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Can Green Technology Innovation Reduce the Operational Risks of Energy-Intensive Enterprises?

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Abstract: Many countries have adopted carbon regulatory policies in pursuit of carbon neutrality, which pose great transition risks for energy-intensive sectors. Using the panel data of 186 Chinese listed enterprises in the energy-intensive sector from 2007 to 2019, this study investigates the impact of green technology innovation on corporate operation risks. Empirical evidence shows that energy-intensive enterprises can effectively reduce their operational risks by participating in green technology innovation activities. This study also proves the mechanism of obtaining the support of public policies and enhancing investor confidence in the capital market, while the mechanism of improving recognition in the consumer market is insignificant. Climate policy uncertainty weakens the stabilizing effect of green technology innovation on operational risks. In addition, green technology innovation has a weak stabilizing effect on the operational risks of state-owned enterprises, while government subsidy can strengthen the stabilizing effect. Finally, the stabilizing effect of green technology innovation on operational risks varies by region, period, scale and ownership. This study and its findings provide theoretical insights for corporate risk management in energy-intensive industries and theoretical analysis for the realization mechanism of the market value of corporate green behavior.

Keywords: green technology innovation; energy-intensive enterprises; operational risks; carbon neutrality; China

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1. Introduction

Global warming and climate change are of widespread concern because of the great threat they pose to the global ecosystem, with more than 120 countries worldwide committed to carbon neutrality [1]. A carbon-neutral target means stricter carbon regulation, which poses operational risks for energy-intensive industries. As the most energy-consuming industry in the national economy, the energy-intensive sector is of vital importance to both national economic development and residents' lives [2,3]. Therefore, it is necessary to adopt measures to hedge the operational risks brought by carbon regulatory policies. Green technology innovation is a kind of technological innovation aimed at achieving sustainable development, which can improve energy efficiency and reduce greenhouse gas emissions in economic activities [4,5]. It can effectively reduce the negative impact of economic activities on the environment [6], thus improving the environmental performance of enterprises and enhancing the competitive advantage of enterprises and countries [7,8]. Green technology innovation can therefore be a proactive strategy for the energy-intensive sector to comply with environmental regulations and respond to climate change policy.

Energy is one of the most important factors affecting economic security and sustainable development [9–11]. It is well known that energy consumption is an important source of greenhouse gas emissions and may be the main cause of ecological degradation and climate change [12,13]. In 2022, non-fossil energy accounts for 17.5 percent of China's total energy consumption. Energy-intensive industries consume a large amount of energy in the production process [14], and also have problems such as uncontrolled expansion of production scale and low investment efficiency [15,16], which also leads to great restrictions on its sustainable development [17]. Due to the extensive economic growth model, the challenge of greenhouse gas emissions in China is becoming increasingly prominent [18,19]. Certainly, China has also given increasing attention to reducing greenhouse gas emissions [20,21]. Energy-intensive enterprises account for about 80 percent of China's industrial carbon emissions, and they can only respond to the pressure of carbon regulatory policies through low-carbon technology innovation, seeking low-carbon alternative raw materials and building green production modes. The experience of China's energy-intensive sector in dealing with the transition risks contains lessons for all countries in the world.

Many studies have found that technological innovation has effectively contributed to the reduction of energy intensity [22,23], or that technological progress is considered to be the main contributor to the reduction of emissions in China [24,25], which provides some research support for further dissection of the role played by green technology innovation. As the threat of global climate change becomes more serious, improving the energy efficiency of economic activities and promoting green development in the energy-intensive sector is of utmost importance and urgency [26]. However, environmental regulatory policies or government strategies to address climate change affect corporate green technology innovation decisions [27,28]. For example, under the pressure of environmental regulation and the vitality of market mechanisms [29,30], enterprises would carry out green technology innovation internally. Green technology innovation is also an effective way to balance the relationship between economic growth and greenhouse gas emissions, which has a prominent role in mitigating climate change [31,32]. Some studies show that green technology innovation can improve resource utilization efficiency and reduce pollution emissions in the production process, thus improving the total factor productivity of enterprises [33,34]. Enterprise green technology innovation can also improve the environment and market efficiency, helping to achieve sustainable competitive advantage [35,36].

Few studies have analyzed the relationship between green technology innovation and corporate operational risks, while many literatures focus on the formation mechanism and management of operational risks of modern enterprises. For example, some studies have examined how factors such as internal business complexity and external financing conditions affect operational risks [37,38]. Not only do the environmental externalities of the energy-intensive sector directly hinder the global sustainable development, but also the collapse of the energy-intensive sector is not conducive to the sustainable development of the national economy. When operational risks are high, enterprises in the energy-intensive sector may collapse due to excessive risk-taking [39,40]. Based on the fact that enterprises in the energy-intensive sector have great operational risks under carbon regulation and the urgent requirements of sustainable development, this paper studies the role of green technology innovation in reducing the operational risks of energy-intensive enterprises. This study holds that green technology innovation can solve the environmental and energy sustainable challenges caused by traditional production models, and effectively help energy-intensive enterprises to hedge operational risks and achieve high-quality development.

The marginal contribution of this study is mainly summarized into three aspects. First, this study innovatively investigated the relationship between green technology innovation and operational risks of energy-intensive enterprises, which made up for the deficiency of relevant research. Most studies examine the influencing factors of green technology innovation [41,42] or examine how other factors affect the operational risks and risk management of energy-intensive enterprises [37,43], while few studies discuss the relationship between the two factors. Second, this study reveals the mechanism of green technology innovation affecting operational risks, and conducts theoretical analysis and empirical testing. Hence, this study effectively clarifies the mechanism of green technology innovation to mitigate the transition risks of energy-intensive sector. Finally, this study examines the heterogeneous stabilizing effect of green technology innovation on operational risks, which has important implications for understanding the effective boundary of its functioning and optimizing policies.

2. Background and Influence Mechanism

This study combines green technology innovation with operational risks in a framework to explore specific practices of energy-intensive enterprises using green technology innovation to hedge against the transition risks. Figure 1 shows the background and theoretical mechanism of this study. In terms of background, in order to tackle the climate crisis the government has formulated a series of carbon and energy regulatory policies, thus imposing constraints on energy-intensive industries. In terms of mechanism, energy-intensive enterprises respond to carbon and energy regulation policies and participate in green technology innovation activities to reduce operational risks. Sections 2.1 and 2.2 introduce the specific background and mechanism.

