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Building Bridges, Not Walls: Financial and Social Synergies for Advancing Corporate Sustainability

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Abstract

Achieving China's dual carbon goals requires both financial innovation and social trust to advance corporate sustainability. This study examines how green bond issuance promotes corporate green transformation and how social trust moderates its effectiveness. Drawing on panel data from A-share listed companies from 2014 to 2021, we measure Green Total Factor Productivity (GTFP) via a Super-SBM model incorporating carbon emissions as undesirable outputs, along with the Global Malmquist-Luenberger index. A progressive difference-in-differences approach supports the empirical analysis. The results show that green bonds significantly enhance GTFP. They also stimulate green ambidextrous innovation-balancing exploratory and exploitative activities-which mediates this effect. Social trust further amplifies this mechanism. These effects are more pronounced in regions with developed financial infrastructure, lower pollution intensity, and stronger emergence of new quality productive forces. The findings highlight the synergy between green finance and social capital in promoting the low-carbon transition of Chinese enterprises.

Keywords

Green Bonds; Green Total Factor Productivity (GTFP); Green Ambidextrous Innovation Balance; Social Trust; Difference-in-Differences.

1. Introduction

Since the 1960s, human activities have driven economic growth, but environmental challenges have increasingly escalated [1]. Among these, climate change emerges as the paramount and highly debated challenge of the 21st century[2]. The World Meteorological Organization (WMO) reports that global near-surface temperatures in 2023 were 1.40°C higher than the 1850–1900 average. In response, governments and global entities have implemented preemptive actions to combat climate change. In China, the 2023 Global Carbon Emissions Report showed a 4.7% increase in emissions, reaching 12.6 billion tons-the largest global rise to date. Considering growing energy consumption and environmental pressures, the Chinese administration has incorporated the "dual carbon" objectives into the future strategic framework, prioritizing green and low-carbon development to foster high-quality economic growth. Corporate activities, central to economic progress, are also key contributors to climate change[3]. As a result, corporate green transformation has become essential for addressing environmental challenges and promoting sustainable development.

Early research viewed green transformation as a shift from focusing solely on economic growth to balancing ecological protection and human development[3]. Initially, scholars assessed this transformation through indicators like green patents[4], the reduction in carbon emissions[5], and enhancements in energy efficiency[6]. However, as the concept evolved, it emphasized greater resource efficiency and environmental sustainability. This broader view suggested that green transformation should be assessed through an integrated system, not just environmental

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indicators[7]. The notion of green total factor productivity (GTFP) has come to the forefront, encompassing the dual aspects of output efficacy and environmental pollution, with a particular emphasis on the inclusion of unexpected emissions. This approach is now a critical metric for evaluating corporate green transformation and sustainability[8]. Under the "dual carbon" goals, corporate-level carbon emissions data offer a more precise and immediate assessment of environmental consequences than regional "three wastes" data, which were commonly used as proxies for unexpected outputs in earlier studies[9]. Thus, the incorporation of carbon emissions as a surrogate for unintended outputs within the context of GTFP is not only pertinent but also crucial for contemporary research.

A comprehensive literature review underscores a multitude of scholarly works that explore the nexus between green innovation[10], environmental regulation[11], and the digital economy[12] with GTFP. However, inadequate funding remains a significant challenge in green development. The China Green Budget Outlook Report estimates that China will need 487 trillion yuan for green and low-carbon initiatives from 2021 to 2050, translating to an annual funding requirement of over 16 trillion yuan for the next three decades. Within this framework, green bonds have risen to prominence as a pivotal component of the green financial architecture, driven by rising public awareness of green investments and increasing business demand for environmental protection funding. Green bonds represent a convergence of ecological needs and financial innovation[13]. By 2023, China had indeed secured its position as the global leader in green bond issuance for three consecutive years, with a cumulative issuance value reaching USD 131.25 billion. This data indicates that China's green bond market has become a significant driver facilitating the country's shift to a more sustainable economic model[14]. Despite notable advancements, the green bond market in China remains in its infancy, with the regulatory infrastructure and associated mechanisms currently in the process of maturation. Some companies may engage in "greenwashing" to exploit policy incentives and enhance their environmental image[15]. Therefore, an important research question remains whether the capital procured via the issuance of green bonds is genuinely allocated to initiatives that foster environmental sustainability, or if it is instead misappropriated for the facade of "greenwashing", potentially diluting the transformative impact of green initiatives.

Furthermore, drawing from the realms of behavioral finance and signaling theory, it is evident that investors' actions within financial markets are shaped not merely by economic considerations but are also significantly swayed by non-economic elements, including societal norms. Enterprises that issue green bonds are thereby conveying their dedication to sustainable development, and this act of issuance is instrumental in fostering the development of social trust. Social trust, an integral component of societal norms, plays an indispensable role in the realms of financial stability and the perpetuation of economic growth[16]. While early research focused on social trust's macroeconomic effects, recent studies have highlighted its corporate-level significance, especially in equity costs[17], ESG performance[18], and financing efficiency[19]. However, the influence of social trust within the domain of green finance, remains underexplored. This research endeavors to address this research lacuna by examining the repercussions of green bond issuance on GTFP and the mediating role of social trust. The primary inquiries posed by this study are outlined below:

RQ1. Does the issuance of green bonds enhance corporate GTFP? If so, what is the underlying mechanism driving this effect?

RQ2. How does social trust moderate the connection between green bond issuance and corporate GTFP?

To tackle the research inquiries, we have opted for the Super-SBM model, which factors in carbon emissions, and has synergized it with the GML index to conduct a quantitative assessment of the GTFP in China. Within this conceptual structure, a progressive difference-in-differences (DID) model is deployed to empirically appraise the repercussions of green bond

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issuance on corporate GTFP. Additionally, we employ mediation and moderation analytical frameworks to delve into the pathways by which green ambidextrous innovation balance and social trust exert their influence on the relationship.

The scholarly contributions of this research are delineated below:

(1) Investigations into green bonds have predominantly concentrated on facets like issuance pricing[20], corporate financial performance[21], and capital market performance[22], frequently neglecting GTFP-a more holistic measure of corporate environmental transition. This study addresses the void by providing empirical evidence of the affirmative effects of green bond issuance on the green transformation of corporations, thereby delivering significant insights for entities engaged in green and low-carbon initiatives. Moreover, previous studies have typically used municipal-level "three wastes" data as proxies for firm-level inefficiencies[9,. However, such "three wastes" data may not accurately reflect the unexpected outputs at the enterprise level. Therefore, within the ambit of the "dual carbon" objectives, this study takes a more precise approach by collecting energy consumption data disclosed by listed companies and, using widely accepted conversion methods, transforms this data into carbon emissions figures as proxies for unexpected outputs. Furthermore, the Super-SBM model is deployed in tandem with the GML index to ascertain the corporation GTFP. This approach offers more detailed, enterprise-level data, which can complement existing macro-level research results. It enriches the research dimension of GTFP and provides policymakers and the academic community with a more comprehensive perspective for evaluating the ramifications of green bond issuance on economic efficacy and environmental outcomes.

