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Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rero20

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To cite this article: Huwei Wen, Yutong Liu & Fengxiu Zhou (2023) Perceived uncertainty, low-carbon policy, and innovation investment: evidence from Chinese listed new energy companies, Economic Research-Ekonomska Istraživanja, ahead-of-print:ahead-of-print, 1-20, DOI: 10.1080/1331677X.2023.2166092

To link to this article: https://doi.org/10.1080/1331677X.2023.2166092

Published online: 13 Jan 2023.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
https://doi.org/10.1080/1331677X.2023.2166092

Perceived uncertainty, low-carbon policy, and innovation investment: evidence from Chinese listed new energy companies

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ABSTRACT
Uncertainty can bring about challenges to the operations of the energy industry, which may inevitably affect corporate innovation decisions. This study uses the firm-level data from the new energy sector in China to examine how perceived uncertainty affects their innovation decisions. It is found that new energy companies significantly increase innovation activities when perceiving high uncertainty. In addition to directly promoting innovation investment, a low-carbon policy can also indirectly increase the innovation investment of new energy companies in response to perceived uncertainty. Specifically, a low-carbon policy can significantly increase government subsidies and reduce the financing constraints of new energy companies, thereby increasing their innovation effect against perceived uncertainty. Furthermore, the uncertainty–innovation nexus is significantly positive in companies with different ownership, but some differences exist in the effects and mechanisms.

ARTICLE HISTORY
Received 16 November 2022
Accepted 3 January 2023

KEYWORDS
Perceived uncertainty; innovation investment; new energy industry; low-carbon policy; government subsidy

JEL CODES
O32; Q43; Q58

1. Introduction

The large amount of energy consumption dominated by traditional fossil energy in the industrial society is a major contributor to carbon dioxide emissions, which poses an irreversible potential threat to global climate change (Zhou & Wang, 2022). Countries are actively promoting the development of non-fossil fuels or renewable energy, which must actively support the innovation of the new energy sector to achieve economic sustainability and address climate change (Lee et al., 2022). Nevertheless, uncertainty in global economic, social, and geopolitical aspects brought about considerable challenges to the operations of the new energy sector (Barradale, 2010; Sendstad & Chronopoulos, 2020). Global uncertainty may lead to the instability of the supply chain of the new energy industry, which may in turn lead to a shortage of key equipment and components and decline in production efficiency. Geopolitical

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conflicts also exacerbated uncertainty in the global energy market, which not only inhibited regional cooperation in renewable energy but also led to the expansion of traditional energy industries and rebound effect of traditional energy (Cui et al., 2021). Therefore, uncertainty is a factor that should be considered in the operations of new energy companies.

The uncertainty encountered by the new energy industry stems from uncertainty in not only the economic and social environment but also technology and market of the new-type energy system (Scott et al., 2020). Government departments typically introduce various industrial policy instruments in the new energy field to mitigate the adverse effect of uncertainty on corporate operations and boost the enthusiasm for investment in the new energy sector (Hao et al., 2021; Zhang et al., 2022). Anchoring the goal of building a new-type energy system, China adopted a series of measures to enhance the ability and confidence of new energy enterprises to cope with uncertainty. The policy intervention of the low-carbon pilot cities in China aims to promote the low-carbon development in pilot regions (Liu et al., 2022). One of its objectives is to develop new energy or renewable energy, which would provide policy support to new energy companies and substantially enhance their ability to actively respond to uncertainty. From the support of public policies, China accomplished great achievements in the new energy industry in the uncertain global environment.

Discussions on corporate investment behavior under uncertainty are a hot topic in the relevant literature, especially in recent years, when global uncertainty increased sharply. The traditional view of real options theory is that corporate investment would be delayed or withdrawn (Bloom et al., 2007). Most empirical evidence on fixed asset investment supported this conclusion (Chen et al., 2019), whereas the role of uncertainty in financial investment and innovation investment decisions may be highly complex (Marcus, 1981; Cui et al., 2021). Specifically, innovation may gain exclusive market ability in the future, and companies may gain dynamic competitive advantages by increasing their investment in the uncertain environment (Freel, 2005). Empirical evidence supported the paradoxical effects of uncertainty on innovation, and the nexus of uncertainty and innovation is affected by the characteristics of corporate risk preference, financing capacity, and market opportunities (Lou et al., 2022). Carbon finance and energy finance are also crucial to the formation of new-type energy system (Charfeddine & Kahia, 2019; Qin et al., 2022a). Carbon emissions, energy use and financial markets have been empirically proven to interact and contribute to the formation of new-type energy system (Su et al., 2022a, 2023). Uncertainty in financial markets intensifies the financing constraints of energy companies (Cao et al., 2020), and an efficient financial market may hedge against the adverse shock of uncertainty.

Existing studies on the micro-economic effects of uncertainty mostly investigated laws for all industries (Goodell et al., 2021). However, the new energy industry is a new industry, with various future opportunities. Innovative investment may give companies a first-mover advantage to seize the market and lead the technological change. When a company perceives uncertainty, it will reduce its fixed asset investment profit opportunities and likely enhance its technological competitive advantage through innovation activities. Some literature has contributed to clarifying the role of uncertainty in energy companies' decision making (Hou et al., 2021; Li et al., 2021), whereas others examined the investment decisions of new energy enterprises against uncertainty (Wen et al., 2022). In addition to focusing on macro uncertainty, an increasing number of studies are finding that perceived uncertainty is closely related to corporate behavior (Afifa & Saleh, 2021). However, there is room for further discussion on how perceived uncertainty affects the corporate behaviors of companies in new energy sector.

