sustainability

MDPI

Article

Unlocking Green Innovation Potential Amidst Digital Transformation Challenges—The Evidence from ESG Transformation in China

Yanfei Wu [1,*], Irina Ivashkovskaya [1], Galina Besstremyannaya [2] and Chunfeng Liu [3]

[1] Corporate Finance Center, School of Finance, National Research University Higher School of Economics, Pokrovsky blvd. 11, 101000 Moscow, Russia; iivashkovskaya@hse.ru
[2] International Laboratory for Macroeconomic Analysis, Department of Applied Economics, Faculty of Economic Sciences, National Research University Higher School of Economics, Pokrovsky blvd. 11, 101000 Moscow, Russia; gbesstremyannaya@hse.ru
[3] Higher School of Management, Peoples Friendship University of Russia, Miklukho-Maklaya Street 6, 117198 Moscow, Russia; 1042238190@pfur.ru
* Correspondence: yavu@hse.ru

Abstract: In the current economic landscape, businesses are challenged by the dual imperatives of digital transformation and sustainability goals. While digital transformation is often heralded as a catalyst for innovation, its potential negative effects on green innovation remain underexplored. This study fills in this gap by analyzing 1443 listed companies on the Shanghai Stock Exchange main board between 2013 and 2022, focusing on the mechanisms by which digital transformation impacts green innovation and on the moderated role of environmental, social, and governance (ESG) performance. Our findings reveal that digital transformation hinders green innovation by increasing financing constraints. However, good ESG performance mitigates these negative impacts by alleviating financing constraints, thereby fostering green innovation. Our findings hold up against endogeneity tests by applying instrumental variable methods. Notably, the effect of digital transformation and ESG differs significantly between state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). While non-SOEs experience more pronounced challenges, ESG also demonstrates a stronger moderating role, unlike in SOEs, where institutional advantages offset some of these constraints. These findings enhance the understanding of dual transformation challenges, offering practical implications for aligning digital and green strategies in diverse organizational contexts.

Keywords: digital transformation; green innovation; ESG; financing constraints; moderating effects; moderated mediation effects

check for updates

Academic Editor: Stephan Weiler

Received: 27 November 2024
Revised: 20 December 2024
Accepted: 1 January 2025
Published: 3 January 2025

Citation: Wu, Y.; Ivashkovskaya, I.; Besstremyannaya, G.; Liu, C. Unlocking Green Innovation Potential Amidst Digital Transformation Challenges—The Evidence from ESG Transformation in China. *Sustainability* **2025**, *17*, 309. https://doi.org/10.3390/su17010309

1. Introduction

In an era where digitalization and sustainability have become intertwined imperatives, enterprises face the critical challenge of harmonizing technological innovation with environmental responsibility. Digital and green transformations, often referred to as "twin transitions", are increasingly recognized as pivotal to ensuring both economic growth and environmental protection. However, a crucial question persists within both academic and policy domains: can twin transitions create synergies, or do they inherently conflict, with one undermining the other [1,2]? This debate remains unresolved, highlighting the need for deeper empirical exploration.

As one of the top energy consumers globally, China faces serious environmental pollution and overconsumption of natural resources due to high energy consumption in traditional industries. A growing number of stakeholders are pressuring heavily polluting enterprises to balance economic and environmental benefits. Therefore, while promoting digital transformation, companies cannot ignore the need for a green transition. Failure to effectively align these transitions may undermine both their corporate competitiveness and sustainability [2]. Green innovation is rooted in ecological protection, helping companies fulfill their environmental responsibilities while ensuring profitability [3]. By enhancing institutional legitimacy, securing government subsidies, improving resource utilization, and reducing pollution emissions [4,5], it has become a vital strategy for achieving a competitive advantage [6].

Digital transformation is recognized as a significant trend that is revolutionizing both society and industry. Digital technologies contribute by offering innovative products and services to customers, streamlining organizational and business processes, optimizing supply chains, and significantly enhancing operational efficiency [7,8] and dynamic capabilities [9]. However, there are still major disagreements in current research on the effect of digital transformation on green innovation. While several studies suggest that digital transformation enhances green innovation [10–13], its benefits should not be oversimplified, as it can also pose challenges [14–17]. With scarce attention and capital, firms may prioritize the allocation of significant resources to technological innovation in order to rapidly establish a competitive advantage, which may divert attention and resources from other key operational functions [18], leading to a "crowding-out" effect. The implementation of digital transformation forces firms to divert investments away from environmental protection initiatives [19], thus somewhat undermining the ability to innovate in a green manner [20]. The complementary pursuit of digital transformation and environmental sustainability strategies may undermine innovation performance due to different strategic objectives and competition for resources [15]. Therefore, enterprises need to carefully manage the resources required for digital transformation and maintain a balance of resources to ensure that short-term performance goals are achieved while avoiding adversely affecting green innovation [21]. Particularly in large, mature firms with large organizational inertia, cross-functional collaboration challenges are likely to lead to a simultaneous erosion of competitiveness and sustainability [18].

