# POLICY EMPOWERMENT AND GREEN TECHNOLOGY TRANSMISSION IN CHINA: THE ROLE OF DUAL EXECUTIVE ENVIRONMENTAL PERCEPTIONS

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**Abstract.** This study conducted an analysis based on the panel data of 726 A-share listed companies in China from 2012 to 2021, and also incorporated indicators such as green patents and R&D investment at the enterprise level. This study employs a two-way fixed-effect model and treats executive environmental perceptions as both a moderator and a threshold variable to explore how environmentally focused financial policies promote the development of sustainable technologies within corporations. Key findings include: First, the demand for green finance significantly impacts the advancement of enterprise green technological innovation. Second, executive environmental perceptions enhance the marginal effect of financial tools on these innovations. Third, mediation analysis indicates that constraints in funding and R&D investments act as intermediaries in the relationship between green finance and the progress of corporate green technology. Finally, a segmented analysis shows that state-owned enterprises, larger firms, and those in the eastern areas are more receptive to incentives associated with sustainable finance.
**Keywords:** *green finance, enterprise green technological innovation, executive environmental perceptions, signaling theory, financing constraints, R&D investment*

## Introduction

Over the past few decades, the rapid progress of industrialization has worsened problems like environmental deterioration and resource exhaustion, thus affecting social and economic growth (Li et al., 2025; Wang et al., 2025c). Global organizations increasingly acknowledge the need to balance economic growth with ecological sustainability (Wang et al., 2024d), and are committed to the search for methods and measures in favor of sustainable development (Wang et al., 2024c). For example, some countries, including the UK, are actively engaged in international climate governance, working together to achieve the goals of the Paris Agreement (Buylova et al., 2024). The European Union has accelerated the innovation and deployment of net-zero technologies through the Green New Deal Industrial Programme and the Net-Zero Industry Act (Obobisa and Ahakwa, 2024). The United States is focusing on decarbonizing the transport sector, promoting the construction of electric vehicle charging networks, and increasing the development of offshore wind energy resources (Hoehne et al., 2023). The Republic of Korea has also put forward a carbon-neutral strategy for the industrial sector, with technological innovation leading the green transition (Park et al., 2025). As the most populous developing nation globally, China has proactively embraced its role as a major player in advancing green innovation and attaining sustainable economic growth (Wang et al., 2024b). In recent years, China has been continuously promoting the greening process (Li et al., 2024e). Green finance—characterized by its environmental orientation


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and innovative mechanisms—has emerged as a vital instrument in steering China's economic transition (Hu et al., 2023). It channels investment into sustainable projects, supports environmentally responsible enterprises, and incentivizes corporate green innovation (Wang, 2024; Liu et al., 2024). In October 2023, at the Party's Central Financial Work Conference, China regarded green finance as the main content of building a financial power. Green finance channels investment into sustainable projects, aligns production factors with environmental goals, supports the green sector, enhances resource allocation, and fosters corporate innovation in green technologies (Fang and Shao, 2022). In China, green finance is pivotal in fostering sustainable economic growth. It catalyzes improving the allocation of resources and promoting innovations in green technology throughout diverse sectors (Zhou et al., 2023). This financial strategy has ignited creativity among companies, bolstered their competitive edge, shifted the emphasis from simple replication to genuine innovation, and motivated Chinese businesses to wholeheartedly adopt green technological practices (Alamgir and Cheng, 2023).

Scholars have thoroughly investigated how green finance affects corporate innovation within sustainable technologies. However, a significant portion of this analysis tends to focus on external elements, such as green financial policies (Wang et al., 2023) and environmental regulations (Wang et al., 2024a). The successful integration of green technology innovations in organizations primarily depends on the expertise and skills of the employees, especially the senior management team, who are essential to driving this initiative forward (Wang et al., 2025a). According to the theory of high-ranking echelon, as a non-fully rational person, when encountering very complex problems and situations that are difficult to fully understand, the existing knowledge, experience, and the mindset of executives significantly influence strategic decisions and assessments of future development trends in enterprises. The environmental awareness of executives, especially their attitude towards environmental responsibility and sustainable development, will directly affect the strategic choice and implementation of green technology innovation (Chen et al., 2024). Environmentally aware leaders typically possess a deep sense of obligation, a spirit of innovation, and a risk appetite, amidst uncertainty and temporary economic challenges, businesses are increasingly inclined to incorporate environmental stewardship into their strategic planning (Li et al., 2024d). This trend drives them to make choices that not only support ecological sustainability but also enhance their long-term viability. As a result, this mindset significantly influences the company's readiness to invest in green technological advancements (Liu and Cao, 2025). Rises and helps them to occupy a favorable position in the market environment that is becoming more and more environmentally oriented. This study explores green finance, executives' environmental views, corporate green-tech innovations, and their mechanisms in prefecture-level cities. This study employs a fixed-effects model to examine A-share listed firms in China for 2012 to 2021, concentrating on three key questions: (1) In what ways does green finance incentivize companies to increase their investments in green technology development? (2) What part do executives' views on environmental issues play in connecting green finance initiatives with advancements in green technology within enterprises? (3) Do factors such as ownership rights, business scale, and location affect the varying effects of green finance on corporate innovation in green technology?

This paper aims to shed light on several key contributions in the following domains: (1) from a theoretical perspective, it advances the integration of signaling theory with upper echelons theory by investigating how executives interpret and transmit policy signals related to green finance, thereby influencing firm-level green technological innovation.