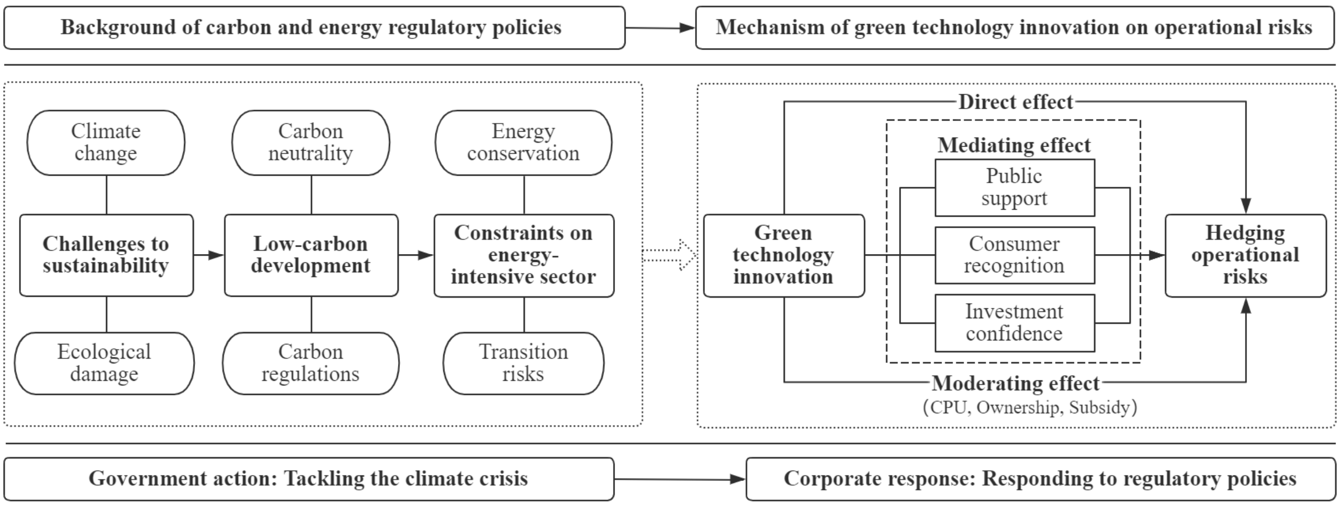

Figure 1. Background and theoretical mechanism of this study.

2.1. Background of Carbon and Energy Regulatory Policies in China

The rapid economic growth in China has been largely driven by increasing energy consumption, and China is also the country with the fastest growth in energy consumption [27]. The long-term dependence on energy for economic development has posed a challenge to China's response to global climate change. China has become the world's largest emitter of greenhouse gases [44]. Climate change would cause serious and irreversible impacts on natural systems and human societies, and countries around the world are jointly adopting carbon regulatory policies to mitigate climate change; China is no exception.

In response to the threat of climate change, China has already adopted strict carbon and energy regulatory policies, such as energy intensity targets, low-carbon cities and carbon trading schemes [45]. Low-carbon development goals and carbon regulation policies impose strong energy constraints on the production and operation of the energy-intensive sector. As the pillar industry of China's national economy, the energy-intensive sector needs a certain period of low-carbon transformation, and its development is sensitive to carbon and energy regulatory policies [46]. Therefore, energy-intensive enterprises would suffer from higher regulatory risks and low-carbon transition risks. In short, it means that energy-intensive enterprises are subject to stricter carbon constraints by governmental agencies due to the adverse impact of climate change. The negative externalities caused by climate change have also attracted the attention of government departments, and green technology innovation has become a common expectation to break the current economic and environmental development dilemma. In fact, green technology innovation has become the driving force for sustainable development in China [47].

Green technology innovation in China is being driven by a combination of government, enterprise and consumer behavior. The Chinese government has invested a lot of resources and formulated a series of public policies to encourage green technology innovation. With the severe punishment of ecological pollution behaviors, green technology innovation becomes a win-win choice for enterprises to cope with environmental regulatory pressure and obtain legitimacy, recognition and economic benefits [48,49]. People are increasingly concerned about the production behavior of enterprises, and consumers are obviously more inclined to choose green products [50]. The above analysis shows that green technology innovation is a feasible option for energy-intensive enterprises to hedge against the transition risks. Operational risk is a challenge for energy-intensive enterprises to cope with global climate change.

2.2. Influence Mechanism of Green Technology Innovation on Operational Risks

Green technology innovation is an important way to alleviate the connection between rapid economic growth and serious environmental pollution [51,52]. A large number of studies have shown that green technology innovation is beneficial to mitigate climate change and reduce environmental pollution [53]. Green technology innovation can promote the green development of the economy and society [28]. In fact, green technology innovation reduces the environmental costs of controlling the emissions of pollutants and greenhouse gases, thereby enhancing industrial and economic competitiveness [54]. Green technology innovation can also help enterprises improve energy efficiency and thus enhance their competitive advantage in the context of strict carbon regulatory policies [21].

The reality of the growing challenge of global climate change has promoted the formulation of carbon emission reduction targets in various countries, which has brought huge transformation risks and operational risks to enterprises in the energy-intensive sector [11,55]. Some studies point to the difficulty and necessity of a low-carbon transition for energy-intensive industries, and green technology innovation is the inevitable way. While implementing stricter environmental policies, enterprises can reduce regulatory risks and environmental costs by participating in green technology innovation activities [56]. Since green technology innovation can directly reduce energy consumption and reduce the emission of greenhouse gases [57,58], the energy-intensive sector may alleviate the transition risks through green technology innovation. In fact, the motivation for enterprises to engage in green technology innovation is to respond to regulatory pressure. As long as the mechanism for realizing the market value of green technology innovation is smooth, green technology innovation can reduce the operation risks of energy-intensive enterprises. Based on the above considerations, this paper proposes the following hypotheses.

Hypothesis 1. *Ceteris paribus, green technology innovation can significantly reduce the operational risks for energy-intensive enterprises.*

Enterprises carry out green innovation activities in response to government regulatory policies, while green technology innovation can help enterprises gain public support, improve consumer recognition and boost investor confidence, and the realization of these values is conducive to reducing the operational risks of enterprises. In addition to these intermediary mechanisms, green technology innovation directly brings energy saving effects to enterprises and the direct effect of reducing regulatory costs, thus reducing operational risks. In addition, climate policy uncertainty, corporate ownership characteristics, and public subsidies also have moderating effects on the reduction effect of green technology innovation on operational risks.

Under the pressure of carbon and energy regulations, the operational risk of an enterprise is more often expressed as a financial capital risk or bankruptcy risk, so the operational risk mitigation of an enterprise should be considered from the perspective of its capital risk. For the financial support of the enterprise, there are three main aspects, namely, the business income obtained from the business operation in the product market, the capital support from investors in the capital market, and the tax relief or subsidy given by the government. Energy-intensive enterprises participating in green technology innovation activities can obtain government support, enhance the competitiveness of enterprises in the product market and improve the performance of the capital market. The government has formulated a series of policies to encourage enterprises to carry out green innovation activities. Enterprises that respond to the government's environmental and carbon regulations can obtain more government support [59]. For example, some studies show that green technological innovation reduces the tax burden of enterprises [38]. Some studies also argue that consumer demand for green products is an important external driver that encourages enterprises to engage in green technology innovation [60]. Therefore, this study holds that consumer recognition in the product market may be the mechanism of green technology innovation to reduce operational risks. In addition, the capital market would respond to enterprises' participation in green technology innovation, thus reducing the operational risks of enterprises. Due to the improvement of future potential earnings, environmental investment behavior would enhance the enterprise value [61,62]. Green behavior has also been shown to be related to corporate financing costs [63]. Hence, the following hypotheses of mediating effects are proposed.