Innovation is a source of industrial endogenous growth, and investigating how uncertainty affects the technological innovation of the new energy sector is necessary. We use the firm-level data of Chinese new energy sector obtained from A-share market from 2007 to 2018 to examine the role of perceived uncertainty in innovation decisions. This study finds that perceived uncertainty significantly improves enterprise innovation in the new energy sector, whereas a low-carbon policy could significantly increase their innovation in response to uncertainty. The study findings support those on the uncertainty of the technology and market opportunities for the new energy sector as a promising emerging industry. Specifically, new energy companies strengthen their technological competitiveness by increasing their innovation investment in the uncertain environment.

This study extends the related research in the following aspects. First, it is designed to evaluate the effect of perceived uncertainty, rather than macro uncertainty, and identifies the actual uncertainty–innovation nexus. Second, based on the characteristics of the uncertainty of the opportunities of emerging industries, this study reveals the law that new energy companies enhance their technological competitiveness by conducting innovation activities in response to uncertainty. Third, this study reveals the role of a low-carbon policy in motivating new energy companies to actively respond to uncertainty and has enlightenments for developing countries on how to optimize new energy industry policies.

2. Relevant literature and theoretical hypotheses

2.1. Discussion of relevant literature

The determinants of corporate innovation investment include not only internal characteristics, such as financing capacity, profitability, and management style (Pham et al., 2018; Kong et al., 2021), but also external environmental factors, such as public policy, the market environment, and industrial characteristics (Lee et al., 2020). Innovation activities have the positive externality of knowledge spillover, and the actual innovation investment of private companies may be lower than the investment corresponding to the largest social welfare. A large number of studies investigated the efficiency or actual effect of industrial policies, such as government subsidies and credit support, that encourage companies to conduct innovation activities (Song et al., 2020).

An increasing number of studies are finding that the uncertain external environment is closely related to corporate innovation behavior, and empirical studies have examined the general laws of the uncertainty–innovation nexus (Marcus, 1981; Chen et al., 2021). However, empirical evidence on how uncertainty affects innovation decisions is inconsistent (Cui et al., 2021; Cao et al., 2022), which may be caused by the heterogeneity of firm-level internal characteristics or the intervention of external environment. Specifically, differences in industrial characteristics may be among the sources of the contradictory empirical evidence. The new energy sector is a promising emerging industry, which has an uncertain technological path and is affected by global industrial chain and product market uncertainty (Pan & Dong, 2022). A growing body of research is focusing on the micro effects of uncertainty on new energy companies (Wen et al., 2022); however, such studies analyzed macro uncertainty rather than firm-level perceived uncertainty.

The innovation behavior of companies is determined by both internal and external factors, and existing studies examined how public policies can be designed to stimulate the renewable energy innovation (Dong & Zheng, 2022). Although uncertainty is an important external factor in new energy companies' decision making (Liu et al., 2021), studies on how new energy companies respond to uncertainty, especially firm-level perceived uncertainty, are scarce. Public policies or low-carbon policies are believed to provide some convenience to new energy companies (Liu et al., 2022), but existing studies did not examine whether low-carbon policies affect the relationship between uncertainty and innovation. Some studies find that the low-carbon policy contributes to innovation and knowledge diffusion (Zhang et al., 2019; Zhu & Lee, 2022), which provides some theoretical basis for this study.

Many recent research has discussed the interactions between carbon regulation, green finance and energy use, and financial support contributes to the low-carbon development and energy transition (Qin et al., 2020; Gao et al., 2022; Wang et al., 2022). Environmental regulations are believed to drive regional low-carbon sustainable development (Wang et al., 2021; Yang et al., 2022), but may also increase the burden on business operations (Wen et al., 2023a). Environmental policies and international shock events have brought many uncertainties to the operation of companies in the emerging industry, and the stability factors in the uncertain environment are conducive to long-term investment and innovation investment (Zhao et al., 2022). A low-carbon policy is a stability factor for new energy companies in an uncertain environment (Zhou & Wen, 2022).

2.2. Theoretical analysis

The role of uncertainty in corporate investment can be traced back to real options theory, and this theory holds that improves the value of waiting options (Li et al., 2022), so companies tend to delay or withdraw their long-term investment. The negative uncertainty-investment nexus derived from real option theory requires companies to have exclusive investment opportunities (He et al., 2022). The new-type energy system is a revolution of energy production and supply, and its derived new energy sector has an uncertain technological path (Su et al., 2022b), which means that uncertainty may be an opportunity for new energy companies. Hence, the companies in the industry are actively seizing the market opportunities of the industry. Innovation investment involves the competitiveness of new energy companies under the uncertain industrial technological change, and innovation investment against uncertainty may give the companies a first-mover advantage in technology and the market.

According to theory of organizational dynamic capability, new energy companies can use their proprietary resources to enhance their competitiveness (Teece et al., 2016; Zhou & Wen, 2022). Innovation investment is a means for new energy companies to obtain unique resources, and the companies must improve their competitiveness through innovation investment in an uncertain environment. This view is consistent with strategic competition theory, which indicates that new energy companies strategically increase their innovation investment against uncertainty (Shen & Hou, 2021). Although uncertainty can reduce the profitability and financial performance of a company, which may tighten the financing constraints, new energy companies can hedge against the adverse shocks of uncertainty on their business activities by promoting technological innovation. Hence, the main hypotheses are as follows:

Hypothesis 1: New energy companies significantly increase their innovation investment against perceived uncertainty.