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While existing literature has mostly focused on macro-policy tools and external constraints, our study highlights a micro-foundation of sustainable finance transmission through managerial cognition. (2) From a methodological angle, the study introduces a novel textual measure of executives' environmental perceptions based on the frequency of green-related terms in annual reports. This data-driven approach offers a replicable and scalable method for capturing managerial environmental orientation, which is often unobservable in standard datasets. (3) In terms of variable construction, existing studies often rely on subjective weighting methods—such as the analytic hierarchy process or simple weighted averages—which may overlook dynamic relationships and introduce bias. To address this, our study employs an entropy-weighting technique to construct a multi-dimensional index of green finance. This index incorporates seven components: green credit, green bonds, green insurance, green investment, green funds, green support, and trading rights, providing a more robust and comprehensive assessment of green financial development. (4) In terms of empirical design, we use city-level green finance indicators and panel data from over 700 listed firms, allowing us to examine regional heterogeneity and institutional asymmetries in policy responsiveness. The integration of firm-level behavioral proxies with meso-level financial policy metrics contributes to bridging the macro–micro analytical gap in the field.

## Theoretical frameworks and research hypotheses

### *Analyses based on signaling theory*

Signaling theory elucidates how green finance mitigates pervasive information asymmetries in markets, where external stakeholders struggle to discern firms' authentic environmental commitments (Wang et al., 2025b). As a distinctive financial mechanism, green finance enables firms to transmit credible signals of environmental responsibility, enhancing investor confidence and directing capital toward sustainable projects (Huang et al., 2019). This signaling function operates through three interconnected pathways: First, at the policy level, green finance signals regulatory priorities for sustainable development, compelling firms to align strategic investments with ecological civilization goals (Bhutta et al., 2022). Second, through structural realignment, green finance elevates financing standards that systematically disadvantage high-pollution enterprises (Xu and Li, 2020), while channeling capital to green sectors to optimize resource allocation (Yu et al., 2021). Crucially, third, green finance corrects fundamental capital market failures. Traditional finance often neglects green innovation due to perceived long payback periods and risks (Xu et al., 2023b), but green finance overcomes this by highlighting social benefits and directing funding to environmentally committed firms (Hu et al., 2021). Collectively, these signaling mechanisms transform green finance into a powerful catalyst for corporate green technological innovation by resolving information frictions across policy, industrial, and financial dimensions. Given this framework, we now put forth Hypothesis 1.:

H1: Green finance significantly promotes enterprise green technological innovation by reducing information asymmetries and sending credible policy signals.

### *Analyses based on advanced ladder theory*

The upper echelons theory establishes that top managers' personal traits critically shape organizational strategic decisions. Recent research particularly examines how executives drive sustainable technology adoption, revealing distinct behavioral patterns


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(He et al., 2021). Environmentally aware executives leverage their judgment to evaluate long-term ecological value, transforming environmental policies into strategic opportunities rather than compliance burdens (Huang et al., 2020; Li et al., 2023a). Their acquired green knowledge progressively molds environmental cognition (Singh et al., 2020), which becomes embedded in core values and strategic decision-making (Huang and Wei, 2023). Crucially, such executives proactively integrate environmental responsibility into corporate governance, reconfigure resources toward green innovation, and enhance operational sustainability (Cao et al., 2021). When externally engaging with green finance mechanisms, executives with heightened environmental cognition effectively decode policy signals, utilizing instruments like green credits and bonds to secure innovation funding (Jia et al., 2023). Internally, they catalyze organizational green transformation by internalizing environmental values, disseminating green consciousness across hierarchies, and fostering collective green innovation practices (Huang and Wei, 2023; Zhang et al., 2023b). This cognitive leadership transforms green finance from mere capital provision into a strategic innovation accelerator. Conversely, executives prioritizing short-term gains undermine green finance ecological potential by neglecting long-term environmental stewardship (Zhang et al., 2023c), highlighting how cognitive orientation determines green finance innovation efficacy. In light of the prior analysis, this paper posits the following hypothesis:

H2a: Executives' environmental perceptions positively moderate the relationship between green finance and enterprises' green technological innovation.

H2b: The marginal impact of green finance on innovation is stronger when executives' environmental perception levels are below a specific threshold, indicating a nonlinear moderating effect.

### *Analyses informed by theories of funding limitations and resource distribution*

Green finance overcomes critical barriers to sustainable innovation by fundamentally restructuring capital allocation dynamics (Fu et al., 2023). Traditional finance often avoids green technology investments due to information asymmetries, market inefficiencies, and inherent risks (Xu and Li, 2020; Biehl et al., 2022), exacerbated by long return cycles and high uncertainty (Du et al., 2022)—constraints that starve innovators of essential funding (Liu et al., 2022). Green finance addresses this through specialized instruments (green loans, bonds, insurance) that directly alleviate financing constraints via lower capital costs, extended repayment terms (Zhu et al., 2023), and risk-sharing mechanisms (Liu and He, 2023). Concurrently, green finance strategically channels capital to sustainability-focused enterprises (Yin et al., 2023), strengthening their financial capacity to increase research and development investment while facilitating access to complementary knowledge and partnerships (Cui and Peng, 2022). By targeting competitive entities in high-potential sectors (Hu and Zhang, 2023), green finance optimizes resource distribution toward advanced green technologies, ensuring sustained innovation funding while mitigating project risks (Zhang et al., 2024). This dual-pathway approach—easing financing constraints while amplifying research and development investment—collectively empowers firms to enhance eco-innovation capabilities, secure market advantages (Zhang and Wei, 2024), and achieve ecological-commercial balance (Li et al., 2024b). Drawing from this analysis, we propose Hypotheses 3a and 3b for additional exploration in this study:

H3a: Green finance enhances green technological innovation by alleviating firms' financing constraints.