Hypothesis 2a. *Green technology innovation helps energy-intensive enterprises obtain public support to reduce operational risks.*

Hypothesis 2b. *Green technology innovation can improve consumer recognition in the product market and reduce the operational risks of energy-intensive enterprises.*

Hypothesis 2c. *Green technology innovation can enhance investor confidence in the capital market and thus reduce the operational risks of energy-intensive enterprises.*

3. Methodology and Data

3.1. Data Sources

This study selects enterprises in the energy-intensive sector listed in the Shanghai and Shenzhen A-share markets of China as research samples. The sample period is from 2007 to 2019. According to the definition of the National Bureau of Statistics of China, this study defines the top six industrial industries in energy consumption as the energy-intensive sector [64]. In this study, the samples are treated as follows and 1955 observations are obtained for 186 energy-intensive enterprises. First, enterprises that have never carried out green technology innovation in the whole period from 2007 to 2019 are excluded from the samples, which is based on better analysis of the effect of whether innovation can mitigate operational risks. Second, to ensure the reliability of the results in the study, this paper has also conducted regressions without excluding these enterprises, and the results are still significant at the 1% level of significance. Third, this study excludes the samples with missing values in the independent variables. The data on green technology innovation are obtained from the State Intellectual Property Office (SIPO) of the People's Republic of China. The index of climate policy uncertainty is obtained from the website: http://www.policyuncertainty.com/climate_uncertainty.html, (accessed on 10 August 2022). Most of the financial data are downloaded from the China Stock Market and Accounting Research (CSMAR) database.

3.2. Model Specification

The main purpose of this study is to investigate the impact of green technology innovation on the operational risks of energy-intensive enterprises, so as to analyze how to mitigate the transition risks and challenges of the energy-intensive sector under strict carbon regulations. This paper adopts a two-way fixed-effects model for the study, thus solving the problem of omitted variables from the model design. Accordingly, the following econometric model is constructed:

$$ORisk_{it} = \beta_1 GUMP_{it} + \beta_2 Size_{it} + \beta_3 Age_{it} + \beta_4 SC_{it} + \beta_5 TAO_{it} + \beta_6 SR_{it} + \beta_7 TobinQ_{it} + \beta_8 TBR_{it} + \lambda_i + \gamma_t + u_{it}, \quad (1)$$

where $ORisk_{it}$ refers to operational risks of enterprise i in the year t. The independent variable of $GUMP_{it}$ refers to corporate green technology innovation, which is measured by the number of enterprise green utility model patent applications. $Size_{it}$ refers to firm size, which is measured by the logarithm of total business assets. Age_{it} represents enterprise age, measured by subtracting the marketing year from the corresponding year. SC_{it} refers to nature of equity, which is measured by the dummy variable of the nature of corporate equity (Equal one for State-Controlling company and zero otherwise). TAO_{it} refers to enterprise external evaluation, which is measured by the type of audit opinion. SR_{it} represents firm equity concentration, measured by the shareholding ratio of the company's largest shareholder. $TobinQ_{it}$ refers to firm market value, measured by the Tobin's Q value of the enterprise. TBR_{it} refers to asset-liability ratio. μ_{it} is a random disturbance term. Considering the trend of macro-economic conditions and the potential, unobserved individual heterogeneity that may affect the investment and financing behavior of enterprises, this study also incorporates the enterprise fixed effects (λ_i) and the year fixed effects (γ_t) in the empirical analysis.

According to Hypotheses 2a to 2c, green technology innovation may reduce operational risks of energy-intensive enterprises through three mechanisms. To further verify whether potential mediating variables play a significant mediating effect on the relationship between green technology innovation and operational risks, this paper constructs the following mediating effect model based on the mediating effect model.

$$ORisk_{it} = \beta_0 + \beta_1 GUMP_{it} + \mathbf{X_{it}}\boldsymbol{\gamma} + \lambda_i + \gamma_t + u_{it}, \quad (2)$$

$$MV_{it} = \alpha_0 + \alpha_1 GUMP_{it} + \mathbf{X_{it}}\boldsymbol{\gamma} + \lambda_i + \gamma_t + u_{it} \quad (3)$$

$$ORisk_{it} = \gamma_0 + \gamma_1 GUMP_{it} + \gamma_2 MV_{it} + \mathbf{X_{it}}\boldsymbol{\gamma} + \lambda_i + \gamma_t + u_{it} \quad (4)$$

where MV_{it} is the potential mediating variable, $\mathbf{X_{it}}$ is a vector of the relevant control variable, and $GUMP_{it}$ and $ORisk_{it}$ are the core explanatory variable and dependent variable in this study, respectively. γ_1 reflects the direct effect of green technology innovation on the operational risks of energy-intensive enterprises, and γ_2 reflects the indirect effect of potential mediating variables on the operational risks of energy-intensive enterprises. The magnitude of the mediating effect is jointly measured by β_1 and γ_2 when α_1 and γ_2 is significant, so the mechanism test in Section 5.1 would analyze the mediating effect by focusing on β_1, γ_1 and γ_2.

3.3. Variable Definition and Description

The dependent variable in this study is the operational risks (ORisk). Referring to the relevant literature [65,66], this study uses the Z-Score method to assign weights to a series of financial indicators and calculate the operating risks of energy-intensive enterprises. The Z-score method is an index combining five different financial ratios with different weights and is used to measure and predict the bankruptcy risk of enterprises in many nations. As mentioned above, the operational risk of a company is also more of a financial capital risk or bankruptcy risk, which can be well measured by the Z-Score method. High operational risk indicates that energy-intensive enterprises suffer from great transition risks. The formula for calculating operational risks is as follows.

$$Z\text{-}Score = 1.2 \times \frac{\text{Working Capital}}{\text{Total Assets}} + 1.4 \times \frac{\text{Retained Earnings}}{\text{Total Assets}} + 3.3 \times \frac{\text{Earnings before Interest and Taxes}}{\text{Total Assets}} + 0.6 \times \frac{\text{Market Value Equity}}{\text{Book Value of Total Debt}} + 0.999 \times \frac{\text{Sales}}{\text{Total Assets}}, \quad (5)$$

The independent variable is the green technology innovation (GUMP). This study adopts the number of green patent applications to measure green technology innovation [19,67]. Compared with other methods for measuring green technology innovation, this method is more intuitive and clearer in quantification [42], and more in line with the variables required by this study.

Regarding the control variables, this study considers firm size (Size), firm age (Age), ownership (SC), auditing situation (TAO), equity concentration (SR), market value (TobinQ) and asset-liability ratio (TBR) as the control variables in the benchmark regression model based on relevant studies. The scale represents the resources owned by an enterprise, while the years of existence represent the accumulated experience of an enterprise, which are conducive to better coping with operational risks. Corporate governance is a key factor affecting enterprise operation risk, so the variables of TAO and SR are selected as control variables. TobinQ reflects the capital market's enthusiasm for investing in enterprises, which may be closely related to the operational risks. The asset-liability ratio is directly related to debt pressure and affects the operational risks of enterprises. To further effectively identify the influencing mechanisms of green technology innovation on the operational risks of energy-intensive enterprises, this paper examines three indicators. The first indicator is the composite tax rate (CTR), which is measured by the ratio of business tax and additional and income tax expense to total operating income. The second indicator is the natural logarithm of the operating income, which is a measure of consumer support in the product market. The third indicator is the price-to-earnings ratio (PER), which is a measure of investor confidence in capital markets. The definitions of the variables involved in this paper are shown in Table 1, and Table 2 shows the descriptive statistics of the relevant variables. None of the variables has significant outliers, and the data of each variable have certain volatility, which reflects the good nature of the sample data.

