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The Impact of Green Bond Financing on Regional Ecological and Environmental Resilience: Evidence from 31 Chinese Provinces

Qingxuan He[1], Yuanchun Yu[2], and Luyao Li[3]

[1] School of Management, Sichuan University of Science & Engineering, Yibin, China

[2] Professor, School of Management, Sichuan University of Science & Engineering, Yibin, China

[3] School of Management, Sichuan University of Science & Engineering, Yibin, China

Abstract

Against the background of global climate change and ecosystem degradation, enhancing regional ecological and environmental resilience has become a core goal of ecological civilization construction in China. As a key instrument of green finance, whether green bonds can effectively empower regional ecological and environmental resilience remains to be tested. To address this issue, this paper uses panel data from 31 Chinese provinces from 2013 to 2023, constructs a comprehensive evaluation index system for regional ecological and environmental resilience covering resistance, adaptation, and recovery, and employs a two-way fixed effects model to examine the impact, mechanisms, and heterogeneity of green bond financing on regional ecological and environmental resilience. The results show that green bond financing significantly improves regional ecological and environmental resilience, and this conclusion remains valid after a series of robustness tests. Mechanism analysis shows that green bond financing does not simply provide funds. Instead, it indirectly strengthens regional ecological and environmental resilience by promoting industrial structure upgrading and green technological innovation. Heterogeneity analysis shows that the ecological benefits of green bonds are more prominent in economically underdeveloped regions and regions with smaller populations. Their effect is mainly reflected in the recovery dimension of ecosystems, while the direct effects on resistance and adaptation are not yet significant. This study demonstrates the practical effect of green bonds on ecological governance and provides a basis for more targeted green finance policies from the perspectives of differentiated policy design, investment optimization, and policy coordination.

Keywords

Green Bond Financing; Ecological and Environmental Resilience; Industrial Structure Upgrading; Green Technological Innovation.

1. Introduction

Climate change is picking up pace, extreme weather events are becoming more routine, and ecosystems globally are showing increasingly visible signs of strain-trends that together present serious roadblocks to lasting human development. Ecological resilience, broadly speaking, is about whether an ecosystem can hold its ground when hit by outside pressures, adjust on the fly, and eventually find its way back to a stable state. This idea has been drawing more and more attention in policy and academic circles alike. On the domestic front, as the Beautiful China Initiative moves forward, environmental protection, pollution abatement, and the low-carbon transition have stayed near the top of the agenda. The newly released "15th Five-Year Plan for Beautiful China Construction" emphasizes the need to align industrial restructuring, pollution control, ecosystem conservation, and climate action, all with the aim of cutting carbon and emissions simultaneously, expanding green cover, and sustaining economic

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growth, while steadily improving the ecological fabric. Within this broader policy context, shoring up regional ecological resilience is not just a box to tick for ecological civilization-it is also essential groundwork for high-quality development down the road.

Green finance has become a key lever to guide the economy to develop in a more sustainable direction. Among many financial instruments, green bonds have attracted much attention because of their clearly defined use of funds. By directing funds to clean energy projects, ecological restoration projects and energy-saving transformation and upgrading, green bonds provide practical financial support for improving the regional environmental situation. Existing literature often regards green finance as a general whole, while this study chooses to focus on green bonds - because of its "dedicated funds" characteristics, we can more effectively track whether and to what extent special green funds have effectively improved the resilience of regional ecosystems.

This study uses the panel data of 31 provincial administrative regions in China from 2013 to 2023 to construct a comprehensive index of ecological resilience covering the three dimensions of resistance, adaptability and resilience, and adopts a two-way fixed effect model to empirically test the relationship between green bond financing and regional ecological resilience.

Compared with the existing literature, this article has two main innovations. First of all, the analytical perspective has been expanded. In the past, research on green finance mostly focused on static outcome indicators (such as pollution level, carbon emission reduction or environmental quality), and paid insufficient attention to the dynamic process behind environmental change. By introducing the concept of "resilience" and analyzing it based on the continuous process framework of "resistance-adaptability-resilience", we have not only broadened the scope of investigation of the environmental effects of green bond issuance, but also have a deeper and more detailed understanding of its long-term ecological impact. Secondly, the analysis unit has been refined. At present, the academic research on green finance is mostly based on the macro total level, while this study further focuses on green bonds, a specific financing instrument. This focused perspective enables us to identify the unique impact of a specific tool on regional ecological resilience from the perspective of the design of financial instruments.

2. Literature Review

2.1. Research on Green Bonds

2.1.1. Definition and Development of Green Bonds

With the increasing status of sustainable development and environmental protection in the public and policy agenda, green bonds, as the cornerstone of the green financial system, have attracted wide attention in the academic community. Researchers have explored it from multiple dimensions, including the definition of concepts, the role in the capital market, and the evolution of issuance and trading mechanisms. The existing literature mainly focuses on the following aspects: financing functions, restrictions on the use of funds raised, macro-market dynamics around its development, and the actual environmental results that have attracted much attention in recent years.

Green bonds, in terms of their financing function, are widely seen as a key capital market instrument that helps close the funding gap often encountered by green projects. Achieving sustainable development clearly calls for a mix of financing channels, yet environmentally oriented projects frequently run into high information-processing costs and institutional hurdles when trying to secure external funds. What makes green bonds different is that they combine environmental benefit verification with the standard functions of capital market financing-this dual feature allows them to deliver a comparatively reliable flow of capital to

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climate-positive initiatives, while also steering private and institutional money toward green industries through price signals and market allocation mechanisms (Bhutta et al., 2022)[1]. In this sense, green bonds are more than just a debt-raising tool; they also play an enabling role in nurturing green project development and, more broadly, in advancing the sustainability agenda.

From the perspective of fund usage restrictions, the key difference between green bonds and ordinary bonds lies in the allocation of raised funds to green projects. Green bonds can enforce the specificity of fund usage through institutional arrangements such as project screening, raised fund management, information disclosure, and subsequent supervision (Hong Yanrong, 2022)[4]. This feature gives green bonds clearer environmental objectives and enables them to play a role in areas such as clean energy, pollution control, energy conservation and emission reduction, and ecological restoration. Xu Gao and Cao Jianhai argue that green bonds are an important green financial product for promoting the low-carbon transformation of the real economy and the development of a circular economy (Xu Gao & Cao Jianhai, 2021)[3]. This shows that the core value of green bonds lies not merely in expanding financing scale, but in improving the efficiency of green capital allocation through fund usage restrictions.