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H3b: Green finance promotes green innovation by increasing the intensity of R&D investment, serving.

## Materials and methods

### *Primary variables*

*Elucidated variable: Enterprise Green Technology Innovation (EGTI)*

In the realm of EGTI assessment, contemporary strategies have resulted in the creation of diverse measurement tools. Key indicators include the number of green patents registered (Li et al., 2024c; Zhao et al., 2021), the amount of funding allocated for research and development (Mohnen, 2019), and the proportion of total energy consumed to the economic worth generated by innovative products (Chen et al., 2019), to name just a few. Each metric provides a distinct perspective, yet when it comes to evaluating a firm's innovation prowess, the simplest and most telling gauge is the number of patent applications submitted (Xu and Cui, 2020). This measure is highly regarded in academic circles because of its straightforward quantification and relative stability. This research underscores that the quantity of green invention patent applications submitted by companies serves as a key barometer of their commitment to fostering sustainable technology. It is worth emphasizing that some companies might opt not to file any green patent applications whatsoever. To counteract possible biases in the data, we employ the logarithm of the total patent filings (post-adding one), guaranteeing the statistical analysis stays robust and reliable.

*Green finance (GF)*

At present, GF products continue to develop and mature, and relevant research on green finance is increasingly abundant. In this research, building upon the contributions of Huang et al. (2022), in developing a GF index, a comprehensive evaluation is performed, This evaluation centers around seven key components: green credit, green bonds, green insurance, green investments, green funds, green support, and the associated rights and interests in environmental projects. Detailed measurement criteria are provided in *Table 1*. The entropy-weight approach quantifies every indicator for appraising the progress of GF.

*Moderating variable and threshold variable: executives' environmental perceptions (EEP)*

This study captures executives' environmental perceptions (EEP) by performing a textual analysis of annual reports. Drawing on the approach developed by Li et al. (2023b), we focus on three core dimensions: the recognition of environmental competition, commitment to social responsibility, and responsiveness to external ecological pressures. Based on this framework, we construct an environmental keyword lexicon including terms such as environmental protection strategy, energy efficiency and emissions reduction, environmental governance, green innovation, and environmental management systems. Two operational variables are developed. First, a binary indicator (EEP1) is assigned a value of 1 if any of the defined keywords appear in a firm's annual report, and 0 otherwise. Second, a continuous variable (EEP2) counts the total frequency of these keywords. A higher count reflects stronger environmental awareness and communication by senior executives.


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***Table 1.*** *GF indicators*

| Primary indicators | Secondary indicators | Specific indicators |
|---|---|---|
| GF | Green Credit | The proportion of total citywide environmental project credits to overall citywide credits |
| | Green Bond | Green-to-total bond issuance ratio |
| | Green Insurance | Share of environmental pollution liability insurance income relative to overall premiums |
| | Green Investment | Ratio of environmental pollution control investment to GDP |
| | Green Fund | Green funds' market value proportion compared to the entire fund sector |
| | Green Support | Ratio of environmental protection financial expenditures to total general budget financial expenditures |
| | Green Benefits | Proportion of carbon, energy rights, & emissions trading in total equity market transactions |

Data source: Derived from CSMAR, Wind, and Ministry of Ecology and Environment of China

While direct measures of managerial cognition are not available in conventional financial databases, this keyword-based method allows us to infer executives' environmental orientation through public disclosures. This approach is increasingly employed in the literature as a reliable proxy for executive perception, particularly when behavioral data are inaccessible (Li et al., 2023b).

This study visualizes executives' green priorities through textual analysis of annual reports. Processed keyword data generates the word cloud in *Figure 1*, where dominant terms like eco-efficiency and sustainability infrastructure reveal strategic emphases. Notably, recurring clusters (resource conservation, low-carbon operations) reflect decision-making priorities. Such lexical patterns align with global sustainability trends, demonstrating managerial adaptation to environmental imperatives.

*Mediating variables: financing constraints (SA) and research and development investment (RD)*

At present, the most widely utilized measures for assessing financing constraints include the KZ index, WW index, and SA index. In this study, we adopt the SA index developed by Hadlock and Pierce (2010) as our primary proxy for firms' financing constraints. The SA index is calculated based on two exogenous firm characteristics: total assets and firm age. Specifically, it is defined as follows:

$$SA = 0.043 \times size^2 - 0.737 \times size - 0.04 \times age \quad \text{(Eq.1)}$$

where *size* is the natural logarithm of the firm's total assets (in millions of RMB), and *age* is the number of years since the firm's establishment. A lower SA value indicates a higher degree of financing constraint. Compared with the KZ and WW indices, the SA index has stronger exogeneity and avoids endogeneity bias arising from firm performance or financial policy variables. Therefore, it is widely recognized for its stability and reliability in panel data analysis.

Research and development (RD) is pivotal for technological progress. Investment strategies typically can be classified into two main types: total research and development


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expenditures (Liu and He, 2023) and the proportion of overall RD investment to total sales revenue (Lu and Wang, 2024). In this study, we focus on RD as our primary measure. By considering factors like the size of the company, we evaluate the firm's RD investment for the current year by comparing RD expenditures with total assets.


