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The Carbon Reduction Effect of Green Finance: Based on the Evaluation of the Effect of China's Green Finance Reform and Innovation Policies

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Abstract: Using green finance to promote developing countries to achieve carbon emission reduction is an effective path for developing countries to fulfill their emission reduction responsibilities in the process of coping with global climate change. In view of this, this paper takes the development of China's green finance as the research object, uses the data of China's city level and enterprise level from 2009 to 2020, and uses the difference-difference method to evaluate the impact of green finance reform and innovation policies on carbon emissions and explore its internal mechanism. The results show that the implementation of GFRI policies can significantly promote urban carbon emission reduction. The mechanism test shows that the implementation of the GFRI policy has promoted the significant increase of green investment in pilot cities, especially in heavily polluting enterprises. At the same time, the implementation of the GFRI policy has also promoted green technology innovation, but there is a "decoupling" of the quantity and quality of innovation. It is further found that the emission reduction effect of green finance has significant industry "spillover effect".

Keywords: green finance reform and innovation policy; carbon reduction; green investment; spillover effect

JEL Classification: Q56; G1; O32

1. Introduction

With the rapid development of global economy and the continuous expansion of population size, human resource consumption and energy consumption continue to increase, and climate change problems such as sea level rise, global warming, air and soil pollution come into being (Datta et al., 2022). Climate change is the most serious challenge facing mankind, and actively responding to climate change has become the consensus of all mankind. However, due to the needs of economic development, the use of breakthrough technologies in developing countries must be at the cost of consuming a large amount of energy such as electricity, coal and oil, which in turn leads to a large amount of carbon emissions and the threat of environmental problems such as climate change (Hu, 2023). As a major carbon emission country, China is facing enormous pressure to reduce emissions. The high pollution of the environment not only leads to the reduction of social welfare, but also

causes certain losses to economic development. Therefore, China urgently needs to make carbon emission reduction efforts, and China's commitment to peak carbon neutrality reflects the determination of developing countries represented by China to reduce carbon emissions.

Finance is the core of modern economy, and green finance plays an important role in promoting green and low-carbon transformation of economic structure and mitigating climate change risks (Zhao & Liu, 2020; Ameli et al., 2021). In fact, China's green finance policy has made steady progress in recent years. Especially in 2017, China decided to build a green finance reform and innovation pilot zone, which organically combines "top-down" policy promotion with "bottom-up" reform and innovation, and provides a series of replicable and scalable experiences for the development and improvement of the green finance system. China's outstanding green loans in local and foreign currencies reached 22.03 trillion yuan, a year-on-year increase of 38.5% and an increase of 6.01 trillion yuan for the whole year. In addition, China's green finance market is gradually expanding, green funds, ESG investment (Environmental, Social, Governance), green insurance are developing rapidly, and a variety of innovative green financial products and low-carbon practices are emerging. This "up-down linkage" approach helps to promote the optimization and adjustment of industrial structure and energy efficiency, and achieve the goal of reaching peak carbon neutrality. Therefore, it is of practical significance to explore the carbon emission reduction effect and transmission path brought about by green finance reform and innovation policies in this context.

Compared with the existing literature, the marginal contribution of this paper is as follows: From the perspective of research, it takes the green finance reform and innovation policy (GFRI policy) as an example to evaluate the carbon emission reduction effect of green finance, which helps to supplement the research results of the existing scholars on green finance. In terms of mechanism analysis, firstly, from the perspective of green investment, the carbon emission reduction effect of green finance reform and innovation policy is explored from both macro regions and micro enterprises. Secondly, from the perspective of green technology innovation, the paper explores whether green finance reform and innovation policy can achieve carbon emission reduction by means of "quality and quantity preservation" of green technology innovation, which enriched the path of carbon emission reduction of green finance in the academic circle. In terms of thinking path, this paper uses micro-enterprise data to further analyze the carbon emission reduction effect of GFRI policy, and discusses the industry spillover of carbon emission reduction effect of key and non-key industries supported by green finance reform and innovation policy. In addition, on this basis, it also sorts out the industries that are most and least impacted by green finance reform and innovation policy.

