2006) [76], using the number of green patents granted (GreenPat_1). Additionally, recognizing that enterprise green innovation includes both strategic and substantive elements, and that non-substantive "green" behavior may affect benchmark regression results, this paper employs the number of green patents granted (GreenPat_2) to gauge enterprise green innovation levels. Columns (1) and (2) in Table 6 confirm that the estimated coefficient of economic policy uncertainty (epu) remains significantly negative at the 1% level, even with the revised green innovation measurement, underscoring the robustness of the benchmark regression's conclusions.

Table 6. Robustness estimation results.

Variables	(1) GreenPat_1	(2) GreenPat_2	(3) IPC	(4) IPC	(5) IPC	(6) IPC
epu	−0.369 *** (−5.41)	−0.594 *** (−9.30)	−0.029 *** (−3.08)			−0.035 *** (−4.07)
epu_robust				−0.232 * (−17.74)		
epu_lag					−0.014 * (−1.79)	
Intercept, control variables	YES	YES	YES	YES	YES	YES
Firm fixed effect	YES	YES	NO	YES	YES	YES
Industry fixed effect	YES	YES	NO	YES	YES	YES
Urban fixed effect	YES	YES	NO	YES	YES	YES
Time trend control	YES	YES	YES	YES	YES	YES
N	13,559	13,559	13,625	13,559	12,258	12,258
Adjust R2	0.1089	0.0825	0.0773	0.3890	0.3981	0.4003

Note: *** and * indicate significance at the 1% and 10% levels, respectively, and in () are *t*-test statistics adjusted for firm clustering.

(2) **Replacement of econometric estimation methods.** The overall green innovation of enterprises (IPC) represents a restricted dependent variable with a substantial number of "0" values and a range within [0,1]. The conventional econometric model is inadequate to handle estimation results from data with truncated characteristics. To address this issue, we employ the Tobit model to conduct further robustness testing. The estimation results in column (3) of Table 6 demonstrate that the estimated coefficient of economic policy uncertainty (epu) remains significantly negative at the 1% level. This finding indicates that the conclusion drawn from the benchmark regression remains unchanged.

(3) **Replacement of the economic policy uncertainty index.** To ensure that the estimated impact of the benchmark regression is independent of how economic policy uncertainty is measured, this paper reevaluates economic uncertainty using the monthly economic policy uncertainty index (epu_robust) calculated by Huang and Luk (2020) [39] with the annual geometric mean treatment applied. The estimation results in column (4) of Table 6 indicate that the estimated coefficient on economic policy uncertainty (epu_robust) is significantly negative at the 10 percent significance level, confirming that the conclusions drawn from the baseline regression remain unchanged.

(4) **Lagging the explanatory variables by 1 period**. Recognizing the time lag between the external transmission of policy and firms' perception of policy uncertainty, the explanatory variables are lagged by 1 period to investigate the dynamic impact of firms' green technology innovation under the influence of economic policy uncertainty. The estimation results in column (5) of Table 6 demonstrate that economic policy uncertainty (epu_lag) with a 1-period lag is significantly negative at the 10% statistical level, confirming that the conclusions drawn from the baseline regression remain unchanged.

(5) **Control variables lagged by 1 period.** Since the control variables selected in this study may also have time-lagged effects on enterprises' green technological innovation, which could potentially confound the estimation results of the baseline regression, we apply a one-period lag to all control variables to reassess the impact of economic policy uncertainty on enterprises' green technological innovation. The estimation results in column (6) of Table 6 reveal that economic policy uncertainty (epu) remains significantly negative at the 1% statistical level, further confirming the consistency of conclusions drawn from the benchmark regression.