***Figure 1.*** *Word cloud of executives' environmental perceptions*

*Control variables*

This study explored various factors influencing the progress of green technology in businesses, relying on the research conducted by Xu et al (2023a) and Jing and Liu (2024). A distinct collection of firm-level control variables was pinpointed, as detailed in *Table 2*. Choosing these variables is intended to minimize the influence of external elements on the relationship among the primary variables. Consequently, this approach facilitates a sharper and more accurate comprehension of the essential link between green finance, innovations in green technology, and the environmental consciousness of business executives.

***Table 2.*** *Definition of control variables*

| Variable name | Sign | Define |
|---|---|---|
| Leverage ratio | Lev | The year-end total liabilities-to-total assets ratio |
| Return on assets | ROA | The ratio of net profit to the average total assets balance |
| Tobin's Q | TobinQ | (Market capitalization of existing shares + quantity of non-current shares × net asset value per share + liabilities' book value) / total enterprise assets |
| Percentage of ownership of the majority shareholder | Top1 | The percentage of total shares held by the largest shareholder |
| Years of business establishment | Age | The logarithm of the sum of one and the number of years the company has been operating |
| Nature of property rights | SOE | Assign a value of 1 for state-owned enterprises and 0 otherwise |
| Enterprise size | SIZE | The natural logarithm of that year's total assets |

Data source: All firm-level variables are obtained from the CSMAR database

## *Sample selection and data sources*

Sample construction involves A-share listed companies (2012-2021) with four-stage purification: (1) Exclusion of ST-series and delisted entities; (2) Financial firms removal;


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(3) Elimination of deficient records; (4) 1%-99% percentile trimming for continuous variables. Sample includes all A-share listed firms across industries, without imposing industry-specific restrictions. This approach enhances the external validity of the findings by capturing a broad spectrum of firm types and environmental contexts. Industry classifications follow the CSRC (China Securities Regulatory Commission) standard codes.

Among them, the data source for enterprise green technology innovation is the CNRDS database, the frequency of senior executives' environmental protection cognition comes from the annual reports of listed companies, and other relevant data sources include the Guotai Nanjing database (CSMAR), Wind database, the official websites of authoritative institutions such as the National Bureau of Statistics, and various authoritative statistical yearbooks. All statistical analyses were conducted using Stata 18.0 and Microsoft Excel.

In the main analysis, we include all prefecture-level administrative regions, including the four centrally governed municipalities (Beijing, Shanghai, Tianjin, and Chongqing). However, in the robustness tests, these municipalities are excluded in a separate specification to assess whether their unique institutional and policy environments significantly affect the empirical results. Detailed variable descriptions and sources are provided in the corresponding tables.

### *Design and construction of models*

To evaluate the influence of GF on EGTI, this research utilizes the framework proposed by Zhang et al. (2023c) and constructs the reference regression equation articulated in *Equation 2*. This model investigates the connection between GF and EGTI by analyzing both the significance and the characteristics of the correlation coefficients.

$$EGTI_{it} = \alpha_0 + \alpha_1 gf_{ic} + \alpha_2 Z_{it} + u_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.2)}$$

where $EGTI_{it}$ represents the EGTI of firm i in period t, $gf_{im}$ denotes the level of GF development in city c during period t, and $gf_{ic}$ matched based on the location of the firms. $Z_{it}$ constitutes a collection of control variables, $u_i$ denotes the firm fixed effect, $\delta_t$ accounts for the time fixed effect, and $\varepsilon_{it}$ is the random error term. The estimated coefficient $\alpha_1$ captures the causal relationship between GF and EGTI.

To examine and establish the relationships between GF, EEP, and EGTI, this paper develops *Equation 3* to evaluate EEP's moderating impact on the connection of GF and EGTI, and develops *Equation 4* to evaluate EEP's threshold effect on the relationship between GF and EGTI, as shown below:

$$EGTI_{it} = \alpha_0 + \alpha_1 gf_{ic} + \alpha_3 EGP_{it} + \alpha_4 EGP \times gf_{ic} + \alpha_3 Z_{it} + u_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.3)}$$

where $EGP_{it}$ is the moderator variable of EEP, and $EGP_{it}$ indicates the level of environmental awareness of executives in enterprise i in period t.

$$EGTI_{it} = \alpha_0 + \beta_1 gf_{it} * I(EEP_{it} \le \tau) + \beta_2 gf_{it} * I(EEP_{it} > \tau) + \gamma' Z_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.4)}$$

$\tau$ represents the threshold value obtained through estimation, which is used to divide different intervals of the sample. $\beta_1$ and $\beta_2$ respectively represent the marginal effects of GF variables on EGTI below and above the threshold value. $\varepsilon_{it}$ is the random error term.


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To delve deeper into assessing GF's capacity to boost the efficient allocation of RD resources and, in turn, foster environmentally sustainable EGTI, this research develops *Equations 5* and *6* to investigate the mediating role of RD investment in the connection between GF and EGTI. The mediation model is depicted as follows:

$$RD_{it} = \alpha_0 + \alpha_1 gf_{ic} + \alpha_2 Z_{it} + u_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.5)}$$

$$EGTI_{it} = \alpha_0 + \alpha_1 gf_{ic} + \alpha_2 RD_{it} + \alpha_3 Z_{it} + u_i + \delta_t + \varepsilon_{it} \quad \text{(Eq.6)}$$

where $RD_{it}$ is the mediating variable is enterprise RD investment intensity, which represents the RD investment level of enterprise i during period t.