From the perspective of market development characteristics, the green bond market has gradually developed relatively distinctive structural features. Liu Yuhan points out that China's green bonds differ significantly from ordinary bonds in terms of project screening, regulatory arrangements, and information disclosure. Issuers are predominantly state-owned enterprises, bond maturities are mostly medium- to long-term, credit rating concentration is high, and product types show a diversified development trend (Liu Yuhan, 2024)[6]. This indicates that China's green bond market has achieved a certain scale and institutional foundation, but still faces issues such as relatively concentrated issuer structures and room for improvement in market balance.

From the perspective of environmental effects, the development of green bonds is reflected not only in financing functions but also in their impact on corporate green governance and regional environmental improvement. Green bond issuance can influence corporate ESG information disclosure and further alter external rating agencies' assessments of corporate green performance (Wang & Liu, 2024)[2]. At the regional level, green bonds can reduce urban carbon emission intensity, with a more pronounced effect in regions with higher financial marketization and weaker environmental regulations (Zhang Ke et al., 2023)[5]. This indicates that green bonds can play an environmental governance role by influencing corporate behavior and regional resource allocation.

Existing studies no longer regard green bonds as a means of financing, but also explore their impact on capital allocation, environmental governance and ecological effectiveness. A key feature of green bonds is that their financial objectives are closely linked to environmental requirements; the funds raised through such bonds are usually invested in green projects, and the regulations on the use of funds and information disclosure may also affect the behavior of enterprises and local governments. It can be seen that green bond financing may affect regional green development through multiple channels. Therefore, relevant research has laid the foundation for exploring its potential impact on the resilience of the ecological environment.

2.1.2. Issuance and Pricing of Green Bonds

Studies on green bond issuance and pricing have largely examined the green premium, the determinants of issuance rates, and the risk-return profile of these bonds. Existing evidence indicates that investor demand for environmentally oriented assets can affect bond pricing. Retail investors, in particular, tend to show stronger interest in green bonds and may accept lower returns, which can result in a measurable green premium. Pricing decisions, however, do not depend on the green label alone. Investors also consider whether the environmental claims are credible and whether the issuer is trustworthy. As a result, the pricing of green bonds

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reflects not only conventional factors such as maturity and credit risk, but also the perceived quality of green information and confidence in the issuer (Pietsch & Salakhova, 2025)[7].

Other studies analyze the primary market pricing mechanism of green bonds from the perspective of specific factors influencing issuance interest rates. Issuance methods and policy support affect green bond issuance interest rates, with bonds backed by stable government subsidies more likely to gain investor recognition (Yang Xiya & Shi Baofeng, 2020)[8]. From the perspective of corporate and regional environments, factors such as the ESG level of listed companies, industry characteristics, and the financial ecosystem of the location also influence green bond issuance interest rates (Guo Shuhua et al., 2022)[9]. Thus, green bond issuance pricing is not determined solely by bond maturity, credit rating, and issuance size, but is also related to policy support, corporate green performance, and regional financial environments.

Other studies discuss the market value of green bonds from the perspectives of return risk and asset allocation. When green bonds are included in green investment portfolios as carbon risk hedging tools, the portfolios perform better in terms of returns and risk hedging effectiveness. Allocating a certain proportion of funds to green bonds aimed at hedging carbon risk can reduce potential portfolio losses to some extent and improve overall investment performance (Qiao Dong et al., 2024)[10]. Although such studies do not directly address the formation of issuance interest rates, they help illustrate the allocation value of green bonds in market trading and risk management.

In summary, existing research has explained the issuance and pricing mechanisms of green bonds from the perspectives of investor preferences, issuance interest-rate determinants, and return-risk characteristics. Green bonds have both financial and green attributes. Their pricing is influenced not only by traditional bond pricing factors, but also by green certification, policy support, corporate environmental performance, market trust, and demand for carbon-risk management. This provides a research basis for subsequent analysis of the ecological and environmental effects of green bond financing.

2.2. Research on Ecological and Environmental Resilience

2.2.1. Measurement of Ecological and Environmental Resilience

Ecological environment resilience refers to the ability of ecosystems to maintain relative stability, adapt to changing conditions and achieve recovery after external shocks, environmental pressures or the impact of human activities. Unlike traditional environmental quality assessments that focus on observations such as pollutant emissions or ecological conditions, the concept of resilience emphasizes how ecosystems respond to interference over time. Therefore, it pays more attention to whether the ecosystem can absorb the impact, make necessary adjustments and restore its function after damage.

Most existing studies assess ecological environmental resilience from the perspectives of resistance, adaptability, and recovery. Resistance describes the extent to which an ecosystem can withstand pressures arising from pollution, resource consumption, and other disturbances. Adaptability concerns its capacity to adjust its structure and functioning as environmental conditions change. Recovery focuses on the restoration of ecological functions and environmental quality after disruption. Taken together, these three dimensions provide a more complete way to capture both the current condition of an ecosystem and its response to environmental risks over time (Bai Limin et al., 2019; Fang Yelin et al., 2022; Zhou Yijing et al., 2025)[11][12].

In terms of specific measurement methods, studies mainly use multi-indicator comprehensive evaluation, ecological footprint methods, single-ratio methods, and entropy methods. Among them, the multi-indicator comprehensive evaluation method is widely used because ecological and environmental resilience itself is multidimensional, and a single indicator cannot fully reflect the overall condition of regional ecosystems. Existing studies generally select indicators

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from aspects such as ecological infrastructure, resource utilization efficiency, pollution emission levels, environmental governance capacity, green space supply, and population pressure (Wang Shaojian et al.,2021;He Xiaorong et al.,2024)[13,14].

As research objects continue to expand, the measurement of ecological environment resilience has gradually extended from urban areas to rural areas and urban-rural integration fields. In studies on rural ecological resilience, the indicator system pays more attention to rural production, living conditions, environmental governance, ecological footprint, and ecological carrying capacity (Wu Wenxu & Wu Yemiao, 2022; Wang Xin, 2023; Cheng Li et al., 2023)[15-17]. This indicates that the measurement of ecological environment resilience needs to be designed in conjunction with the research object, regional characteristics, and data availability.