4.3.2. Endogenous Treatment

(1) **Bidirectional causal endogeneity.** With China's local development model shifting from "competition for growth" to "competition for innovation" in recent years [77], the performance of firms' green innovation activities can prompt local governments to introduce targeted and biased policies, leading to fluctuations in economic policy uncertainty. Additionally, the performance of enterprises' green innovation activities may prompt local governments to implement specific policies, influencing economic policy uncertainty in return. This creates a bidirectional causal endogenous problem between economic policy uncertainty and enterprises' green technological innovation. To address the potential error in baseline regression estimation results due to bidirectional causal endogeneity, this study adopts the approach of Yu et al. (2021) by using the U.S. economic policy uncertainty index (epu_IV) calculated by Baker et al. (2016) as an instrumental variable for two-stage least squares (2sls) estimation [41,78]. The selection of this instrumental variable is based on the usual correlation between China's economic policy uncertainty and that of the U.S. in the context of economic globalization. However, U.S. economic policy uncertainty does not directly impact firms' green technological innovations. The green innovation behaviors of China's micro firms have limited influence on U.S. economic policy uncertainty [79]. Therefore, using U.S. economic policy uncertainty as the instrumental variable generally satisfies the requirements of relevance and exogeneity.

Columns (1) to (2) of Table 7 present the results of instrumental variable regressions. Firstly, in the first stage of column (1), the regression results for U.S. economic policy uncertainty (epu_IV) on China's economic policy uncertainty (epu) are significantly positive at the 1% level. The Cragg–Donald Wald F-value is greater than 10, and the Anderson LM value rejects the original hypothesis that instrumental variables are not identifiable, indicating that U.S. economic policy uncertainty (epu_IV) is not a weak instrumental variable. In the second stage of sub-column (2), economic policy uncertainty (epu) remains significantly negative at the 1% statistical level, which suggests that the results of this paper's baseline regression are robust even when considering bidirectional causal endogeneity of variables.

(2) **The problem of endogeneity due to omitted variables.** Economic policy uncertainty influences corporate green innovation decisions, with corporate executives' personal experience and management structure characteristics playing a significant role [80]. Ignoring these factors in the benchmark regression may lead to an endogeneity problem caused by omitted variables. To enhance the robustness of the benchmark regression, this study employs CEO green experience (Green) and managerial power (Dual) as measurement variables for corporate executives' personal experience and managerial and structural characteristics, respectively, and includes them in model (1) for re-regression. The CEO's green experience is represented as a "0–1" variable, where 1 indicates that the CEO has received green education or been involved in green work, while 0 indicates otherwise. Managerial power is represented as a "0–1" variable, where a value of 1 indicates that the chairman of the board of directors and general manager are the same person, while 0 indicates otherwise.

The estimation results in column 7(3) account for the endogeneity of omitted variables by controlling for CEO green experience (Green) and managerial power (Dual). Even after considering these factors, economic policy uncertainty (epu) remains significantly negative at the 10% statistical level. This indicates that the baseline regression conclusions of this study remain robust in the face of the endogeneity problem associated with omitted variables.

Table 7. Endogeneity estimation results.

Variables	(1) epu	(2) IPC	(3) IPC	(4) IPC	(5) IPC
epu		−0.205 *** (−5.86)	−0.020 * (−1.81)	−0.030 *** (−3.88)	−0.030 *** (−3.79)
epu_IV	0.001 *** (30.92)				
Green			0.023 * (1.74)		
Dual			−0.002 (−0.35)		
Intercept, control variables	YES	YES	YES	YES	YES
Cragg–Donald Wald F-value	956.3				
Anderson canon. corr. LM statistic	889.16				
Firm fixed effect	YES	YES	YES	YES	YES
Industry fixed effect	YES	YES	YES	YES	YES
Urban fixed effect	YES	YES	YES	YES	YES
Joint firm–industry fixed effects	NO	NO	NO	YES	NO
Joint firm–city fixed effects	NO	NO	NO	NO	YES
Time Trend Control	YES	YES	YES	YES	YES
N	13,625	13,625	13,625	13,559	13,559
Adjust R^2	0.1485	0.0825	0.0775	0.1205	0.1166

Note: *** and * indicate significance at the 1% and 10% levels, respectively, and in () are *t*-test statistics adjusted for firm clustering. Control variables are those listed for the benchmark regression in Table 5, and the coefficients will not be shown one by one.