2. Methodology

Most countries and regions are experiencing the development and reform of the financial industry, and the rapid development of the financial industry will promote economic development, which is closely related to regional carbon emissions. GFRI policies can promote the transformation of regional economic growth mode to green by guiding funds to

resource-saving green projects to achieve carbon emission reduction targets. Based on this, this paper puts forward the following hypothesis.

Hypothesis 1: Green finance reform and innovation policies can effectively reduce regional carbon emissions.

The implementation of green projects or the realization of enterprises' emission reduction targets will promote the green and coordinated development of the economy and further promote eco-friendly growth (Rogge & Schleich, 2018). Green investment is one way to achieve these goals. However, energy conservation and emission reduction can improve efficiency and save money, and reduce pollution will increase the cost of enterprises. The implementation of the green finance reform and innovation policy has alleviated the financing constraints of enterprises in terms of financing costs and financing methods, and the expansion of financing scale has actively promoted enterprises to make green investment and realize comprehensive low-carbon transformation.

As a general term for technologies, processes or products that can reduce environmental pollution and energy consumption, green technology innovation is undoubtedly one of the key factors to promote high-quality green development of the economy (Braun & Wield, 1994; Su et al., 2020). GFRI policies provide capital allocation to enterprises from the inside, and create favorable conditions for enterprises' green innovation activities from the outside through risk control and competition incentives, so as to expand the innovation compensation effect generated by the market mechanism.

Hypothesis 2: Green finance reform and innovation policies reduce carbon emissions by increasing corporate green investment and green technology innovation.

The realization of effective carbon emission reduction in a region mainly depends on the behavior of enterprises, and carbon emission reduction involves many decisions. If these decisions are made by a single enterprise, it is difficult to unify the carbon emission reduction activities of all enterprises. Obviously, only by comprehensively considering the distribution of carbon emission reduction in the supply chain can the optimal effect be achieved. Green finance reform and innovation policies can provide long-term and low-cost funds, help balance the risks and benefits of carbon emission reduction for enterprises (Lin & Teng, 2022). Based on this, this paper puts forward the following hypothesis.

Hypothesis 3: The carbon emission reduction effect of green finance reform and innovation policies has significant "spillover effect" between industries.

In summary, based on the relationship and influence mechanism between green finance reform and innovation pilot zone and carbon emissions, this paper makes the above assumptions, and the path is shown in Figure 1.

This paper focuses on the emission reduction effect of green finance development, so the measurement of carbon dioxide is the focus of our attention. In order to measure carbon emissions more comprehensively, this paper calculates carbon emissions accurately from the