Existing research has developed relatively mature approaches for measuring ecological and environmental resilience. Resistance, adaptation, and recovery are frequently adopted to describe how regional ecosystems respond to environmental pressure and disturbance. On this basis, multi-indicator evaluation systems are often combined with objective weighting methods such as the entropy method to obtain a comprehensive resilience index. Following this approach, this study uses provincial panel data to construct an ecological and environmental resilience evaluation system covering resistance, adaptation, and recovery, and applies the entropy method to calculate the resilience level of each region.

2.2.2. Influencing Factors of Ecological and Environmental Resilience

Research on the influencing factors of ecological environment resilience mainly focuses on natural conditions, socioeconomic factors, environmental regulations, and urbanization development. From the perspective of natural conditions, topography and vegetation cover are important internal factors affecting ecological environment resilience, capable of enhancing the stability of regional ecosystems to some extent, while water conditions do not always show a positive effect on ecological environment resilience (Tao Jieyi et al., 2022)[18]. From the perspective of rural social-ecological systems, county-level rural ecosystems in underdeveloped regions are more susceptible to resource endowments, governance capacity, and changes in the external environment, exhibiting certain instability (Zhu Yanjun et al., 2022)[19]. From the perspective of policy factors, environmental regulations can effectively enhance local ecological resilience, with formal environmental regulations having a stronger effect than informal ones (Zhang Mingdou et al., 2022)[20]. From the perspective of factor constraints, population, technology, and land affect the improvement of urban ecological resilience, with different factor allocation patterns altering the carrying capacity and regulatory capacity of ecosystems (Lü Tiangui et al., 2023)[21]. Furthermore, there is an interactive relationship between new urbanization and ecological resilience: urbanization can improve ecological resilience through infrastructure improvement and governance capacity enhancement, but it may also bring ecological pressure due to population agglomeration and increased resource consumption (Guo Haihong & Liu Mingxin, 2023)[22].

Overall, ecological and environmental resilience is jointly affected by natural foundations, resource endowments, institutional arrangements, and socioeconomic development levels, and therefore shows clear comprehensiveness and regional heterogeneity.

2.3. Research on the Impact of Green Bond Financing on Ecological and Environmental Resilience

Research on the environmental effects of green bonds has expanded in recent years, although direct studies linking green bond financing with ecological and environmental resilience are still relatively limited. Most of the existing literature examines related outcomes such as green technological innovation, improvements in environmental performance, and regional carbon reduction. These studies provide a useful basis for exploring how green bond financing may affect regional ecological and environmental resilience.

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From the perspective of green technological innovation, green bonds can promote corporate green technological innovation by alleviating financing constraints, increasing R&D investment, and enhancing external attention. Green bond issuance can promote both the quality and quantity of corporate green technological innovation, with larger issuance scales and longer maturities yielding more pronounced effects (Li Boyang et al., 2023)[23]. Green bonds can also support corporate green technological innovation through direct financing (Shen Yue et al., 2023)[24]. This shows that green bonds not only provide funds but also enhance green development capacity through innovation incentives. For regional ecological environment resilience, green technological innovation can improve resource utilization efficiency, reduce pollution emissions, and provide technical support for ecological restoration and environmental governance.

Studies on environmental performance also show positive effects of green bond issuance. In addition to improving the environmental performance of issuing firms, green bonds may influence the behavior of other firms in the same industry. Corporate green bond issuance can encourage industry peers to adopt more environmentally beneficial practices and can generate positive effects on environmental performance (Wu Yuhui et al., 2022)[25]. This suggests that the influence of green bonds is not confined to the projects directly financed by them. Through demonstration effects and market signals, green bond issuance may encourage broader participation in green governance. Since regional ecological and environmental resilience is closely related to the environmental behavior of firms, improvements in corporate environmental performance and the spread of greener practices across industries can help support the stability and recovery of regional ecosystems.

Green bonds also appear to contribute to regional carbon reduction. Green bond issuance can significantly promote regional carbon reduction, with this effect working through greater environmental concern from governments and the public, stronger technological innovation, and higher green total factor productivity (Dong Kangyin et al., 2025)[26]. This finding indicates that the environmental influence of green bonds can extend from individual firms to the regional level. Lower carbon emissions, improved environmental governance, and stronger green productivity can all enhance the capacity of regional ecosystems to withstand shocks, adjust to environmental changes, and recover after disturbance.

Overall,existing studies mainly discuss the environmental effects of green bonds from the perspectives of green technological innovation, environmental performance, and carbon reduction, while paying insufficient attention to ecological and environmental resilience as a comprehensive indicator. Ecological and environmental resilience focuses not only on environmental quality improvement, but also on ecosystems' resistance, adaptation, and recovery under external shocks. Therefore, this paper further examines the impact of green bond financing on regional ecological and environmental resilience and analyzes its mechanisms through industrial structure upgrading and green technological innovation.

3. Theoretical Analysis and Hypotheses

3.1. Direct Impact of Green Bond Financing on Regional Ecological and Environmental Resilience

The provisions of green bonds on the purpose of raising funds help to direct funds to ecological restoration, pollution control, green infrastructure, clean energy and other environment-related projects. Such investments can not only improve resource utilization efficiency and reduce pollutant emissions, but also provide relatively stable financial support for regional environmental improvement. A considerable part of green bond funds flow to renewable energy projects such as wind and solar energy, which helps reduce dependence on fossil fuels and reduce greenhouse gas emissions. With the development of green finance, more funds are

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expected to be attracted to environmentally friendly industries, thus supporting the continuous improvement of regional ecological conditions. These effects show that green bond financing can enhance the ability of regional ecosystems to withstand environmental pressures and recover from disturbances. Based on this, the following assumptions are put forward:

Hypothesis 1: Green bond financing can enhance the resilience of the regional ecological environment.

3.2. Indirect Impact of Green Bond Financing on Regional Ecological and Environmental Resilience

3.2.1. Green Bond Financing, Industrial Structure Upgrading, and Ecological and Environmental Resilience

With the support of regulations on the use of funds raised and policy incentives, green bonds can guide the flow of funds to green industries and reduce the concentration of capital in industries with high pollution and high energy consumption. The funds raised by it can be used for wind power and photovoltaic power generation projects, industrial energy efficiency improvement and transformation, and the research and development of pollution control technology. This kind of targeted financing helps to ease the capital constraints faced by the green industry and creates favorable conditions for the transformation of the industrial structure to a cleaner and more advanced direction.