(2) This study conceptualizes green ambidextrous innovation balance as a mediating variable, capturing the dynamic interplay between exploratory and exploitative green innovations. Prior research has typically analyzed their mediating effects through separate regressions of exploratory and exploitative innovations[24], neglecting their complementary nature. Concentrating exclusively on a single aspect may result in suboptimal distribution of resources and impede the advancement of complementary areas. In practice, exploitative innovation provides the resources and market impetus for exploratory innovation, while exploratory innovation generates knowledge that propels exploitative innovation. Thus, our approach offers a more integrated framework, better reflecting the innovation process's complexity and providing fresh insights for theoretical model development.

(3) This research underscores the critical function of social trust as an informal institution that influences corporate strategies within the green finance domain. While academic scrutiny has predominantly been aimed at the impact of formal institutions, such as legal structures and regulatory guidelines, within the realm of green finance[25], studies on informal institutions have primarily addressed macro-level factors like urban development[26], globalization[27], and political dynamics[28]. Nevertheless, the sway of social trust within the realm of green finance remains an area that is yet to be exhaustively explored. We address the noted research gap by examining the role of social trust in the ecological metamorphosis of corporations and introducing an innovative framework that reveals the dynamics propelling green financial initiatives.

The structure of this paper is as follows: Section 2 presents a literature review and the development of hypotheses. Section 3 introduces the data and empirical research design. Section 4 reports the empirical results. Section 5 further discusses the mechanisms and heterogeneity analysis. Finally, Section 6 concludes the study.

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2. Literature Review and Hypotheses Development

2.1. Green Bond Issuance and Corporate GTFP

Traditional total factor productivity (TFP) has primarily focused on economic growth, often overlooking the environmental impact, which distorts the true measure of production efficiency[29]. To address this, economists have introduced unexpected outputs into traditional models, proposing the notion of GTFP. GTFP highlights the necessity for a harmonized strategy that promotes economic growth while preserving environmental integrity, serving as a critical driver for promoting sustainable economic development and green transformation[30]. At the enterprise level, GTFP encourages the adoption of resource efficiency, innovation, environmental management, and employee training to promote growth[31]. Progress is achieved by reducing waste, controlling emissions, fostering innovation, and improving workforce engagement[32]. Strategies for enhancing GTFP include advancing green innovation[33], energy-saving measures[34], better resource utilization[35], and industrial upgrades[36]. These elements are instrumental in facilitating the green transformation and exert a salutary impact on GTFP. From the above perspectives, it is evident that enhancing GTFP requires reducing environmental damage and pollution emissions during the production process, concurrently optimizing economic and ecological outcomes. The core goal is to achieve low input, high output, and low pollution emissions. Achieving this objective has become a key challenge within the purview of the dual carbon objectives.

Green finance, a rapidly growing financial model, has gained global prominence, with green bonds emerging as a pivotal asset within the fixed-income securities domain. The overarching objective of green bonds is to supply funding for projects with a low-carbon footprint and to foster the development of green technologies[37]. It offers several benefits: (1) lower credit spreads, reducing financing costs[38], while providing long-term capital and easing constraints[39]; (2) improved environmental risk management, facilitating green strategies[40]; (3) enhanced reputation for issuers[41]; and (4) a new investment tool for long-term returns[42]. Green development theory asserts that economic growth must align with environmental protection for long-term sustainability. Studies show that green bonds, as a key financing tool, support the low-carbon transition, decoupling growth from ecological risks and promoting both economic and environmental sustainability. Thus, green bond issuance is critical in enhancing corporate GTFP, as detailed below:

From the perspective of corporate economic performance, integrating green bonds into financing strategies incentivizes companies to adopt environmentally sustainable practices, yielding substantial economic benefits. Green bond issuance allows companies to reduce factor costs[14], improve production efficiency[43], and leverage government tax incentives[44]. These cost reductions and tax rebates enhance profitability, while greater production efficiency maximizes output with minimal resource input[37]. Thus, green bonds serve as an effective incentive, driving profitability and economic benefits by promoting sustainable practices[45]. Additionally, they improve corporate environmental awareness, support social responsibility, and enhance environmental disclosures and social reputation[46]. From the investors' perspective, green bonds, as medium-to-long-term environmentally sustainable financial instruments, align with investment preferences and are more likely to be incorporated into investment portfolios. As a result, the company's social recognition is strengthened, and its intangible economic benefits are enhanced[47]. The improvement in economic benefits is a key driver of enhanced GTFP.

From an environmental standpoint, signaling theory suggests that the act of issuing green bonds is indicative of a corporation's dedication to mitigating carbon emissions [48]. Investors expect these funds to support energy-efficient technologies, pollution control, and green supply chains, enhancing environmental performance[37]. Empirical studies confirm that green bonds

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enhance corporate environmental responsibility by tightening pollution regulations, improving environmental ratings, and reducing CO2 emissions [49], improving corporate environmental ratings, and reducing CO2 emissions[50]. As a result, investors gain confidence in these bonds' environmental impact, driving more capital into genuine green investments.

H1. Issuing green bonds contributes to enhancing corporate GTFP.

2.2. Green Bond, Green Ambidextrous Innovation Balance, and Corporate GTFP

Green innovation, a forward-looking practice, follows sustainable development principles to enhance environmental performance and secure lasting competitive advantages[51]. At the corporate level, it involves assessing the environmental impact of activities such as technology innovation, product development, service optimization, and market expansion, and implementing strategies for sustainability[20]. Rooted in ambidextrous innovation theory, green ambidextrous innovation is a dual process where firms pursue both green exploratory innovation (GER) and green exploitative innovation (GEI) in the environmental sector[52]. Exploratory innovation focuses on pioneering ideas to develop untapped technologies, markets, and products, advancing sustainability[23]. Exploitative innovation optimizes existing knowledge and capabilities to improve current green products and systems[53]. Balancing these approaches enables firms to secure competitive advantages while promoting sustainable development [54].