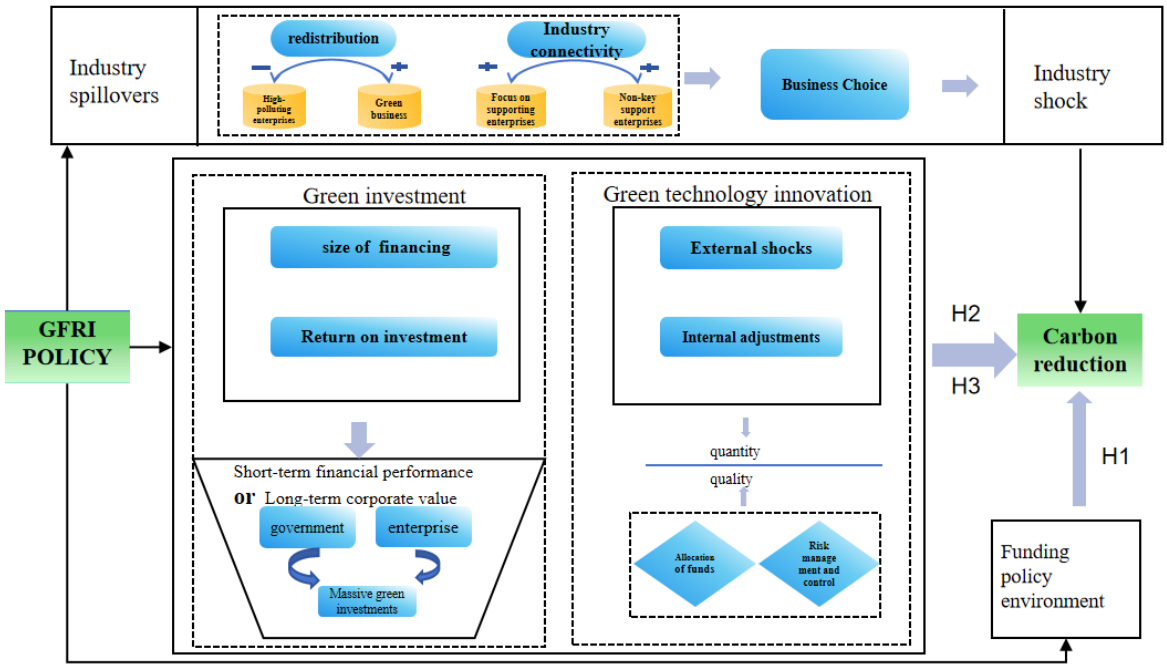

Figure 1. The interaction path between green finance and carbon emission reduction

city level (formula (1)) and the enterprise level (formula (2)). At the city level, urban carbon dioxide emissions (CO2) and per capita carbon dioxide emissions (perCO2) were selected as explained variables, respectively. The carbon emission calculation formula is as follows:

$$CO_2 = ad \times ef_1 + ec \times ef_2 + (Q_{consume} + Q_{revenue}) \quad (1)$$

$$TC = ad_{enterprise} \times ef + ec_{enterprise} \times ef \quad (2)$$

CO2 and TC is the total carbon dioxide emission, ad is the activity level data of the fossil fuel consumed by the city and enterprise respectively, and ef1 is the emission factor of the fossil fuel by the city and enterprise respectively, *ec* is the purchased electricity of the city and enterprise respectively, and ef2 is the emission factor calculated by the average power grid of the region where the city and enterprise are located. $Q_{consumption}$ is the carbon dioxide produced by consumption, $Q_{revenue}$ is the carbon dioxide produced by revenue.

In this paper, the implementation of green finance reform and innovation policy in 2017 is taken as an external impact to construct a quasi-natural experiment, and the effect evaluation is carried out using differential difference. Therefore, the core explanatory variable of this paper first takes the implementation of the green finance reform and innovation policy in 2017 (GFRI policy) as the explanatory variable. If the city implements the green finance reform policy in 2017 and later, the value is 1, and if the city implements the green finance reform policy in 2017 and before, the value is 0. Area is the virtual variable of the pilot area. If the area is in the pilot area, the value is 1. In non-pilot areas, the value is 0. Furthermore, in order to measure the intensity of the policy implementation, we selected the Green Credit Index (GFRI policy_credit), Green Insurance Index (GFRI policy_insurance), Green Bond Index (GFRI policy_bond), and Green Fund Index (GFRI policy_funds) of pilot cities after 2017 as explanatory variables. Among them, the green credit index is calculated by the proportion of total

credit of regional environmental protection projects in total credit, the green insurance index is calculated by the proportion of regional environmental pollution liability insurance income in total premium income, and the green bond index is expressed by the proportion of total regional green bond issuance in total bond issuance. The Green Fund Index is expressed as a proportion of the total market value of regional green funds to the total market value of all funds.

This paper selects two mechanism variables of green investment and green technology innovation to explore the effect of green finance reform and innovation policies on urban carbon emissions.

