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ORIGINAL ARTICLE

How Do Regional Climate-Friendly Technological Innovations Affect Corporate Leverage? Evidence from China

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Abstract:
Regional climate-friendly technologies can reduce regional carbon emissions and lower the intensity of local governments' policies faced by firms. How does this affect corporate leverage? Using theoretical analysis, this paper conducts empirical tests of Chinese city data and samples of A-share listed companies in Shanghai and Shenzhen from 2008 to 2020 to study the impact of regional climate-friendly technological innovations on corporate leverage and its transmission path. The results of the study show that regional climate-friendly technological innovations increase corporate leverage, and corporate leverage rises gradually as the level of climate-friendly technological innovation in urban areas increases. Additionally, regional climate-friendly technological innovations indirectly affect enterprise leverage by influencing short-term financial investment and long-term real investment. Specifically, regional climate-friendly technological innovations reduce enterprises' short-term financial investment and promote enterprises' long-term physical investment. The reduction of short-term financial investment and the improvement of long-term physical investment both increase the leverage ratio of enterprises.
Keywords: Regional climate-friendly technological innovation, short-term financial investment, long-term real investment, corporate leverage

Introduction

As the second-largest economy in the world, China faces the daunting task of achieving the 2030 peak carbon and 2060 carbon neutrality targets. Regions use climate-friendly technologies to mitigate or adapt to climate change and reduce carbon emissions (Carattini et al., 2019, 2020; Fischer et al., 2012; Nguyen et al., 2023; Otte, 2021). A high level of regional climate-friendly technological innovation can reduce China's carbon emissions and allow resource allocation to economic development in order to promote economic growth. Therefore, regional climate-friendly technological innovation is a macro variable that affects China's economic growth. At the micro level, corporate leverage is a key variable driving corporate development (Ruwanti et al., 2019). It is a micro variable contributing to China's economic growth (Chen et al., 2021) and is profoundly affected by factors such as macroeconomic policy uncertainty (Almustafa et al., 2023; Schwarz & Dalmá cio, 2021). A high level of regional climate-friendly technological innovation can lower the pressure on local governments in China to reduce carbon emissions and can reduce uncertainty faced by local firms regarding economic policies, such as carbon reduction policies. As such, **how does the level of regional climate-friendly technological innovation affect corporate leverage**? The existing literature has mainly studied climate-friendly technological innovation in terms of influencing factors and has rarely explored its effects on corporate leverage. For this reason, we explore this topic.

The level of climate-friendly technological innovation in urban areas is the independent variable in this paper. The European Patent Office (EPO) and the U.S. Patent Office jointly released the Cooperative Patent Classification (CPC) in 2013, and the Y02 classification in the CPC is defined as technologies for mitigating or adapting to climate change. To determine the level of climate-friendly technological innovation in urban areas in China, we collect the number of patent applications and the number of patents granted under the Y02 classification in each city from 2008 to 2020 from Wisdom Dental, which is derived from the State Intellectual Property Office (SIPO) but has easier data access. Then, referring to Lu, Jingjing et al. (2021) and Li, Zheng, and Siyoung, Yang (2018), we calculate the number of climate-friendly patents granted per capita *rCFTI* and the number of applications per capita *CFTI*, which are used as proxy variables for the level of climate-friendly technological innovation in cities.

Enterprise leverage is the dependent variable in this paper. Based on the findings of Shang et al. (2018) and referring to the existing literature (Chen et al., 2021,2023a), *Lev* is obtained by using (short-term bank borrowings + long-term bank borrowings)/total assets*100 as a proxy variable for corporate leverage, and *rLev* is obtained by using (short-term bank borrowings + long-term bank borrowings + accounts payable + notes payable)/total assets*100 as another proxy variable for corporate leverage.

To determine the causality between regional climate-friendly technological innovation and enterprise leverage, first, we empirically test the impact of regional climate-friendly technological innovation on enterprise leverage by using enterprise leverage as a dependent variable, the level of regional climate-friendly technological innovation in the city where the enterprise is located as an independent variable, and the two-way fixed effect model of enterprise and year. Drawing on the practice of Chen et al. (2022, 2023c), we use short-term financial investment and long-term real investment as mediating variables, the level of enterprise leverage as a dependent variable, and the level of regional climate-friendly technological innovation in the city as an independent variable, and we conduct a mediating effect test to explore the indirect effect of regional climate-friendly technological innovation on enterprise leverage. We find that, first, regional climate-friendly technological innovation increases corporate leverage and second, regional climate-friendly technological innovation reduces firms' short-term financial investment and promotes firms' long-term physical investment, thus increasing firms' leverage.

Our paper expands the research related to climate-friendly technological innovation. Research and Development(R&D) and diffusion of climate-friendly technological innovations are important in addressing climate change (Rave & Goetzke, 2013), and scholars have mainly focused on climate-friendly technological innovations themselves and the factors influencing their diffusion. In terms of climate-friendly technological innovation itself, the existing literature focuses on the importance of R&D investment support policies (Fischer et al., 2012), financial support (Fischer et al., 2012; Nguyen et al., 2023), social norms (Carattini et al., 2019), and micro-level corporate mergers and acquisitions (da Cruz, 2023). International cooperation (Golombek & Hoel, 2011; Urom et al., 2022) and domestic multisectoral cooperation (Wang et al., 2021) can facilitate the diffusion of climate-friendly technological innovations, while regulation and intellectual property rights tend to form barriers to this process (Brown & Sovacool, 2011). Overall, there is a paucity of research in the existing literature on the economic impacts of climate-friendly technological innovations. Our study of the impact of climate-friendly technological innovations on corporate leverage extends the scope of the research to the level of microeconomic impacts.