Emerging scholarly work is progressively delving into the repercussions of green bond within the realm of corporate green innovation, which is pivotal for the sustainability of enterprises and necessitates considerable financial backing. Traditional financial markets often limit firms with low credit ratings or insufficient collateral from securing external funding[55]. Green bonds, tailored for environmental projects, provide crucial capital and align with the long-term R&D cycles and capital recovery periods of green initiatives, ensuring steady cash flow[56]. The high uncertainty and risks of green R&D often deter firms from pursuing such projects under financial constraints, missing innovation opportunities. However, green bonds' stringent disclosure requirements reduce information asymmetry, attracting eco-conscious investors and broadening funding sources[57]. From a regulatory standpoint, stakeholder theory suggests that investors monitor fund allocation, holding companies accountable for their green innovation. Media exposure of corporate environmental behavior can also generate public pressure, encouraging firms to adopt responsible practices and accelerate green innovation[58].

Schumpeter's innovation theory posits that innovation optimizes resource allocation, enhances efficiency, and reshapes economic structures, driving growth. Green ambidextrous innovation allows firms to sustain existing green processes while exploring new technologies, a crucial strategy for improving GTFP. Economically, exploratory green innovation boosts resource productivity through novel designs and practices, capturing green market premiums[51]. It also creates first-mover advantages and competitive barriers[59]. In contrast, exploitative green innovation refines existing technologies, improving efficiency, reducing costs, and fostering sustainability[60]. Environmentally, green ambidextrous innovation balances exploration and refinement: exploratory innovation delivers breakthrough solutions with significant environmental benefits[61], while exploitative innovation reduces waste through process optimization[62].

H2. Green ambidextrous innovation balance mediates the relationship between green bond issuance and corporate GTFP.

2.3. Moderating Effect of Social Trust

Social trust, representing the mutual trust between entities[63], is a cornerstone of social capital. As a key informal institution, it guides individual behavior and exerts a broader

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influence on economic development and societal progress [64]. Within the realm of organizational dynamics, social trust is pivotal in molding the corporate culture and guiding collective actions, which in turn have a subtle yet significant bearing on the company's economic endeavors[65].

According to social norm theory, individuals conform to social norms to secure approval and avoid exclusion, internalizing them into their value systems[66]. High social trust in a region strengthens social norms, prompting managers to emphasize reciprocal relationships with stakeholders. This shift transforms moral responsibility into strategic decisions aligned with sustainability goals[67]. Specifically, the dual character of green bonds as instruments of both environmental and financial nature means that investors from regions with robust social trust are more likely to entrust their capital to companies, secure in the belief that these entities will direct the funds responsibly towards eco-friendly initiatives. In turn, firms are more likely to prioritize social and environmental responsibility, enhancing their green innovation capabilities in response to societal demand for sustainability[68]. This results in improved resource efficiency, better environmental performance, and, ultimately, a higher level of GTFP.

From the perspective of social network theory, networks shape organizational behavior by facilitating information flow, resource sharing, and collaboration[69]. In high-trust environments, firms can forge extensive partnerships, effectively disseminating green bond information and attracting investor interest, which enhances funding access for green projects[70]. Moreover, strong social trust enables timely, frequent information exchange, providing enterprises with access to cutting-edge green technologies and methodologies, thereby reducing information asymmetry[71] and optimizing resource allocation.

In high-trust societies, firms lower transaction costs and accelerate resource allocation through efficient collaboration, which improves both economic and environmental performance. This collaboration fosters the adoption of innovative green technologies, enhancing GTFP. Additionally, firms are more likely to fulfill social responsibilities, increasing their social capital and support for green transformation.

H3. In regions with high social trust, the affirmative correlation between green bond issuance and firms' GTFP is strengthened.

The theoretical framework is depicted in Figure 1.

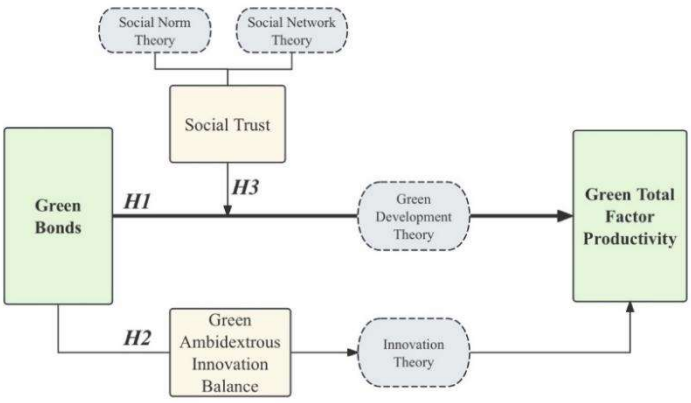

Figure 1. Theoretical framework

3. Data and Methodology

3.1. Samples and Data Collection

This study is centered on companies listed on the A-share market, examining the period spanning from 2014 to 2021. The empirical data underwent the subsequent treatment: First,

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sample selection was conducted by excluding firms with special stock market statuses (ST, *ST, PT) and financial industry companies. Second, missing data were handled by removing firms with missing values for core indicators. Third, outlier treatment was applied at the 1% levels on both ends, and continuous variables with units of measurement were logarithmically transformed. As a result, 9506 annual sample observations were retained. The financial information was extracted from the China Securities Market & Accounting Research (CSMAR) database, while the data on green invention patents and green utility model patents for the listed entities were procured from the China National Research Data Service Platform (CNRDS), energy consumption data came from annual reports and official company websites, while social trust data were gathered from the Chinese Entrepreneur Survey System (CESS).

3.2. Main Variables

(1) *Dependent Variable: GTFP*

GTFP extends traditional TFP by incorporating energy input and unexpected outputs. The Super-SBM model, an enhancement of the DEA model, is more suitable for evaluating efficiency in systems with multiple, interdependent decision units. It tackles the often-neglected issue of variable slack in traditional models, offering a more precise assessment of decision-making units with efficiency scores surpassing the threshold of 1. Additionally, the GML index overcomes the linear programming infeasibility associated with the ML index, ensuring feasible and reliable solutions by meeting transitivity and cyclicality requirements.