Changes in industrial structure will also affect the regional environment. The increase in the proportion of low-carbon and resource-efficient industries usually means lower pollution intensity and higher efficiency of energy and other resource utilization. In addition, it can also reduce the emission of wastewater and atmospheric pollutants, and reduce the dependence of economic growth on resource-intensive production models. These changes help reduce environmental pressure and enhance the ability of regional ecosystems to resist and recover from external interference.

Therefore, green bond financing may enhance the resilience of the regional ecological environment by promoting the upgrading of industrial structure. Based on this, the following assumptions are put forward:

Hypothesis 2: Green bond financing enhances the resilience of the regional ecological environment by promoting the upgrading of industrial structure.

3.2.2. Green Bond Financing, Green Technological Innovation, and Ecological and Environmental Resilience

Green bonds can mobilize capital for green technological innovation and provide funding for the development and application of environmentally friendly technologies. Such innovation is closely related to the improvement of regional ecological and environmental resilience. Advances in green technology can raise resource use efficiency, reduce waste and carbon emissions, and lessen the environmental burden associated with economic activities. They can also support the adjustment of industrial production toward cleaner and more efficient modes.

The application and diffusion of ecological restoration and environmental treatment technologies further improve the ability of ecosystems to recover from disturbance. Better technological support can reduce ecological damage, improve environmental carrying capacity, and help regions respond more effectively to external shocks and changing environmental conditions. Green bond financing may therefore strengthen regional ecological and environmental resilience by encouraging green technological innovation. On this basis, the following hypothesis is proposed.

Hypothesis 3: Green bond financing enhances regional ecological and environmental resilience by promoting green technological innovation.

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4. Research Design

4.1. Data Sources

This study uses panel data from 2013 to 2023 of 31 provincial administrative regions in China's mainland (excluding Hong Kong, Macao and Taiwan).The data are collected from the China Urban Statistical Yearbook, China Urban Construction Statistical Yearbook, China Insurance Yearbook, provincial statistical yearbooks and statistical bulletins, as well as the CSMAR database.

4.2. Variable Definitions

4.2.1. Dependent Variable

Regional ecological resilience (eco_res) is measured using an indicator system covering resistance, adaptability, and recovery. These three dimensions are further represented by 13 specific indicators. Following Zhou et al. (2025)[27], this study adopts the resistance-adaptability-recovery framework to describe regional ecological resilience. The entropy method is used to determine the weight of each indicator and calculate the composite resilience index for each region. The detailed indicators are presented in Table 1.

Table 1. Measurement Index System of Ecological and Environmental Resilience

Primary Indicator	Secondary Indicator	Tertiary Indicator
Ecological Environment Resilience Index	Resistance Capacity:The ecosystem's ability to withstand external disturbances (e.g.,pollution, resource consumption)	Proportion of built-up area
		Electricity consumption per unit of GDP
		Industrial wastewater discharge per unit of GDP
		Sulfur dioxide emissions per unit of GDP
		Carbon emissions per unit of GDP
	Adaptability Capacity:The ecosystem's ability to self-regulate and respond to environmental changes	Proportion of days with air quality above Grade II
		Comprehensive utilization rate of industrial solid waste
		Harmless treatment rate of domestic waste
	Recovery Capacity:The ecosystem's ability to return to its original state after being damaged	Green coverage rate in built-up areas
		Per capita park green space area
		Annual average PM2.5 concentration
		Environmental investment as a share of GDP
		Proportion of built-up area

4.2.2. Core Explanatory Variable

For the measurement of regional green bond financing, we take the ratio of green bond issuance to total bond issuance within a given region. This approach captures how prominent green bonds are within the broader bond financing mix, and it also makes cross-regional comparisons fairly straightforward (Xu & Yang, 2025)[28].

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4.2.3. Mediating Variables

This paper selects industrial structure upgrading (upgrade) and green technological innovation (Green_patents) as mediating variables. Industrial structure upgrading is measured by the ratio of the added value of the tertiary industry to that of the secondary industry, which reflects the degree of transformation from an industry-led economy to a service-led economy (Gan Chunhui et al., 2011)[29]. Green technological innovation is measured by the number of green patent grants, reflecting the level of regional green technology R&D and innovation output (Li Qingyuan & Xiao Zehua, 2020)[30].

4.2.4. Control Variables

This study selects population size, economic development level, urbanization level,openness,and fiscal intervention as control variables that may affect ecological and environmental resilience. The specific definitions are shown in Table 2.

Table 2. Variable Definitions

Category	Variable symbol	Variable name	Measurement
Dependent variable	eco_res	Ecological resilience index	Core dependent variable. It is calculated by applying the entropy method to multiple indicators from resistance, adaptation, and recovery dimensions.
Core explanatory variable	green_debt	Green bond financing	Measured by the ratio of regional green bond issuance to total bond issuance.
Mediating variable	upgrade	Industrial structure upgrading	Measured by the ratio of value added of the tertiary industry to value added of the secondary industry.
	Green_patents	Green technological innovation	Number of authorized green patents, in ten thousand.
Control variable	ln_pop	Population size	Natural logarithm of year-end resident population, in ten thousand persons.
	ln_gdp_pc	Economic development level	Natural logarithm of per capita regional GDP, in yuan per person.
	urban_rate	Urbanization level	Ratio of urban population to total year-end resident population.
	ln_trade	Openness	Natural logarithm of total import and export value by business location, in thousand US dollars.
	fiscal_ratio	Fiscal intervention	Ratio of local general public budget expenditure to regional GDP.

4.3. Model Specification

To examine the impact of green bond financing on ecological and environmental resilience, this paper constructs the following two-way fixed effects model:

$$\text{eco_res}_{i,t} = \delta_0 + \delta_1 \text{green_debt}_{i,t} + \sum_{k=1}^{n} \delta_k \, \text{control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

The subscripts i and t stand for region and year, respectively. eco_res is our dependent variable—ecological and environmental resilience-while green_debt takes the role of core explanatory variable. Control covers a set of covariates: population size, urbanization rate, and economic development level, to name a few. mu_i captures individual fixed effects, soaking up time-invariant provincial attributes like geography or cultural factors; gamma_t accounts for

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year fixed effects, sweeping out common macroeconomic shocks. epsilon_it is the usual error term. The coefficient we care most about is delta_1-if it turns out positive and significant, that would point to a beneficial role of green bond financing in enhancing regional ecological resilience.