By comparing the differences of carbon emissions between pilot cities and non-pilot cities before and after the implementation of green finance reform and innovation policies, the net effect of policy implementation on carbon emissions in pilot areas is identified. The following model is constructed:

$$CO_{2it} = \alpha_0 + \alpha_1 GFRI\ policy_{it} + \rho X_{it} + \delta_i + \gamma_t + \varepsilon_{it} \quad (3)$$

In the above formula, CO_{2it} is the carbon emission and per capita carbon emission in year t of region i; The core explanatory variable $GFRI\ policy_{it}$ includes the implementation of the Green Finance Reform Innovation policy (GFRI policy) in 2017 and the intensity of the implementation of the policy. Specific for the pilot cities after 2017 green credit index (GFRI policy_credit), green insurance index (GFRI policy_insurance), green bond index (GFRI policy_bond), Green Fund index (GFRI policy_funds).α_0 is the constant term, and α_1 is the doubled-difference estimate, which is the focus of this paper. X_{it} is a set of control variables that affect urban carbon emissions.ρ is the coefficient that controls the variable. δ_i represents the city fixed effect, γ_t represents the year fixed effect, and ε_{it} represents the random disturbance term.

$$Me_{it} = \beta_0 + \beta_1 GFRI\ policy_{it} + \phi X_{it} + \vartheta_i + \varpi_t + \sigma_{it} \quad (4)$$

In the above formula, Me_{it} is the mechanism variable, including enterprise green investment, proportion of enterprise green investment, number of enterprise green patent applications, number of enterprise green patent citations, and proportion of enterprise green patent authorization in the number of green patent applications. β_0 is the constant term, β_1 is the interaction term coefficient, which is the coefficient concerned in this paper, ϕ is the coefficient that controls the variable. ϑ_i、ω_t and σ_{it} are the regional fixed effect, the year fixed effect and the random disturbance term respectively, and the other variables are the same as (1).

3. Results

3.1. Baseline Regression

This paper first examines the impact of green finance reform and innovation policies on carbon emissions. We perform regression on model (1), and the specific results are shown in Table 1. Table 1 shows the regression results of model (1) green finance reform and innovation policy as the core explanatory variable. The results in Table 1 show that GFRI policy significantly reduces regional carbon emissions. Columns (1) and (2) in Table 1 are

regression results of urban carbon emissions as explained variables. The coefficients of GFRI policy in these two columns are -0.210 and -0.413, which are significant at the 5% confidence level. Column (3) and (4) listed regional per capita carbon emissions are regression results of explained variables, and the coefficients of GFRI policy are -1.001 and -1.082, which are significant at the 1% level, indicating that green finance reform and innovation policies are conducive to promoting carbon emission reduction. Hypothesis 1 is verified.

Table 1. Impacts of green finance reform and innovation policies on urban carbon emissions

	(1) CO2	(2) CO2	(3) perCO2	(4) perCO2
GFRI policy	-0.210**	-0.413**	-1.001***	-1.082***
	(0.100)	(0.191)	(0.347)	(0.416)
Constants	3.111***	1.607	10.263***	25.872**
	(0.073)	(3.823)	(0.132)	(12.145)
Controls	YES	YES	YES	YES
Observations	4,560	1,289	3,458	1,289
F	31.641	11.572	19.207	9.964
R-squared	0.190	0.685	0.180	0.245

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively. The fixed effects of year and individual are controlled.

In addition to examining the implementation of green finance reform and innovation policies in Table 1, this article attempts to characterize the intensity of policy implementation by selecting the pilot city green credit index (GFRI policy_credit), green insurance index (GFRI policy_insurance), green bond index (GFRI policy_bond), and green fund index (GFRI policy_funds) as explanatory variables to regress model (1), as shown in Table 2. As can be seen from Table 2, the overall intensity of policy implementation has a significant promoting effect on carbon emission reduction.