First, each listed company is treated as a decision-making unit (DMU) to construct the production frontier. Assuming the k-th DMU ($j=1,2,\ldots,n$) has input vector $x \in R^M$, expected output vector $y^g \in R^{s_1}$, and unexpected output vector $y^b \in R^{s_2}$. We also define matrices $X=[x_1,x_2,\ldots,x_n] \in R^m \times n, Y^g=[y_1^g,\ldots,y_n^g] \in R^{s_1} \times n$, and $Y^b=[y^{b_1},\ldots,y_n^b] \in R^{s_2 \times n}$. The directional distance function of the Super-SBM model is herein introduced, as delineated in Equation (1), where λ represents weight vector, s_i^-, s_r^g and s_t^b represent slack vectors. $\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{ik}$ signifies the average level of input inefficiency, $\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} s_r^g / y_{rk}^g + \sum_{t=1}^{s_2} s_t^b / y_{tk}^b\right)$ corresponds to the average level of output inefficiency. ρ denotes the efficiency score of the DMU. Subsequently, the GML index is utilized to ascertain the GTFP of corporations, as illustrated in Equation (2), wherein the directional distance function is applied. Here, $D_G^T(x^t, y^t, b^t)$ is designated to represent the efficacy of the Super-SBM model.

$$
\begin{aligned}
&\min \rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1-\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^g}+\sum_{t=1}^{s_2}\frac{s_t^b}{y_{tk}^b}\right)} \\
&s.t. \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \\
&\sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j + s_r^g \geq y_{rk}^g \\
&\sum_{j=1, j\neq k}^{n} y_{tj}\lambda_j - s_t^b \leq y_{tk}^b \\
&\sum_{j=1}^{n}\lambda_j = 1, \lambda \geq 0, s^g \geq 0, s^b \geq 0, s^- \geq 0
\end{aligned}
\tag{1}
$$

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$$GML^{t,t+1}(x^{t+1},y^{t+1},b^{t+1};x^t,y^t,b^t)=\frac{1+D_G^T\left(x^t,y^t,b^t\right)}{1+D_G^T\left(x^{t+1},y^{t+1},b^{t+1}\right)} \quad (2)$$

For the model, the computation of input and output indicators proceeds as outlined: (1) Inputs. The labor force is quantified by the final count of personnel at the conclusion of the fiscal year (in thousands). The capital input is ascertained by the aggregate value of fixed assets (in billion yuan)[72]. Energy input is reflected through the company's yearly electricity usage (in thousands of kilowatt-hours) [73]. (2) Outputs. The expected output is represented by the firm's main operating revenue (in billion yuan). The unexpected output is represented by the firm's carbon emissions, which are quantified employing the approach detailed by Wang et al. [74], in accordance with the Greenhouse Gas Emission Calculation and Reporting Guidelines promulgated by China's National Development and Reform Commission (NDRC). It provides industry-specific carbon emission calculation protocols.

Table 1. GTFP indicator system

Type	Variable	Explanation
Input indicators	Labor input	The year-end employee headcount (in thousands)
	Capital input	Total value of fixed assets (in billion yuan)
	Energy input	Annual electricity consumption (in thousands of kilowatt-hours)
Output indicators	Expected output	Main operating revenue (in billion yuan)
	Unexpected output	Carbon emissions (in ten thousand tons)

(2) *Independent Variable:* $Green \times Post$

The $Green \times Post$ variable is introduced in this study, following the approach of Tang and Zhang [75], and serves as a DID term. Both *Green* and *Post* are binary variables. If a firm has issued or is currently issuing green bonds, *Green* takes the value of 1; and by 0 otherwise. $Post$ serves as a time dummy variable, assuming a value of 1 for the year of green bond issuance and all subsequent years, and 0 for all other periods. $Green_{i,t} \times Post_{i,t}$ indicates whether the firm i has issued or is issuing green bonds in the year t.

(3) *Mediating Variable: Balance*

Green Ambidextrous Innovation Balance (*Balance*). In this research, the construct of exploratory green innovation is quantified through the annual count of green invention patents, while exploitative green innovation is gauged by the annual filings of green utility model patents[76]. Early research treated exploration and exploitation as distinct, competitive activities[77], but the evolving technological landscape now requires firms to balance both to address external challenges effectively. The scholarly community is increasingly concentrating on the interplay between exploratory and exploitative endeavors[54]. Some scholars initially assessed the balance between exploratory green innovation(X) and exploitative green innovation(Y) by calculating the absolute difference between them ($|X-Y|$). However, this approach, which defines balance based solely on equal values or equal differences between X and Y, regardless of their magnitudes, fails to account for variations in firms' innovative capabilities and represents a mechanistic view of balance. Adhering to the methodology of Cao et al.[78], we employ Formula (3) in our analysis, which offers a more nuanced approach, reflecting firms' distinct innovation capacities and providing a dynamic perspective on balance.

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$$Balance = 1 - \frac{|X - Y|}{X + Y} \tag{3}$$

(4) *Moderating Variable: Trust*

Social Trust (*Trust*). Conforming to the precedent set by Chen [19] this inquiry utilizes the regional trust indices from the CESS to quantify the levels of social trust among various provinces. The CESS data, covering over 1500 companies in 31 regions of China, provides a reliable, nationally representative sample of firm conditions across regions.

(5) *Control Variables*

Considering that the efficacy of green bond ($Green \times Post$) on GTFP could be contingent upon a multitude of additional factors, this study follows previous research [23,79] and selects several control variables, including firm size (*Size*), return on assets (*ROA*), sales growth rate (*Growth*), and firm age (*Firmage*). Furthermore, as noted by Wang et al. [42], the leverage ratio can affect a firm's willingness to engage in green transformation; thus, the leverage ratio (*Lev*) is included as an additional control variable. Additionally, certain scholarly investigations have underscored the relationship between a corporation's internal liquidity and its GTFP [80], prompting the inclusion of the cash flow ratio (*Cashflow*) as another control variable to mitigate potential estimation biases caused by omitted variables. Appendix provides the definitions and names of all variables.

3.3. Model Specification

In 2015, China marked a milestone by issuing its inaugural green bond in Hong Kong, followed by a nationwide rollout. This offers a significant opportunity for a quasi-natural experimental setup. To tackle the disparate issuance schedules and the possibility of endogeneity inherent in pooled OLS models, the research deploys a progressive DID framework to scrutinize the repercussions of green bonds on GTFP, as articulated in Equation (4):

$$GTFP_{i,t} = \beta_0 + \beta_1 Green_{i,t} \times Post_{i,t} + \lambda X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \tag{4}$$

In the model, the subscript i represents listed firms, *and* t represents the year. $\varepsilon_{i,t}$ is the random disturbance term, β and λ are the coefficients to be estimated. Additionally, the model controls for industry fixed effects (μ_i) and time fixed effects (ν_t).

4. Data Analysis and Results

4.1. Descriptive Statistical Analysis and Correlation Analysis of Variables

Table 2 delineates the descriptive statistics for the pivotal variables, while Table 3 exhibits the correlation matrix. The correlation coefficient between the issuance of green bonds and GTFP, which stands at 0.076, is statistically significant at the 1% threshold, indicating a positive association. Table 4 shows that the average variance inflation factor (VIF) is 1.27, with no values exceeding 10, indicating low multicollinearity.