A low-carbon policy is designed to reduce carbon dioxide emissions, and its long-term goal is to build a new-type energy system in which renewable energy dominates or build a zero-carbon-emissions energy supply system (Su et al., 2022c; Wen et al., 2023a). Such a policy not only directly supports the new energy industry but also boosts the investment confidence of companies and their stakeholders (Shao et al., 2022). Owing to the characteristics of technological uncertainty and knowledge spillover, the prospects of the new energy sector is affected by public policies. Thus, low-carbon policies are the basis of new energy companies' innovative investment decisions. New energy companies may be willing to increase their innovation investment in response to uncertainty, which requires the public support of financial resources. In an uncertain environment, a low-carbon policy can help new energy companies conduct strategic innovation activities. Hence, another hypothesis is proposed:

Hypothesis 2: A low-carbon policy can significantly increase the innovative investment of new energy companies against perceived uncertainty.

The low-carbon and clean energy system is one of the key goals and tasks anchored by the low-carbon policy, which means that a low-carbon policy enables companies in new energy sector to obtain more government subsidies or some other preferential policies (Wen et al., 2023b). Government subsidy not only directly provides the company with funds for innovation activities, but also restricts the company to carry out innovation activities to meet the requirements for technological innovation. In addition, government subsidies provide a signal to the company's stakeholders that the industry is promising and expected, so enterprise innovation activities would receive much more support from stakeholders. Property rights protection and government-enterprise relations have improved, and favorable environmental factors encourage enterprises to invest in innovation (Su et al., 2022d). Hence, the following hypothesis is proposed.

Hypothesis 3: A low-carbon policy significantly increases the government subsidies of new energy companies, thus encouraging innovation.

A low-carbon policy generally includes financing guarantee or other convenient services, and the government participation in financing activities reduces the information asymmetry between new energy companies and financial institutions. In addition, the low-carbon policy has also improved the performance expectations of financial institutions on the new energy sector, thereby reducing the valuation of default risk of companies in related industries. In general, a low-carbon policy reduces the financing constraints of companies in the renewable energy chain. Innovation activities in the new energy sector are generally long cycle, uncertain and high input, and there is a large demand for funds (Qin et al., 2022b). Financing support can improve the ability of new energy companies to respond to uncertainty and carry out innovative activities (Su et al., 2021). Based on the above analysis, it raises a new hypothesis.

Hypothesis 4: A low-carbon policy significantly reduce the financing constraints, thus encouraging innovation.

3. Samples and methodology

3.1. Data Sources and samples

The study sample is obtained from the Shanghai and Shenzhen Stock Markets in China and includes the companies in the new energy business chain, with 1,972 firm-year observations from 2011 to 2018. New energy companies include companies engaged in new energy power generation and related equipment manufacturing, as well as companies in the industrial chain of new energy vehicles. The accounting standards for Chinese listed companies were adjusted in 2007; thus, the statistical caliber of financial variables may have changed. In addition, the latest year with data on corporate perceived uncertainty is 2018, so this study chooses the time span of 2007–2018 as the research period. The firm-level financial data are obtained from the China Stock Market and Accounting Research Database. The sample with missing or abnormal data are eliminated, and the financial variables are winsorized at the 1% quantile.

The firm-level perceived uncertainty is provided by the study of Nie et al. (2020), which can be obtained from http://www.niehuihua.com/a/zuopin/521.html. Words and sentences regarding policy uncertainty are extracted from the annual reports via text mining to serve as proxy variables for the perception of firm-level policy uncertainty. Perceived uncertainty is mainly the policy uncertainty. If policy words and uncertainty words appear simultaneously in a sentence of the company's annual report, it is considered as a description of perceived policy uncertainty. Figure 1 presents the average trend of corporate perceived uncertainty and R&D intensity, which indicates a positive correlation.

3.2. Econometric regression model

A panel model with two-way fixed effects is used to examine how perceived uncertainty affects corporate innovation. The following formula is specific econometric regression model:

$$RD\_Intensity_{it} = \alpha + \beta_1 \times Uncertainty_{it} + \sum_{k=1}^{K} \gamma_k Controls_{k,it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (1)$$

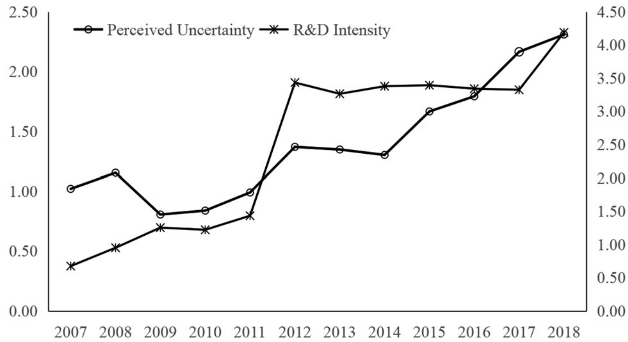

Figure 1. Trend of perceived uncertainty and R&D intensity. Source: Author's estimations.

where company and year are correspondingly represented by the subscripts i and t. R&D intensity (*RD_Intensity*) refers to investment in research and development divided by total revenue.