## Results

### *Benchmark regression*

*Table 3* displays the results of the benchmark regression analysis. The first column shows the model executed without any control variables; however, it does incorporate fixed effects for both time and firms. Notably, the coefficient for the GF indicator is markedly positive and reaches significance at the 1% threshold. Moving to the second column, several additional control variables have been introduced, with only the year fixed effects remaining in place. The third column keeps these control variables and adjusts solely for individual fixed effects; however, the GF coefficient remains significantly positive. In the final column, additional controls for both annual and individual fixed effects are integrated. The resulting regression coefficient stands at 0.494, which unmistakably crosses the 1% significance mark. This discovery suggests that GF wields a sizeable positive influence on EGTI, offering solid empirical backing for Hypothesis 1.

### *Robustness tests and endogeneity tests*

*VIF testing*

The findings presented in *Table 4* indicate that all variables exhibit VIF values below 10, with SIZE (1.69) and Lev (1.64) recording the highest values. These numbers are worlds apart from the generally acknowledged VIF threshold of 10. This indicates that, within the current models, multicollinearity is not a major concern regarding the model's robustness and the dependability of the outcomes. Moreover, it implies that the degree of collinearity among the variables in the model is quite acceptable and will not significantly affect the final research conclusion.

*Replacement of explanatory variables*

When exploring the reasons behind why companies pursue patents, the diverse motivations can make it challenging to interpret the initial results of the regression analysis. This research draws on the findings of Xu and Cui (2020) and employs the ratio of green patents to total patents as a measure of reliability. A significant benefit of this approach is its capacity to mitigate confounding factors that influence both the numerator (green technology patent applications) and the denominator (total patent applications). For example, subsidy programs that do not distinguish between different types of patented technologies may artificially increase the total patent application numbers, thus skewing


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the statistics for green technology filings. To beef up the credibility of our benchmark results, we swap out the explanatory variables in Model (1) for the proportion of green patent applications. This tweak enables us to look into the influence of green finance policies on environmentally-focused EGTI. The regression analysis outcomes are presented in columns (1) and (2) of *Table 5*. These findings indicate that, following the change in explanatory variables, the coefficient associated with the GF indicator remains significantly positive, aligning with our earlier results.

*Adjustment of sample period*

Building on the insights from the literature by Zhang et al. (2023a), the sample period was recalibrated to facilitate more rigorous testing. For this analysis, the timeframe from 2012 to 2018 was selected as the revised sample window. The reasoning behind this choice stems from the notable volatility observed in conventional markets throughout the COVID-19 pandemic. This turbulence pushed investors to explore hedging strategies and diversification opportunities within the GF market. Consequently, there was a notable surge in interest among investors in the GF market. *Table 5,* column (3) results indicate that, post-sample period adjustment, GF has a significant positive impact on EGTI between 2012 and 2018. This suggests that the estimation results from the benchmark model discussed earlier exhibit a high level of robustness.

***Table 3.*** *Benchmark regression results*

| Variant | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | **EGTI** | **EGTI** | **EGTI** | **EGTI** |
| GF | 0.494*** | 0.196** | 0.538*** | 0.494*** |
| | (0.167) | (0.081) | (0.156) | (0.167) |
| lev | | 0.0334 | -0.0034 | -0.0112 |
| | | (0.0445) | (0.0421) | (0.0427) |
| ROA | | -0.0275 | 0.0808 | 0.0735 |
| | | (0.1157) | (0.0948) | (0.0947) |
| TobinQ | | 0.0166*** | 0.0067* | 0.0089* |
| | | (0.0058) | (0.0038) | (0.0047) |
| Top1 | | -0.0004 | 0.0001 | 0.0001 |
| | | (0.0006) | (0.0006) | (0.0006) |
| Age | | -0.0916*** | -0.0232 | -0.0681 |
| | | (0.0271) | (0.0405) | (0.0832) |
| SOE | | -0.0011 | 0.0430 | 0.0401 |
| | | (0.0166) | (0.0352) | (0.0351) |
| Size | | 0.0304*** | 0.0106 | 0.0139 |
| | | (0.0094) | (0.0113) | (0.0126) |
| Individual control effect | Yes | No | Yes | Yes |
| Time control effect | Yes | No | No | Yes |
| Cons | -0.0720 | -0.3937* | -0.2861 | -0.2117 |
| | (0.0662) | (0.2164) | (0.2153) | (0.3977) |
| *N* | 7260 | 7260 | 7260 | 7260 |
| adj. $R^2$ | 0.2945 | 0.0178 | 0.2947 | 0.2947 |

Estimates provided in parentheses correspond to clustered robust standard errors at the prefecture-temporal level, where asterisks (*, **, ***) mark significance thresholds of 10%, 5%, and 1% correspondingly. All following tables adhere to this standardized notation system


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***Table 4.*** *Model test results*

| Variant | Sise | Lev | ROA | TobinQ | SOE | Age | Top1 |
|---|---|---|---|---|---|---|---|
| VIF | 1.69 | 1.64 | 1.34 | 1.24 | 1.21 | 1.11 | 1.09 |
| 1/VIF | 0.590 | 0.612 | 0.745 | 0.805 | 0.823 | 0.901 | 0.916 |