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Table 2. Descriptive statistical analysis

Variable	N	Mean	Sd	Min	Median	Max
GTFP	9506	1.0218	0.0624	0.9066	1.0214	1.1480
Green×Post	9506	0.0051	0.7161	0.0000	0.0000	1.0000
Balance	9506	0.8306	0.3495	0.0000	1.0000	1.0000
Trust	9506	0.8281	0.6432	0.0270	0.7770	2.1890
Size	9506	22.6872	1.3091	19.6393	22.496	26.4297
Lev	9506	0.4311	0.1946	0.0505	0.4269	0.9246
ROA	9506	0.0417	0.5659	-0.3749	0.0356	0.2538
Cashflow	9506	0.0545	0.0647	-0.1719	0.0513	0.2558
Growth	9506	0.1496	0.3629	-0.6534	0.0945	3.8082
Firmage	9506	2.9812	0.2843	1.9459	2.9957	3.6109

Table 3. The correlation matrix

	GTFP	*Green×Post*	*Balance*	*Trust*	*Size*	*Lev*	*ROA*	*Cashflow*	*Growth*	*Firmage*
GTFP	1									
Green×Post	0.076***	1								
Balance	-0.053***	0.011	1							
Trust	0.001	0.001	-0.003	1						
Size	0.175***	0.104***	-0.133***	0.067***	1					
Lev	0.053***	0.068***	-0.092***	-0.011	0.571***	1				
ROA	-0.038***	-0.020**	-0.003	-0.014	0.033***	-0.321***	1			
Cashflow	0.056***	-0.007	-0.010	-0.052***	0.075***	-0.144***	0.429***	1		
Growth	0.015	0.006	0.008	0.010	0.041***	0.032***	0.224***	0.032***	1	
Firmage	0.407***	0.048***	0.043***	-0.045***	0.167***	0.167***	-0.021**	0.022**	-0.016	1

Table 4. VIF

Variable	VIF
Green×Post	1.01
Balance	1.02
Trust	1.02
Size	1.68
Lev	1.85
ROA	1.51
Cashflow	1.25
Growth	1.07
Firmage	1.05
Mean VIF	1.27

4.2. Results of Empirical Analyses

Table 5 delineates the outcomes of the baseline regression analysis. Without control variables, the key independent variable's coefficient ($Green \times Post$) amounts to 0.0063, demonstrating a significantly positive association at the 1% level of statistical significance. Upon the incorporation of control variables, the coefficient of the $Green \times Post$ increases to 0.0068, remaining significantly positive at the 1% level. These results suggest that the issuance of green bonds is significantly positively correlated with GTFP, supporting Hypothesis H1.

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Table 5. Baseline regression results

Variable	(1)	(2)
	GTFP	*GTFP*
Green×Post	0.0063***	0.0068***
	(0.0020)	(0.0020)
Size		-0.0005***
		(0.0001)
Lev		0.0011
		(0.0011)
ROA		-0.0020
		(0.0035)
Cashflow		0.0032
		(0.0026)
Growth		0.0001
		(0.0004)
Firmage		-0.0002
		(0.0006)
Constant	1.0220***	1.0350***
	(0.0001)	(0.0038)
Industry FEs	YES	YES
Year FEs	YES	YES
R^2	0.9490	0.9500
N	9506	9506

Note: ***, **, * denote significance at the 1%,5%, and 10% levels, respectively. The values in parentheses are robust standard errors. (The same as below)

4.3. Parallel Trends

Table 6. Parallel trend test results

Variable	*GTFP*
$Before_7$	0.0017
	(0.0061)
$Before_6$	0.0045
	(0.0055)
$Before_5$	0.0070
	(0.0046)
$Before_4$	0.0034
	(0.0044)
$Before_3$	0.0013
	(0.0045)
$Before_2$	0.0055
	(0.0040)
Current	0.0044
	(0.0040)
$After_1$	0.0182***
	(0.0061)
$After_2$	0.0126**
	(0.0060)
$After_3$	0.0156**
	(0.0074)
$After_4$	0.0264***
	(0.0093)
Constant	1.0500***
	(0.0188)
R^2	0.9550
N	9506

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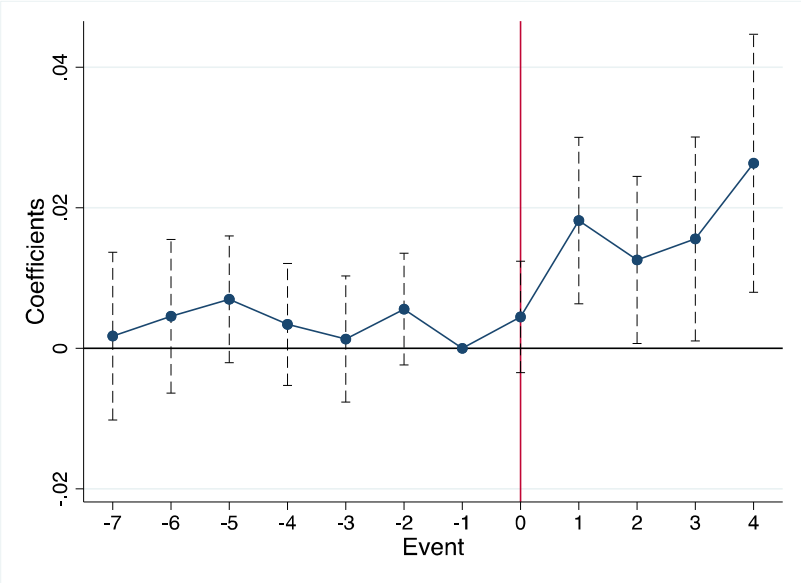

Figure 2. Parallel trend test graph

The DID model is predicated on the parallel trends assumption, stipulating that, devoid of the policy intervention, the trajectories of GTFP for both the treatment and control groups should be congruent over time. To test whether the empirical sample satisfies the parallel trend assumption, we define $Before_n$ as a dummy variable for the *n* years prior to issuance, $Current$ as a dummy variable for the year of issuance, and $After_n$ as a dummy variable for the *n* years following issuance. If the empirical results pass the test, it will confirm that any observed improvement in GTFP is attributed to the impact of green bond issuance.

Table 6 tells us that the coefficients associated with $Before_n$ do not reach statistical significance, whereas the coefficients linked to $After_n$ exhibit a significant positive correlation. The results in Figure 2 further illustrate that the policy dynamic intervals for $Before_n$ all include zero, while the policy dynamics for $After_n$ consistently fall above zero. These findings imply that the GTFP of publicly listed companies saw a marked enhancement following the issuance of green bonds. The consistency of the significance level over time further suggests that the impact is enduring. Thus, the baseline regression results of this study remain valid.