(3) Endogeneity due to control error in enterprise green technology innovation trend. In the baseline regression, this paper includes industry and city fixed effects to mitigate the impact of enterprise green innovation shocks resulting from industry and regional differences. However, given the variation in enterprise green technology innovation trends among different industries and cities, individual fixed effects alone cannot effectively control the coefficient bias caused by trend errors. To address this endogeneity problem, the paper further introduces "enterprise-industry" joint fixed effects and "enterprise-city" joint fixed effects.

Columns (4) and (5) of Table 7 present the estimation results after accounting for joint fixed effects. After additionally introducing the "firm-industry" joint fixed effects and "firm-city" joint fixed effects, economic policy uncertainty (epu) remains significantly negative at the 1% statistical level. This indicates that this paper's baseline regression conclusions remain robust in addressing endogeneity issues arising from controlling for errors in firms' green technology innovation trends.

4.4. Mechanism Analysis

The theoretical analysis in the previous section demonstrates that elevated financing constraints and reduced executive risk preferences influence firms to reduce green technology innovation under economic policy uncertainty. In order to test the feasibility of this mechanism, this paper adopts the three-step mediated effect test approach. It formulates the mediated effect test models (2) and (3) based on the benchmark model (1):

$$Medvar_{it} = \beta_0 + \alpha_1 epu_t + \alpha_2 Controls\_firm_{it} + \alpha_3 Controls\_other_{it} + \mu_i + \theta_j + \delta_t + \varepsilon_{it} \quad (2)$$

$$IPC_{it} = \beta_0 + \alpha_1 epu_t + \alpha_2 Controls\_firm_{it} + \alpha_3 Controls\_other_{it} + \mu_i + \theta_j + \delta_t + \varepsilon_{it} \quad (3)$$

Among them, $Medvar_{it}$ represents the mechanism variable, which includes corporate financing constraints (FC) and the degree of management risk preference (Risk_Preference). Model (2) examines the effect of economic policy uncertainty on the mechanism variable, and model (3) tests the mediating effect of the mechanism variable in the relationship between economic policy uncertainty (epu) and green technological innovation (IPC) in enterprises. In measuring the mechanism variable, this paper adopts the approach used in Hadlock and Pierce's study (2010) [81] to measure the firm's financing constraints (FC) using the absolute value of the SA Index (SA Index = $-0.737 \times Size + 0.043 \times Size^2 - 0.04 \times firmage$). When the SA index is negative, a larger absolute value indicates a higher degree of financing constraints for the firm. Drawing on Zhou et al. (2021) [82], principal component analysis is employed to measure the risk preference of corporate management based on asset structure, solvency, profit structure, profit distribution, and cash flow. A lower Risk_Preference indicator suggests that corporate management is more risk-averse.

Table 8 presents the mechanism analysis results. Columns (1) to (2), based on model (2), reveal that the coefficients of economic policy uncertainty (epu) on corporate financing constraints (FC) are significantly positive at the 1% level, while those of management's risk preference (Risk_Preference) are negative at the 1% level. This signifies a negative impact on corporate financing under uncertainty and an adjustment in executives' risk preferences. Columns (3) and (4), using model (3), show that the regression coefficient of FC on green technology innovation (IPC) is negative at 1%, while that of Risk_Preference on IPC is positive at 5%. The coefficient of epu on IPC aligns with the benchmark regression's sign and significance, with the Z-value of Sobel, Aroian, and Goodman tests passing at 5%. This highlights the influence of rising financing constraints and decreasing risk appetite in reducing green innovation under uncertainty. In summary, the paths of economic policy uncertainty to rising financing constraints to green innovation and uncertainty to risk appetite reduction to green innovation are confirmed, verifying H2 and H3b.

Table 8. Mechanism analysis test results.