Table 2. Impacts of green finance reform and innovation policies on urban carbon emissions

	(1) CO2	(2) CO2	(3) CO2	(4) CO2	(5) perCO2	(6) perCO2	(7) perCO2	(8) perCO2
GFRI	-9.164**				-2.052**			
policy_credit	(4.962)				(0.936)			
GFRI		-1.024***				-2.785***		
policy_insurance		(0.476)				(0.472)		
GFRI			-1.480**				-7.795**	
policy_bond			(0.834)				(3.831)	
GFRI				-1.340***				-3.138***
policy_funds				(0.479)				(1.333)
Constants	3.905**	4.129**	3.647*	3.243	33.428***	33.499***	33.318***	30.679***
	(1.795)	(1.875)	(1.976)	(1.987)	(10.783)	(10.810)	(11.065)	(11.024)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Observations	936	936	936	936	936	936	936	936
F	43.436	38.664	45.236	37.842	55.673	54.583	41.253	35.633
R-squared	0.531	0.512	0.482	0.503	0.664	0.664	0.659	0.659

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively.

3.2. Mechanism Analysis

1. Impact of Green Financial Reform and Innovation Policies on Green Investment

One of the objectives of implementing green financial reform policies is to increase green investment in pilot cities, thereby achieving environmental benefits. This paper selects the database of listed companies from 2000 to 2020 and measures a company's green investment based on the amount of green investments and its proportion in total investment. Regression analysis is performed according to Model (2), and the results are shown in Table 3. Based on the analysis of Table 3, from the perspective of all companies in columns (1) and (4), both the total amount and proportion of green investment by companies are significantly positive. Given that heavily polluting companies are more affected by the GFRI policies, the sample is divided into two categories: heavily polluting and non-heavily polluting companies. Columns (2) and (5) show that both green investment amount and proportion of green investment are significantly positive for heavily polluting enterprises, indicating that GFRI policies have a greater promoting effect on the greening of heavily polluting enterprises. On the other hand, columns (3) and (6) indicate that the regression coefficients for non-heavily polluting companies are not significantly positive, suggesting that the GFRI policy does not have a significant role in affecting non-heavily polluting companies.

Table 3. Analysis of the mechanism for realizing carbon emission reduction through green financial reform and innovation policies

	Amount of green investments			Percentage of green investments		
	(1)	(2)	(3)	(4)	(5)	(6)
	All companies	Heavily polluting companies	Non-heavily polluting companies	All companies	Heavily polluting companies	Non-heavily polluting companies
GFRI policy	0.345**	0.538***	0.154	0.263**	0.401**	0.180
	(0.188)	(0.193)	(0.281)	(0.187)	(0.192)	(0.278)
Controls	YES	YES	YES	YES	YES	YES
Constants	14.823***	15.357***	14.314***	-6.078***	-5.715***	-6.440***
	(0.291)	(0.316)	(0.528)	(0.334)	(0.277)	(0.595)
Observations	2,205	1,077	1,118	2,205	1,077	1,118
F	7.218	18.126	5.567	2.959	5.799	3.728
R-squared	0.224	0.193	0.262	0.166	0.117	0.233

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively. The fixed effects of year, individual and industry are controlled.

2. Impact of Green Financial Reform and Innovation Policies on Enterprises' Green Technological Innovation

The implementation of GFRI policies aims to compensate for the funding required for environmental governance during the development of the real economy. Therefore, by expanding the allocation of financial resources, it can alleviate the funding constraints faced by enterprises in technological innovation and stimulate their enthusiasm for participating in green technology innovation activities. In view of this, this section will focus on analyzing the impact of GFRI policies on enterprise green technology innovation, and conduct regression analysis on the total number of patents and the number of green patents for enterprises based

on Model (2), as shown in Table 4. It can be seen that the total number of patents in column (1) and the number of green patents in column (2) both increased significantly, indicating that the implementation of green finance reform and innovation policies significantly increased the number of green technology innovations by enterprises. Specifically, the regression coefficient for non-heavily polluting enterprises was not significant, which may be due to the relatively sufficient financing channels and financial support for non-heavily polluting enterprises, resulting in a lack of sufficient motivation for green technology innovation.