Our study also contributes to the literature on corporate leverage. Recent scholars have studied the macro and micro factors influencing corporate leverage. On the macro side, government debt (Demirci et al., 2019; Rodríguez-García & Budría, 2019), monetary policy (Alter & Elekdag, 2020; Grosse-Rueschkamp et al., 2019), economic policy uncertainty (Almustafa et al., 2023; Schwarz & Dalmácio, 2021), and social trust (Jin et al., 2022) are important factors affecting corporate leverage. For example, government debt pushes up bond yields and absorbs funds from the financial market, which makes it more difficult for firms to raise capital and reduces their leverage (Demirci et al., 2019). The loose monetary policy of the United States has increased the leverage of non-financial firms in emerging market countries (Alter & Elekdag, 2020). At the micro level, corporate social responsibility (Ehsan, 2022; Ho et al., 2021), firm size (Bhat et al., 2023; Gulzar & Haque, 2022), and asset depreciation policy (Zhao & Fang, 2022) are the factors affecting corporate leverage. Corporate social responsibility decreases leverage (Ho et al., 2021), and accelerated depreciation increases it (Zhao & Fang, 2022). Overall, there is little literature on the impact of climate-related issues on corporate leverage, and our study expands the scope of research to the climate dimension.

The remainder of the paper is organized as follows: Section 2 articulates our testable hypothesis. Section 3 describes our econometric model, variables, and data. Section 4 discusses our main empirical results with robustness tests. Section 5 conducts conduction path tests. Section 6 conducts a heterogeneity analysis. Section 7 provides a discussion. Finally, the paper is summarized.

2. Research and Development

2.1 Direct Impacts

China has a bank-dominated financial system (Li et al., 2023), and bank loans are the main source of external finance for Chinese firms (Chen et al. 2021, 2023a). Climate-friendly technological innovation reduces the intensity of local governments' carbon reduction policies by reducing the uncertainty of these policies, which in turn increases corporate leverage.

First, regional climate-friendly technological innovations can reduce carbon reduction policy uncertainty and increase firms' demand for debt financing. Government carbon reduction policy uncertainty is a significant outcome of environmental pollution, such as carbon emissions (Saltari & Travaglini, 2011). In China, ecological and environmental governance is heavily weighted in the performance appraisals of local government officials, and strengthening environmental regulation and improving environmental performance often become important choices for local government officials (Cui & Jiang, 2019). Facing the dual tasks of reducing carbon emissions and promoting economic growth, the uncertainty of local government carbon reduction policies in China will be more obvious; that is, they will be constantly revised and adjusted (Wang et al., 2018) to improve environmental and economic performance. This will inevitably cause enterprises to face various uncertainties as well as carbon risks (Chen et al., 2023b; Barradale, 2014). Since all businesses generate carbon emissions during production and operation (Subramaniam et al., 2015), this means that uncertainty in carbon emission policies will affect all firms.

Climate-friendly technological innovations can reduce carbon emissions (Carattini et al., 2020; Nguyen et al., 2023; Otte, 2021). This means that the higher the level of regional climate-friendly technological innovation, the greater the effectiveness of carbon reduction in the region, which decreases the pressure on local governments to reduce carbon emissions and reduces the carbon reduction policy uncertainty faced by enterprises. Since higher carbon reduction policy uncertainty causes high cash flow uncertainty for enterprises (Chen et al., 2023b), the liquidity risk faced by enterprises will also be higher (Jory et al., 2020). Regional climate-friendly technological innovations reduce the uncertainty associated with local government carbon reduction policies and reduce firms' liquidity risk. This can incentivize firms to use the excess risk quota from the reduced liquidity risk to undertake external debt financing in order to increase profit (Ruwanti et al., 2019), thereby increasing firm leverage.

Second, regional climate-friendly technological innovations can reduce the intensity of carbon-reducing regulations and increase firms' demand for debt financing. Risk is an important factor affecting the cost of corporate debt financing. If the risk of corporate debt default is higher than the market average, creditors will demand higher interest earnings as compensation (Yang et al., 2022). Firms benefit the most from environmental pollution. The Chinese government forces firms to pay environmental regulatory costs, and firms' environmental expenditures increase their financial burdens (Zhao & Sun, 2016), which increases their debt default risk.

Since climate-friendly technological innovations reduce carbon emissions, the higher the level of climate-friendly technological innovation in a region, the less intense the local government is in implementing carbon-reducing regulations. This will result in lower environmental expenditures paid by enterprises and a lower risk of corporate debt default. As a result, the interest rate demanded by banks will also be lower, and enterprises' demand for corporate debt financing through banks will be higher. At the same time, in order to meet the pollutant emissions standards required by the government, firms will be forced to increase their environmental investments, purchase emission reduction equipment, and update production lines (Greenstone et al., 2012; Ryan, 2012), which reduces their competitive advantage (Zhao & Sun, 2016) and leads to crowding out of productive investments. As a result, output, productivity, and profitability subsequently decline (Greenstone et al., 2012; Ryan, 2012), and the risk of defaulting rises. Climate-friendly technological innovations can provide carbon-reducing technology support for firms, helping them reduce environmental investments, thereby increasing their productivity and profitability, which, in turn, reduces their debt default risk and incentivizes bank-based debt financing. When enterprises face strict environmental regulations, the marginal cost of production may exceed the marginal benefit. To maximize profits, enterprises may respond by reducing their economic activities (Chen, Shi, et al., 2021). Climate-friendly technological innovations can increase firms' economic activity by reducing the intensity of local governments' carbon-reducing regulations. This may also increase firms' demand for debt financing.