Variables		**Panel A: Results of the Analysis of Mechanisms**			
		(1) FC	**(2) Risk_Preference**	**(3) IPC**	**(4) IPC**
epu		0.349 *** (34.22)	−0.434 *** (−12.97)	−0.036 *** (−3.35)	−0.030 *** (−2.61)
FC				−0.017 * (−1.65)	
Risk_Preference					0.006 ** (2.12)
Intercept, control variables		YES	YES	YES	YES
Firm fixed effect		YES	YES	YES	YES
Industry fixed effect		YES	YES	YES	YES
Urban fixed effect		YES	YES	YES	YES
Time trend control		YES	YES	YES	YES
N		13,522	13,482	13,522	13,482
Adjust R^2		0.8355	0.6092	0.3867	0.3195
Panel B: Mediation effect test					
		Sobel	Aroian		Goodman
Z-Value	FC	10.286 ***	10.283 ***		10.290 ***
	Risk_Preference	2.094 **	2.089 **		2.099 **

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively, and in () are *t*-test statistics adjusted for firm clustering. Control variables are those listed for the benchmark regression in Table 5, and the coefficients will not be shown one by one.

4.5. Heterogeneity Analysis

Although the benchmark regression has shown the robust negative impact of economic policy uncertainty on green technological innovation, the question remains whether enterprises will necessarily abandon such innovation due to ownership structure and varying environments. Therefore, this paper explores the diverse impacts of economic policy uncertainty on green technological innovation, considering factors such as ownership structure, enterprise size, industry type, regional property rights protection, industry competition, and enterprise pollution.

(1) **Enterprise ownership structure.** Compared to privately listed firms, SOEs, due to their strong government connections, have more advantages in obtaining bank loans and biased policy support. They are slightly less sensitive to policy's negative impacts [83], fostering a greater willingness to undertake high-cost, long-term green technological innovation. In this paper, the research sample is divided into two groups based on the ownership structure of enterprises, utilizing model (1) for sub-sample regression. The results in columns (1) and (2) of Table 9 indicate that, when differentiating by ownership structure, the negative effect of economic policy uncertainty (epu) on green technology innovation is more significant among non-state-owned firms and not significant among state-owned firms. In a context of high economic policy uncertainty, non-state-owned firms, lacking financial or biased policy support, are less likely to pursue green innovation activities.

(2) **Enterprise size.** The impact of economic policy uncertainty on green technological innovation varies among enterprises of different sizes. Faced with economic policy uncertainty, large firms often invest in risky opportunities while hedging their bets. Small firms, constrained by capital flows, tend to act "conservatively," receiving government subsidies and shelving high-cost, high-uncertainty projects like green innovation [84]. In this paper, the research sample is divided into two groups: those with enterprise sizes greater than the median of 22.309 form a larger group, and the rest form a smaller group. This grouping is based on model (1) regression. The results in columns (3) and (4) of Table 9 indicate that economic policy uncertainty's negative effect on green technology innovation is more pronounced among smaller firms and less so among larger ones. Under high uncertainty, smaller firms tend to be more "conservative" and avoid green innovation.

(3) **Enterprise industry type.** The demand for green technology innovation varies across industries; thus, the influence of economic policy uncertainty on firms' innovation varies too. Referencing Zhou (2021) [85] and using the "Guidelines for the Classification of Listed Companies in China (2012 Revision)," firms are grouped into labor-intensive, capital-intensive, and technology-intensive categories, and then analyzed using model (1). Table 9, columns (5)~(7), reveal that the negative impact of economic policy uncertainty on green innovation is more pronounced in labor-intensive and capital-intensive industries, but not in technology-intensive ones. This indicates that under high uncertainty, labor- and capital-intensive firms often delay green innovation, while technology-intensive firms remain unaffected.