Table 1. Variable definition.

Type	Variable	Calculation Methods
Dependent variables	ORisk	Operational risk, calculated according to Equation (5)
Independent variables	GUMP	Number of green utility model patent applications
Control variables	Size	Natural logarithm of the total assets of the enterprise
	Age	Natural logarithm of the number of IPO years
	SC	Dummy variable of state-controlled enterprise
	TAO	Type of Audit Opinion
	SR	Shareholding ratio of the largest shareholder
	TobinQ	Ratio of market value to total assets
	TBR	Total debt ratio, ratio of total debt to total assets
Mediating variables	CTR	Composite tax rate, denoted the support of national policies
	CTRCA	Composite tax rate, divided into five grades
	Income	Natural logarithm of the operating income
	PER	P/E ratio, a measure of investor confidence in capital markets
Moderating variables	CPU	Climate Policy Uncertainty, provided by Gavriilidis (2021) [68]
	SO	Equal one for state-owned enterprise and zero otherwise
	Subsidy	Dummy variable indicating whether a firm receives government subsidies

Table 2. Descriptive statistics.

Variable	Observation	Mean	Std. Dev.	Min	Max
ORisk	1955	5.208	6.071	0.446	40.105
GUMP	1955	1.092	5.883	0.000	195.000
Size	1955	22.634	1.421	19.373	26.748
Age	1955	9.944	6.400	0.000	27.000
SC	1955	0.225	0.418	0.000	1.000
TAO	1955	9.880	0.697	1.000	10.000
SR	1955	36.832	15.963	0.286	85.232
TobinQ	1955	1.678	0.955	0.699	13.698
TBR	1955	0.501	0.218	0.014	2.290
CTR	1955	0.023	0.029	−0.231	0.485
CTRCA	1955	3.000	1.415	1.000	5.000
Income	1955	22.174	1.554	17.701	26.443
PER	1955	94.951	320.174	2.911	922.039
CPU	1955	4.687	0.370	4.083	5.298
SO	1955	0.515	0.500	0.000	1.000
Subsidy	1955	0.971	0.167	0.000	1.000

4. Empirical Results and Analysis

4.1. Benchmark Regression Results and Analysis

The main concern of this study is whether green technology innovation can help energy-intensive sector hedge against the transition risks. Table 3 reports the benchmark results of the impact of green technology innovation on operational risks. In order to avoid a situation where control variables would exclude the indirect effects of green technology innovation, Column (1) does not include control variables, while it controls the firm and year fixed effects. Columns (2) to (4) include the control variables of enterprise characteristics, and the difference lies in the control of fixed effects.

Table 3. Empirical results of benchmark regression.

Variables	Dependent Variable: ORisk			
	(1)	(2)	(3)	(4)
GUMP	−0.061 *** (0.017)	−0.101 *** (0.021)	−0.068 *** (0.016)	−0.098 *** (0.020)
Size		−1.482 * (0.889)	−0.577 ** (0.242)	−1.851 ** (0.847)
Age		−0.020 (0.184)	0.006 (0.088)	0.117 (0.182)
SC		−0.338 (0.701)	0.371 (0.493)	0.146 (0.632)
TAO		−0.213 (0.327)	−0.077 (0.244)	−0.095 (0.291)
SR		0.075 ** (0.036)	0.038 *** (0.014)	0.068 * (0.035)
TobinQ		1.687 *** (0.551)	1.586 *** (0.477)	1.244 * (0.683)
TBR		−25.060 *** (4.628)	−22.431 *** (3.452)	−24.258 *** (4.374)
TFE	Yes	No	Yes	Yes
EFE	Yes	Yes	No	Yes
R-squared	0.052	0.148	0.162	0.165
Observations	1955	1955	1955	1955

Notes: Numbers reported in parentheses are standard errors. Asterisks * (10%), ** (5%), and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

It is found that green technology innovation can significantly reduce the operational risks of energy-intensive enterprises. The coefficients of green technology innovation

(GUMP) are all significantly negative at the 1% level in Table 3, and the results verify Hypothesis 1. The coefficient of GUMP is −0.098 in Column (4), implying that that a standard deviation increase in green technology innovation would lead to a 0.5765 reduction in enterprise operational risks. This value is 10.31 percent of the average operational risks of energy-intensive enterprises, which has economic significance. Although increasingly stringent climate change policies and environmental regulations make the energy-intensive sector face greater transition risks, enterprises can respond to transition risks by strengthening green technology innovation. The benchmark regressions of Table 3 show that green technology innovation can stabilize operational risks of energy-intensive enterprises. Green technology innovation may bring about improvement in financial performance, but there is literature showing that the improvement of corporate financial status can reduce operational risks [43].

Other control variables also show some of the formation mechanisms of corporate operational risks. The coefficient of enterprise scale is significantly negative at the 10% level, indicating that there is a significant scale effect in resisting operational risks, and the ability of small and medium-sized enterprises to resist risks is worse than that of large enterprises. Enterprises with concentrated equity have worse stability risks and less ability to respond to climate policy changes, which significantly increases the operational risks of enterprises. The relationship between financial market performance and operational risks appears to be inconsistent with logical expectations. Enterprises with high enterprise value have higher operational risks, while those with high asset-liability ratios have lower operational risks. These results may come from the market strategy and financing strategy of energy-intensive enterprises. Companies with higher market value are more willing to adopt aggressive strategies, which increases operational risks [68]. Correspondingly, enterprises with low operational risks can obtain debt financing at lower costs, and companies tend to maintain higher leverage ratios.

4.2. Robustness Regression Results in Terms of Dependent Variables

The indicator of operational risks refers to the Z-Score in Section 4.1, while there is no unanimous opinion on the measurement of operational risks. In order to avoid the bias caused by the measurement methods, this study replaces the dependent variable with the current liability ratio (CLR). Besides, in order to avoid the bias caused by the extreme values, this study Winsorizes the continuous variables at the 1% and 99% quantiles level. The empirical results are shown in Table 4. Columns (1) to (3) are the regression results of replacing the measurement method of the dependent variable, and the other columns are the results for these the continuous variables are Winsorized.

The impact of green technology innovation on operational risks is significantly negative regardless of changing the core explanatory variable or Winsorizing the variables. In Columns (1) to (3), green technology innovation significantly reduces the cash debt ratio of energy-intensive enterprises at the 1% level, that is, green technology innovation reduces the cash flow risk of enterprises. Existing studies have also shown that environmental regulation pressure leads to the change of corporate financing term and intensifies corporate debt risk [32]. After censoring the extreme values of the sample, the coefficient of green technological innovation is still significant at the 1% level, indicating that the extreme values would not interfere with the research conclusions. Not surprisingly, the relationship between green technology innovation and operational risks is robust. Since extreme values represent serious operational risks, the indicators of enterprise operational risks may not be suitable for Winsorizing treatment, otherwise important information about risks would be lost. Hence, the variable of operational risks is not truncated for extreme values.

Table 4. Robustness analysis results for changing dependent variable measures.