In addition, digital transformation requires significant upfront investments in time, money, and people to realize significant benefits [22]. No consistent conclusions have been reached on whether digital transformation exacerbates or alleviates financing constraints, due to variations in samples and performance metrics in research. Some studies reveal a negative correlation between the two [23], while others suggest that digital transformation contributes to financing constraints and also elevates operational risks and demand for financing [24,25]. In addition, green innovation demands even more extensive and sustained financial support. According to resource scarcity, increased financial allocations to digital transformation may crowd out funding available for green innovation. However, current research does not consider the financing conflict between the dual transformations or the increase in financing constraints due to the specific risks, such as uncertainty and compliance, that digital transformation poses to large, well-established firms that rely on traditional business models to thrive. Our study addresses these gaps by exploring the mediating mechanisms through which financing constraints affect the interplay between twin transitions.

Furthermore, from an externality perspective, green innovation exhibits dual externalities, generating both knowledge spillovers and environmental benefits [26,27]. These positive externalities often lead to market failure, as firms may underinvest in green innovation without adequate incentives. Effective external regulation and internal self-governance are thus essential to drive firms toward green innovation. While environmental, social, and governance (ESG), with its dual attributes of "internal governance" and "external evaluation", plays a pivotal role in this process, its moderating effect has been largely overlooked in prior research. This study explores ESG's moderating role in the relationship between twin transitions and its moderating role for the mediating mechanism of financing constraints, addressing the above-mentioned key research gap.

We contribute to the literature in several ways.

Our research makes a unique contribution to the growing discourse on the twin transformation of digitalization and sustainability by addressing critical gaps in the existing research. First, existing studies predominantly explore the benefits of digital transformation on green innovation [12], but they often neglect the potential conflicts between these twin transitions, leaving theoretical frameworks ambiguous and practical applications uncertain. To address this gap, we focus on large, mature Chinese enterprises to investigate the relationship between digital transformation and green innovation. These enterprises significantly contribute to the national output but face distinct challenges, such as greater organizational inertia, complex resource competition, and structural resistance to change [28,29]. However, this specific aspect has often been overlooked in previous studies. By centering on the group of large-scale companies based on traditional business models, we provide a detailed perspective on the complexity of the resource trade-offs in the face of simultaneous digital transformation and green innovation.

Second, by emphasizing internal resource competition, we analyze the mediating role of financing constraints under twin transformation. Unlike most studies that assume successful digital transformation, our research emphasizes the substantial initial investment required, high failure rates, and slow returns of digital transformation, as well as the uncertainty risks posed by its disruption of traditional business models and competitive landscapes. We theorize how twofold transformation increases specific risks and information asymmetries, affecting firms' financing capabilities, thus affecting resource inputs for green innovation. Our findings align with Gebauer et al. [30] on the digital paradox, offering new insights from the perspective of financing constraints.

Third, while most studies analyze the moderating effects between digital transformation and green innovation from a single viewpoint of either "external supervision" [31,32] or "internal governance" [33] variables, this paper incorporates overall ESG performance, which has dual attributes of "internal governance" and "external evaluation". By examining the moderating role of ESG within the twin transitions, this study reveals complex dynamics that are often overlooked when these factors are considered in isolation, emphasizing the importance of external oversight and self-monitoring in fostering the alignment of economic and environmental objectives within the framework of eco-modernization strategies [34].

2. Literature Review

2.1. The Impact of Digital Transformation on Green Innovation

Several studies have shown that digital transformation is generally regarded as a driving force of green innovation [12] by enhancing resource utilization, expanding knowledge bases [13], improving internal control [35], and getting government subsidies [10], thereby boosting both quality and quantity of green innovation [11].

Conversely, some authors propose that digital transformation does not facilitate, or even hinders, innovation under certain conditions [14–17]. For instance, Ghasemaghaei et al. [14] analyzed big data characteristics, noting that while data type and velocity positively influence innovation, data volume often fails to yield significant improvements. Similarly, in a study of 369 North American SMEs, Ardito et al.'s research [15] observed that aligning digital transformation with environmental sustainability strategies often negatively impacts process innovation performance. Using a large dataset of EU-based firms, Usai et al. [16] found that excessive reliance on digital technologies can strain long-term innovation capacity. Cicerone et al. [17] discovered that the accumulation of artificial intelligence knowledge has helped EU regions already focused on green technology in the past to continue developing green technology, but it has limited or negative effects on regions not yet involved in green technology.