(4) **Degree of industry competition.** Robinson et al. (2012) [86] demonstrated that in an uncertain environment, firms considering the benefits and costs of delaying innovation see a gradual increase in waiting costs. Thus, under fierce industry competition, firms are more likely to enhance R&D investment to preserve competitiveness, possibly lessening the negative impact of economic policy uncertainty on green innovation. Using the Herfindahl Index (HHI) based on Spiegel's (2021) method ($HHI = \sum_{i=1}^{N} \left(\frac{X_i}{X}\right)^2$, where X_i denotes firm size, N denotes the number of firms in the industry, and X_i/X reflects the market share of the ith firm) [87], the study samples are divided into low- and high-competition groups, based on a 0.159 median. Regression is conducted on model (1), post-grouping. Table 10, columns (1) and (2), indicate that the negative effect of economic policy uncertainty on green innovation is pronounced in low-competition firms but not in high-competition ones. This highlights that intensifying industry competition can alleviate the adverse effects of uncertainty on green innovation.

(5) **Regional property rights protection.** The influence of economic policy uncertainty on green technological innovation varies with regional property rights protection levels. High input costs and the long-term nature of green innovation require effective intellectual property rights (IPR) protection to encourage firms. Following Grimaldi et al. (2021) [88], regional IPR is measured using the arithmetic average of intellectual property infringements per capita and lawyers per capita. The sample is split into two groups by the median IPP of 0.744: those above are the high IPP group, and the rest are treated as another group. Regression on these groups reveals (Table 10, columns (3) and (4)) a significantly milder negative effect of economic policy uncertainty on green innovation in areas with strong property rights protection, confirmed by a statistically significant Fisher combination test.

(6) **Degree of enterprise pollution.** The cost of emissions varies across firms due to differences in pollution and energy consumption related to their products. For heavily polluting firms, their characteristics of high pollution and emissions lead to increased environmental taxes and charges. (According to the "Listed Companies Environmental Verification Industry Classification and Management List" (Environmental Affairs Office Letter [2008] No. 373), the industries that heavily polluting enterprises belong to include coal mining and washing; oil and natural gas mining; ferrous and non-ferrous metal mining and processing; non-metallic mining and processing; textile, leather, fur, feather products, and footwear; paper and paper products; petroleum refining; chemical raw materials and products manufacturing; pharmaceutical manufacturing; chemical fiber manufacturing; rubber and plastic products; non-metallic mineral products; ferrous and non-ferrous metal smelting and rolling processing; and thermal power.) Therefore, irrespective of economic policy uncertainty, green technological innovation becomes a favored means of avoiding harsh environmental penalties. (This includes purchasing green equipment as a form of innovation.) For non-heavily polluting firms, their relatively light pollution emissions do not result in serious environmental costs. In the face of economic policy uncertainty, these firms often reduce their green technology innovation projects to minimize business risks. The estimation results in columns (5) to (6) of Table 10 show that economic policy uncertainty (epu) has a more pronounced negative effect on green technology innovation in non-heavily polluted firms and a less significant impact in heavily polluted firms. Fischer's combined between-groups coefficient test also reveals that this difference is statistically significant. The influence of economic policy uncertainty on green innovation activities is confirmed, considering the differences in pollution levels among enterprises.

Table 9. Results of heterogeneity estimation 1.

Variables	**(1)** **State-Owned Enterprise** **IPC**	**(2)** **Non-State-Owned Enterprise** **IPC**	**(3)** **Larger Scale** **IPC**	**(4)** **Smaller Scale** **IPC**	**(5)** **Labor-Intensive** **IPC**	**(6)** **Capital-Intensive** **IPC**	**(7)** **Technology-Intensive** **IPC**
epu	−0.010 (−0.72)	−0.038 *** (−2.62)	−0.017 (−1.23)	−0.035 ** (−2.19)	−0.038 ** (−2.18)	−0.033 * (−1.74)	−0.016 (−0.94)
Intercept, control variables	YES	YES	YES	YES	YES	YES	YES
Firm fixed effect	YES	YES	YES	YES	YES	YES	YES
Industry fixed effect	YES	YES	YES	YES	YES	YES	YES
Urban fixed effect	YES	YES	YES	YES	YES	YES	YES
Time trend control	YES	YES	YES	YES	YES	YES	YES
N	5563	7789	6737	6733	4637	4217	4642
Adjust R^2	0.4780	0.3452	0.4611	0.3847	0.2841	0.4081	0.4800
Between-group coefficient test *p*-value	0.09 *		0.02 **			0.02 **	

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. In () are *t*-test statistics adjusted for firm clustering. Control variables used in the benchmark regression (Table 5) are not individually displayed. *p*-values for testing coefficient differences between groups are obtained using Fisher's combined test (1000 samples).