4.4. Endogeneity Problems

4.4.1. PSM-DID

Since green bond issuances are not random, with firms exhibiting higher GTFP more likely to issue green bonds, this study addresses potential endogeneity from self-selection bias by employing Propensity Score Matching (PSM). The approach incorporates control variables from the initial regression analysis as covariates, and a logistic model calculates each firm's propensity score for issuing green bonds. A 1:4 nearest neighbor matching strategy is applied, with year fixed effects to control for macroeconomic factors. The balance test reveals that the standard deviation of all matched covariates is below 10%. Kernel density plots in Figure 4 further confirm that the treatment and control groups are comparable. After matching, the relationship between green bond issuance and GTFP is re-examined using the progressive DID model, with results in Table 7, Column (1), remaining robust.

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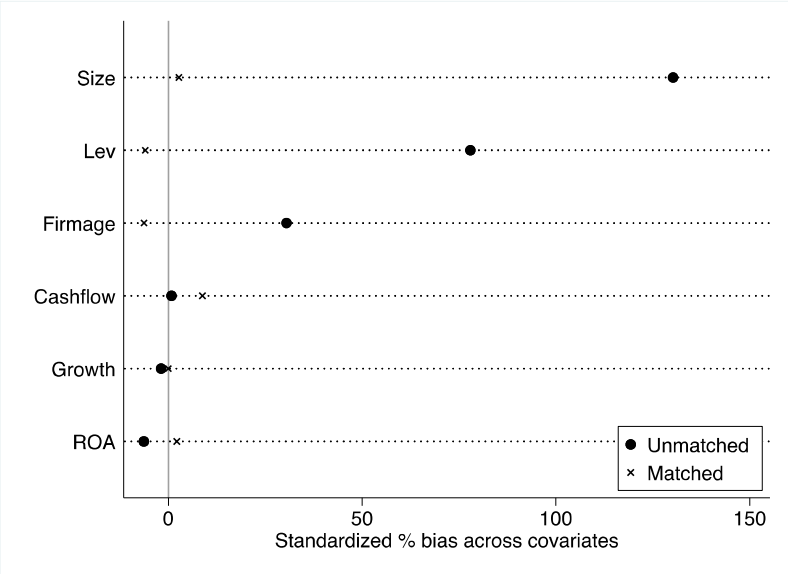
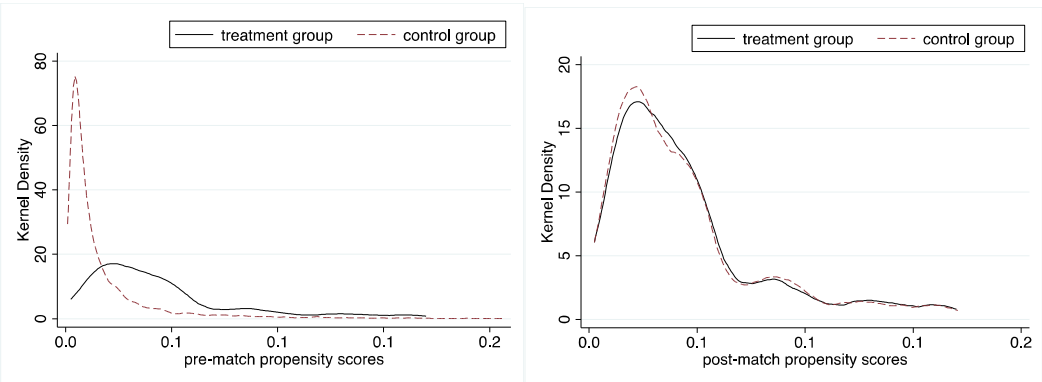


Figure 3. Balance test results for propensity score matching



(a) Before (b) After

Figure 4. Kernel density plot

Table 7. Robustness Test

Variable	(1)	(2)	(3)
	PSM-DID	One-period lag	Narrow the sample period
	GTFP	*GTFP*	*GTFP*
Green×Post	0.0080***		0.0096***
	(0.0022)		(0.0032)
$Green \times Post_{t-1}$		0.0115**	
		(0.0049)	
Controls	YES	YES	YES
Constant	1.0390***	1.0490***	1.0320***
	(0.0155)	(0.0042)	(0.0052)
Industry FEs	YES	YES	YES
Year FEs	YES	YES	YES
R^2	0.9520	0.9330	0.8170
N	9506	9506	4884

4.4.2. Placebo Test

To ascertain the impact of unobservable variables, we employ a placebo test, which involves the random assignment of years and policy implementation dates. Using 500 random samples,

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we re-estimate the effect on GTFP. Figure 5 displays a horizontal dashed line at a p-value of 0.1. Points below the line indicate significance at the 10% level, while those above suggest no significance. Most points cluster around zero, with the majority above the dashed line, showing no statistical significance. These results confirm that the positive relationship is not driven by unobservable factors, validating the baseline regression results.

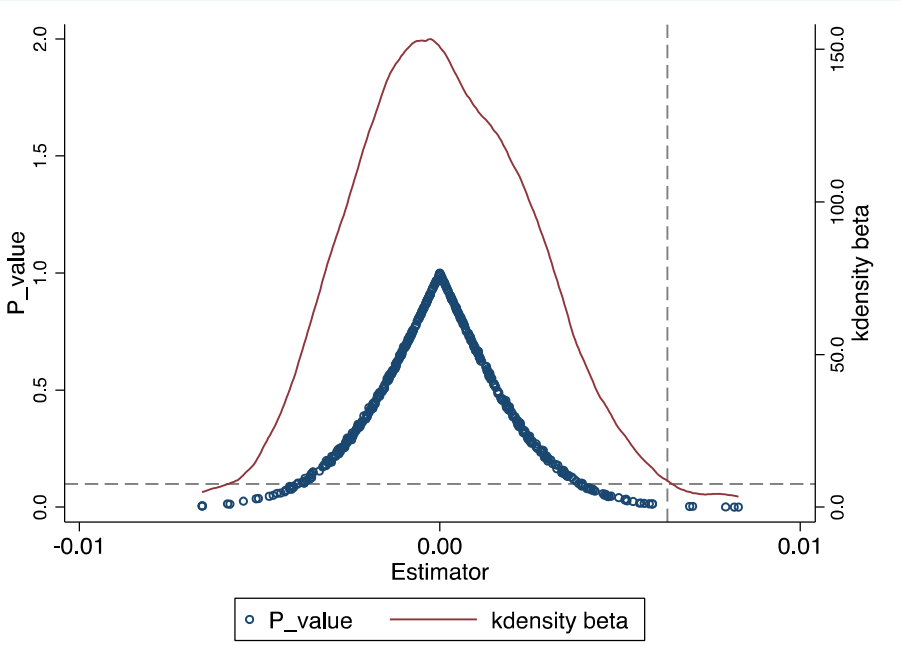

Figure 5. Placebo test

4.5. Robustness Checks

4.5.1. One-period Lag

Acknowledging the potential time lag effect of green bond issuance on corporate GTFP, this study incorporates a one-period lag ($Green \times Post_{t-1}$) into the green bond issuance variable and re-evaluates its impact on GTFP. As detailed in Table 7, Column (2), the regression analysis reveals that the coefficient of the interaction term is still significantly positive, suggesting that the findings are consistent and robust.