Moreover, some research has found a nonlinear relationship between the two [20,21]. For example, Wang et al.'s [21] study of Chinese industrial firms suggests that the technological paradigm shift triggered by digitization in the early stages can increase green innovation in firms, but when firms exceed a certain threshold of digitization, digitized information overload leads to a higher threshold of decision-making for managers and crowds out firms from investing the resources needed for technological innovations.

These conflicting conclusions indicate that the relationship between digital transformation and green innovation is highly context-dependent, influenced by corporate characteristics, organizational structures, geographical characteristics, and resource allocation strategies. Our study fills this gap, focusing on the resource allocation within mature, large-scale enterprises.

2.2. The Impact of ESG on Green Innovation

Green innovation has substantial environmental and economic benefits. This highlights its importance to both internal and external stakeholders. ESG, in turn, is critical to balancing a company's economic benefits and sustainability by directing its limited capital to innovations that have long-term developmental value.

Research shows that ESG performance is a key factor in improving green innovation by reducing financing constraints, increasing corporate environmental awareness [36], strengthening human capital [37], increasing investment in research and development, enhancing risk-taking levels, and improving employee innovation efficiency [38]. Wang et al. [39] find that companies evaluated by ESG rating agencies experienced a 3.9% growth in the output of green innovation. This impact was particularly significant in companies with longer-term-focused investors, greater financing constraints, and non-state-owned enterprises. A study by Wang and Sun [40] indicates that ESG performance both promotes green innovation and substitutes for stringent environmental regulations in fostering it. However, Yang and Albitar [41] argue that the relationship is not linear: low ESG ratings focus on improving governance and operations, potentially neglecting green innovation. But as corporations raise ESG scores, they increasingly prioritize green innovation.

As digital technologies continue to mature, the sustainability of digital transformation has also become a focal point for stakeholders. Consequently, stakeholders such as investors [42], employees [43], and consumers [44] are increasingly attentive to ESG performance. Scholars have been prompted to examine the interaction between ESG and digital transformation in shaping firm outcomes. Fu and Li [45] found that integrating ESG performance into digital transformation strategies enhances financial performance, while Alkaraan et al. [46] show that ESG strengthens the correlation between Industry 4.0 and operational efficiency. Nevertheless, the literature does not thoroughly explore the influence of synergies between the two on green innovation.

3. Theoretical Analyses and Research Hypotheses

3.1. Digital Transformation and Green Innovation Performance

Green innovation is not merely a technical concept but embodies the principles and pathways of green development. It involves innovations in products, processes, or business models that elevate a company's environmental performance [47]. While digital transformation, as a disruptive organizational process, holds the potential to optimize operational efficiency [7,8] and enhance dynamic capabilities [9], its implementation often prioritizes short-term technological advancements over long-term environmental sustainability. This dual nature of digital transformation offers both advantages and obstacles for green innovation: on one side, it can act as an enabler by optimizing resource utilization and providing critical tools to address external environmental challenges; and on the other side, its potential is constrained by significant resource barriers and strategic mapping [20,48], especially in large, established firms. Due to the nature of the stage of the transformation and the path dependency, as well as the excessive focus on short-term performance to cope with intense competition, not only do potential positive effects of digital transformation take a much longer time span to materialize, thus also limiting direct and timely support for green innovation, but the competition for resources between it and long-term development goals also hinders green innovation. The dual pressures of core business performance and the effectiveness of digital transformation implementations make it difficult for organizations to consider green innovations with long-term sustainability in mind.

Specifically, within large conglomerates with complex organizational structures, departments with similar functions often compete for scarce resources, intensifying the "crowding-out" effect between the twin transitions. Both initiatives are innovation activities that require substantial investment and are characterized by high uncertainty [49]. However, their goals and implementation strategies differ significantly: digital transformation typically aims to optimize short-term efficiency and market competitiveness, whereas green innovation prioritizes long-term strategic value and environmental externalities. These differences create conflicts in resource allocation, leading to internal power games, inefficient resource allocation, and impeded organizational synergy [15,50]. Moreover, mature large-cap corporations often face organizational inertia [28] and employee resistance to disruptive changes [51]. This path dependency further compounds the challenges of resource allocation and reduces the resources that would otherwise be available to support green innovation.

The inherent uncertainty and risks associated with digital transformation further exacerbate the conflict between the dual transformations. Internally, digital transformation's high failure rates [52] and slow returns disrupt internal organizational stability. Externally, digital transformation increases external competition from knowledge spillovers and the erosion of industry barriers [53,54]. To maintain operational balance and to fend off increased external competition, companies tend to focus on technological R&D investments and marketing strategies that can rapidly increase market competitiveness [55]. This approach aims to establish a market isolation mechanism and create "temporary advantages" while maintaining good financial performance of the enterprise to maintain market leadership and social image. In contrast, green innovation, characterized by dual externalities that lead to knowledge and environmental spillover effects [26,27], offers long-term strategic value but lacks immediate financial returns. This misalignment between short-term stress and long-term sustainability is causing companies to scale back resources allocated to green innovation, especially under the dual pressures of financial performance of the core business and digital transformation implementation effectiveness.