Finally, regional climate-friendly technological innovations can reduce the intensity of carbon-reducing regulations and increase banks' credit supply. In July 2007, the former State Environmental Protection Administration, the People's Bank of China, and the former China Banking Regulatory Commission jointly issued the Opinions on the Implementation of Environmental Protection Policies and Regulations for the Prevention of Credit Risks, which required banks to strictly limit loans to polluting firms. Environmental regulations, such as carbon-reducing regulations imposed by local governments, have led to a rise in the uncertainty of firms' future earnings (Yang et al., 2022). China has a bank-dominated financial system (Chen et al., 2021, 2023a), and China's banking system is dominated by large state-owned banks (Shang et al., 2018) that allocate credit resources nationwide. Implementation of stronger carbon-reducing regulations by local governments increases uncertainty about firms' future earnings, which prompts banks to allocate credit funds to other regions, leading to a decrease in credit supply in regions with high carbon-reducing regulations. After several reforms, banks in China have become more efficient and credit supply has become more effective (Shang et al., 2018). This means that banks' credit supply is more focused on the credit risk of the region where the borrowing firms are located. Regions with high levels of climate-friendly technological innovation experience a decline in the intensity of carbon-reducing regulations imposed by local governments, which contributes to a decline in the uncertainty of firms' future earnings. As a result, the risk of bank lending declines, thus incentivizing banks to increase credit supply. In addition, in the context of the government's efforts to promote the development of green finance, banks are increasingly emphasizing the development of green credit. Green environmental information, such as climate-friendly technological innovation, is an important basis for banks to effectively implement green credit policies (Ma, 2021). Thus, the higher the level of regional climate-friendly technological innovation, the more favorable it is for banks to increase the supply of green credit in the region.

In summary, reducing carbon reduction policy uncertainty and mitigating the intensity of carbon reduction regulations increases firms' demand for debt financing and increases banks' credit supply. Ultimately, climate-friendly technological innovation can increase corporate leverage. Thus, we propose the following hypothesis:

H1: Regional levels of climate-friendly technological innovation can increase corporate leverage.

2.2 Indirect Impacts

2.2.1 Climate-Friendly Technology Innovation and Corporate Investment Behavior

In order to reduce carbon emissions and environmental pollution, the Chinese government has increasingly emphasized the implementation of carbon reduction regulations for enterprises. This greatly influences the behavior of firms (Zhao & Sun, 2016), prompting Chinese firms to make trade-offs between short-term financial investments and long-term physical investments (Chen et al., 2021; Wang et al., 2018). Climate-friendly technological innovations can reduce the intensity of carbon reduction regulations imposed by local governments. This will affect Chinese firms' short-term financial investment and long-term physical investment decisions, which, in turn, will affect firms' leverage.

On the one hand, climate-friendly technological innovations can induce firms to reduce short-term financial investments. As discussed earlier, the carbon reduction policies of local governments in China are highly uncertain. This triggers uncertainty in the expected cash flows of real firms, increasing the incentive for precautionary savings and leading firms to increase their financial asset allocation to smooth the volatility of real investment (Acharya et al., 2007). Environmental regulations, such as carbon reduction policies, may lead to an increase in corporate environmental uncertainty. In order to offset or buffer the negative impact of business risk and future cash flow uncertainty, firms will strengthen the "reservoir" motive of financial asset allocation, prompting them to increase their holdings of financial assets (Zhang & Song, 2022). At the same time, a greater intensity of carbon regulation will cause firms to face a high carbon risk and more difficulty with debt financing (Chen et al., 2023b). As a result, the risk of firms falling into financial distress will be higher. As a precautionary measure (Phan et al., 2018), firms allocate more financial assets when facing rising debt financing difficulty (Duchin et al., 2017), and they increase their liquid financial asset allocations in times of financial distress (John, 1993). In addition, concealing bad news is an important determinant of stock price crash risk. During periods of high economic policy uncertainty, managers' incentives and ability to conceal bad news are enhanced as economic policy uncertainty increases the risk of stock price crashes for listed firms (Luo & Zhang, 2020). To protect against the risk of stock price collapse, firms must make short-term financial investments to increase their returns. Climate-friendly technological innovation reduces the intensity of carbon reduction regulations imposed by local governments, reduces the carbon risk faced by enterprises, weakens the precautionary incentive of enterprises, and can prompt enterprises to reduce their holdings of financial assets. Additionally, climate-friendly technological innovation reduces the uncertainty of local government carbon reduction policies, which can reduce the risk of share price collapse for enterprises, weakening their incentives to invest in short-term financial assets for this purpose, and can reduce investment in short-term financial assets.

Conversely, climate-friendly technological innovations will prompt firms to increase long-term physical investments. According to the real options theory, under uncertainty, both delaying and waiting for real asset investment have option value, and local government carbon reduction policy uncertainty will increase the option value of delayed real asset investment, which will make firms more cautious about long-term physical investment (Chen et al., 2021). Therefore, during the period of carbon reduction policy uncertainty, firms will become more risk-averse and thus will reduce their long-term investments (Jory et al., 2020). As discussed previously, climate-friendly technological innovation can reduce the uncertainty of local governments imposing carbon reduction policies. This can induce firms to be less risk averse, thus increasing long-term physical investment. At the same time, carbon-reducing regulations increase the environmental requirements of firms' production processes, forcing them to retrofit and install higher-fixed-cost equipment, which increases the "compliance cost" of production and reduces the return on firms' long-term physical investments (Zhang, Chao, Song, & Hua, 2022), thereby weakening the incentives for firms to make long-term physical investments. On the contrary, climate-friendly technological innovation reduces the intensity of carbon reduction regulations imposed by local governments, thus increasing the return on long-term physical investment and incentivizing long-term physical investment. In addition, when firms face strict environmental regulations, such as carbon reduction policies or a significant increase in sewage charges, the marginal cost of production may exceed the marginal benefit. In order to re-maximize profits, firms will respond by reducing economic activities such as long-term physical investment (Chen, Shi, et al., 2021). Climate-friendly technological innovation weakens the intensity of local governments' carbon-reducing regulations and lowers the marginal cost of production for firms, which may induce firms to increase their long-term physical investments in order to maximize profits again.