As mentioned in the previous theoretical discussion, green bond financing may play a role through two indirect channels: green technology innovation and industrial structure upgrading.To put these mediating pathways to the test, we set up the following model specification:

$$\text{upgrade}_{i,t} = \alpha_0 + \alpha_1 \text{green_debt}_{i,t} + \alpha_2 \text{control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

$$\text{eco_res}_{i,t} = \beta_0 + \beta_1 \text{green_debt}_{i,t} + \beta_2 \text{control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

$$\text{Green_patents}_{i,t} = \mathcal{E}_0 + \mathcal{E}_1 \text{green_debt}_{i,t} + \mathcal{E}_2 \text{control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

$$\text{eco_res}_{i,t} = \partial_0 + \partial_1 \text{green_debt}_{i,t} + \partial_2 \text{control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (5)$$

5. Empirical Analysis

5.1. Descriptive Statistics

Table 3 reports the descriptive statistics. The mean value of regional ecological and environmental resilience is 0.681, and the standard deviation is 0.0520. The mean value of green bond financing is only 0.00800, and its standard deviation is relatively small. This indicates that green bonds account for a low share of total bond financing overall, although there are still development differences across regions. Other variables fall within reasonable ranges.

Table 3. Descriptive Statistics

Variable	N	Mean	SD	p50	Min	Max
eco_res	341	0.681	0.0520	0.676	0.615	0.790
upgrade	341	1.442	0.762	1.286	0.665	5.690
green_patents	341	0.115	0.184	0.0500	0	1.288
green_debt	341	0.00800	0.00400	0.00800	0.00200	0.0290
ln_pop	341	8.137	0.840	8.270	5.759	9.450
ln_gdp_pc	341	10.97	0.440	10.92	10.00	12.21
urban_rate	341	0.609	0.123	0.601	0.240	0.896
ln_trade	341	17.70	1.735	17.79	12.65	20.97
fiscal_ratio	341	0.289	0.203	0.232	0.105	1.354

5.2. Baseline Regression

To pin down the effect of green bond financing on regional ecological resilience, we adopt a two-way fixed effects specification. This setup does two things at once: it absorbs time-invariant provincial traits and also accounts for period-specific shocks that hit all regions alike. The net effect of green bond financing can then be identified with a bit more confidence.

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Table 4. Baseline Regression Results

	(1)	(2)	(3)	(4)	(5)
	eco_res	*eco_res*	*eco_res*	*eco_res*	*eco_res*
green_debt	2.116***	2.140***	2.414***	2.560***	2.568***
	(0.797)	(0.787)	(0.829)	(0.800)	(0.809)
ln_pop		-0.195***	-0.229***	-0.240***	-0.241***
		(0.047)	(0.052)	(0.055)	(0.055)
ln_gdp_pc			0.047	0.038	0.027
			(0.030)	(0.030)	(0.033)
urban_rate				0.116	0.121
				(0.103)	(0.103)
ln_trade					0.002
					(0.005)
fiscal_ratio					-0.045
					(0.061)
_cons	0.664***	2.248***	2.012***	2.122***	2.230***
	(0.006)	(0.384)	(0.417)	(0.438)	(0.470)
Prov_FE	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes
N	341	341	341	341	341
r2_a	0.840	0.848	0.849	0.850	0.849
F	7.056	13.454	9.574	7.397	5.122

Note: Robust standard errors clustered at the provincial level are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The same applies below.

Table 4 shows the results of the benchmark regression, in which the control variables are included in each column in turn. Column (1) is not included in the control variable. The result shows that the coefficient of `green_debt` (green bond financing) is 2.116, which is significant at the level of 1%; this initially indicates that there is a positive correlation between green bond financing and regional ecological resilience. With the addition of control variables from column (2) to column (5) one by one, the coefficient increased from 2.116 to 2.568 and remained at the significance level of 1%. The conclusion drawn from this is obvious: whether the control variables are included or what control variables are included, green bond financing continues to show significant positive effects, thus strongly supporting hypothesis 1.

5.3. Robustness Tests

Are the benchmark results really reliable? Or is it just a man-made result caused by model setting, sample selection or failure to consider endosity?To put that question to the test, we run a series of robustness checks, with the main findings laid out in Table 5.

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Table 5. Robustness Test Results

	(1)	(2)	(3)	(4)
	Excluding pandemic-period sample (2019-2022)	Excluding municipalities	First difference of core variable	PSM matching
	eco_res	*eco_res*	*D.eco_res*	*eco_res*
green_debt	2.422***	2.937***		2.749**
	(0.912)	(0.939)		(1.243)
L.eco_res				
L.green_debt				
D.green_debt			1.675**	
			(0.662)	
ln_pop	-0.217***	-0.240***	-0.036	-0.051
	(0.064)	(0.052)	(0.056)	(0.088)
ln_gdp_pc	0.067*	0.045	-0.046*	0.030
	(0.037)	(0.033)	(0.026)	(0.050)
urban_rate	-0.029	0.025	0.186	0.138
	(0.108)	(0.149)	(0.133)	(0.198)
ln_trade	0.002	0.001	0.004	-0.020**
	(0.006)	(0.005)	(0.005)	(0.009)
fiscal_ratio	0.025	-0.022	-0.120	0.096
	(0.071)	(0.056)	(0.079)	(0.103)
_cons	1.647***	2.112***	0.665	1.010
	(0.523)	(0.461)	(0.533)	(0.684)
Prov_FE	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes
N	248	297	310	195
r2_a	0.848	0.849	-0.045	/
F	3.124	4.882	1.597	/
ar1_p	/	/	/	0.847
ar2_p	/	/	/	1.860

5.3.1. Excluding the Pandemic-Period Sample

One might reasonably ask whether the COVID-19 pandemic-which ran roughly from the end of 2019 to 2022-distorted the economic landscape across all regions in ways that could muddy our estimates. To rule out that possibility, we simply drop those years from the sample and re-estimate the model on the remaining data.Column (1) shows that the coefficient of green_debt is 2.422 and significant at the 1% level, indicating that the core conclusion is not driven by this special external shock.