According to the theoretical analysis provided above, we propose Hypothesis 1:

H1. *Digital transformation may inhibit the enhancement of green innovation of mature large-cap companies.*

3.2. The Mediating Role of Financing Constraints

From the perspective of financing constraints, innovation is inherently a risky, long-term event requiring substantial and stable financial support [49]. Eco-innovation, in particular, is characterized by higher technological risks, longer investment recovery periods [26], and significant externalities that limit private financial returns [56]. These factors make green innovation more challenging to finance compared to traditional innovation.

As a resource-intensive activity, digital transformation requires continuous and substantial funding to support digital technologies, equipment, and workforce training [57,58]. According to the data from the State Information Center in 2020, over half of Chinese firms remain in the initial stages of digital equipment transformation and technology adoption, largely due to low profitability and financing constraints, and the issue of funding has become a major challenge in the early stages of digital transformation [24,25]. For mature enterprises with entrenched organizational structures, the financial demands of digital transformation are particularly pronounced, as they must overcome significant structural inertia and resistance to change [28]. However, different strategic intentions tend to make the funding needs for digital transformation frequently conflict with those needed for eco-innovation. These demands tend to crowd out internal funding for green innovation initiatives, intensifying resource allocation challenges.

The financing constraints associated with digital transformation are further explained by the Information Asymmetry Theory [59], which posits that the distribution of information among different participants in a transaction or decision is usually uneven. While most studies presuppose the success of digital transformation and uncritically affirm its positive signaling effects, the reality often diverges. Digital technologies can theoretically enhance information transparency through systematic data analysis [60,61], but their complexity and high failure rates introduce significant uncertainty for external investors [52]. This uncertainty is exacerbated by the disruption of traditional business models [62] and firms' path dependence [63], which constrains their ability to adapt to new technologies and paradigms. For large, mature firms that thrived in the pre-digital economy, these challenges can pose existential threats [29]. Consequently, investors lacking technical expertise face greater decision-making challenges in the face of these uncertainties, leading to more stringent financing conditions and higher capital costs.

Furthermore, the application of big data technologies introduces substantial privacy protection and regulatory compliance risks [64]. Investors often struggle to ascertain whether firms possess the requisite capabilities to ensure compliance with data regulations and legal frameworks that mitigate potential legal consequences or unfavorable social perceptions. This uncertainty heightens investor concerns regarding the legal and reputational risks associated with digital transformation, prompting them to impose stricter financing conditions. Such constraints further limit firms' ability to secure external capital, increasing the financial burden [65].

Considering the above theoretical analysis, we propose the second hypothesis:

H2. *Digital transformation increases financing constraints, thereby negatively impacting green innovation.*

3.3. The Moderating Effect of ESG Performance

The perspective of ecological modernization [66] advocates for minimizing environmental harm while maintaining economic growth, thereby achieving harmony between economic and environmental goals. However, relying solely on enterprises' voluntary commitment to aligning economic performance with environmental quality often proves insufficient. In practice, the key to integrating environmental quality into economic decision-making lies in the combined effects of external oversight and internal governance [34]. This paper proposes that ESG functions as a holistic measure of sustainability, influenced by both external stakeholder oversight and internal governance mechanisms. This dual supervision mechanism not only provides internal drivers [38,67] and external incentives [67,68] for green transformation but also unlocks the potential for optimized resource allocation during digital transformation, guiding digital technologies to support environmentally friendly technological innovation.

The Resource-Based Theory points out that an enterprise's competitive advantage comes from the acquisition and utilization of scarce, unique, and hard-to-imitate resources [69]. Companies with strong ESG performance provide intrinsic motivation and a stable setting for green innovation activities, which are seen as resources for firms to build competitive advantage. ESG-aligned firms attract high-quality talent through green human resource management practices [43], strengthening the human capital quality, enhancing employees' sense of belonging, and stimulating their work enthusiasm needed to manage the complexities of integrating digital technologies [70]. This talent pool not only enhances firms' ability to implement digital tools effectively but also mitigates risks such as skilled labor shortages and loss of managerial expertise, common during digital transformation [71]. Importantly, ESG-aligned risk management capabilities [72,73] further mitigate operational uncertainties and idiosyncratic risk [74,75], including technology adoption failures, market resistance, regulatory uncertainty, and various other challenges and threats associated with digital transformation [29,76], providing a stable operational environment for digital transformation.