2.2.2 Corporate Investment Behavior and Corporate Leverage

Long-term real investment of enterprises will increase the enterprise leverage ratio, while short-term financial investment will reduce the enterprise leverage ratio (Chen et al., 2021). This occurs because long-term physical investment will increase the enterprise leverage ratio. Long-term physical investment has a large capital demand and a long payback period, and enterprises have to engage in external debt financing to meet the capital demand. This will increase the leverage ratio of enterprises. At the same time, the information asymmetry between enterprises and banks will increase the difficulty of enterprises obtaining financing (Myers & Majluf, 1984; Kaplan & Zingales, 1997). Long-term real investment, especially fixed asset investment, has a good collateral value, which can significantly reduce the information asymmetry between banks and firms, thus reducing the difficulty in obtaining funds from banks, which, in turn, increases the leverage ratio of firms. On the other hand, short-term financial investment will reduce corporate leverage. According to the theory of financing preferential order (Myers & Majluf, 1984), external equity financing will dilute shareholders' equity, while external debt financing will increase financial risk. Therefore, the enterprise will carry out financing according to the order of first endogenous financing and then external financing in order to satisfy its capital needs. Short-term financial investments are highly liquid and are the preferred choice of firms for endogenous financing. This will reduce the need for debt financing and lower the leverage ratio of enterprises. At the same time, short-term financial asset investments have low returns, and the holding of short-term financial asset investments by enterprises will signal to banks the lack of long-term real investment opportunities and the weaker profitability of enterprises, thus prompting banks to reduce their loan investment in enterprises. This will reduce the leverage ratio of enterprises.

To summarize, climate-friendly technological innovation can induce enterprises to reduce short-term financial investment and increase long-term real investment, and both the reduction of short-term financial investment and the increase of long-term real investment will increase the leverage of enterprises. To this end, we propose the following hypotheses:

H2: The level of regional climate-friendly technological innovation induces firms to reduce their short-term financial investments, thereby increasing their leverage.

H3: The level of regional climate-friendly technological innovation induces firms to increase their long-term physical investments, thus increasing their leverage.

3. Models, Variables, and Data

3.1 Models

3.1.1 Modeling of Direct Impacts

We refer to the literature on corporate leverage (e.g., Chen, S. F. et al., 2021, 2023a) and design the following two-way fixed-effects model of time and firms to test for the direct effects:

$$Lev_{it} = \alpha_0 + \beta_1 * Cfti_{it} + +\boldsymbol{\eta} * \boldsymbol{X} + \alpha_i + \lambda_t + \varepsilon_{it} \qquad (1)$$

where i and t are firm and time subscripts, respectively; α_i is capturing firm fixed effects; λ_t is capturing year fixed effects, and $\varepsilon_{i,t}$ is the random error term. Lev_{it} is the dependent variable, which is the firm leverage ratio of firm i in year *t*. $Cfti_{it}$ is the independent variable, which is the regional level of climate-friendly technological innovation in year t in the city where the i*th* firm is located. β_1 is the coefficient of primary interest. If it is significantly positive, then regional climate-friendly technological innovation increases firm leverage. $\boldsymbol{x}$ is the control variable, as described below.

3.1.2 Modeling of Indirect Impacts

To test the indirect effects, the following model is designed with reference to the existing literature on studying transmission paths (e.g., Chen et al., 2022; Chen, 2023).

$$MED_{it} = \alpha_0 + \theta * Cfti_{it_{it}} + \boldsymbol{\eta} * \boldsymbol{Z} + \alpha_i + \lambda_t + \varepsilon_{it} \qquad (2)$$

$$Lev_{it} = \alpha_0 + \beta_1 * Cfti_{it_{it}} + \beta_2 * MED_{it} + \boldsymbol{\eta} * \boldsymbol{X} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (3)$$

MED_{it} are the mediating variables, i.e., short-term financial investment (*Sinv*) and long-term real investment (*Capx*). X in equation (3) is the control variable, as in equation (1). ***Z*** in equation (2) is the control variable, as described later.

The testing procedure is as follows: First, we estimate equation (2) to determine the effect of regional climate-friendly technological innovation on the mediating variable. Second, we estimate equation (3), if the coefficient θ in equation (2) and the coefficient β_2 in equation (3) are significant, it indicates that the mediating effect exists. Third, if only one of the coefficients θ and β_2 is significant, the mediating effect is yet to be tested by Sobel.

3.2 Variables

With reference to the existing literature, the independent, dependent, mediating, and control variables of this study are presented in Table 1.

3.2.1 Dependent Variables

The dependent variable in this paper is the corporate leverage ratio. We mainly base our theoretical analysis on banks as debt capital providers, and therefore, we calculate corporate leverage based on bank loans, which include short-term and long-term borrowings (Chen, S. F. et al., 2021). For this reason, we borrowed from Chen et al. (2021, 2023a) and obtained *Lev* as a proxy variable for corporate leverage based on (short-term bank borrowings + long-term bank borrowings)/total assets*100. In addition to bank loans, commercial credit is also an important source of debt funding for firms (Chen et al., 2021). For this reason, we borrowed from Chen et al. (2021, 2023a) and obtained *rLev* as another proxy variable for firms' leverage based on (short-term bank borrowings + long-term bank borrowings + accounts payable + notes payable)/total assets*100.