The independent variable of interest is the policy uncertainty (*Uncertainty*) perceived by the new energy companies. This study also controls for K control variables, which are represented by *Controls* in the empirical model. The company-level fixed effects (μ_i) and year-level fixed effects (λ_t) are controlled for to incorporate the time-invariant company characteristics and macro-level trend characteristics into the regression. This research mainly focuses on the coefficient (β_1) of corporate perceived uncertainty. If β_1 is significantly positive, then Hypothesis 1 is supported.

$$\begin{aligned} RD\_Intensity_{it} = \alpha + \beta_2 \times Uncertainty_{it} + \beta_3 \times Uncertainty_{it} \times Carbon_{it} \\ + \beta_4 \times Carbon_{it} + \sum_{k=1}^{K} \gamma_k Controls_{k,it} + \mu_i + \lambda_t + \varepsilon_{it}, \end{aligned} \tag{2}$$

where *Carbon* refers to the intervention of a low-carbon policy. If the coefficient of *Uncertainty* × *Carbon* is significant and positive, then Hypothesis 2 is supported.

3.3. Definition and descriptive statistics of variables

This study focuses on the innovative behaviors of companies involved in the new energy business against perceived uncertainty; thus, the dependent variable (*RD_Intensity*) is R&D intensity, and the core explanatory variable is firm-level perceived uncertainty (*Uncertainty*). Perceived uncertainty is denoted by the proportion of relevant sentences in the total number of sentences in a corporate annual report (*Uncertainty1*) and the proportion of relevant words in the total number of words in a corporate annual report (*Uncertainty2*). In addition to the dependent and core explanatory variables, this study includes some related variables, whose definitions are listed in Table 1.

Some moderator variables and mechanism variables are used to analyze how the low-carbon policy affects the uncertainty–innovation nexus. Low-carbon policy (*Carbon*) refers to the binary variable of the pilot policy of low-carbon cities, and the value is one after the low-carbon pilot policy has been implemented, and zero otherwise. The government subsidy (*Subsidy*) reflects a new energy company obtaining policy support from the government, denoted by the government subsidy divided by

Table 1. Variable definitions.

Variable	Connotation	Definition
RD_Intensity	Innovation Investment	Investment in research and development divided by total revenue
Uncertainty1	Perceived uncertainty	100 × number of sentences about uncertainty/total number of sentences
Uncertainty2	Perceived uncertainty	100 × number of words related to uncertainty/total number of words
Carbon	Low-carbon policy	Dummy variable of low-carbon cities pilot policy
Loan	Long-term loans	Proportion of long-term loans in the amount of assets of a company
Subsidy	Government subsidy	Proportion of corporate government subsidy in total assets
SA	Financing constraints	Absolute value of SA index measuring financing constraints
Size	Operating scale	Logarithm of employees in a company
Age	Survival year	Logarithm of survival years of a company
Leverage	Leverage ratio	Proportion of total liabilities in the amount of assets
Tobin	Tobin's Q	Ratio of market value to capital replacement cost
ROA	Return on assets	Net income divided by the average amount of assets
Fixed	Fixed asset ratio	Proportion of corporate fixed assets in the amount of assets
Growth	Corporate growth	Growth rate of corporate sales revenue of a company
Cash	Cash flow	Proportion of total operating cash flow in the amount of assets
SOE	Ownership	Dummy variable of state-owned ownership
Share	Equity concentration	Equity shares concentration of top 10 shareholders

Source: Author's definitions.

the amount of the assets. Long-term loans (*Loan*) reflect a new energy company's access to bank credit, measured as the proportion of long-term loans in the amount of assets. Financing constraint is measured by the SA index (*SA*), and a high valuation implies tight financing constraints.

This research has controlled for some other factors by referring to the literature (Wen et al., 2022). Operating scale (*Size*) refers to the ability to bear innovation risks, measured as the logarithm of the employees in a company. The survival year (*Age*) represents experience in relevant businesses, measured as the number of years the company has lived, and it is logarithmic. The leverage ratio (*Leverage*) is the asset liability ratio, reflecting debt dependence, and a high leverage ratio indicates a heavy debt burden. Tobin's Q (*Tobin*) is the ratio of capital market value to its replacement cost, and return on assets (*ROA*) is the net income divided by the average amount of assets in a year. The fixed assets ratio (*Fixed*) is denoted by the proportion of fixed assets in the amount of assets, indicating the capital deepening degree of a company. Growth indicator (*Growth*) is denoted by the growth rate of the sales revenue. Cash flow (*Cash*) is measured as the proportion of the operating cash flow in the amount of assets, which affects the funds available to the company to conduct innovation activities. The ownership characteristic (*SOE*) is a binary variable, which is equal to one for a state-owned company and equal to zero for other companies. The equity concentration (*Share*) refers to the equity share concentration ratio of the top 10 shareholders, which is an important indicator of corporate stability. Table A1 in the Appendix A lists some statistical indicators of the relevant variables.

4. Empirical results and analysis

4.1. Impact of perceived uncertainty on innovation investment

Table 2 shows how perceived uncertainty affects the innovation of companies involved in the new energy business. The difference between the columns is mainly whether to control for the two-way fixed effects. To avoid standard error estimation

Table 2. Empirical results of perceived uncertainty affecting innovation.