Additionally, companies with strict ESG principles put more emphasis on green development. They inspire corporate managers and R&D teams to incorporate sustainability considerations into the design of their digital processes, integrating environmental objectives at every stage of the value chain, from the selection of raw materials to sales, and achieving green process innovation. Moreover, sound corporate governance mechanisms play a critical role in ensuring efficient resource allocation. Transparent and objective decision-making processes not only prevent resource misallocation and mitigate the negative effects of employee negative emotions on innovation [77] but also strategically invest limited funds in high-potential green technology research and development in accordance with the principles of fairness and meritocracy, enabling firms to balance both economic and environmental objectives.

In terms of external regulation, superior ESG performance signals a firm's strong environmental awareness and commitment, increasing access to external stakeholder support like government subsidies [78]. These subsidies reduce the financial risks of green technology development and incentivize participation in policy-driven green innovation initiatives [79]. Furthermore, according to the stakeholder theory, firms must meet the multiple expectations of different stakeholder groups to fulfill their responsibilities to stakeholders [80]. Such support and subsidies come with accountability mechanisms that require firms to meet green innovation benchmarks established by governments and other stakeholders. This external monitoring pressure serves as a critical incentive for firms to optimize resource allocation. It encourages the integration of digital technologies into green innovation processes, mitigates short-term decision-making tendencies during digital transformation, and fosters increased investment in green innovation [68]. Thus, we propose the third hypothesis:

H3. *ESG performance can mitigate the adverse impact of digital transformation on corporate green innovation.*

3.4. The Moderating Effect of ESG on the Mediating Mechanism

Based on the Signaling Theory [81], in the presence of information asymmetry, the party with superior information can reduce uncertainty by proactively acting to convey reliable information. Companies that excel in ESG typically demonstrate robust risk management systems and heightened organizational legitimacy, demonstrating a commitment to sustainability and enduring value creation, and thus boosting investors' confidence in the firm [82]. It mitigates the negative perceptions of potential failures and slow returns associated with digital transformation and increases stakeholders' tolerance for potential short-term operational or financial performance dips during digital transformation, thereby increasing access to external finance and lowering debt costs [83,84].

It reduces the cost of issuing green bonds due to investors' environmental preferences [85]. Additionally, ESG practices attract government subsidies and tax incentives related to greening and social responsibility, further lowering the financial barriers associated with digital transformation [41]. Furthermore, investors focused on sustainability are likely to invest more in equity crowdfunding [86]. In addition, crowdfunding serves as social capital, fostering emotional connections between companies and green consumers. These consumers, who strongly identify with ESG-driven brands, show greater investment willingness and risk tolerance, enhancing the availability of crowdfunding capital. At the supply chain level, ESG performance reinforces trust among supply chain partners and customers, ensuring stable commercial relationships that reduce the incidence of commercial fraud. Consequently, they are more inclined to establish long-term, stable supply chain relationships, facilitating greater access to commercial credit financing [87]. Green financing can alleviate the financial pressure of twin transitions, optimize innovation input structures, and coordinate resource allocation, promoting green innovation [88].

Based on our theoretical analysis provided above, we propose the fourth hypothesis as follows:

H4. *Good ESG performance can mitigate the financing constraints caused by digital transformation, alleviating its negative impact on green innovation.*

Based on the above hypotheses, the research model is depicted in Figure 1.

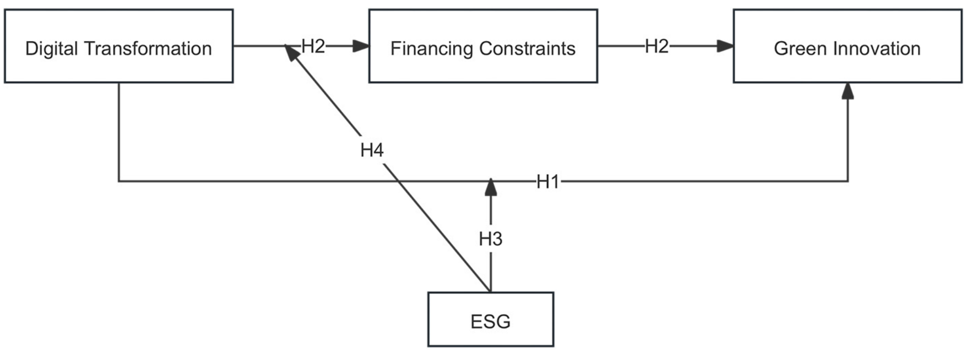

Figure 1. Research model.