Variables	Dependent Variable: CLR			Dependent Variable: OLR		
	(1)	(2)	(3)	(4)	(5)	(6)
GUMP	−0.105 ***	−0.102 ***	−0.104 ***	−0.180 ***	−0.156 ***	−0.162 ***
	(0.030)	(0.035)	(0.028)	(0.019)	(0.022)	(0.020)
Size	−8.797 ***	−6.593 ***	−8.828 ***	−6.148 ***	−4.112 ***	−5.945 ***
	(1.325)	(0.848)	(1.346)	(1.799)	(1.158)	(1.818)
Age	1.195 ***	0.376 **	0.986 ***	0.845 ***	0.473 **	0.975 ***
	(0.187)	(0.151)	(0.205)	(0.238)	(0.222)	(0.262)
SC	−0.189	−1.349	−0.425	−0.538	−0.867	−0.704
	(1.113)	(1.207)	(1.187)	(1.289)	(1.224)	(1.256)
TAO	−0.486	−0.491	−0.451	−1.293 ***	−1.378 ***	−1.208 ***
	(0.500)	(0.465)	(0.521)	(0.430)	(0.421)	(0.414)
SR	0.022	0.125 **	0.034	−0.069	0.037	−0.066
	(0.075)	(0.058)	(0.075)	(0.094)	(0.076)	(0.095)
TobinQ	0.219	0.372	0.180	0.868	1.338 *	0.971
	(0.427)	(0.462)	(0.492)	(0.611)	(0.743)	(0.726)
TBR	−11.904 ***	−11.291 ***	−11.101 ***	−51.759 ***	−51.607 ***	−51.080 ***
	(3.548)	(3.259)	(3.607)	(6.006)	(5.449)	(5.943)
TFE	No	Yes	Yes	No	Yes	Yes
EFE	Yes	No	Yes	Yes	No	Yes
Observations	1955	1955	1955	1955	1955	1955
R-squared	0.112	0.115	0.120	0.229	0.235	0.239
Firms	186	186	186	186	186	186

Notes: Numbers reported in Notes: Numbers reported in parentheses are standard errors. Asterisks * (10%), ** (5%), and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

4.3. Robustness Regression Results in Terms of Model and Sample

This study further examines the robustness of the relationship between green technology innovation and operational risk by changing control variables. The operating risk of an enterprise is closely related to debt and debt paying ability. Therefore, this study gradually increases the ratio of long-term debt to equity (LDR), total current debt (TCD) and total non-current debt (TNCD) as three control variables. These control variables can reflect the debt status of energy-intensive enterprises. By observing whether the core explanatory variables would occur after controlling the debt situation, it can be judged whether it is the difference in the operational risks caused by financing problems. Table 5 shows the results after controlling for debt characteristics.

The results in Table 5 show that the effect of green technology innovation on the operational risks of energy-intensive enterprises remains consistent with the results of the benchmark regression. The coefficients of GUMP are all significantly negative at the 1% level, and the values of the coefficients do not vary significantly, indicating that the findings in this study are robust after adding the control variables. In addition, long-term debt poses insignificant operational risks to the energy-intensive enterprises. In fact, only low-risk enterprises are backed by long-term debt. Both short-term cash debt and non-cash debt significantly increase the operational risk of an enterprise, and short-term liabilities greatly increase the operational pressure and risk of an enterprise. The results in Table 5 mean that after excluding the interference of financing factors, the stabilizing effect of green technology innovation on the operational risks of energy-intensive enterprises is still statistically and economically significant.

The carbon regulatory policy in China has been tightening, and a series of green finance policies have also been formulated [17]. For example, the China Securities Regulatory Commission has gradually tightened restrictions on the A-share market for heavily polluting enterprises, and listing requirements have increased for companies in energy-intensive industries. Therefore, enterprises listed in A-share market later may have lower operational risks, and the bias of sample selection caused by enterprise entry may interfere with the findings of this study. Based on the above considerations, this study conducts regression analysis by excluding enterprises listed after 2015 and after 2010. Table 6 shows the robustness analysis results.

Table 5. Robustness analysis results for adding control variables.

Variables	Dependent Variable: ORisk					
	Controlling Long-Term Debt			Controlling Long-Term and Short-Term Debt		
	(1)	(2)	(3)	(4)	(5)	(6)
GUMP	−0.100 *** (0.021)	−0.067 *** (0.016)	−0.098 *** (0.020)	−0.089 *** (0.016)	−0.075 *** (0.018)	−0.087 *** (0.015)
LDR	0.259 (0.187)	0.358 (0.220)	0.228 (0.165)	−0.196 (0.179)	−0.319 (0.255)	−0.197 (0.178)
TCD				−16.877 *** (4.999)	−14.687 *** (4.125)	−16.820 *** (4.995)
TNCD				−0.838 ** (0.371)	−0.819 ** (0.348)	−0.826 ** (0.364)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
TFE	No	Yes	Yes	No	Yes	Yes
EFE	Yes	No	Yes	Yes	No	Yes
Observations	1955	1955	1955	1955	1955	1955
R-squared	0.149	0.162	0.166	0.386	0.392	0.394
Firms	186	186	186	186	186	186

Notes: Numbers reported in parentheses are standard errors. Asterisks ** (5%) and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

Table 6. Robustness analysis results of enterprise entry.

Variables	Dependent Variable: ORisk					
	Excluding Enterprises Listed after 2015			Excluding Enterprises Listed after 2010		
	(1)	(2)	(3)	(4)	(5)	(6)
GUMP	−0.098 *** (0.020)	−0.057 *** (0.015)	−0.093 *** (0.021)	−0.101 *** (0.022)	−0.057 *** (0.017)	−0.098 *** (0.022)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
TFE	No	Yes	Yes	No	Yes	Yes
EFE	Yes	No	Yes	Yes	No	Yes
Observations	1857	1857	1857	1393	1393	1393
R-squared	0.138	0.153	0.158	0.254	0.248	0.261
Firms	160	160	160	110	110	110

Notes: Numbers reported in parentheses are standard errors. Asterisks *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

The change in the listing threshold for energy-intensive enterprises does not lead to serious sample selection bias. After excluding new entrants, the impact of green technology innovation on operational risks is still significantly negative. The coefficients of GUMP in Table 6 are significantly negative at the 1% level, implying a negative correlation between green technology innovation and operational risks. In addition, the coefficient is also close to the results in Table 3, indicating that the enterprise entry does not interfere with the estimation of the stabilizing effect of green technology innovation on operational risks. Therefore, this study reaffirms the validity of Hypothesis 1 that there is a causal effect between green technology innovation and operational risks.

5. Further Analysis: Mediating Effect, Moderating Effect and Heterogeneity

5.1. Empirical Results and Analysis of Mediating Effects

In order to reveal the internal mechanism of green technology innovation reducing the operational risk of energy-intensive enterprises, this study uses the mediation effect model to conduct regression analysis. Specifically, this paper considers three mediating variables, namely, gaining support from national policies (CTR/CTRCA), improving consumer recognition in the product market (Income) and enhancing investor confidence in the capital market (PER). The estimated results of the mediation effect model are shown in Table 7.

Table 7. Mechanism analysis: Intermediary effect analysis.