	Response Variable: *RD_Intensity*					
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Uncertainty1	0.2395***	0.2745***	0.1743***			
	(0.0788)	(0.0691)	(0.0584)			
Uncertainty2				4.2355***	5.0282***	3.2277**
				(1.4560)	(1.5035)	(1.3183)
Size	0.1586	0.3972***	0.2070	0.1445	0.3867***	0.2017
	(0.1066)	(0.1254)	(0.1349)	(0.1064)	(0.1254)	(0.1349)
Age	−0.6192***	1.0747***	−0.3066	−0.6242***	1.0931***	−0.2854
	(0.1383)	(0.1901)	(0.2214)	(0.1363)	(0.1823)	(0.2226)
Leverage	−1.5118***	−0.5267	−0.5285	−1.5004***	−0.5457	−0.5433
	(0.5684)	(0.3793)	(0.3495)	(0.5562)	(0.3661)	(0.3429)
Tobin	0.3879*	0.0108	0.0983	0.3806*	0.0058	0.0955
	(0.2185)	(0.1106)	(0.1604)	(0.2199)	(0.1124)	(0.1614)
ROA	−0.7241*	−0.0372	−0.1993	−0.7123*	−0.0300	−0.1955
	(0.3909)	(0.2010)	(0.2905)	(0.3933)	(0.2039)	(0.2920)
Fixed	−2.1773**	1.0658	1.1034	−2.1301**	1.2406	1.2057
	(0.8973)	(1.3443)	(1.3388)	(0.9003)	(1.3552)	(1.3425)
Growth	−0.1923***	−0.0811**	−0.0866**	−0.1928**	−0.0863**	−0.0898***
	(0.0717)	(0.0390)	(0.0343)	(0.0759)	(0.0371)	(0.0329)
Cash	−3.0256	−2.5340	−2.6714	−2.9155	−2.3506	−2.5670
	(2.8396)	(2.2562)	(2.2535)	(2.8201)	(2.1976)	(2.2119)
SOE	−0.5896**	−1.1501**	−0.7440*	−0.5962**	−1.2809***	−0.8287*
	(0.2665)	(0.4463)	(0.4096)	(0.2688)	(0.4652)	(0.4295)
Share	−0.205	−0.9064	0.3674	−0.2306	−0.9570*	0.3207
	(0.5393)	(0.5792)	(0.5845)	(0.5431)	(0.5778)	(0.5677)
Year fixed effect (FE)	No	Yes	Yes	No	Yes	Yes
Company FE	Yes	No	Yes	Yes	No	Yes
Adjusted-R^2	0.2766	0.1413	0.2255	0.2759	0.1420	0.2258
Observations	1,792	1,792	1,792	1,792	1,792	1,792

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations.

errors caused by the cross-section correlation, this study uses the firm-level clustering standard error. This study finds that some internal influences have a significant impact on enterprise innovation. However, the control of fixed effect has a considerable influence on the results of estimated parameters, which indicates that a two-way fixed-effects model is necessary. Columns (3) and (6) list the benchmark results of this study.

It is found that the companies involved in the new energy business significantly improve their innovation investment in response to high perceived uncertainty. In all the columns in Table 2, the regression coefficients of *Uncertainty1* and *Uncertainty2* are significant and positive at the 1% level, which means that a significant positive nexus exists between perceived uncertainty and corporate innovation. This finding seems to contradict the traditional view of real options theory. The new energy industry has various technological and market opportunities in an uncertain environment, and companies must carry out innovation activities to improve their dynamic capabilities (Lütjen et al., 2019). Existing literature has shown that renewable energy companies are actively engaged in innovative activities responds to the uncertain environment (Shen & Hou, 2021; Wen et al., 2022). The findings of this study enrich this conclusion from the perspective of firm-level perceived uncertainty, and there is more and stronger evidence to support the view of strategic competition. Therefore,

Table 3. Moderating effect of low-carbon policy.

	Response Variable: *RD_Intensity*				
Variables	(1)	(2)	(3)	(4)	(5)
Carbon	0.5838**	1.3728***	0.4715*	1.3803***	0.5121**
	(0.2851)	(0.2306)	(0.2399)	(0.2199)	(0.2271)
Uncertainty1		0.2510**	0.1338		
		(0.1027)	(0.0930)		
Carbon × *Uncertainty1*		0.2427***	0.2160**		
		(0.0904)	(0.0853)		
Uncertainty2				4.6795**	2.6687
				(1.9730)	(1.7617)
Carbon × *Uncertainty2*				4.3686**	3.8401**
				(1.9450)	(1.8930)
Control Var.	Yes	Yes	Yes	Yes	Yes
Company FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No	Yes
Adjusted-R^2	0.2223	0.1775	0.2302	0.1780	0.2304
Observations	1,792	1,792	1,792	1,792	1,792

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations.

Hypothesis 1 is established, and the view of strategic competition is established for the new energy companies. Nevertheless, the uncertain environment has a negative effect on the profitability and cash flow of the new energy companies (Goodell et al., 2021), which are necessary to provide financial support to the companies' positive response to perceived uncertainty.

4.2. Impact of low-carbon policy on uncertainty–innovation nexus

Public policies may change the ability of new energy companies to respond positively to perceived uncertainty, and Table 3 shows how the low-carbon policy affects innovation decisions by new energy companies in an uncertain environment. This study uses the intervention policy of low-carbon pilot cities as a shock event.

The empirical results show that a low-carbon policy can not only directly motivate the new energy companies to conduct innovation activities but also enhance their positive response to uncertainty. In column (1), the regression coefficient of *Carbon* is significant and positive at the 5% level, which means that a significant positive relationship exists between the low-carbon policy and corporate innovation investment. It means that we have found results consistent with existing studies and low-carbon policies support regional or enterprise innovation, which are also valid for companies in the new energy sector (Pan et al., 2022; Wen et al., 2023a). A low-carbon policy can increase the innovation investment of the new energy companies. In columns (2)–(5), the coefficients of the interaction terms for policy shocks and perceived uncertainty are significantly positive, implying that the low-carbon policy strengthens the innovation effect of perceived uncertainty. This finding supports research Hypothesis 2, stating that a low-carbon policy would increase the ability of new energy companies to respond positively to perceived uncertainty.