4. Research Design

4.1. Data Sources

This study uses a sample of companies listed on the main board of the Shanghai Stock Exchange from 2013 to 2022, primarily comprising large blue-chip enterprises. The starting point of the year 2013 was selected for studying China's digital and green transformation due to significant policy and technological developments. In 2013, the Chinese government issued the "Opinions on Promoting Information Consumption to Expand Domestic Demand", which, among other things, launched the national informatization strategy, provided policy support for digital transformation, and established the measures to enhance green technology development and promote sustainable economic growth. Additionally, 2013 marked the beginning of China's 4G network construction, rapidly advancing mobile internet technology and supporting digital transformation [89]. Data were collected from April to June 2024. As green innovation data for 2023 have not been fully disclosed by the government, the year 2023 is excluded from the analysis. The digital transformation data were collected manually, using text analytics with the Python word frequency statistics function; the data for green innovation are from the China National Intellectual Property Administration (CNIPA), using the International Patent Classification (IPC) system to identify relevant innovation, while other sample data were sourced from the Wind financial terminal database and the CSMAR database. The sample selection was based on the following principles: (1) samples with absent data on the main explanatory variables and financial explanatory variables are excluded; (2) financial and insurance companies are excluded on account of their particularity [10,90,91]; (3) excluding ST, PT, and *ST companies [92,93]; and (4) to avoid the effect of outliers, all continuous variables were minorized at the 1% and 99% levels [94,95]. The final sample consists of 620–1252 companies in different years (9521 observations with 1443 companies).

4.2. Description of Variables

4.2.1. Dependent Variable: Green Innovation (GI)

In prior studies, the main metrics used to measure corporate green innovation capability include green patent applications [96,97], citations of green patents [98], and green patents granted [99,100]. As an accurate measure of environmental innovation achievements, the total green patent portfolio serves as an accurate metric that captures all green invention disclosures, invention patent grants, and utility models obtained by the company. The data sources include patent-related data from the CNIPA and green patent category numbers from the World Intellectual Property Organization IPC Green Inventory.

4.2.2. Explanatory Variable: Digital Transformation (DT)

Based on existing studies [60,89,101], this research calculated word frequencies of 74 keywords, covering five dimensions to measure DT. These keywords (shown in Figure 2) encompass various technologies and a wide range of application areas. The words used in the annual report reflect the operating philosophy and development trajectory of firms [102], making it a viable approach to assessing digital transformation through annual report analysis. The word-frequency data were obtained by analyzing the text of annual reports using the "jieba" segmentation tool of Python 3.9. To avoid ambiguity caused by the broad meanings of some commonly used words, this study manually filtered out words that were less relevant to AI applications. For example, the term "artificial intelligence" was matched with the phrase "Artificial Intelligence Co., Ltd.", and its frequency was calculated. Then, such expressions were excluded from the overall frequency of the "artificial intelligence" keyword. This process was repeated to obtain the final adjusted frequency for each term. Following Liu et al. [89], these word frequencies were then summed and logarithmically transformed to derive the quantitative indicators of a company's digital transformation as follows:

$$\ln\left[\left(\sum_{n}^{74}\text{keyword frequency}\right)+1\right] \quad [1]$$

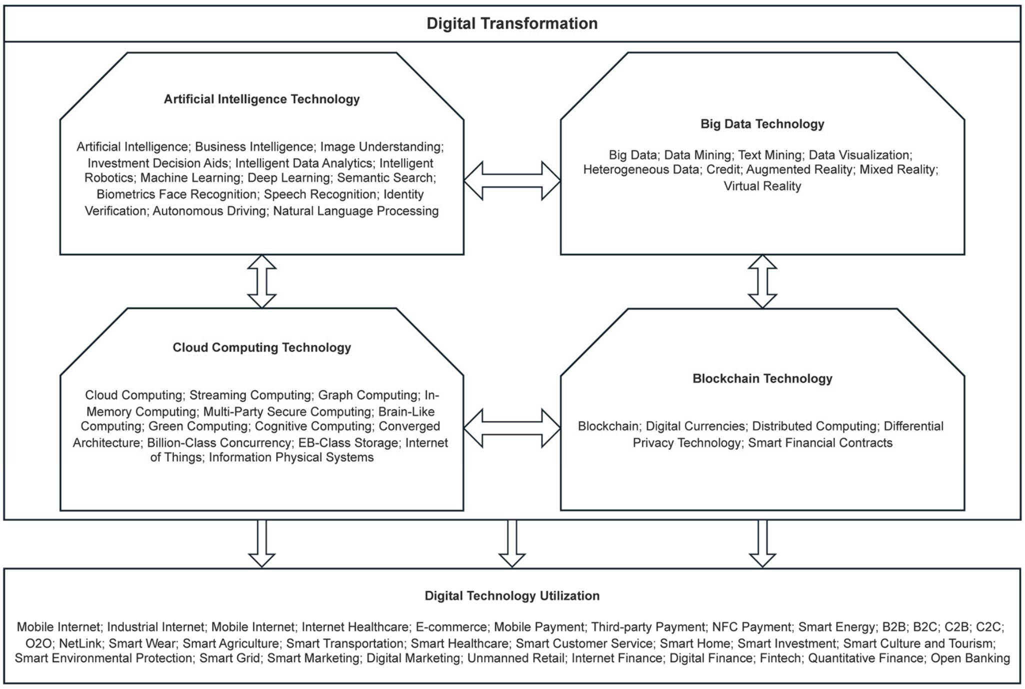

Figure 2. Keywords for digital transformation research model.