***Table 5.*** *Robustness test and endogeneity test*

| Variant | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | EGTI1 | EGTI | EGTI | EGTI | EGTI | EGTI |
| GF | 0.089*<br>(0.052) | 0.088*<br>(0.052) | 0.530**<br>(0.225) | 0.628***<br>(0.201) | | |
| L.GF | | | | | -0.4007*<br>(0.2060) | |
| L2.GF | | | | | | 0.2634<br>(0.2430) |
| Control variable | No | Yes | Yes | Yes | Yes | Yes |
| Individual control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Time control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Cons | -0.009<br>(0.021) | -0.021<br>(0.107) | -0.847<br>(0.549) | -0.556<br>(0.517) | -0.6155<br>(0.5207) | -0.8235<br>(0.5777) |
| N | 7260 | 7260 | 5808 | 5970 | 6534 | 5808 |
| $R^2$ | 0.253 | 0.253 | 0.416 | 0.386 | 0.3409 | 0.3502 |

*Exclusion of municipalities*

Considering the significant disparities in environmental conditions and economic development between municipalities and autonomous regions compared to standard prefecture-level cities, this study intentionally omits Beijing, Shanghai, Tianjin, and Chongqing. This exclusion aims to avoid any potential skewing of the policy evaluation findings. *Table 5,* especially in column (4), illustrates the findings. When excluding the municipalities that are directly administered, the coefficient for the crucial independent variable, GF, reveals a notably significant positive effect at the 1% significance level. This suggests that GF continues to exert a robust positive influence on EGTI in other typical prefecture-level cities.

*Lagged explanatory variables*

Considering the intrinsic connection between GF and EGTI, this study builds on the findings of Zhou Yan (2024). In the regression analysis, it incorporates both the first and second lags of GF as independent variables. As presented in *Table 5,* columns (5) and (6) reveal a notably positive association with the first lag of GF, whereas the effect of the second lag appears to be virtually non-existent. This pattern implies that GF has a delayed effect on improving EGTI, with its influence waning over time. Such a phenomenon might be linked to the inherently long-term and high-risk characteristics of EGTI projects. While the benefits from GF might have manifested initially, the resulting innovations likely did not produce significant economic and technological advancements in the following period, making the latter's effect relatively insignificant.


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## Discussion

### *Further analysis*

*Adjustment effect test*

*Table 6* shows whether EEP exists or not and how their level of awareness affects the role of GF on EGTI. Specifically, *Table 6,* column (2), reveals that the positive correlation between GF and EGTI strengthens when a firm has EEP. Following the resolution of the excessive multicollinearity present among the interaction terms, independent variables, and moderating variables through centering, a more precise regression analysis was performed on the model. The findings presented in column (3) of *Table 6* indicate that when leaders prioritize environmental sustainability and vigorously promote the integration of green technologies in their organizations, the beneficial moderating impact of GF becomes significantly more evident. Furthermore, column (5) of *Table 6* demonstrates that the link between GF and EGTI is considerably strengthened when the level of EEP rises. This suggests that a higher level of EEP enhances the impact of GF on EGTI. After a similar centralized treatment, the results in column (6) confirm again that executives' strong environmental awareness significantly enhances GF's role in promoting EGTI. To sum up, it is clear that the EEP enhances the promotional impact of GF on EGTI. Additionally, the EEP is more adept at integrating environmental insights and experiences into corporate decision-making processes. Furthermore, there is a stronger focus on fostering environmentally friendly and sustainable business practices. This finding supports Hypothesis 2, which claims that EEP has a positive effect on the role of GF in promoting EGTI.

***Table 6.*** *Moderating effects test*

| Variant | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **No interaction term** | **With interactions** | **Post-centralization** | **No interaction term** | **With interactions** | **Post-centralization** |
| GF | 0.5015*** | 0.4275** | 0.4924*** | 0.5064*** | 0.4107** | 0.5061*** |
| | (0.1663) | (0.1713) | (0.1664) | (0.1660) | (0.1677) | (0.1656) |
| EEP1 | 0.0353*** | -0.0337 | 0.0367*** | | | |
| | (0.0094) | (0.0357) | (0.0096) | | | |
| EEP2 | | | | 0.0108*** | -0.0119 | 0.0119*** |
| | | | | (0.0027) | (0.0095) | (0.0028) |
| GFEEP1 | | 0.1772* | | | | |
| | | (0.0925) | | | | |
| c_GFc_EEP1 | | | 0.1772* | | | |
| | | | (0.0925) | | | |
| GFEEP2 | | | | | 0.0600** | |
| | | | | | (0.0251) | |
| c_GFc_EEP2 | | | | | | 0.0600** |
| | | | | | | (0.0251) |
| Control variable | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Time control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Cons | -0.2400 | -0.2222 | -0.2479 | -0.2745 | -0.2476 | -0.2855 |
| | (0.3943) | (0.3954) | (0.3944) | (0.3957) | (0.3969) | (0.3958) |
| *N* | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| $R^2$ | 0.2962 | 0.2965 | 0.2965 | 0.2968 | 0.2975 | 0.2975 |


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*Analysis of threshold effect*

This study employs threshold regression analysis to investigate the potential non-linear impact of environmental governance performance (EEP) on the relationship between green finance and corporate green innovation. The threshold structure is statistically evaluated using F-statistics and associated p-values. Empirical testing supports the adoption of a single-threshold model, which achieves statistical significance at the 1% level ($p = 0.000$), whereas models with double and triple thresholds are not statistically significant ($p = 0.1467$ and 0.5167, respectively).