5.3.2. Excluding Municipality Samples

After further excluding municipality samples, Column (2) shows that the coefficient remains 2.937 and significant at the 1% level, indicating that the conclusion is not driven by a few special regional samples.

5.3.3. First-Difference Model of the Core Variable

After applying the first-difference model, Column (3) shows that the coefficient of the change in green bond financing is 1.675 and significant at the 5% level. This further verifies the robustness of the conclusion from a dynamic-change perspective.

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5.3.4. PSM Matching

To mitigate reverse-causality concerns, we replace the contemporaneous green bond variable with its one-year lag. The coefficient on L.green_debt is 3.417 and significant at the 5% level, suggesting two things: the ecological effect of green bond financing takes time to materialize, and it is unlikely that current resilience levels would have influenced bond issuance a year earlier.The control variables are consistent with the benchmark model - the average population size, income and urbanized water show significant positive effects, thus confirming the core conclusion. We also adopted the systematic GMM (Generalized Moment Estimation) method to further deal with endogene and dynamic characteristic problems. The results show that ecological resilience shows strong sustainability over time; at the same time, green bond financing in the lag period still has a positive effect, indicating that the impact has a cross-term continuity. Overall, the estimated results of the lag variable model and the GMM model strongly support the conclusion that green bond financing has a stable and positive effect on regional ecological resilience.

In the tendency score matching (PSM) analysis, we divide each region into the processing group and the control group according to whether the scale of green bond issuance is higher than the sample median. The standardized deviation chart before matching (the left panel of Figure 1) shows that there are significant differences between the two groups in the covariables; after matching, these deviations are greatly reduced and within the acceptable range, confirming that the balance test has been passed. The nuclear density map (right panel) also shows that the overlap of the matched distribution in the common support area has increased significantly, indicating that the selection bias has been alleviated and the common support hypothesis has been met.

Based on the matched sample, the regression result shows that the coefficient of the green bond financing variable (green_debt) is 2.749 and the statistics are significant, which shows that after controlling the sample selection bias, green bond financing can still significantly improve the resilience of the regional ecological environment.

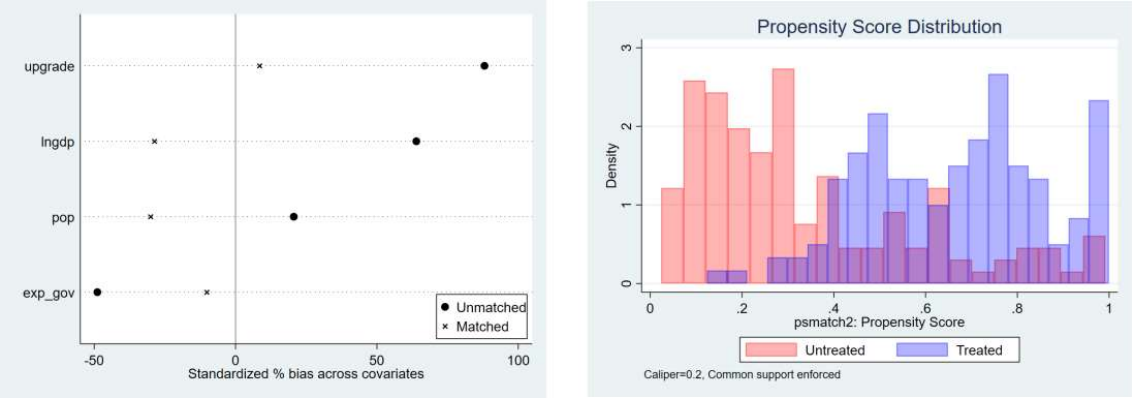


Figure 1. PSM Matching

5.4. Endogeneity Test

In order to test the possible endogenous problems in the relationship between green bond financing and regional ecological environment resilience, this paper adopts two methods: regression of the core explanatory variables after the first phase, and using System GMM.

In response to potential endogenous problems - especially inverse causality - we re-estimated the model by using the lagging green bond financing as a core explanatory variable. The results show that the coefficient of the lag term (L.green_debt) is 3.417, which is significant at the level of 5%. This discovery has two meanings: first, it shows that the ecological benefits of green bond financing do not appear immediately, but there is a certain time lag; second, it alleviates

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the concern about the reverse causal relationship in the same period to a certain extent. After all, the current level of ecological resilience in a region is unlikely to affect the green a whole year ago. Decision-making on the issuance of color bonds. At the same time, the symbol and significance level of each control variable are consistent with the benchmark regression; the population size, economic development level and urbanization rate continue to show a positive and significant correlation with ecological resilience, which further confirms the robustness of our core conclusions.

Table 6. Endogeneity Test Results

	(1)	(2)
	Lagged core explanatory variable	System GMM
	eco_res	*eco_res*
green_debt		1.453**
		(0.625)
L.eco_res		0.822***
		(0.047)
L.green_debt	3.417**	
	(1.721)	
D.green_debt		
ln_pop	-0.346***	-0.007
	(0.052)	(0.005)
ln_gdp_pc	0.062***	0.010*
	(0.020)	(0.006)
urban_rate	0.361***	-0.063*
	(0.106)	(0.032)
ln_trade	-0.001	0.002
	(0.004)	(0.002)
fiscal_ratio	-0.039	-0.034*
	(0.069)	(0.017)
_cons	2.600***	0.078
	(0.467)	(0.049)
Prov_FE	Yes	Yes
Year_FE	Yes	Yes
N	310	310
r2_a	0.864	/
F	81.459	89689.402
ar1_p	/	/
ar2_p	/	/

In order to further test the endogeneity and examine the dynamic effect, we adopted the system GMM estimation method. The results show that the ecological resilience of the lag period has a significant positive impact on the current level, reflecting a strong time continuity. At the same time, green bond financing in the sluggish period also shows obvious positive effects, which shows that the role of green bonds in promoting ecological resilience is not a one-time event, but a cross-term continuity. This estimation strategy helps to alleviate the remaining endogensic concerns and enhances our confidence in interpreting the relationship between the two as a causal relationship.

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Overall, the results of lag variable regression and system GMM estimation point to the same overall conclusion: green bond financing has a steady positive impact on the resilience of the regional ecological environment.