Table 1 Variable Description

Typology	**Name (Of a Thing)**	**Notation**	**Variable Definition**	**Bibliography**
Dependent variable	Level of corporate leverage	*Lev*	(Short-term bank borrowings + long-term bank borrowings)/total assets*100	Chen et al. (2021,2023a)
		rLev	(short-term bank loans + long-term bank loans + accounts payable + notes payable)/total assets * 100	
Independent variable	Level of innovation in climate-friendly technologies in urban areas	*Cfti*	Number of climate-friendly patent applications in the city where the company is located/total population of the city	Lu et al. (2021), Zheng and Yang (2018), Carattini et al. (2019, 2020), Nguyen et al. (2023), Otte (2021)
		rCfti	Number of climate-friendly patents granted in the city where the enterprise is located/total population of the city	
Intermediary variable	Short-term financial investments	*Sinv*	(Monetary funds + financial assets held for trading)/total assets*100	Chen et al. (2021)
	Investments in long-term entities	*Capx*	Cash paid for the purchase of fixed assets, intangible assets and other long-term assets/total assets*100	
control	Enterprise	*Size*	Ln (total assets)	Alter & Elekdag

variable	size			(2020), Chen et al. (2021,2023a), Demirci et al. (2019)
	Age of business	*Age*	Ln (1 + number of years the enterprise has been in existence as of that year)	
	Fixed assets as a percentage	*Tang*	Fixed assets/total assets*100	
	Bankability	*Roa*	EBIT/average total assets*100	
	Growth	*Grow*	Revenue growth rate	
	Board size	*Bsiz*	Ln (number of board members)	
	Board independence	*Indr*	Number of independent directors/number of board of directors*100	
	Two jobs in one	*Dual*	The chairman of the board of directors, who is also the managing director, takes the value of 1, otherwise it takes the value of 0	
	Property rights	*SoE*	State-owned enterprises take the value of 1, otherwise, they take the value of 0	
	Shareholding concentration	*First*	The shareholding ratio of the largest shareholder	
	Level of economic development	*Pgdp*	Ln (real GDP per capita in the city where the firm is located)	Demirci et al. (2019), Li et al. (2023)
	Level of credit resource allocation	*Fsiz*	Loans per capita in the city where the enterprise is located	

3.2.2 Independent Variables

The independent variable in this paper is the level of climate-friendly technological innovation in urban areas. For the reasons stated in Section 1, we calculate the number of climate-friendly patent applications and grants per capita in cities as variables *CFTI* and *rCFTI*, respectively. We treat *CFTI* and *rCFTI* as proxy variables for the level of climate-friendly technological innovation in cities.

3.2.3 Mediating Variables

The mediating variables in this paper are short-term financial investment (*Sinv*) and long-term entity investment (*Capx*). Referring to the existing literature (Chen et al., 2021), we obtain *Sinv* as a proxy variable for short-term financial investment by calculating (money funds + trading financial assets)/total assets*100 and *Capx* as a proxy variable for long-term physical investment by calculating cash paid for the purchase of fixed assets, intangible assets, and other long-term assets/total assets*100.

3.2.4 Control Variables

Regarding the control variables in equation (1), with reference to the existing literature (e.g., Chen et al., 2021, 2023; Alter & Elekdag, 2020; Demirci et al., 2019), we control for firm size, firm age, share of fixed assets, profitability, growth, board size, board independence, bifurcation, ownership attributes, equity concentration, level of economic development, and level of credit resource allocation. Li et al. (2023) also controlled for economic- and finance-related variables when examining the impact of macro variables on firms' micro variables. For this purpose, we also control for the level of economic development and the level of credit resource allocation.

Regarding the control variables in equation (2), with reference to the existing literature (e.g., Chen et al., 2021), when using short-term financial investment as the mediating variable, we control for firm size, profitability, growth, operating cash flow, fixed asset ratio, board size, board independence, and two-ranking. In particular, operating cash flow is the amount of cash flow from operating activities divided by the difference between total assets and cash or equivalents. With reference to the existing literature (e.g., Chen et al., 2021), when using long-term entity investment as the mediating variable, we control for firm size, asset turnover, operating cash flow, growth, profitability, share of fixed assets, age of the firm, size of the board of directors, and board independence. Similarly, referring to Li et al. (2023), we also control for two macro variables: the level of economic development and the level of credit resource allocation.

3.3 Data

3.3.1 Data Sources

Carbon reduction regulation in China can be traced back to 2008, and the data from the China Urban Statistical Yearbook is updated to 2020. For this reason, this paper conducts an empirical analysis with the data of Chinese cities and A-share listed companies in Shanghai and Shenzhen from 2008 to 2020. In this paper, we process the data as follows: (1) eliminate the missing samples; (2) eliminate the samples of financial firms; (3) eliminate the samples of firms with ST and *ST; (4) eliminate the influence of outliers by carrying out Winsorize shrinkage of 1% up and down on the continuous variables other than taking the natural logarithm. As a result of this process, we obtain 32,264 year-firm observations.

The patent applications and granted numbers for climate-friendly technologies are from Zhihui Ya, a patent query platform that gets its data from the State Intellectual Property Office but has a more convenient data query function. Other data are from the China Urban Statistical Yearbook, the People’s Bank of China, and the Wind database.

3.3.2 Summary Statistics

Table 2 reports the descriptive statistics of the variables. The table shows the mean value of China's corporate leverage level (*Lev*), which is 13.8798%; the minimum value, which is 0.0000%; and the maximum value, which reaches 54.9356%. There is a large gap between the maximum and minimum value of the corporate leverage level. This is consistent with the basic national situation of unbalanced development. Secondly, the average value of the climate-friendly technological innovation level (*Cfti*) in urban areas is 6.2572, the minimum value is 0.0342, and the maximum value reaches 35.4537, and the gap between the maximum and minimum value of the climate-friendly technological innovation level is also large, which is also in line with the basic situation of China's unbalanced development.