Table 4. Analysis of the mechanism of green investment for realizing carbon emission reduction through green financial reform and innovation policies

	Total number of patents	Number of green patents		
	(1)	(2)	(3)	(4)
	All companies	All companies	Heavily polluting companies	Non-heavily polluting companies
GFRI policy	0.181***	0.035***	0.084**	0.014
	(0.059)	(0.013)	(0.049)	(0.043)
Constants	2.027***	0.593***	0.377***	0.720***
	(0.149)	(0.026)	(0.115)	(0.088)
Controls	YES	YES	YES	YES
Observations	17,984	33,785	12,447	21,338
F	46.214	980.962	38.332	10.418
R-squared	0.264	0.358	0.376	0.356

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively. The fixed effects of year, individual and industry are controlled.

Table 5. Analysis of the mechanism of green technology innovation for realizing carbon emission reduction through green financial reform and innovation policies

	All companies	Heavily polluting companies	Non-heavily polluting companies	All companies	Heavily polluting companies	Non-heavily polluting companies
	(1)	(2)	(3)	(4)	(5)	(6)
	Number of citations to green patents in the last five years			Green Patent License/Green Patent Application		
GFRI policy	-0.065***	-0.106*	-0.045	-0.493**	-0.437**	-0.487**
	(0.032)	(0.060)	(0.031)	(0.198)	(0.179)	(0.231)
Constants	0.877***	1.005***	0.806***	1.347***	0.986***	1.492***
	(0.092)	(0.087)	(0.072)	(0.404)	(0.365)	(0.492)
Controls	YES	YES	YES	YES	YES	YES
Observations	4,257	1,666	2,591	7,041	2,504	4,537
F	5.549	1.329	9.358	14.851	19.868	20.661
R-squared	0.281	0.219	0.333	0.216	0.260	0.203

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively.

With the greening of the product market, the innovation of green technology can bring greater profits to the enterprise. This "profitability" is likely to become a driving force for enterprises' "greenwashing" behavior, leading them to be more inclined to increase the

Table 6. Inter-industry carbon emission reduction spillover effects under green financial reform and innovation policies

	Key supported industries of green finance										Non-Key supported industries of green finance									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(19)	(20)	(21)
	CO2	tCO2	CO2	CO2	CO2	CO2	tCO2	tCO2	tCO2	tCO2	CO2	tCO2	CO2	CO2	CO2	CO2	tCO2	tCO2	tCO2	tCO2
GFRI policy	-0.081**	-0.081**									-0.056***	-0.056***								
	(0.037)	(0.037)									(0.020)	(0.020)								
GFRI			-1.053**				-1.053**						-1.250**				-1.250**			
policy_credit			(0.924)				(0.924)						(0.563)				(0.563)			
GFRI				-0.032**				-0.032**						-0.105*				-0.105*		
policy_insurance				(0.091)				(0.091)						(0.056)				(0.056)		
GFRI					-0.174**				-0.174**						-0.279*				-0.279*	
policy_bond					(0.247)				(0.247)						(0.148)				(0.148)	
GFRI						-0.130***				-0.130***						-0.099**				-0.099**
policy_funds						(0.089)				(0.089)						(0.055)				(0.055)
Observations	4,925	4,925	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	14,085	14,085	14,085	5,324	5,324	5,324	5,324	5,324	5,324	5,324
F	274.201	63.554	120.163	119.933	120.141	120.753	62.074	61.887	62.056	62.553	923.031	115.972	923.031	248.815	248.430	248.334	248.226	56.207	55.919	55.848
R-squared	0.870	0.543	0.909	0.909	0.909	0.909	0.643	0.643	0.643	0.644	0.882	0.551	0.882	0.884	0.884	0.884	0.884	0.561	0.560	0.560

quantity of green technological innovations without giving much consideration to their quality in order to meet public expectations of green environmental protection. To detect whether enterprises engage in "environmental fraud," this paper conducts regression analysis on the quality of enterprise green technology innovation based on Model (2), and the results are shown in Table 5. We found that the regression coefficient for the quality of green innovation for all enterprises decreased significantly.