*Table 7* presents the estimated coefficients across threshold segments. The results indicate a significant positive impact of green finance on green innovation when EEP levels are at or below the identified threshold of 0.4203 ($p = 0.002$). However, this effect diminishes and becomes statistically insignificant when EEP exceeds the threshold ($p = 0.438$). These findings suggest a non-linear interaction pattern: Green finance is more effective in promoting innovation under relatively low EEP conditions, while its marginal influence weakens as environmental governance performance improves. This may reflect diminishing marginal returns or institutional inertia in higher-EEP environments, where other mechanisms may already dominate policy effectiveness.

***Table 7.*** *Regression results of the threshold effect*

| Variant | Regression coefficient | Std. Error | P-value | Controls | N |
|---|---|---|---|---|---|
| EEP ≤ 0.4203 | 0.0119 | (0.0065) | 0.002*** | Yes | 3118 |
| EEP > 0.4203 | 0.0048 | (0.0061) | 0.438 | Yes | 4142 |

*Analysis of impact mechanisms*

Empirical evidence from *Tables 8* and *9* confirms that SA and RD as significant transmission channels linking GF to EGTI. The bootstrap tests demonstrate statistically robust mediation effects at the 1% significance level for both pathways, with confidence intervals excluding zero. This indicates GF alleviates capital market imperfections by reducing information asymmetry and credit risks, which traditionally constrained green innovation funding. Specifically, GF instruments directly ease corporate financing pressures through mechanisms like preferential loan terms and risk-sharing arrangements, thereby resolving short-term capital limitations (SA pathway). Simultaneously, GF strategically redirects financial resources toward sustainability-oriented RD initiatives, enabling firms to amplify investments in green technology development (RD pathway). The Soble test further validates these dual mediation effects, confirming GF's impact operates not only through relaxing financial constraints (H3a) but also by actively boosting RD expenditure intensity (H3b). This dual-channel mechanism ultimately facilitates scalable eco-innovation capabilities essential for sustainable transformation.

## *Heterogeneity analysis*

*Examination of diversity about property-rights characteristics*

The impact of GF on EGTI exhibits significant divergence across ownership structures, rooted in institutional resource allocation mechanisms. SOEs, benefiting from preferential policy support and softer budget constraints, demonstrate heightened


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responsiveness to GF initiatives as they align with both governmental environmental mandates and intrinsic social responsibility objectives (Cai et al., 2020). This institutional embeddedness enables efficient translation of financial resources into EGTI outcomes. Conversely, non-SOEs face structural barriers including credit discrimination and limited collateral capacity, constraining their ability to leverage GF instruments despite comparable policy exposure. Empirical results (*Table 10,* columns 1-2) confirm GF's positive effect on both groups, but the significantly stronger coefficient for SOEs (1% vs. 5% significance for non-SOEs) underscores how institutional advantages-such as guaranteed credit access and reduced compliance costs-amplify GF's effectiveness in state-owned entities. This divergence highlights that GF's innovation-promoting function operates not merely through capital provision but is fundamentally mediated by institutional frameworks governing resource distribution.

***Table 8.*** *Bootstrap test*

| **SA** | **Observed coefficient** | **Bootstrapstd. err.** | **z** | **p > \|z\|** | **Normal-based [95%conf. interval]** | |
|---|---|---|---|---|---|---|
| _bs_1 | -0.026 | 0.0055 | -4.66 | 0.000 | -0.037 | -0.015 |
| _bs_2 | 0.253 | 0.0416 | 6.16 | 0.000 | 0.173 | 0.334 |
| **RD** | **Observed coefficient** | **Bootstrapstd. err.** | **z** | **p > \|z\|** | **Normal-based [95%conf. interval]** | |
| _bs_1 | 0.056 | 0.0079 | 7.12 | 0.000 | 0.041 | 0.071 |
| _bs_2 | 0.174 | 0.0422 | 4.12 | 0.000 | 0.091 | 0.257 |

***Table 9.*** *Soble test*

| | **SA** | **RD** |
|---|---|---|
| Indirect effect (p-value) | 0.001 | 0.001 |
| N | 7260 | 7260 |
| $R^2$ | 0.0084 | 0.0146 |

*Heterogeneity analysis based on firm size*

The efficacy of GF in driving EGTI is critically mediated by firm scale, reflecting institutionalized disparities in resource allocation and innovation capacity. Large enterprises leverage structural advantages—including preferential access to policy-backed financing, established RD infrastructures, and greater bargaining power with financial institutions—to effectively convert GF resources into substantive innovation outcomes. Their scale also subjects them to heightened regulatory scrutiny, incentivizing strategic alignment with environmental mandates. Conversely, small firms face institutional barriers: credit rationing by risk-averse lenders restricts GF accessibility, while fragmented policy support and limited absorptive capacity hinder the translation of available financing into viable green projects. Empirical results (*Table 10,* columns 3-4) corroborate this divergence, revealing significant GF-EGTI linkages only among large firms. This stark contrast underscores how institutional frameworks governing financial market structures and innovation ecosystems systematically advantage scaled entities in capitalizing on GF, leaving smaller firms structurally marginalized despite formal policy inclusion (Jiang et al., 2022; Zeng et al., 2023).