Table 2 Summary Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max.
Lev	32,264	13.8798	13.4524	0.0000	54.9356
rLev	32,264	19.3796	15.5232	0.0417	65.3737
Cfti	32,264	6.2572	7.8028	0.0342	35.4537
rCfti	32,264	2.3869	2.7410	0.0135	12.6136
Capx	32,264	5.2018	4.9926	0.0249	26.8413
Sinv	32,264	20.3153	14.8561	1.2929	71.8818
Size	32,264	12.8047	1.3845	5.7313	19.4262
Age	32,264	2.8528	0.3493	0.0000	4.1897
Tang	32,264	21.5763	16.4020	0.1616	69.8322
Roa	32,264	6.8576	7.3022	-17.2166	41.5428
Grow	32,264	1.1792	0.4170	0.4571	3.7075
Bsiz	32,264	2.1275	0.2203	0.0000	2.8904
Indr	32,264	37.1330	6.2654	0.0000	57.1429
Dual	32,264	0.2763	0.4472	0	1

First	32,264	35.6285	15.4378	8.8000	80.6500
Pgdp	29,949	11.4838	0.7778	8.6088	13.0060
Istr	32,264	35.1958	24.7619	0.0000	85.7566
SoE	32,264	0.3525	0.4777	0	1
Fsiz	32,264	1.5338	0.6385	0.3968	3.3902
Pgdp	32,264	11.4913	0.7774	8.6088	13.0060

4. Results

4.1 Benchmark Regression

Equation (1) can be estimated using an individual fixed effects model (FE) and a random effects model (RE). In this paper, the Hausman test is performed on the FE and RE estimation results. The Hausman test chi-square statistic is 469.06 with a p-value of <0.0001, which should be estimated using FE. For this reason, this paper estimates equation (1) with FE based on gradually increasing control variables, and the results are shown in Table 3. From columns (1)–(5) of Table 3, the coefficients of the level of climate-friendly technological innovation (*Cfti*) in urban areas are all significantly positive at the 1% significance level, and regional climate-friendly technological innovation can increase corporate leverage. The empirical results support hypothesis H1.

Table 3 FE Estimation Results for Equation (1)

	(1)	(2)	(3)	(4)	(5)
Variables	*Lev*	*Lev*	*Lev*	*Lev*	*Lev*
Cfti	0.1763***	0.1307***	0.1128***	0.1166***	0.0725***
	(0.0172)	(0.0167)	(0.0165)	(0.0165)	(0.0188)
Size		3.5254***	3.4347***	3.4931***	3.4948***
		(0.1347)	(0.1349)	(0.1345)	(0.1343)
Age		8.0839***	6.4490***	7.4989***	7.5379***
		(0.7467)	(0.7329)	(0.7451)	(0.7451)
Tang		0.1684***	0.1495***	0.1464***	0.1464***
		(0.0082)	(0.0081)	(0.0081)	(0.0081)
Roa			-0.2162***	-0.2245***	-0.2248***
			(0.0114)	(0.0116)	(0.0116)
Grow			0.2894**	0.2513*	0.2505*
			(0.1414)	(0.1411)	(0.1410)
Bsiz				-2.1636***	-2.1639***
				(0.3375)	(0.3371)
Indr				-0.0723***	-0.0720***
				(0.0100)	(0.0100)
Dual				-0.2178	-0.2209
				(0.1641)	(0.1640)
First				0.0567***	0.0564***
				(0.0090)	(0.0090)
SoE				0.5385	0.5305
				(0.4023)	(0.4013)
Fsiz					0.0782
					(0.2208)
Pgdp					-2.6958***
					(0.6438)
Constant	17.4494***	-47.7488***	-40.8741***	-38.9589***	-9.6602
	(0.3101)	(2.2374)	(2.2043)	(2.4307)	(7.5282)

Enterprise FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	32,264	32,264	32,264	32,264	32,264
R-squared	0.0286	0.0977	0.1193	0.1242	0.1250
N	3,458	3,458	3,458	3,458	3,458

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, same below.

4.2 Robustness Checks

1. Endogenous treatment. The previous theoretical analysis and empirical tests have shown that regional climate-friendly technological innovation has a significant impact on enterprise leverage. On the contrary, as a micro variable, the enterprise leverage ratio has difficulty influencing the macro variable of the level of climate-friendly technological innovation in urban areas. However, it is still possible that the level of climate-friendly technological innovation in urban areas is endogenous due to measurement error or unobservable factors. For this reason, and with reference to Chen et al. (2022, 2023b) and Chen (2023), we calculated the mean value of the level of climate-friendly technological innovation in urban areas of other cities in the same year to obtain *ivCfti* as an instrumental variable. The level of climate-friendly technological innovation in urban areas of other cities and the level of climate-friendly technological innovation in urban areas of the city are affected by measurement error or unobservable factors. Therefore, *ivCfti* is correlated with *Cfti*, and *ivCfti* satisfies the condition of "correlation". On the other hand, the level of climate-friendly technological innovation in other cities is less likely to affect the cash holdings of firms in the city, and *ivCfti* satisfies the condition of "exogeneity". Using *ivCfti* as an instrumental variable, we re-estimate equation (1) using the instrumental variable method (IV), and the Cragg-Donald F-statistic for the weak instrumental variable test is 38,000, which is much larger than the critical value of 16.38 under the 10% bias. Therefore, the hypothesis of a weak instrumental variable is rejected, and *ivCfti* is a valid instrumental variable.

Table 4 Robustness Test for Equation (1)

	(1)	(2)	(3)	(4)	(5)
Variant	*Lev*	*rLev*	*Lev*	*Lev*	*Lev*
Cfti	0.1076***	0.0688***		0.0431**	0.0948***
	(0.0251)	(0.0208)		(0.0183)	(0.0134)
rCfti			0.3584***		
			(0.0632)		
Capx				0.0576***	
				(0.0133)	
Sinv				-0.1557***	
				(0.0047)	
Control	YES	YES	YES	YES	YES
Enterprise FE	YES	YES	YES	YES	NO
Year FE	YES	YES	YES	YES	YES
Industry FE	NO	NO	NO	NO	YES
Observations	32,264	32,264	32,264	32,264	32,264
R^2	0.1248	0.1265	0.1255	0.1610	0.1212
N	3,458	3,458	3,458	3,458	3,458

Using *ivCfti* as an instrumental variable, we estimate equation (1) using the IV, and the results are in column (1) of Table 4. From column (1), regional climate-friendly technological innovation increases firm leverage. Therefore, hypothesis H1 still holds with respect to the exclusion of endogeneity.