4. Discussion

To verify the differences in carbon emission reduction effects and industry spillover effects of green finance reform and innovation policies on various industries, we conducted regression analysis based on Model (1) for both key supported industry enterprises and non-key supported industry enterprises, after screening for a list of key supported industries under the green finance reform and innovation policy. The regression results are shown in Table 6. Analysis of the results indicates that the regression coefficient for enterprises belonging to key supported industries under the green finance reform and innovation policy is significant at the 5% confidence level, demonstrating a significant inhibitory effect of green finance reform and innovation policies on carbon emissions for green industry enterprises. Meanwhile, the regression coefficient for non-key supported industries is significant at the 1% confidence level but with a relatively smaller effect coefficient, indicating the existence of an industry spillover effect.

The development of GFRI policies can screen out leading green industries. Therefore, this paper conducts regression analysis based on Model (1) for enterprises in different industries, as shown in Table 7. It can be observed that the industries most impacted by GFRI policies are concentrated in the construction, textile, transportation, manufacturing, and processing industries. These industries have long relied on fossil energy sources for their survival and development, and their related production technologies, infrastructure, and industrial systems are adapted to fossil energy, resulting in a "high-carbon lock-in" for some

Table 7. Impact of green finance on different sectors

	Industry	Coefficient	Standard error	Observations
Five industries with the greatest impact	E50 Building decoration and other construction industries	-0.4505**	(0.2563)	198
	G54 Road transport industry	-0.2890**	(0.1144)	420
	C37 Railway, shipbuilding, aerospace and other transportation equipment manufacturing	-0.2196***	(0.1107)	575
	C13 Agricultural and sideline food processing industry	-0.2113**	(0.0934)	463
	D44 Electricity, heat production and supply industry	-0.2073**	(0.0995)	861
The four sectors with the least impact	C14 Food manufacturing	-0.1961**	(0.0909)	489
	K70 Real estate	-0.1912***	(0.0975)	1,356
	C39 Computer, communications and other electronic equipment manufacturing	-0.1644***	(0.0484)	3,319
	C35 Automotive manufacturing	-0.1402***	(0.0439)	1,968

Note: Robustness standard errors are in parentheses; ***, ** and * represent significance levels of 1%, 5% and 10% respectively.

industries and making carbon emission reduction difficult for them. However, GFRI policies can not only provide policy and economic support for these industries, but the existence of environmental disclosure systems can also force industries to transition towards green development. The combined effect of these two factors leads to significant carbon emission reduction effectiveness in these industries. On the other hand, the industries with the least impact are mostly high-end manufacturing and service industries. These industries often have higher technological levels, larger financing scales, stronger talent pools, and higher self-advantages, allowing for faster transformation and the carbon emission reduction effect of the impact of GFRI policies is very small.

5. Conclusions

The research results show that the implementation of green finance reform and innovation policies can significantly promote urban carbon emission reduction. Mechanism tests show that the implementation of green finance reform and innovation policies has promoted a significant increase in green investment in pilot cities, especially for heavily polluting enterprises. At the same time, the implementation of this policy has also promoted green technological innovation, but led to a decrease in the quality of green innovation, with a "decoupling" of innovation quantity and quality. Further, it is found that the emission reduction effect of green finance can not only achieve carbon emission reduction in capital-intensive industries, but also achieve carbon emission reduction in non-capital-intensive industries, with significant industry "spillover effects".

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