Although the new energy companies are willing to conduct innovation activities under perceived uncertainty, the decline in their profitability and cash flow from the

Table 4. Empirical results of dynamic panel model.

	Response Variable: *RD_Intensity*					
Variables	(1)	(2)	(3)	(4)	(5)	(6)
RD_Intensity	0.3367***	0.3529***	0.3467***	0.3276***	0.3780***	0.3573***
	(0.0257)	(0.0266)	(0.0207)	(0.0267)	(0.0242)	(0.0307)
Uncertainty1	0.3927***		0.8014***	0.1974	18.6608***	6.7668**
	(0.0754)		(0.1536)	(0.1418)	(2.6633)	(2.9637)
Uncertainty2		3.3408**				
		(1.6435)				
Carbon			1.1663***	−0.6004	1.5576***	0.5888
			(0.3885)	(0.5893)	(0.3656)	(0.6166)
Carbon × *Uncertainty1*			0.5916***	0.4442***		
			(0.0784)	(0.0847)		
Carbon × *Uncertainty2*					8.4891***	3.5712
					(1.8725)	(2.1718)
Control Var.	Yes	Yes	Yes	Yes	Yes	Yes
Company FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	Yes	No	Yes
Arellano–Bond test for AR (1)	0.062	0.069	0.052	0.068	0.044	0.068
Arellano–Bond test for AR (2)	0.330	0.325	0.368	0.325	0.361	0.347
Observations	1,564	1,564	1,564	1,564	1,564	1,564

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations.

uncertainty will reduce their funds for innovation investment. Some studies have found that a low-carbon policy increases the transformation risk of carbon-intensive companies for enterprises, thus forcing innovation (Huang et al., 2021). Although the conclusion seems similar, the innovation behavior of these companies is different from that of companies involved in the new energy business. Companies involved in the new energy business are supported by low-carbon policies to carry out innovation activities. Low-carbon policies may not only directly provide policy support to new energy companies but also improve their stakeholders' confidence.

4.3. Empirical analysis of dynamic panel regression model

Innovation projects generally require multiple cycles of continuous investment, thereby making innovation investment dynamically dependent. If this dynamic dependency is ignored, then it may lead to an endogenous regression. In this study, the dynamic hysteresis is included in the two-way fixed-effects model, and the estimated results are listed in Table 4.

The findings in the dynamic panel regression model are consistent with those of the static panel model. In column (1) and column (2), the coefficient of perceived uncertainty is significant and positive, thereby implying that the new energy companies significantly increase their innovation investment in response to perceived uncertainty, which supports research Hypothesis 1. In columns (3)–(5), the coefficients of perceived uncertainty and a low-carbon policy are significantly positive, thereby indicating that the low-carbon policy strengthens the innovation effect of perceived uncertainty, which supports research Hypothesis 2. Although the coefficient of the interaction term in column (6) is insignificant, it does not conflict with the conclusion in the other columns. The Arellano–Bond test for sequence autocorrelation

Table 5. Empirical results of robustness test.

	Resp. Var.: *RD_Intensity*		Resp. Var.: *lnRD*		Resp. Var.: *lnPat*	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
UncertaintyFis	0.1724** (0.0713)	0.0449 (0.0806)				
Uncertainty1			0.8027*** (0.1283)	0.5344*** (0.1817)	0.0229 (0.0226)	0.0217 (0.0211)
Carbon	1.2666*** (0.2742)	0.0449 (0.0806)		−0.5058 (0.8439)		
Carbon × *Uncertainty*		0.3857*** (0.0906)		0.5079** (0.2550)		
Control Var.	Yes	Yes	Yes	Yes	Yes	Yes
Company FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	Yes	Yes
Adjusted-R^2	0.1552	0.1414	0.4710	0.4730	0.0517	0.0511
Observations	1792	1792	1792	1792	1792	1792

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors; *Uncertainty* refers to *UncertaintyFis* in the column (2) and *Uncertainty1* in the column (4).
Source: Author's estimations.

supports the model setting of the first-order lag term, and the coefficients of the first-order lag term are significant, thereby implying that the findings in the dynamic panel model is reliable.

4.4. Empirical analysis of robust analysis

In order to reduce the endogeneity of the perceived uncertainty, we also use the fiscal policy uncertainty as an alternative variable. The variable of fiscal policy uncertainty (*UncertaintyFis*) is the residual term of fiscal policy regresses on industrial growth, investment growth, export growth and other economic variables, which is an exogenous uncertainty of fiscal policy. Besides, the logarithm of investment in research and development ((*lnRD*) and the logarithm of patents (*lnPat*) is used to measure innovation for robustness test. Table 5 shows the empirical analysis of robust analysis.

Fiscal policy is the most important economic policy for new energy companies (Wen et al., 2022), the company's response to the uncertainty of fiscal policy is consistent with its response to perceived uncertainty. The innovation scale is also consistent with the innovation intensity, while the impact of perceived uncertainty on patent output is insignificant. It can be seen that the perceived certainty significantly promotes innovation investment for new energy companies, and low-carbon policy enhances this effect. On the contrary, the regression coefficients of *Uncertainty1* in columns (5) and (6) are insignificant. Because it takes a certain period for an enterprise's innovation achievements to form a patent, it may be that the patent effect cannot be captured due to the model.