4.2.3. Mediating Variable: Financing Constraints (FCs)

Scholars have proposed various metrics to measure financing constraints, including single factors such as asset size and dividend payout ratio; and composite indices, like the SA index [103], KZ index [104,105], and WW index [106]. Hadlock and Pierce [103] developed the SA index by categorizing constraints based on qualitative information from financial filings of firms from 1995 to 2004 and estimating ordered logit models with firm size and age as significant predictive factors. The SA index is generally considered to be more valid than the KZ index [92]. The calculation of the SA index is performed using the mathematical formula provided below [103]:

$$\text{SA} = -0.737 \times \text{Size} + 0.043 \times \text{Size}^2 - 0.04 \times \text{Age} \quad [2]$$

In Equation [2], Size refers to the logarithm of total assets (in million RMB); and Age represents the firm's age, determined by subtracting the listing year plus 1 from the current year. The higher absolute value of the SA reflects a higher level of financing constraints [107,108]. Since size and age are firm characteristics that are not easily influenced by internal firm decisions, the scholars consider these variables more reliable to capture the resource availability and financing constraints of a firm [92,108,109]. Considering the possible internal resource competition between twin transitions, we applied the SA index to capture financing constraints.

4.2.4. Moderator Variable: ESG

We selected the Huazheng ESG rating index due to its extensive coverage, frequent updates, and advanced calculation methods [110]. It is frequently employed in numerous studies as a standard for evaluating ESG ratings [111–113]. The index includes over 300 indicators across environmental, social, and governance dimensions, ensuring a thorough evaluation. It is updated quarterly, providing more current data compared to other indices that are updated semi-annually or annually. Additionally, it employs integrated semantic analysis and natural language processing algorithms, enhancing its accuracy and scientific validity. These advantages make the Huazheng ESG rating index an efficient means for measuring ESG performance. The ratings are classified into nine levels, from AAA to C; updates occur quarterly. Based on these ratings, we assign values from one to nine and use an average score of the quarterly scores in a year to gauge ESG performance for that year. A higher score means better ESG performance.

4.2.5. Control Variables

Drawing on prior research [90,92], this study incorporates the following control variables into the model: To capture profitability, we use return on assets (ROA) and growth rate of operating revenue (Growthrate). Tobin's Q (TbQ) is used for future growth opportunities. Other corporate indicators are firm size (Size), leverage ratio (Lev), firm age (Age), and firm research and development expenditures (R&D). Since green bonds provide dedicated funding for green environmental projects, directly influencing the financial resources for green innovation activities [114], we introduce the green bond issue size (Greenbonds). We also introduce corporate governance variables, such as board of directors' independence (Ind), property rights contexts (SOE), and shareholding concentration (Top1). The definitions and quantification of all variables can be found in Table 1.

Table 1. Variable definitions.

Variable Type	Variable Name	Variable Symbol	Variable Description
Dependent variable	Green innovation	GI	Sum of green invention disclosure, invention patent grant, and utility model
Explanatory variable	Digital transformation	DT	Using text mining, word frequencies of 74 keywords were summed and logarithmized
Mediator variable	Financial constraints	FCs	Absolute value of SA index
Moderator variable	Environmental, social, and governance	ESG	Using the ratings from the Huazheng database, each rating was converted into a score, and the quarterly average score was used to represent the annual score
Control variable	Return on total assets	ROA	Net profit divided by total assets
	Enterprise size	Size	Total assets taken in logarithms
	Gearing	Lev	Total liabilities divided by total assets and taken in logarithms
	Enterprise age	Age	Years of observation minus years listed and taking natural logarithms
	R&D expenditure	R&D	Total firm R&D expenditures taken in logarithms
	Tobin's Q	TbQ	Market value of assets divided by replacement cost of assets
	Board independence	Ind	Number of independent directors divided by number of directors
	Growth rate of revenue	Growthrate	(Current operating income − prior operating income) divided by prior operating income and taking natural logarithms
	Property rights contexts	SOE	In the case of state-owned enterprises, the value is "1"; in the case of non-state-owned enterprises, the value is "0"
	Percentage of green bonds	Greenbonds	Green bond issue size
	Shareholding concentration	Top1	Equity shareholding ratio of the largest shareholder of the enterprise

The table comprehensively explains and quantifies all the variables used in the empirical analysis.