Variables	National Policy Support				Consumer Recognition		Investor Confidence	
	(1) CTR	**(2) ORisks**	**(3) CTRCA**	**(4) ORisks**	**(5) Income**	**(6) ORisks**	**(7) PER**	**(8) ORisks**
GUMP	−0.0002 ***	−0.0482 ***	−0.0039 **	−0.0497 ***	−0.0004	−0.0514 ***	2.6039 ***	−0.0490 ***
	(0.000)	(0.014)	(0.002)	(0.014)	(0.001)	(0.015)	(0.351)	(0.014)
CTR		14.2233						
		(8.648)						
CTRCA				0.3089 **				
				(0.155)				
Income						−1.0151		
						(0.802)		
PER								−0.0007 *
								(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1955	1955	1955	1955	1955	1955	1955	1955
R-squared	0.054	0.357	0.107	0.356	0.755	0.356	0.029	0.355
Enterprises	186	186	186	186	186	186	186	186

Notes: Numbers reported in parentheses are standard errors. Asterisks * (10%), ** (5%), and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

It can be seen that the mechanism for green technology innovation to reduce the operating cost of energy-intensive enterprises by obtaining the support of public policies is significantly established. This study uses the composite tax rate to measure the support from national policies. The higher the comprehensive tax rate of energy-intensive enterprises, the stronger the carbon constraints of the corporate government and the lower the level of national policy support [69]. Since corporate green technology innovation is consistent with the government's carbon regulation goals, green innovation enterprises would receive more public policy support, that is, they can enjoy lower tax rates, thereby reducing external regulatory pressure and operational risks. As shown in Columns (1) and (2), green technology innovation significantly reduces the comprehensive tax rate at the 1% level. The composite tax rate (CTR) is an inverse proxy variable supported by the government, and its coefficient in Column (2) is insignificant and positive. Hence, this study divides the composite tax rate into five ranges from low to high, assigning a value from one to five, and re-examines the mechanism of obtaining government support. As shown in Columns (3) and (4), participating in green technology innovation puts the enterprises in a lower tax bracket, and a lower tax bracket corresponds to a lower operational risk. Therefore, this study confirms that green technology innovation helps enterprises to obtain policy support, and Hypothesis 2a is established.

However, empirical evidence does not support mechanisms for increasing recognition in consumer markets. This study uses the logarithm of operating income (Income) to measure recognition in consumer markets. Consumer demand for green products may be higher, and green technology innovation can help energy-intensive enterprises increase product sales and prices, which means enterprises could obtain a higher operating income. Columns (5) and (6) in Table 7 show that the mechanism of improving recognition in the consumer market fails to pass the mediating effect test. Green technology innovation may not reduce the operational risk of energy-intensive companies by increasing product recognition in the consumer market. The realization of the market value of green products is a challenge for energy-intensive enterprises, and certain institutional arrangements should be adopted to enhance the value realization of green products in the consumer market [41,61]. The empirical evidence here does not prove Hypothesis 2b, which means that there may be more room to improve the stabilizing effect of green technology innovation on operational risks for energy-intensive enterprises.

The effect of green technology innovation on operational risks through the mechanism of improving investor confidence in the investment market is significant and valid. This study employs the price-to-earnings ratio (PER) to measure investor confidence in the investment market. A high price-earnings ratio indicates that investors have a strong willingness to invest, which in turn promotes energy-intensive enterprises to obtain financing support in the capital market, thereby effectively reducing the operational risks of energy-intensive enterprises. Energy-intensive enterprises actively engaged in green technology innovation have higher interest and confidence from investors in the capital market, and investor information can help enterprises stabilize operational risks. Columns (7) to (8) in Table 7 show that the mechanism of enhancing investors' confidence in the capital market exists, and Hypothesis 2b is established. The capital market can help green products or green technologies realize value more than the consumer market. It can be said that the capital market in China pays more attention to the green transformation of energy-intensive enterprises, while the green awareness of consumers is still not enough. In summary, energy-intensive enterprises can rely on green technology innovation to develop competitive advantage in the capital market and mitigate their operational risks.

In fact, the regression results of the above three mediating mechanisms are in line with the theoretical expectations of economics. For the government, energy-intensive enterprises can receive strong support from the government because of the social and ecological benefits of green technology innovation. For capital market investors, investors are concerned about the future development value and potential of enterprises. Since energy-intensive enterprises are facing increasingly stringent environmental regulations, enterprises that actively engage in green technology innovation have better development prospects in the long run and are therefore more favored by investors. However, consumers mainly consider the maximization of their own utility brought by consumption behavior, and there is no difference between green technology innovation products and ordinary products for consumers in the short term [61], while innovation behavior may bring higher product cost, so consumers may not be sensitive to enterprise green technology innovation behavior.

5.2. Empirical Results and Analysis of Moderating Effects

In order to study whether the impact of green technology innovation on the operating risks of energy-intensive enterprises is regulated by interference factors, this paper introduces the interaction terms between green technology innovation and some related variables in the regression. Referring to existing studies [70,71], this study investigates moderating effects of the climate policy uncertainty, corporate ownership, and government subsidies. Table 8 presents the empirical results of the moderating effect.

Table 8. Empirical results of the moderating effects.

Variables	Dependent Variable: ORisk					
	Climate Policy Uncertainty		Enterprise Ownership		Government Subsidy	
	(1)	(2)	(3)	(4)	(5)	(6)
GUMP	−0.8074 *** (0.298)	−0.7920 ** (0.320)	−0.1181 *** (0.008)	−0.1137 *** (0.009)	0.0331 (0.054)	0.0790 (0.055)
CPU	0.4166 (0.446)	0.9333 ** (0.433)				
GUMP × CPU	0.1582 ** (0.067)	0.1549 ** (0.072)				
SO			0.1917 (0.943)	0.1420 (0.903)		
GUMP × SO			0.1247 *** (0.034)	0.1159 *** (0.038)		
Subsidy					0.7466 (0.493)	0.0821 (0.422)
GUMP × Subsidy					−0.1346 ** (0.064)	−0.1780 *** (0.064)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
TFE	No	Yes	No	Yes	No	Yes
EFE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1955	1955	1955	1955	1955	1955
R-squared	0.149	0.166	0.148	0.166	0.148	0.166
Enterprises	186	186	186	186	186	186

Notes: Numbers reported in parentheses are standard errors. Asterisks ** (5%) and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

It can be found that climate policy uncertainty is not conducive to green technology innovation to reduce operational risks. Climate policy is an important basis for energy-intensive enterprise operation and innovation decision-making, and it would definitely affect the stabilizing effect of green technology innovation on operational risks. Hence, this study includes both global climate policy uncertainty and its interaction term with green technology innovation in the regression. The empirical results of the moderating effect of climate policy uncertainty are shown in Columns (1) to (2) of Table 8. The coefficients of green technology innovation are significantly negative at the 5% level, while the coefficients of the interaction terms are significantly positive at the 5% level. These results suggest that climate policy uncertainty reduces the role of green technology innovation in reducing operational risks. Climate risk or climate policy uncertainty has been shown to reduce the liquidity of corporate assets [26]. In fact, the international political climate policy is always in dispute and negotiation, which increases the risk of transition to low-carbon development for energy-intensive industries.