5. Empirical analysis of mechanisms and ownership heterogeneity

5.1. Empirical analysis of mechanism of government subsidies

Government subsidies play a guiding role in the technological innovation of an infant industry or a promising emerging industry, especially in an uncertain environment

Table 6. Empirical results of mechanism of government subsidies.

	Resp. Var.: *Subsidy*		Resp. Var.: *RD_Intensity*			
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Carbon	0.2751***	0.2542**				
	(0.0911)	(0.1199)				
Uncertainty2			5.2737***	3.4289**	3.6854***	1.1886
			(1.5679)	(1.3863)	(1.2409)	(0.9545)
Subsidy			0.3335***	0.3237**		
			(0.1172)	(0.1382)		
Uncertainty2 × *Subsidy*					2.1023**	2.1265**
					(0.9296)	(1.0584)
Control Var.	Yes	Yes	Yes	Yes	Yes	Yes
Company FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes
Adjusted-R^2	0.0539	0.1462	0.1656	0.2459	0.1559	0.239
Observations	1,792	1,792	1,792	1,792	1,792	1,792

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations.

(Li et al., 2021), and this study investigates whether a low-carbon policy promotes the innovation of the new energy companies, as shown in Table 6. Columns (1) and (2) reveal whether it increases the government subsidies obtained by the new energy companies, and columns (3)–(6) show whether government subsidies increase the innovation of the companies responding to perceived uncertainty.

As shown in Table 6, the intervention of low-carbon policy enables the new energy companies to obtain increased government subsidies, and government subsidies can enhance positive response to uncertainty. In first two columns, the coefficients of *Carbon* are significant and positive, thereby implying that the policy intervention targets the new energy industry to increase government subsidies for companies in the new-type energy filed. Columns (3) and (4) show the significantly positive role of subsidy affecting innovation, whereas columns (5) and (6) demonstrate that subsidy could significantly increase the companies' innovation investment in response to uncertainty. Hence, Hypothesis 3 is established. The new-type energy business always belongs to the promising emerging industry, and the companies suffer from technological immaturity and high uncertainty. Government subsidies can encourage new energy companies to conduct innovation activities, which is also the goal of industry polices and means that new energy innovation requires the support of a promising government.

5.2. Empirical analysis of mechanism of financing constraints

Innovative projects in the new energy industry require abundant financial support, especially under uncertainty. Financial performance may decline, and companies may suffer from strong financing constraints. Public policy support can directly reduce the credit risk of new energy companies and improve the confidence of their stakeholders through signaling. Table 7 reveals the effect of a low-carbon policy on the available long-term bank loans and how it affects the innovation decisions of the new energy companies in an uncertain environment. Columns (1) and (2) demonstrate whether a

Table 7. Empirical results of mechanism of financing constraints.

	Resp. Var.: *Loan*		Resp. Var.: *RD_Intensity*			
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Carbon	0.0279***	0.0205***				
	(0.0063)	(0.0069)				
Uncertainty2			3.1279***	1.6735*	1.891	34.0398
			(1.0604)	(0.9039)	(55.0476)	(58.0771)
Loan			14.5753***	13.1586***		
			(3.0889)	(3.0348)		
Uncertainty2 × *SA*					0.8223	−8.1189
					(14.2274)	(15.1333)
Control Var.	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	Yes	No	Yes	No	Yes
Adjusted-R^2	0.2149	0.2341	0.2903	0.3663	0.1415	0.2289
Observations	1,784	1,784	1,784	1,784	1,792	1,792

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations.

low-carbon policy increases the long-term loans obtained by the new energy companies, thereby providing financial support to conduct innovation activities.

The results in Table 7 indicate that the intervention of low-carbon policy enhances the ability of the new energy companies to obtain long-term loans, thereby leading them to actively respond to uncertainty and increase their innovation investment. Columns (1) and (2) show that a low-carbon policy could increase the long-term loans obtained by the new energy companies, thereby providing financial support to conduct innovation activities. Columns (3) and (4) also reveal that long-term loans are conducive to promoting enterprise innovation. As shown in last two columns, the coefficients of the *Uncertainty2* × *SA* interaction are insignificant, whereas the reduction of profitability and available funds in an uncertain environment is known and thus long-term loans can increase the companies' innovation ability to respond to uncertainty. In summary, the findings support the mechanism of financing constraints, and Hypothesis 4 is established.

5.3. Some discussion on the ownership heterogeneity

The low-carbon policy is a public policy that can affect the new energy industry, which also raises concern that the policy lacks competition neutrality. Table 8 shows the heterogeneity effects of the low-carbon policy on the companies with different ownership in the new energy industry, including R&D intensity, government subsidies, and long-term loans.

The supporting effect of the pilot policy differs mainly in the government subsidies received by the companies, but no difference exists in the bank loans. Although columns (1) and (2) reveal different policy effects, the coefficient size is relatively close, so this study does not infer whether there are ownership differences in the role of the low-carbon policy in the uncertainty–innovation nexus. Similarly, columns (5) and (6) indicate the impact of a low-carbon policy on long-term loans, which shows the absence of ownership discrimination in the bank loans for the new energy sector. Column (3) shows that a low-carbon policy significantly increases the government

Table 8. Empirical results of heterogeneity analysis.