2. Change the measure of dependent variables. Equation (1) is re-estimated using FE with *rLev* as the dependent variable, and the results are in column (2) of Table 4. From column (2), the conclusion that research hypothesis H1 holds is robust.

3. Replace the independent variables. Replacing the independent variable with *rCfti* and re-estimating equation (1) using FE results in column (3) of Table 4. From column (3), the conclusion that research hypothesis H1 holds is robust.

4. Control intermediary variable type. The analysis in Section 2 shows that short-term financial investment and long-term real investment affect firms' leverage, which is treated as a mediating variable in this paper and not as a control variable. Here, we control the two mediating variables and re-estimate equation (1) using FE, and the results are in column (4) of Table 4. From column (4), the conclusion that research hypothesis H1 holds is robust.

5. Control for industry fixed effects. Existing literature (e.g., Chen, S. F. et al., 2023a) controls for industryfixed effects and year-fixed effects when studying corporate leverage. For this reason, we re-estimate equation (1) by controlling for industry fixed effects and year fixed effects, which results in column (5) of Table 4. From column (5), the conclusion that research hypothesis H1 holds is robust.

5. Indirect Impact Test

5.1 Short-Term Financial Investment Channels

With *Sinv* as the mediator variable and *Cfti* as the independent variable, we estimate equation (2) using FE, and the results are in column (1) of Table 5, Panel A. With *ivCfti* as the instrumental variable, we use IV to estimate equation (2), and the results are in column (2) of Table 5, Panel A. Replacing the independent variable with *rCfti*, we use the FE estimating equation (2), and the results are in column (3) of Table 5, Panel A. Controlling for industry fixed effects and year fixed effects, we re-estimate equation (2), and the results are in column (4) of Table 5, Panel A. According to Table 5, Panel A, climate-friendly technological innovation reduces short-term financial investment.

We use *Lev* as the dependent variable, *Sinv* as the mediator, and *Cfti* as the independent variable, and we use FE to estimate equation (3), which results in column (1) of Table 5, Panel B. We refer to Section 4.2 and use the mean value of short-term financial investments of other firms in the same year, *ivSinv*, as an instrumental variable, together with *ivCfti*, and we use IV to estimate equation (3), which results in Table 5, Panel B, column (2). The dependent variable is replaced with *rLev*, and we use FE to estimate equation (3), which results in column (3) of Table 5, Panel B. The independent variable is replaced with *rCfti*, and we use the FE estimating equation (3), which results in column (4) of Table 5, Panel B. As shown in Table 5, Panel B, short-term financial investment reduces corporate leverage.

Synthesizing Table 5, Panel A and Panel B, shows that climate-friendly technological innovation reduces short-term financial investment, thereby increasing firm leverage.

Table 5 Estimated Results for the Short-Term Financial Investment Channel

Panel A				
	(1)	(2)	(3)	(4)
Variables	*Sinv*	*Sinv*	*Sinv*	*Sinv*
Cfti	-0.1811***	-0.2403***		-0.1223***
	(0.0234)	(0.0323)		(0.0168)
rCfti			-0.6719***	
			(0.0788)	
Control	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes

Industry FE	No	No	No	No
Observations	32,264	32,264	32,264	32,264
R-squared	0.2086	0.2085	0.2090	0.2072
N	3,458	3,458	3,458	3,458
Panel B				
	(1)	(2)	(3)	(4)
Variables	*Lev*	*Lev*	*rLev*	*Lev*
Cfti	0.0445**	0.0678***	0.0353*	
	(0.0183)	(0.0246)	(0.0204)	
rCfti				0.2544***
				(0.0621)
Sinv	-0.1580***	-0.1685***	-0.1890***	-0.1576***
	(0.0046)	(0.0055)	(0.0053)	(0.0046)
Control	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	32,264	32,264	32,264	32,264
R-squared	0.1603	0.1601	0.1659	0.1606
N	3,458	3,458	3,458	3,458

Note: Instrumental variables are tested for validity.

5.2 Long-Term Physical Investment Channels

Using long-term physical investment (*Capx*) as the mediating variable and referring to Section 5.1, we estimate equations (2) and (3), and the results are shown in Table 6. As shown in Table 6, regional climate-friendly technological innovations can encourage firms to make long-term physical investments, which can increase firms' leverage, and hypothesis H3 is valid and robust.

Table 6 Estimated Results of Investment Channels for Long-Term Entities

Panel A				
	(1)	(2)	(3)	(4)
Variables	*Capx*	*Capx*	*Capx*	*Capx*
Cfti	0.0275***	0.0342***		0.0140**
	(0.0087)	(0.0118)		(0.0056)
rCfti			0.0777**	
			(0.0302)	
Control	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	No
Year FE	Yes	Yes	Yes	Yes
Industry FE	No	No	No	No
Observations	32,264	32,264	32,264	32,264
R-squared	0.1020	0.1020	0.1019	0.0888
N	3,458	3,458	3,458	3,458
Panel B				
	(1)	(2)	(3)	(4)
Variables	*Lev*	*Lev*	*rLev*	*Lev*
Cfti	0.0695***	0.1034***	0.0646***	

	(0.0187)	(0.0250)	(0.0208)	
rCfti				0.3494***
				(0.0631)
Capx	0.0997***	0.1127***	0.1376***	0.0994***
	(0.0136)	(0.0171)	(0.0155)	(0.0136)
Control	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	32,264	32,264	32,264	32,264
R-squared	0.1271	0.1269	0.1297	0.1276
N	3,458	3,458	3,458	3,458

Note: Instrumental variables are tested for validity.