4.5.2. Narrow the Temporal Scope of the Sample

Before 2016, the green bond market was small and underdeveloped. However, following intensified policy support and broader adoption of green investment principles post-2016, green bond issuance and market activity surged. To avoid biases from the market's early phase, this study focuses on 2016–2019, offering a more precise evaluation of green bond issuance on firms' GTFP. Table 7, Column (3), substantiates the robustness of the derived results.

5. Further Discussion

5.1. Mechanism Analysis

5.1.1. Mediation Effect Test

Based on the previous theoretical framework, green bonds strengthen green ambidextrous innovation balance, thereby enhancing the firms' GTFP. To test whether this transmission mechanism holds, this study draws on Jiang's operational recommendations [81] for impact mechanisms to empirically examine whether green bonds can promote GTFP through green ambidextrous innovation balance. The model is specified in Equation (5):

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$$Balance_{i,t} = \beta_0 + \beta_1 Green_{i,t} \times Post_{i,t} + \lambda X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (5)$$

The regression results are shown in Table 8. From a firm-level perspective, green ambidextrous innovation balance demonstrates that exploratory and exploitative green innovations are not mutually exclusive. Their simultaneous enhancement creates a synergistic effect[82]. Specifically, exploratory innovation introduces new knowledge and technologies, which exploitative innovation helps integrate into daily operations through optimization. Meanwhile, exploitative innovation enhances resource efficiency, laying the groundwork for further exploratory efforts[83,84]. This continuous cycle fosters more efficient, environmentally friendly production methods, driving an increase in GTFP. In essence, balancing both types of green innovation enables firms to achieve short-term economic gains while investing in long-term technological progress, contributing to sustainable development and improving GTFP by increasing expected outputs and reducing undesired ones.

Table 8. Mediation effect regression results

Variable	(1)	(2)
	GTFP	*Balance*
Green×Post	0.0063*** (0.0020)	0.1220** (0.0486)
Controls	YES	YES
Constant	1.0220*** (0.0001)	2.0480*** (0.1050)
Industry FEs	YES	YES
Year FEs	YES	YES
R^2	0.9490	0.9490
N	9506	9506

5.1.2. Moderation Effect Test

Based on the previous theoretical framework, this section further explores the moderation effect from the perspective of social trust. The model is specified in Equation (6):

$$GTFP_{i,t} = \beta_0 + \beta_1 Green_{i,t} \times Post_{i,t} + \beta_2 Trust_{i,t} + \beta_3 Green_{i,t} \times Post_{i,t} \times Trust_{i,t} + \lambda X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (6)$$

Table 9. Moderation effect regression results

Variable	(1)	(2)
	GTFP	*GTFP*
Green×Post	0.0063*** (0.0020)	0.0060** (0.0029)
Green×Post×Trust		0.0114** (0.0057)
Trust		-0.0004 (0.0023)
Controls	YES	YES
Constant	1.0220*** (0.0001)	1.0490*** (0.0189)
Industry FEs	YES	YES
Year FEs	YES	YES
R^2	0.9490	0.9550
N	9506	9506

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In this model, *Trust* represents the social trust indicator, and the interaction term between the core explanatory variables is constructed as $Green \times Post \times Trust$. The results are presented in Table 9. Overall, these results indicate that social trust, as a moderating variable, positively moderates the relationship between the issuance of green bonds and the firm's GTFP.

5.2. Heterogeneity Analysis

This study extends its inquiry by conducting a heterogeneity analysis across three dimensions: macro, meso, and micro, to investigate the varying influence of green bond issuance on GTFP within diverse contextual frameworks.

5.2.1. Macro-level-New Quality Productive Forces

At the macro level, this study classifies firms based on the new quality productive forces of their provinces, which reflect regional economic development and industrial sophistication. Provinces with higher new quality productive forces generally exhibit stronger technological innovation, more efficient resource allocation, and higher-quality production factors, enabling firms to achieve better green innovation and GTFP growth potential[85]. These regions also tend to have higher public awareness of green development, increasing the likelihood of utilizing green bonds to support corporate green transformations. Therefore, in areas with high new quality productive forces, the effect should be more pronounced.

To test this, the study uses the new quality productive forces index developed by Liu and He[86], applying the entropy method to assign weights to each indicator. Provinces are classified by the median NQPF value, with those above the median labeled NQPF=1 and those below as NQPF=0. As evidenced in Table 10, within columns (1) and (2), the result is significantly positive in regions with high New Quality Productive Forces. In contrast, regions with lower NQPF show no significant results. This indicates that regions with higher new quality productive forces benefit from better infrastructure, market conditions, and more efficient green fund utilization, fostering green technology development and improving GTFP.

5.2.2. Meso-level-Financial Marketization Index

Regional financial disparities in China are stark. Economically advanced areas, particularly the eastern coastal regions, have well-developed financial markets, abundant institutions, diverse products, and strong infrastructure. These regions also enjoy better policy support and a larger talent pool, fostering greater environmental awareness among investors and a stronger preference for green investments. Therefore, in regions with highly developed finance, the effect should be more pronounced.