Table 10. Results of heterogeneity estimation 2.

Variables	(1) High Industry Competition IPC	(2) Low Industry Competition IPC	(3) High-IPP IPC	(4) Low-IPP IPC	(5) Heavy-Polluting IPC	(6) Non-Heavy-Polluting IPC
epu	−0.022 (−1.58)	−0.041 *** (−2.66)	−0.023 * (−1.67)	−0.028 * (−1.85)	−0.028 (−1.36)	−0.028 ** (−2.59)
Intercept, control variables	YES	YES	YES	YES	YES	YES
Firm fixed effect	YES	YES	YES	YES	YES	YES
Industry fixed effect	YES	YES	YES	YES	YES	YES
Urban fixed effect	YES	YES	YES	YES	YES	YES
Time trend control	YES	YES	YES	YES	YES	YES
N	YES	YES	YES	YES	YES	YES
Adjust R^2	8001	5473	6899	6605	4738	8791
Between-group coefficient test *p*-value	0.01 ***		0.05 **		0.01 ***	
Intercept, control variables	0.4297	0.3708	0.4540	0.3856	0.3504	0.4328

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. In () are *t*-test statistics adjusted for firm clustering. Control variables used in the benchmark regression (Table 5) are not individually displayed. *p*-values for testing coefficient differences between groups are obtained using Fisher's combined test (1000 samples).

5. Discussion

Policy changes influence both the business environment and corporate behavior. In recent years, with the rise in economic policy uncertainty, its relationship with corporate behavior has attracted significant academic attention. Existing studies have explored the relationship between economic policy uncertainty and various corporate activities, such as innovation, operational risks, and mergers and acquisitions. However, the literature on its impact on green technology innovation remains limited. This paper aims to bridge this gap by investigating the connection and mechanisms between economic policy uncertainty and green innovation in micro-enterprises.

This study aligns with the existing literature on "economic policy uncertainty" in several ways. First, regarding research conclusions, we determined that economic policy uncertainty negatively impacts corporate green technology innovation. Studies by Cui et al. (2021) and Ren et al. (2023), using Chinese listed companies as samples, also found a decline in green technology innovation due to economic policy uncertainty, corroborating our findings [30,89]. Second, regarding mechanism pathways, we propose that economic policy uncertainty heightens corporate financing constraints and diminishes management's risk appetite, hindering green technology innovation. Our perspective resonates with findings from Makosa et al. (2021) [54], Cheng and Masron (2023) [90], and Lou et al. (2022) [91]. Specifically, Makosa et al. (2021) determined, using data from Chinese listed companies, that economic policy uncertainty amplifies long-term financing constraints [54]. Cheng and Masron (2023) proposed a similar view. Lou et al. (2022), using data samples from Chinese listed companies between 2001 and 2017, suggested that economic policy uncertainty reduces the risk preference of corporate management, ultimately leading to a decrease in company innovation levels [91]. These scholars' conclusions suggest that corporate financing constraints and management risk preferences are viable mechanisms affected by economic policy uncertainty in green technology innovation. Third, in our research methodology, we use standard error robust regression to counteract heteroscedasticity bias. This approach aligns with methods in studies like Xu (2020) [20] and Guan et al. (2021) [92] on the impact of economic policy uncertainty on micro-enterprises.