	Resp. Var.: *RD_Intensity*		Resp. Var.: *Subsidy*		Resp. Var.: *Loan*	
Variables	(1) SC	(2) Non-SC	(3) SC	(4) Non-SC	(5) SC	(6) Non-SC
Uncertainty2	−0.2381	3.4778				
	(0.9812)	(2.5252)				
Uncertainty2 × *Carbon*	3.8825**	3.2165				
	(1.6758)	(2.3846)				
Carbon	0.4632	0.6201*	0.4738***	0.0318	0.0270***	0.0236***
	(0.3533)	(0.3230)	(0.1371)	(0.1600)	(0.0094)	(0.0075)
Control Var.	Yes	Yes	Yes	Yes	Yes	Yes
Company FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.3844	0.1927	0.1368	0.1554	0.2953	0.2287
Observations	682	1,110	682	1,110	680	1,104

Note: Asterisks indicate significance at corresponding P-values: *(10%), **(5%), ***(1%); figures in brackets are firm-level clustering standard errors.
Source: Author's estimations..

subsidies received by the state-owned companies (SC), whereas column (4) demonstrates that the government subsidies for the non-state-owned companies (Non-SC) are not significantly improved. As government subsidies provide important support to new energy companies in an uncertain environment, they may lead to the non-state-owned companies' weak ability to respond to uncertainty.

6. Conclusion and insights

This study identifies the innovation behavior of companies involves the new energy business in response to uncertainty using company-level perceived uncertainty and financial data. Empirical evidence shows that perceived uncertainty significantly increases the innovation of companies in the new energy sector, which is consistent with theory of organizational dynamic capability and the view of strategic competition. These findings further confirm the characteristics of the new energy sector as a promising emerging industry. In a high-uncertainty environment, companies actively conduct innovation activities to obtain technological advantages and seize market opportunities.

It is also found that a low-carbon policy contributes to the development of the new energy companies. In addition to directly spurring new energy companies to innovate, a low-carbon policy also increase new energy companies' investment in innovation in response to perceived uncertainty. In terms of the mechanisms, the low-carbon policy provides public support to the new energy industry, which significantly increases government subsidies and significantly reduces financing constraints, thereby enhancing the innovative effect of the new energy companies on perceived uncertainty. Some differences are observed in the nexus of perceived uncertainty and innovation in different ownership companies, while it generally supports the view that the new energy companies engage in positive investment behavior in response to uncertainty.

These findings provide some insights for countries to formulate industry policies for new energy development. First, every country should pay attention to the high uncertainty of the new-type energy system in technology and the market and improve technology and market competitiveness in the field of new-type energy system by encouraging companies to conduct innovation activities. Second, governments should attach importance to the ambitious goal of carbon neutrality and formulate public policies or low-carbon policies to help technological innovation in the new-type energy filed. Third, promoting the design of government subsidies and credit support for anchored new-type energy systems and improving the ability of new energy companies to address uncertainty in the macro environment and technology are necessary. Finally, new energy industry policies should adhere to competition neutrality and reduce the ownership discrimination of government subsidies, thereby strengthening market competition in the new energy industry.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Financial support is provided by the Youth Program of National Social Science Foundation of China (Grant No. 20CJY031).

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Appendix A

Table A1. Some statistical indicators of related variables.

Variables	Obs.	Mean	Std. Dev.	Min.	Max.	Corr1	Corr2	Corr3
RD_Intensity	1,792	2.6768	3.1636	0.0000	56.7435	1.0000	0.1722	0.1609
Uncertainty1	1,792	1.4520	1.4520	0.0000	9.5238	0.1722	1	0.8319
Uncertainty2	1,792	0.0710	0.0789	0.0000	0.6447	0.1609	0.8319	1
Carbon	1,792	0.4877	0.5000	0.0000	1.0000	0.2282	0.0992	0.072
Loan	1,784	0.1029	0.0956	0.0000	0.6133	0.0623	0.0838	0.0512
Subsidy	1,792	1.0169	1.2755	0.0000	8.6307	0.2602	0.0025	−0.0239
SA	1,792	3.7100	0.2501	2.2923	4.4866	−0.0025	0.1757	0.1658
Size	1,792	7.9102	1.2935	1.0986	12.3021	−0.0114	−0.0343	0.0016
Age	1,792	2.1122	0.8182	0.0000	3.3322	−0.1442	0.177	0.195
Leverage	1,792	0.4994	0.3043	−0.1947	7.0343	−0.2194	−0.0032	−0.0037
Tobin	1,792	1.9768	4.6490	0.7978	192.7051	0.0084	−0.0219	−0.0164
ROA	1,792	0.0902	2.5621	−2.5551	108.3657	−0.0223	−0.0254	−0.0227
Fixed	1,792	0.2692	0.1715	0.0000	0.8597	−0.2067	0.0282	0.0019
Growth	1,792	0.3464	1.0317	−0.6182	8.2377	−0.0356	0.1082	0.1133
Cash	1,792	0.0385	0.0669	−0.1662	0.2208	−0.103	−0.0016	−0.0193
SOE	1,792	0.3806	0.4857	0.0000	1.0000	−0.2671	−0.0153	0.0095
Share	1,792	0.4649	0.2076	0.1239	0.9644	−0.1764	−0.0509	−0.0284

Note: Corr1, Corr2, and Corr3 indicate the correlation coefficient between the related variable and *RD_Intensity*, *Uncertainty1*, and *Uncertainty2, respectively*.
Source: Author's estimations.