Table 10. Heterogeneity test

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	NQPF=1	*NQPF*=0	*FIMI*=1	*FIMI*=0	*HPI*=0	*HPI*=1
Green×Post	0.0350***	0.0035	0.0058**	0.0015	0.0094***	-0.0018
	(0.0065)	(0.0031)	(0.0028)	(0.0028)	(0.0030)	(0.0026)
Controls	YES	YES	YES	YES	YES	YES
Constant	1.0320***	1.0440***	1.0390***	1.0170***	1.0250***	1.0310***
	(0.0029)	(0.0031)	(0.0052)	(0.0051)	(0.0068)	(0.0043)
Industry FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES
R^2	0.2420	0.9520	0.9530	0.9400	0.9490	0.9490
N	4959	4547	4730	4776	6818	2688

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To test this hypothesis, we employ the financial marketization index (FIMI), derived from the regional marketization index as advocated by Lucey et al. [87], to quantify the level of financial development. Provinces are classified based on the median FIMI value, with regions above the median marked as FIMI=1 and those below as FIMI=0. The results in columns (3) and (4) of Table 10 show that in high-FIMI regions, the coefficient is statistically significant, while in low-FIMI regions, the coefficient is not significant. This discrepancy reflects the weaker regulatory frameworks and lack of transparency in less-developed financial regions, heightening the risk of "greenwashing". In these regions, even if firms issue green bonds, funds may not be directed to genuine green projects. Additionally, the limited understanding of green finance and ESG principles among investors and corporate managers hinders the effective use of green bonds to improve GTFP. Consequently, in lower-financial-development regions, green bond issuance does not significantly enhance firms' GTFP.

5.2.3. Micro-level-Pollution-intensive Enterprises Or Not

We also focus on pollution-intensive enterprises. These firms face stricter environmental regulations, higher transformation costs, and greater investor skepticism compared to non-pollution-intensive enterprises, which encounter fewer barriers to adopting green practices.

Building on Pan et al.[88]and Li et al.[89], pollution-intensive enterprises (HPI=1) are categorized with 15 industries. Non-pollution-intensive enterprises (HPI=0) comprise the rest. The results in Table 10 (columns 5 and 6) show a significant positive for non-pollution-intensive enterprises (*Green × Post*), while for pollution-intensive enterprises, the coefficient is not statistically significant.

The results indicate that enterprises with lower pollution intensity reap greater benefits from the issuance of green bonds concerning their GTFP. Pollution-intensive enterprises, however, face increased environmental risks and compliance costs, which may negate potential GTFP improvements [89]. Additionally, skepticism from green investors about their ability to implement green projects may dampen the positive impact of green bonds, limiting the benefits for Pollution-intensive enterprises.

6. Conclusion

6.1. Conclusion

This research investigates the repercussions of green bond issuance on the GTFP of Chinese firms from 2014 to 2019, employing a progressive DID model. Key findings are as follows:

First, we assess corporate green transformation using the Super-SBM model with the GML index, integrating economic efficiency and environmental performance for a comprehensive sustainability evaluation. Carbon emissions, derived from energy consumption data, serve as proxies for unexpected outputs, improving GTFP accuracy and aligning with China’s carbon peak and neutrality goals. Results show that green bond issuance significantly boosts GTFP by financing green industries, reducing costs, and enhancing production efficiency.

Second, we explore the mediating role of green ambidextrous innovation balance. Treating exploratory and exploitative green innovations as complementary, we find that green bond issuance enhances firms' innovation capacity. The interaction between exploratory and exploitative innovation fosters a feedback loop: new technologies are introduced through exploratory innovation and optimized via exploitative innovation, driving both technological advancement and resource efficiency.

Third, while most research focuses on formal institutions (laws, regulations, policies), this study highlights the underexplored role of social trust as a moderator in the green finance process. Within contexts characterized by high levels of trust, financiers exhibit greater willingness to invest in environmentally friendly initiatives, which, in turn, stimulates

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corporate innovation and advancement in environmental stewardship. This paradigm offers novel insights into the operational dynamics of green finance.

Finally, a heterogeneity analysis at macro, meso, and micro levels reveals that green bond issuance has a stronger impact in regions with higher new quality productive forces and financial development, underscoring the link between regional economic maturity and green finance success. Additionally, non-high-pollution firms benefit more from green bonds than high-pollution firms.

6.2. Managerial Implications

In China, the green bond market is pivotal in advancing the green transformation and achieving the "carbon peak" and "carbon neutrality" goals. To accelerate its development and more effectively support corporate green initiatives, this study offers the following recommendations:

From a governmental perspective, the green bond standard system should be strengthened to ensure domestic consistency and alignment with international standards, attracting global investors and fostering market internationalization. Additionally, policy support for investors should be enhanced, including reducing capital requirements and offering tax incentives to encourage participation. Finally, stricter disclosure requirements for issuers are necessary to ensure transparency and prevent "greenwashing".

From a corporate perspective, management plays a key role in enhancing green ambidextrous innovation balance. By embedding environmental awareness into the company's mission and values and providing regular training, management can boost employee engagement in green innovation. Furthermore, integrating both exploratory and exploitative green innovations fosters synergy, driving sustainable long-term growth.

From a societal perspective, building social trust requires collective action. The government can foster this by enhancing transparency, strengthening enforcement, and promoting integrity to create a trustworthy business environment. Companies, in turn, should embrace social responsibility, improve internal controls, and strengthen crisis management to build a positive image and gain investor confidence.

6.3. Limitations and Prospects

This study has several limitations. First, it focuses on the impact of green bond issuance by Chinese publicly listed firms on GTFP, excluding non-listed and international firms, which limits generalizability. Future research could expand the sample to explore both universal and context-specific effects. Second, social trust was proxied by the firm's registered province, which may not reflect actual operational locations; future studies could use verified office locations and local trust data for greater accuracy. Third, while environmental regulations are typically command-and-control, market-based, or voluntary, this study does not examine corporate responses within these frameworks. Future research could investigate how firms navigate regulatory types and how informal institutions, such as Confucian culture, influence green transformation.

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Appendix: Definition of Variables

Type	Symbol	Name	Definition
Dependent Variable	*GTFP*	Green Total Factor Productivity	Measured using Super-SBM-GML model.
Independent Variables	*Green*	Green Bond Issuance Indicator	Takes the value 1 if the company issued green bonds during the sample period, otherwise 0.
	Post	Post-Green Bond Indicator	Takes the value 1 if the company issued green bonds in the current year or later, otherwise 0.
Mediating Variable	*Balance*	Green Ambidextrous Innovation Balance	Exploratory Green Innovation: the number of green patent applications by listed companies in the current year; Exploitative Green Innovation: the number of green utility model patent applications by listed companies in the current year.
Moderating Variable	*Trust*	Social Trust	Weighted value of regional trust data from the China Entrepreneur Survey System.
Control Variables	*Size*	Firm Size	The natural logarithm of the company's total assets each year.
	Lev	Leverage	Total liabilities / Total assets.
	ROA	Return on Assets	Net profit / Total assets.
	Cashflow	Cash Flow Ratio	Net cash flow from operating activities / Total assets.
	Growth	Revenue Growth Rate	(Current year revenue / Previous year revenue) - 1.
	Firmage	Firm Age	(Current year - founding year) + 1, then taking the natural logarithm.