The state-owned feature of ownership reduces the stabilizing effect of green technology innovation on operational risks, while government subsidies strengthen the stabilizing effect. Due to the unique institutional characteristics of China's state-owned enterprises, state-owned enterprises are always stronger in resisting the impact of uncertainty. Carbon regulation policies bring less transformation pressure and operational risks to state-owned enterprises, so the demand and contribution of green technology innovation of state-owned enterprises to resist transition risks is low. Columns (3) to (4) in Table 8 show that the interaction term between green technology innovation and enterprise ownership (SO) is significantly positive at the 1% level, which indicates that the state-owned feature of ownership reduces the stabilizing effect of green technology innovation on operational risks for energy-intensive enterprises. On the contrary, government subsidies can help enterprises in low-carbon transformation, so as to strengthen the role of green technology innovation in resisting operational risks. Columns (5) to (6) in Table 8 show that the interaction between green technology innovation and government subsidies (Subsidy) is significantly negative, indicating that government subsidies enhance the stabilizing effect of green technology innovation to reduce the operational risks. The moderating effect of government subsidies is also consistent with Hypothesis 2a that the mechanism of government support plays a positive role in the relationship between green technology innovation and operational risks.

5.3. Empirical Results and Analysis of Heterogeneity

In order to explore the heterogeneity effect of green technology innovation on enterprise operational risks, this study conducts sub-sample regression analysis from the perspectives of region, period, scale and ownership. First, according to geographical location, this study divides enterprises into three categories: enterprises in the eastern region, enterprises in the central region and enterprises in the western region. Second, based on the reform of ecological civilization construction in China, this study divides the sample period into two stages before 2013 and after 2013. Third, according to the enterprise scale, this study classifies enterprises into large enterprises, medium-sized enterprises and small enterprises. Finally, according to the ownership of enterprises, this study divides enterprises into two sub-samples: state-owned enterprises and non-state-owned enterprises. The results of regional and period heterogeneity are shown in Table 9, and the results of ownership and scale heterogeneity are shown in Table 10.

Table 9. Empirical results of the regional and period heterogeneity.

Variables	Regional Heterogeneity			Period Heterogeneity			
	(1) Eastern	**(2) Central**	**(3) Western**	**(4) Pre 2013**	**(5) Pre 2013**	**(6) Post 2013**	**(7) Post 2013**
GUMP	−0.116 ***	−0.048	0.218	−0.032	0.069	−0.160 ***	−0.229 ***
	(0.019)	(0.058)	(0.329)	(0.097)	(0.129)	(0.023)	(0.026)
Size	−1.633	−3.160 ***	−0.445	−0.120	−1.024	−0.283	−1.330
	(1.289)	(1.168)	(1.313)	(0.432)	(0.986)	(0.254)	(1.164)
Age	0.187	0.397 *	−0.536	−0.143 *	−0.278	0.013	0.072
	(0.300)	(0.211)	(0.563)	(0.085)	(0.262)	(0.112)	(0.212)
SC	0.460	0.715	−1.490	0.503	0.274	0.127	0.033
	(0.709)	(0.536)	(2.989)	(0.762)	(0.788)	(0.237)	(0.293)
TAO	0.413	−0.141	−0.431	−0.273	−0.097	0.067	−0.118
	(0.316)	(0.290)	(0.842)	(0.276)	(0.244)	(0.172)	(0.194)
SR	0.082	0.072 *	0.018	0.003	−0.000	0.034	0.073 *
	(0.061)	(0.042)	(0.066)	(0.033)	(0.041)	(0.022)	(0.041)
TobinQ	1.743 ***	4.456 **	−2.351	2.271 ***	1.895 **	2.255 ***	2.562 ***
	(0.458)	(1.897)	(3.070)	(0.767)	(0.790)	(0.477)	(0.532)
TBR	30.943 ***	16.388 ***	20.252 **	27.403 ***	22.561 ***	17.578 ***	18.729 ***
	(5.933)	(3.709)	(9.941)	(6.212)	(5.182)	(2.982)	(3.520)
TFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EFE	Yes	Yes	Yes	No	Yes	No	Yes
Observations	1078	467	410	764	764	1191	1191
R-squared	0.297	0.501	0.115	0.115	0.116	0.272	0.280
Enterprises	106	42	38	159	159	186	186

Notes: Numbers reported in parentheses are standard errors. Asterisks * (10%), ** (5%), and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

Table 10. Empirical results of the scale and ownership heterogeneity.

Variables	Scale Heterogeneity			Ownership Heterogeneity			
	(1) Large	(2) Medium	(3) Small	(4) Non-SOE	(5) Non-SOE	(6) SOE	(7) SOE
GUMP	−0.005	−0.137 ***	−1.259	−0.062 ***	−0.123 ***	−0.011	0.004
	(0.010)	(0.018)	(0.836)	(0.017)	(0.013)	(0.025)	(0.027)
Size	0.104	−5.385 *	−6.076 **	−1.164 *	−2.156	−0.160	−0.529
	(0.163)	(2.938)	(2.514)	(0.597)	(1.543)	(0.167)	(0.700)
Age	−0.064 **	0.677	−0.285	0.089	0.253	−0.028	−0.048
	(0.025)	(0.541)	(0.273)	(0.170)	(0.362)	(0.030)	(0.099)
SC	−0.011	1.176	0.994	−1.377	−3.132 *	0.516	0.637
	(0.089)	(1.023)	(2.499)	(1.662)	(1.853)	(0.397)	(0.537)
TAO	0.086 *	0.485	−0.471	−0.999 **	−0.725	0.162	0.071
	(0.046)	(0.413)	(0.821)	(0.501)	(0.454)	(0.123)	(0.125)
SR	0.015 *	0.162	0.056	0.041	0.171 *	0.006	0.003
	(0.009)	(0.137)	(0.202)	(0.026)	(0.095)	(0.010)	(0.017)
TobinQ	1.744 ***	2.621 ***	0.929	2.097 ***	1.598	1.271 ***	1.226 ***
	(0.148)	(0.722)	(0.831)	(0.576)	(0.968)	(0.412)	(0.465)
TBR	−8.646 ***	−21.600 ***	−49.282 ***	32.232 ***	40.868 ***	11.039 ***	10.275 ***
	(0.792)	(7.213)	(15.416)	(5.607)	(7.743)	(2.167)	(2.018)
TFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EFE	Yes	Yes	Yes	No	Yes	No	Yes
Observations	788	687	480	949	949	1006	1006
R-squared	0.748	0.315	0.213	0.209	0.219	0.257	0.259
Enterprises	99	123	91	108	108	91	91

Notes: Numbers reported in parentheses are standard errors. Asterisks * (10%), ** (5%), and *** (1%) indicate that the coefficients are significant. TFE and EFE denote the time fixed effects and enterprise fixed effects.