However, our study also diverges from the existing literature in areas like statistical model design, mechanism pathway exploration, empirical mechanism design, and research conclusions. First, in terms of statistical model design, both Ren et al. (2023) and Cui et al. (2023) employed time-fixed models to account for time-specific attributes of omitted variables [30,89]. Given the potential multicollinearity between economic policy uncertainty and time-fixed effects, we refined the model by incorporating a time trend term, reducing multicollinearity-induced bias. While our findings align with Cui et al. (2023) and Ren et al. (2023) in suggesting a decline in corporate green technology innovation due to economic policy uncertainty [30,89], our core variable's explanatory coefficient (epu) is less pronounced than their studies' core coefficient estimates. Overlooking multicollinearity could potentially exaggerate the adverse effects of economic policy uncertainty on corporate green technology innovation.

Moving to mechanism pathways, while our study focuses on corporate management's risk preference and financing constraints, other research has delved into alternative mechanisms. Ren et al. (2023) [89] suggest that economic policy uncertainty fosters pessimistic investor sentiment, which often correlates with reduced investment [93]. Thus, pessimistic investor sentiment could be a conduit by which economic policy uncertainty hampers green technological innovation in corporations. William and Fengrong (2022) posit that economic-policy-uncertainty-induced information asymmetry complicates investors' accurate evaluation of intangible assets, like innovative projects [94]. Consequently, this might diminish investors' enthusiasm for backing innovative projects. Hence, information asymmetry could also mediate the negative effects of economic policy uncertainty on corporate green technology innovation. Ren et al. (2023) and William and Fengrong (2022) highlight that economic policy uncertainty's influence on green technology innovation is not confined to just financing constraints or management risk preferences [89,94]. Multiple mechanisms underpin the effects of economic policy uncertainty on corporate green technology innovation. Yet, commonly, "risk assessment" and "fundraising" emerge as the principal mechanisms influencing green technology innovation under economic policy uncertainty. Future studies should further probe these mechanisms, drawing from these insights.

From an empirical mechanism design standpoint, this study employs a mediation effect model to elucidate how economic policy uncertainty might curtail enterprises' pursuit of green technology innovation, primarily via external financing constraints and internal managerial risk aversions. Contrasting our empirical approach, certain studies adopt a moderation effect model to determine the conditions under which economic policy uncertainty variably impacts green technology innovation. For instance, Cui et al. (2023) employed a moderation effect model, revealing that firms with higher risk-bearing capacities experience diminished negative effects from economic policy uncertainty on green innovation [30]. Guan et al. (2021) observed that heightened market competition lessens the dampening impact of economic policy uncertainty on green technological innovation [92]. Lastly, regarding research outcomes, not all findings in the literature align with this study's results. For example, both Peng et al. (2023) and Yang et al. (2022) concluded that economic policy uncertainty fosters green technology innovation in corporations [95,96]. However, what leads research with identical samples and methodologies to yield divergent conclusions?

Upon examining the theoretical frameworks and empirical designs in the articles, the divergent conclusions of Peng et al. (2023) and Yang et al. (2022) stem from their omission of macro indicators, like the "PMI index" and "GDP growth rate," in their regression analyses. The presence or absence of macro indicators significantly influences the final impact estimations [95,96]. Notably, macro indicators are intricately linked to corporate green technology innovation. Omitting macro indicators from a model can introduce significant endogeneity issues because of the missing variables. Consequently, future studies on the influence of economic policy uncertainty on corporate green technology innovation should consider these factors.

The contributions of this paper to the existing literature exploring the relationship between economic policy uncertainty and corporate green technology innovation are as follows. (1) In terms of model setting, unlike the existing literature that includes time-fixed effects or directly omits time controls, this paper adds a time trend term to the model, making the regression estimates more robust. (2) In terms of research mechanisms, unlike the existing literature that explores "what" mechanisms can mitigate the negative effects of economic policy uncertainty on corporate green innovation, this paper focuses on "why" economic policy uncertainty suppresses the willingness of enterprises to seek green technology innovation through external corporate financing constraints and internal management risk preferences. (3) In terms of theoretical validation, the mechanism analysis of this paper also re-validates the application of the real options theory in corporate green technology innovation, i.e., against the backdrop of economic policy uncertainty, the "wait option" value of corporate executives increases, and the decline in the risk preference of executives leads to a delay in corporate green technology activities.