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*Heterogeneity analysis based on firm location*

The effectiveness of GF in promoting EGTI exhibits pronounced regional divergence due to institutionalized disparities in financial market development and governance capacity. Coastal regions benefit from mature financial ecosystems, efficient policy implementation frameworks, and dense innovation networks that collectively enhance GF's translation into tangible innovation outcomes. These areas leverage institutional advantages such as streamlined regulatory processes, sophisticated risk assessment systems, and robust market incentives to efficiently channel GF resources toward productive green RD. In contrast, inland regions face institutional constraints including fragmented financial infrastructure, weaker regulatory enforcement, and limited technological spillover channels, which impede GF's operationalization despite formal policy availability. Empirical results (*Table 10,* columns 5-6) reflect this institutional gradient: GF demonstrates significantly stronger effects in coastal provinces (5% significance) compared to inland regions (10% significance), underscoring how regional governance capacity and financial market maturity fundamentally mediate GF's innovation impact (Li et al., 2024a; Wang et al., 2022). This divergence highlights that GF's efficacy depends critically on place-specific institutional architectures governing capital allocation and innovation governance.

***Table 10.*** *Heterogeneity analysis*

| Variant | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **Non-SOE** | **SOE** | **Big** | **Small** | **East** | **Midwest** |
| GF | 0.378** | 0.890*** | 0.543** | 0.363 | 0.682** | 0.408* |
| | (0.190) | (0.326) | (0.263) | (0.237) | (0.268) | (0.219) |
| Control variable | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Time control effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -0.192 | -1.055 | -0.212 | 0.126 | -0.026 | -0.519 |
| | (0.457) | (0.757) | (0.420) | (0.376) | (0.582) | (0.530) |
| N | 5547 | 1694 | 3318 | 3872 | 3,800 | 3,460 |
| $R^2$ | 0.367 | 0.412 | 0.433 | 0.356 | 0.388 | 0.342 |

## Conclusion

### *Research conclusions*

In today's business world, GF is recognized as a critical driver for fostering EGTI within companies. Given that EGTI capabilities serve as a crucial barometer for a firm's sustainable growth, particularly within a market-oriented economic framework, the importance of EEP simply cannot be brushed aside. Their decisions hold the reins in determining the success and execution of EGTI initiatives. This study examines China's A-share listed firms from 2012 to 2021. By assessing GF at the local government tier and utilizing a dual fixed-effects approach, this study probes into the direct effects and underlying mechanisms by which GF impacts EGTI, all the while taking into account the sway of EEP. The primary findings of this inquiry are outlined as follows:

(1) Empirical findings show that GF promotes EGTI, and this result holds after a set of robustness checks.


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(2) In further study, it is found that executives with high environmental awareness or management teams showing excellent environmental awareness can more effectively strengthen the implementation effect of GF policies, thus significantly enhancing the promotion effect of GF on EGTI.

(3) The mechanism evaluation validates that financial constraints and research and development outlays act as mediators in the impact of GF on EGTI. Put differently, GF can beef up EGTI by ironing out funding snags and ramping up RD spending.

(4) Ultimately, the heterogeneity analysis reveals that the impact of GF on EGTI varies based on firms' ownership structures, dimensions, and locations. Specifically, the impact of GF on the development of emerging EGTI is particularly pronounced among state-owned enterprises and larger organizations. From a geographic standpoint, GF is instrumental in promoting EGTI in the eastern region of the country; however, its influence is less noticeable in the central and western areas.

### *Policy suggestion*

Drawing from these results, this paper presents the subsequent policy recommendations:

(1) Build an efficient financing system to solve the financing problems of EGTI. To effectively address the financing challenges in EGTI, a collaborative effort across society is necessary to establish an efficient and systematic financing framework. From the government's perspective, strategies such as establishing targeted funds, providing tax incentives, and offering appealing loan conditions are designed to alleviate the financial strain on businesses. We intend to introduce green bonds and equity investment funds, all while cultivating a strong, multi-faceted green financial marketplace. On the business side, firms ought to increase their expenditure on research and development focused on environmentally friendly EGTI, along with investing in the training and hiring of relevant personnel. It is essential to emphasize the application and safeguarding of intellectual property rights, enhance independent innovation capabilities, and protect the outcomes of EGTI endeavors. As for financial institutions, they should create a thorough risk assessment and management system that can effectively identify and address the potential risks linked with green technology initiatives.

(2) Enterprises should formulate phased improvement strategies based on the threshold characteristics of executives' environmental awareness (EEP): For enterprises with low awareness levels, priority should be given to conducting modular environmental training and assessment incentives (such as incorporating the proportion of environmental keywords in the annual report into KPIs); For enterprises with a high level of cognition, the focus is on promoting the transformation of cognition into action and establishing a joint decision-making mechanism between green finance (GF) and the RD department. At the same time, differentiated empowerment of enterprises is required—state-owned enterprises need to take the lead in the construction of industry-university-research platforms and incorporate the EEP threshold into the ESG disclosure requirements. Small and medium-sized enterprises and those in the western region have alleviated resource constraints through cognitive subsidies and customized policy push. This phased strategy can avoid the diminishing marginal benefits caused by cognitive overload, achieve a systematic improvement in the conversion efficiency of GF policies, and ultimately strengthen the sustainable driving force of enterprises' green technological innovation.

(3) Strengthen policy support for GF to promote EGTI. To enhance the effectiveness of GF policies and drive EGTI, the government must implement a series of


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comprehensive measures. First, it should establish and refine the GF policy framework, clearly defining the direction of support and preferential policies, while ensuring effective coordination with other relevant policies. Second, it is essential to create a regulatory mechanism for GF. The government should strengthen the GF supervision system, develop a robust risk warning and management framework, and impose credit restrictions on enterprises and projects that fail to meet environmental protection standards, encouraging them to improve their environmental awareness. Ultimately, the government should promote global cooperation and engagement in GF, learning from international best practices, and jointly advancing the development of GF to support EGTI and promote sustainable economic growth.

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**Data availability statement.** The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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