6. Further Analysis

6.1. Mediating Effect Test

Table 7. Mediating Effect Test Results

	(1)	(2)	(3)	(4)
	upgrade	*eco_res*	*green_patents*	*eco_res*
green_debt	8.574*	2.379***	8.902***	1.962***
	(5.163)	(0.858)	(2.361)	(0.570)
upgrade		0.022**		
		(0.010)		
green_patents				0.025*
				(0.014)
ln_pop	0.122	-0.244***	0.758***	-0.289***
	(0.308)	(0.051)	(0.204)	(0.049)
ln_gdp_pc	-0.810***	0.045	0.561***	0.074***
	(0.187)	(0.032)	(0.068)	(0.018)
urban_rate	-3.402***	0.196**	-2.421***	0.265***
	(0.544)	(0.096)	(0.368)	(0.093)
ln_trade	0.125***	-0.001	0.016	-0.002
	(0.030)	(0.005)	(0.018)	(0.004)
fiscal_ratio	1.081***	-0.069	0.730***	-0.005
	(0.315)	(0.053)	(0.181)	(0.044)
_cons	8.807***	2.036***	-11.289***	2.074***
	(2.625)	(0.442)	(1.723)	(0.434)
Prov_FE	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes
N	341	341	341	341
r2_a	0.974	0.851	0.777	0.846
F	29.713	5.037	37.704	99.944

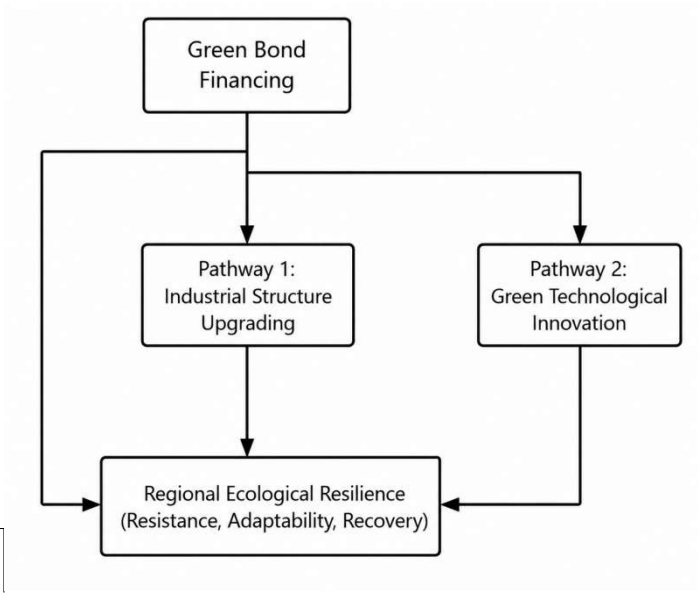


Figure 2. Mediating-Variable Paths

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The empirical findings above do suggest that green bond financing gives a significant boost to regional ecological resilience. But that still leaves a key question unanswered—how exactly does this effect come about? To shed light on the underlying transmission channels, we bring two mediating factors into the analytical framework: green technological innovation, on the one hand, and industrial structure upgrading, on the other.

Equations (2) and (3) are used to test the role of industrial structure upgrading, and the results are reported in Columns (1) and (2) of Table 7. The coefficient of green bond financing on industrial structure upgrading is 8.574 and significant, indicating that green bond financing effectively promotes the transformation of regional industrial structures toward service-oriented and advanced development. This supports Hypothesis 2.

Green technology innovation is widely regarded as the pillar of green transformation. It can improve resource utilization efficiency, strengthen source pollution control, reduce emissions, and help create a cleaner urban environment. The data in columns (3) and (4) of Table 7 clearly show the intermediary effect of this channel. This shows that green bond financing can stimulate technological innovation in the environmental field, which in turn promotes macroeconomic development in a greener direction - a model that provides strong support for hypothesis 3.

6.2. Heterogeneity Tests

In order to further explore the mechanism of green bond financing affecting the resilience of the regional ecological environment, this section carries out heterogeneity testing from the three perspectives of economic development level, population size and regional ecological resilience dimension.

6.2.1. Heterogeneity by Regional Economic Level

Table 8 shows the results of heterogeneity analysis based on the dimension of economic development level. The study is bounded by the median GDP per capita, and divides the whole sample into two groups: the economically underdeveloped area group and the economically developed area group.

Estimates show that there is a significant difference between the two groups. In the group of underdeveloped areas, the coefficient of green bond financing is 4.479, and the statistics are significant at the level of 1%, indicating that it has a steady positive effect on regional ecological resilience. In contrast, in the more developed regional group, although the coefficient symbol is positive, it does not reach the level of significance, which implies that even if there is some beneficial effect, its effect is quite weak.

This difference reveals that there are obvious regional heterogeneities in the ecological benefits of green bond financing: that is, the improvement in areas with lower levels of economic development is more significant. What could be the cause of this phenomenon? A reasonable explanation is that ecological compensation projects and green finance policies tend to lean more towards underdeveloped regions, and this close synergy with green bond initiatives may amplify the overall policy effectiveness. Another factor worth considering is that underdeveloped areas face more severe financial constraints on environmental governance projects; against this background, the injection of green bond funds can often produce higher marginal returns - each unit of funds can play a greater role when making up for the existing gaps in biological restoration and pollution control. Utiality.

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Table 8. Heterogeneity Analysis by Economic Development Level

	(1)	(2)
	Economically underdeveloped (per capita GDP below the national median)	Economically developed (per capita GDP above the national median)
	eco_res	eco_res
green_debt	4.479***	1.301
	(1.433)	(1.058)
ln_pop	-0.444***	-0.131
	(0.074)	(0.115)
ln_gdp_pc	0.033	0.051
	(0.048)	(0.051)
urban_rate	0.669***	0.221
	(0.224)	(0.152)
ln_trade	0.005	-0.019
	(0.006)	(0.015)
fiscal_ratio	-0.131**	0.125
	(0.066)	(0.139)
_cons	3.386***	1.388
	(0.574)	(1.047)
Prov_FE	Yes	Yes
Year_FE	Yes	Yes
N	164	173
r2_a	0.855	0.855
F	8.281	0.631

6.2.2. Heterogeneity by Population Size

Table 9 further groups the samples according to the size of the population. The analysis takes the standard of whether the resident population at the end of the year exceeds the national average, divides the sample into areas with small population and large population, and examines the differentiated impact of green bond financing on the resilience of the ecological environment.