This study, while comprehensive, has some limitations. (1) Given the varied perceptions of economic policy uncertainty across enterprises and challenges in extracting data from corporate financial reports, this study did not account for green technology innovation under these differential perceptions. (2) The study did not delve into compensatory mechanisms that might boost enterprises' inclination towards green innovation. Building on these limitations, we suggest the following avenues for future research. (1) Employ advanced text mining on corporate financial reports to gauge enterprises' perception coefficients related to economic policy uncertainty, aiming to understand green technology innovation under varied perceptions. (2) Investigate potential compensatory strategies to enhance enterprises' green innovation enthusiasm, considering factors like government subsidies, digital technology adoption, and consumer green preferences.

6. Conclusions

This paper empirically examines how economic policy uncertainty impacts green technological innovation in manufacturing firms, using the instrumental variables method and clustered standard error regression, with data from China's A-share listed firms (2008–2020). The study reveals firms' reluctance to pursue green innovation under policy uncertainty. This result holds after various tests: altering green innovation indicators, changing econometric methods, adjusting economic policy uncertainty metrics, and addressing endogeneity issues such as bi-directional causality, omitted variables, and control trends. Mechanism analysis identifies higher financing constraints and lower executive risk preferences as key influences. Heterogeneity analysis further reveals that the negative correlation between policy uncertainty and green innovation is more pronounced in firms with specific characteristics such as weaker government links, greater monopoly, lax intellectual property rights, reduced pollution, and a higher labor-to-capital ratio.

Based on the primary findings of this paper, we propose the following policy recommendations for China. (1) **Stabilize economic policies.** Uncertainty in economic policies may hinder enterprises' willingness to innovate in green technology. Therefore, the government should focus on the frequency and intensity of policy changes and emphasize policy coherence, transparency, and effective internal and external oversight during policy planning and implementation. This will ensure a stable external environment for enterprises to innovate in green technology. (2) **Financial incentives for green initiatives.** Uncertainty in economic policies may lead banks and other financial institutions to tighten lending standards, thus reducing enterprise willingness to invest in green technological innovation. To address this, the government should take financial measures, such as providing timely subsidies and reasonable tax incentives, to ease the cost of enterprise financing. This will ensure that financial constraints do not hinder green technological innovation in enterprises. (3) **Enhance risk tolerance in management.** Economic policy uncertainty can reduce the risk appetite of enterprise management, leading to risk aversion and hindering the development of green technological innovation projects. The local government should consider introducing a manager liability insurance system through administrative orders or legislation. This system should expand the coverage and amount of managerial liability insurance, thereby increasing the risk tolerance of enterprise managers. (4) **Strengthen regional intellectual property protection.** Economic policy uncertainty has a more substantial negative impact on corporate green innovation in regions with weak intellectual property protection. Therefore, the government should enhance the enforcement of intellectual property protection in these regions to safeguard the legitimate innovation achievements of enterprises and boost their motivation for innovation. (5) **Targeted support for specific enterprises.** The government should target enterprises with weak government–enterprise connections, high monopolies, low pollution, and a high proportion of labor and capital factors. It should provide targeted policy support and incentives for these enterprises to encourage their investment in green technological innovation.

Emerging market countries can derive insights from this paper's findings, emphasizing (1) policy stability, as frequent changes can reduce firms' confidence and innovation incentives, and stable policies encourage green technology innovation; (2) alignment between policy and market demand, as abrupt policy shifts can affect innovation; thus, government should consider market needs to target policies effectively; (3) flexible and transparent policy making, as rigid, opaque policies may stifle innovation, so policy formulation must be adaptable and clear to aid enterprise compliance; (4) pursuit of global vision and cooperation, as isolated policies limit this aspect; thus, government and market agencies must foster global collaboration, resource sharing, and green technology globalization. In summary, this study offers lessons for developing nations on crafting policy environments favorable to green technology innovation, highlighting stability, flexibility, transparency, and global cooperation.

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