There is regional heterogeneity in the stabilizing effect of green technology innovation on business risks, and only the eastern region shows a significant effect. The regression results show that green technology innovation is significant and negative at the 1% level in Column (1) of Table 9, while the coefficients in Columns (2) to (3) are insignificant. Green technology innovation has a significant effect on reducing the operating risks of energy-intensive enterprises in the eastern region, while in the central and western regions there is insufficient evidence to show that green technology innovation has a significant effect on mitigating the operating risks of energy-intensive enterprises. Compared with the central and western regions, the eastern region has a higher level of economic and social development, which may have several advantages in realizing the role of green technology innovation in mitigating the operational risks of energy-intensive enterprises. For example, the eastern region has better green infrastructure and stronger environmental regulations and institutions. The eastern region also has the advantages of industrial agglomeration and economies of scale, as well as more innovation resources and a better transformation mechanism for innovation achievements.

In addition, the role of green technology innovation in reducing the operational risks of energy-intensive enterprises before 2013 is insignificant, but it is significant after 2013. The results show that the coefficients of GUMP in Columns (4) to (5) are insignificant, while the coefficients in Columns (6) to (7) are significantly negative at the 1% level. These results indicate that the mitigating effect of green technology innovation on operational risks of energy-intensive enterprises is significant after China implemented the ecological civilization strategy in 2012. Under the constraints of ecological civilization, energy-intensive enterprises, as polluters relying on a large amount of energy consumption, would suffer significantly greater operational risks if they continued to develop in accordance with the traditional mode. Accordingly, enterprises actively carry out green technology innovation activities, in order to reduce regulatory pressure and reduce operational risks.

It is worth reiterating that in the technical details of econometrics, the insignificant empirical results in central and western China do not mean that green technology innovation cannot reduce the operational risks of energy-intensive enterprises. It is more likely that the green technology innovation mechanism of energy-intensive enterprises in central and western China is not perfect, which makes it difficult to realize the value of green technology innovation through the market. It is necessary to build the environment system and transform the achievements of green technology innovation in completely underdeveloped areas. Consistent with the restriction of ecological civilization, the central and western regions can effectively promote the realization of the value of green technology innovation by strengthening environmental constraints.

Among enterprises of different sizes, the effect of green technology innovation on reducing the operational risks of energy-intensive enterprises is significant only in medium-sized enterprises. In Columns (1) to (3) of Table 10, only the coefficient of green technology innovation in Column (2) is significant at the 1% level, while the corresponding coefficients in other columns are insignificant. Although the coefficient of green technology innovation for small enterprises is insignificant, the T value is −1.51 indicating that green technology innovation has a stabilizing effect on the operational risks of small enterprises with a high probability. In fact, these results are consistent with our research expectations. Large-scale enterprises not only have the advantages of economies of scale in production, but also have a high degree of recognition in the consumer market and capital market. In addition, large enterprises can take advantage of their scale to allocate resources in geographic space, technological space and industrial space to avoid the pressure of environmental regulation or carbon regulation. Therefore, the ability of large enterprises to resist the risks of low-carbon transition is relatively strong, and the motivation to use green technology innovation to resist operational risks becomes smaller.

Consistent with the moderating effect of enterprise ownership, green technology innovation significantly reduces the operational risk of non-state-owned enterprises (Non-SOE), but the impact on state-owned enterprises is not significant (SOE). Columns (4) and (5) in Table 10 show that the regression coefficients of green technology innovation are significantly negative at the 1% level, while the regression coefficients in Columns (6) to (7) are insignificant. These results indicate that the mitigation effect of green technology innovation on operational risks has a significant effect for non-state-owned enterprises, while it is not yet significant in state owned enterprises. The above results are likely to be similar to the analysis of scale heterogeneity, that is, innovation motivation is intrinsically decisive for enterprise behavior choice. Due to the preference of government policies and financial institutions, state-owned enterprises tend to have low operational risks and strong ability to resist the risks of low-carbon transition. Therefore, state-owned enterprises may not use green technology innovation to resist operational risks in their innovation decisions.

6. Conclusions and Implications

Rapid expansion of economic activities leads to excessive use of energy resources and the global greenhouse effect; thus, promoting low-carbon transformation of economic activities is a major challenge for industrial countries [50]. The energy-intensive sector in China accounts for more than 80 percent of total industrial carbon emissions, and suffers from the pressure of transformation and upgrading under the stricter carbon regulation. As a modern weapon for the sustainable development of economic and social activities, green technology innovation has an important role in the low-carbon transformation of the energy-intensive sector. This study empirically analyzes the impact of green technology innovation on the operational risks of energy-intensive enterprises in China.

The main conclusions are as follows. (1) Green technology innovation can significantly reduce the operational risks of energy-intensive enterprises. After a series of robust regressions, the stabilizing effect of green technology innovation on operational risks still holds. (2) Green technology innovation can significantly help enterprises gain the support of public policies and improve investor confidence in the capital market, and these intermediary transmission mechanisms can reduce corporate operational risks. (3) Although green technology innovation can theoretically reduce corporate operational risks by improving recognition in the consumer market, empirical evidence on the intermediary mechanism of consumer market recognition is insignificant. (4) The uncertainty of climate policy inhibits the role of green technology innovation in reducing operational risks; that is, climate policy uncertainty is not conducive to the realization of the value of green technology innovation. (5) Although state ownership reduces the stabilizing effect of green technology innovation on operational risks, government subsidy strengthens the stabilizing effect. (6) There is heterogeneity in the stabilizing effect of green technology innovation on the operational risks for energy-intensive enterprises. For example, the stabilizing effects on operational risks are significant for eastern enterprises, medium-sized enterprises and non-state-owned enterprises, while these are insignificant for other enterprises. (7) In addition, the role of green technology innovation in reducing operational risks is significant only after the implementation of the ecological civilization strategy in China.

The findings in this study provide the reader with several important insights. First, industrial countries should actively support green technology innovation as an important tool for low-carbon transition, and encourage energy-intensive sectors to hedge against operational risks through green technology innovation. Green technology innovation can not only directly reduce business risks under the pressure of carbon regulation, but also promote the transformation and upgrading of the energy-intensive sector through knowledge spillover. Second, the government should formulate policies or take measures to smooth the value realization mechanism of corporate green technology innovation or other green investment. For example, label certification could be adopted to strengthen the recognition of green innovative products in the consumer market [61]. In addition, the construction of green systems in backward areas and the promotion of green products by small and medium-sized enterprises are also effective measures. Third, it should strengthen the stability and foresight of climate policies, and introduce supporting policies for low-carbon transition. For example, it is necessary to strengthen the stability of climate policies, actively encourage enterprises to carry out low-carbon innovation. It also should provide transformation finance for upgrading activities, such as technological innovation in energy-intensive sector. Fourth, it should pay attention to the fairness of carbon or energy regulatory policies, and formulate classified policies to help different types of enterprises out of the dilemma of low-carbon transition. For example, it is more difficult for small businesses to adapt to changes in climate policy, and public policies should be adopted to encourage the formation of coalitions for low carbon transition of small businesses.

Some limitations can be expanded in future studies. Future research can classify different types of green technology innovation and track their effects. It can also use engineering methods to build control, monitoring, supervision and decision support models aimed at rational use of energy at the factory floor level, so as to better understand the role of green technology innovation in reducing operational risks. In addition, green technology innovation is long-cycle and high-cost, and early investment behavior may bring higher operational risks. This study only considers the benefits of green technology innovation, but does not include the risks brought by the innovation process into the analysis.

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