6. Discussion

Chen et al. (2021) found that regional carbon emissions increase the uncertainty of local governments' carbon reduction policies, prompting firms to increase short-term financial investment and reduce long-term physical investment, thereby reducing corporate leverage. Our study shows that regional climate-friendly technological innovation reduces the uncertainty of local government carbon reduction policies, decreases the intensity of carbon reduction regulations, and prompts firms to reduce short-term financial investment and increase long-term physical investment, thus increasing the corporate leverage ratio. In addition, climate-friendly technological innovation can reduce carbon emissions, and according to Chen et al. (2021), reducing carbon emissions can increase corporate leverage. Therefore, climate-friendly technological innovation can increase corporate leverage. Our study is consistent with the findings of Chen et al. (2021). In addition, Chen et al. (2023) found that improving regional carbon efficiency can increase economic output per unit of carbon emissions, which reduces corporate cash holdings. This implies that holding reducing carbon emissions reduce corporate cash holdings for the same output. This also implies that regional climate-friendly technological innovations can reduce corporate cash holdings. Cash is a typical short-term financial asset. According to Chen et al. (2023b), regional climate-friendly technological innovation reduces short-term financial investment. Our study is also consistent with Chen et al. (2023b).

Firms' investment policies are affected by economic policy uncertainty (Akron et al., 2020), which exacerbates firms' financing constraints by reducing the return on assets and increasing the cost of debt (Brogaard & Detzel, 2015). This implies that economic policy uncertainty reduces firms' leverage. Conversely, reducing economic policy uncertainty can increase firm leverage. Our study finds that regional climate-friendly technological innovation reduces local government carbon reduction policy uncertainty and increases firm leverage. Thus, regarding the economic consequences of economic policy uncertainty, our findings are consistent with those of Akron et al. (2020) and Brogaard & Detzel (2015).

7. Conclusion, Implications, and Outlook

7.1 Conclusion

Our paper studies the impact of regional climate-friendly technological innovation on corporate leverage. We conduct a theoretical analysis of the direct and indirect impacts of regional climate-friendly technological innovation on corporate leverage, then empirically test it based on Chinese city data from 2008 to 2020 and the samples of A-share listed companies in Shanghai and Shenzhen using both corporate and yearly two-way fixed effects. We find that, **first**, regional climate-friendly technological innovation increases corporate leverage, and with the gradual increase of regional climate-friendly technological innovation, corporate leverage gradually increases. **Second**, regional climate-friendly technological innovation indirectly affects corporate leverage by influencing corporate short-term financial investment and long-term real investment. Specifically, regional climate-friendly technological innovation reduces enterprises' short-term financial investment and promotes enterprises' long-term physical investment. The reduction of short-term financial investment and the increase of long-term physical investment both increase the leverage ratio of enterprises. These findings are consistent with the general conclusions of current scholars on regional carbon emissions and economic policy uncertainty.

7.2 Implications

Our findings have certain theoretical and practical implications. **First**, reducing carbon emissions and promoting economic growth can go hand in hand. Reducing carbon emissions to combat global climate change is a common task for all countries around the world. In developing countries, where technology is relatively backward and resources are relatively scarce, reducing carbon emissions may reduce economic growth. Our research finds that climate-friendly technological innovation can increase corporate leverage, which, in turn, promotes corporate development and, thus, economic growth at the macro level. At the same time, climate-friendly technological innovation can, in turn, reduce carbon emissions. This means that the promotion of climate-friendly technological innovation can have the combined effect of reducing carbon emissions and promoting economic growth. Therefore, the majority of developing countries can take measures to promote climate-friendly technological innovation toreduce carbon emissions and achieve economic growth simultaneously.

Second, global companies wishing to make direct investments in China can choose their investment locations accordingly. Since the implementation of the reform and opening-up policy, China's investment environment has been improving day by day, and it is becoming one of the ideal investment countries for global enterprises. China is a vast country with uneven development. It has a government-led economy, and government policies have a significant impact on investment returns. In regions with high levels of climate-friendly technological innovation, there is less uncertainty about the government's carbon reduction policies, and the intensity of carbon reduction regulations is weaker, so banks are more willing to invest credit resources in these regions; therefore, it is easier to obtain credit capital for setting up a business in these regions. This means that global firms intending to make direct investments in China can use the level of climate-friendly technological innovation as a reference indicator for choosing a specific investment location.

Finally, investors need to include the level of climate-friendly technological innovation as an assessment of value in the location of their invested enterprise. Due to China's government-led economy, government behavior has a profound impact on corporate behavior, which, in turn, has a significant impact on corporate value. In regions with higher levels of climate-friendly technological innovation, less uncertainty about local governments' carbon reduction policies and weaker carbon reduction regulations allow enterprises to increase their leverage ratios. Additionally, there is more potential to use debt financing to promote corporate development and increase corporate profits and value. The reverse remains true. Therefore, global investors need to consider the level of climate-friendly technological innovation in a company's location when valuing Chinese companies, especially listed Chinese companies.

7.3 Outlook

Our paper studies the impact of regional climate-friendly technological innovation on corporate leverage, but due to the level of research and the availability of research data, we have not studied whether there are country-specific differences in the impact of climate-friendly technological innovation on corporate leverage. As the level of economic and financial development and the basis of technological innovation differ from country to country, there may be country-specific differences in the impact of climate-friendly technological innovation on the leverage ratio of enterprises, and what kind of differences exist have yet to be studied.

Statement

Conflict of interest

I certify that this manuscript is original, has not been published, and will not be submitted elsewhere for publication while being considered by Weather, Climate, and Society. Furthermore, the study is not split into several parts to increase the number of submissions submitted to various journals or one journal over time. No data were fabricated or manipulated (including images) to support your conclusions. No data, text, or theories by others are presented as if they were our own.

The submission has been received explicitly by all co-authors. Moreover, authors whose names appear on the submission have contributed sufficiently to the scientific work and share collective responsibility and accountability for the results.

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Data availability statement

Data associated with our Study hasn't been deposited into a publicly available repository, and our Data will be made available on request.

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