After grouping by population size, the results showed significant differences. In areas with low population density, the coefficient of green bond financing is as high as 4.958, which is significant at the level of 1%; this strongly shows that green bonds play an important role in improving the ecological resilience of these areas. In contrast, in more populous areas, the coefficient has dropped to only 0.309 and is not statistically significant, which means that the impact of green bonds in such areas is minimal. How to explain this difference? A reasonable inference is that ecosystems in low-population areas tend to have weak initial resilience - which may be due to weak infrastructure, single economic activity or insufficient capacity of environmental management systems. Under such conditions, given the low benchmark level of ecological resilience, the injection of green financing may generate disproportionately high marginal returns in system recovery. In other words, the same amount of green bond funds may be more effective in areas with more fragile ecological benchmarks, because there is more room for improvement in these areas.

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Table 9. Heterogeneity Analysis by Population Size

	(1)	(2)
	Smaller population (year-end resident population below national average)	Larger population (year-end resident population above national average)
	eco_res	*eco_res*
green_debt	4.958***	0.309
	(1.309)	(1.080)
ln_pop	-0.349***	-0.246**
	(0.068)	(0.104)
ln_gdp_pc	0.021	0.153***
	(0.043)	(0.047)
urban_rate	0.274**	-0.438**
	(0.114)	(0.221)
ln_trade	0.005	-0.008
	(0.007)	(0.012)
fiscal_ratio	-0.146**	0.461***
	(0.064)	(0.141)
_cons	2.814***	1.487
	(0.519)	(0.910)
Prov_FE	Yes	Yes
Year_FE	Yes	Yes
N	165	176
r2_a	0.848	0.870
F	7.107	2.611

6.2.3. Heterogeneity across Dimensions of Ecological and Environmental Resilience

Table 10 further refines the analysis and examines the three components of ecological and environmental resilience: resistance, adaptability and resilience. First of all, let's look at the resistance dimension. The estimated coefficient of green bond financing is 1.522, but it has not reached the statistical significance level. The situation of the adaptive force dimension is similar. Its coefficient is -0.388, which also does not reach the conventional significance level. Overall, these two sets of results show that, at least at this stage, green bond financing has not had a significant impact on the ecosystem's ability to withstand external interference or adapt to environmental changes.

In contrast, the results of the resilience dimension are particularly prominent. The coefficient of this dimension jumped to 4.378, which was significant at the level of 5%; this clearly shows that green bond financing has played a substantial role in enhancing the resilience of ecosystems after the impact. This model reveals a fairly clear characteristic of capital investment: green bond funds seem to flow mainly to restoration-oriented projects, such as ecological restoration, pollution control and green space expansion. The core goal of such initiatives is to repair damaged ecosystems and promote their recovery after the impact, rather than focusing on preventing damage from the source. In other words, its path of action seems to be more reflected in "governance" than "prevention"-this difference is of important significance for how to optimize green bond-related policies in the future.

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Table 10. Heterogeneity across Dimensions of Ecological and Environmental Resilience

	(1)	(2)	(3)
	resistance_capacity	*adaptation_capacity*	*recovery_capacity*
green_debt	1.522	-0.388	4.378**
	(0.963)	(1.646)	(1.715)
ln_pop	-0.059	-0.383***	-0.376***
	(0.057)	(0.098)	(0.102)
ln_gdp_pc	0.056	-0.104*	-0.060
	(0.035)	(0.060)	(0.062)
urban_rate	0.467***	0.140	0.559***
	(0.101)	(0.174)	(0.181)
ln_trade	-0.011**	-0.022**	0.004
	(0.006)	(0.009)	(0.010)
fiscal_ratio	-0.028	-0.177*	-0.107
	(0.059)	(0.100)	(0.104)
_cons	0.446	5.370***	3.899***
	(0.489)	(0.837)	(0.872)
Prov_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	341	341	341
r2_a	0.847	0.850	0.804
F	6.066	6.031	4.458

7. Conclusion and Policy Implications

This study uses panel data from 31 provinces in China from 2013 to 2023 to empirically examine the impact of green bond financing on the resilience of regional ecological environment and its mechanism. By adopting a two-way fixed effect model, supplemented by robustness test and heterogeneity analysis, we draw the following main conclusions:

First, green bond financing has a significant positive impact on regional ecological resilience. The benchmark regression coefficient is 2.568 (significant at the 1% level), and the result remains robust in multiple robustness tests, indicating that this relationship is not caused by model setting or sample composition deviation.

Second, the ecological benefits brought by green bond financing are more significant in economically underdeveloped areas and areas with small populations. Further dimensional analysis reveals an interesting phenomenon: green bond financing mainly enhances the resilience of the ecosystem, while the direct impact on resistance and adaptability is relatively weak. This shows that more funds may flow to projects such as ecological restoration and pollution control that focus on "post-recovery" than to take measures to actively build resilience.

Third, green bond financing also plays an indirect role by accelerating the upgrading of industrial structure and stimulating green technology innovation. In other words, the role of green bonds is not limited to filling the capital gap, but also to strengthen the regional ecological governance capacity through structural transformation and the promotion of clean production technology.

Based on the above conclusions, we put forward the following policy suggestions:

First of all, differentiated green bond policies should be formulated according to the actual regional situation, focusing on ecologically fragile areas and economically lagging areas. Given that the positive effect of green bond financing is more significant in underdeveloped and

sparsely populated areas, policymakers can consider using tools such as risk compensation funds to guide more funds to flow to central and western provinces and ecologically fragile areas. This will help ease the financing constraints faced by green projects in these regions, improve the efficiency of green capital allocation, and promote the balance of ecological development between regions.

Secondly, the investment of funds raised by green bonds should be optimized to effectively enhance the overall resilience of the ecosystem. At present, green bond funds are mainly concentrated in areas that focus on ecological restoration, such as ecological restoration and pollution prevention, and there is still huge room for improvement in improving the resilience and adaptability of ecosystems. If climate-adaptive infrastructure, biodiversity conservation and green city construction can be included in the green bond project catalog, capital flows to broader resilience construction goals can be guided.

Third, it will be of great benefit to establish a cross-policy coordination framework that coordinates green finance, technological innovation and industrial upgrading. By establishing a cross-departmental coordination mechanism, we can promote the deep integration of green bond policies with industrial development strategies and science and technology plans, so as to amplify the synergy of various policies and measures.

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