4.3. Descriptive Statistics of the Variables

Table 2 provides descriptive statistics for 9521 observations. The green innovation's mean value is 0.422, with a standard deviation of 1.878, a maximum of 41, and a minimum of 0, reflecting substantial variation in green innovation among the sample firms. The mean ESG score is 4.230, suggesting an average ESG rating between B and BB. The mean digital transformation is 1.442, with keyword frequency in annual reports averaging 8.763, ranging from 0 to 426. Distribution of other control variables within reasonable limits.

Table 2. Descriptive statistics of the variables.

Variables	Obs	Mean	Std. Dev	Min	Max
GI	9521	0.422	1.878	0	41
DT	9521	1.442	1.258	0	6.057
ESG	9521	4.230	0.994	1	8
FC	9521	3.575	0.362	2.014	4.438
ROA	9521	4.407	6.671	−97.52	65.54
Size	9521	8.835	1.408	4.478	14.79
Age	9521	12.541	0.951	1	32
R&D	9521	3.502	2.182	0	10.81
Lev	9521	3.698	0.559	−0.179	5.042
Growthrate	9521	4.680	0.306	−0.142	8.885
GreenBonds	9521	0.0268	0.628	0	34.40
TbQ	9521	1.805	9.679	0.0353	666.3
Top1	9521	37.677	15.44	3.390	89.09
SOE	9521	0.492	0.500	0	1
Ind	9521	0.377	0.0643	0.143	0.800

Additionally, we calculated the variance inflation factors (VIFs) and found that the highest VIF value among the variables is 2.76, with an average VIF value of 1.74, both lower than the threshold of 10. Thus, multicollinearity does not appear to be an issue in this study.

4.4. Methodological Approach

A company's green innovation is greatly affected by specific and unobservable firm individual characteristics, such as industry characteristics [115,116], corporate culture [117], and management style [118,119]. The two-way fixed-effects models effectively mitigate the influence of unobservable variables related to year and individual, reduce estimation biases, and enhance the statistical reliability of findings [120,121], but they require panel data and a substantial sample of observations [121].

Model (1) is designed to verify the correlation between DT and GI:

$$GI_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \alpha_2 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \quad (1)$$

where subscript i denotes the firm; t represents time; $GI_{i,t}$ indicates the green innovation of firm i at year t; $DT_{i,t}$ indicates the level of digital transformation of firm i at year t; $Controls_{i,t}$ indicates a set of control variables; $\sum Year$ and $\sum Ind$ represent the time fixed effects and individual fixed effects of the firm; and $\varepsilon_{i,t}$ is the exogenous disturbance term, which follows a normal distribution with mean 0 and variance σ2. Based on the theoretical analysis, α_1 is expected to be significantly negative.

To verify the mediating role of financing constraints between DT and GI, this paper draws on the causal-steps approach to mediation [122] of models (1)–(3):

$$GI_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \alpha_2 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \quad (1)$$

$$FC_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \beta_2 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{2}$$

$$GI_{i,t} = \gamma_0 + \gamma_1 DT_{i,t} + \gamma_2 FC_{i,t} + \gamma_3 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{3}$$

where $FC_{i,t}$ represents the corporate financing constraints, and the other variables are the same as in the above model. If β_1 is significantly positive and γ_2 is significantly negative, it confirms the validity of the mediating effect of $FC_{i,t}$.

The approach outlined by Baron and Kenny (1986) is widely used in empirical studies dealing with the mediation effect [12,89,123]. The mediation effect can elucidate intricate causal mechanisms, as well as facilitate the comprehension of the causal pathways between dependent and independent variables and improve the model's explanatory power. Wen and Ye [124] recommend prioritizing the causal steps approach since, when the causal steps approach yields significant results, other methods (such as bootstrap and Markov chain Monte Carlo, MCMC) will inevitably yield significant results as well. The results of the causal-steps approach may even be better than those of the bootstrap or other methods [124].

To verify the moderating effect of ESG, this paper constructs Model (4). This is based on previous studies [12,13,125] targeted at estimating the moderating effect model [122,126,127].

$$GI_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \alpha_2 ESG_{i,t} + \alpha_3 ESG_{i,t} \times DT_{i,t} + \alpha_4 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{4}$$

where $ESG_{i,t} \times DT_{i,t}$ represents the moderating role played by ESG performance in the impact of DT for GI. If it is significant, it means that the moderating effect of ESG exists. Based on the theoretical analysis, the coefficient α_3 is expected to be significantly positive.

Based on Edwards and Lambert's [127] interpretation of the moderated mediation effect model and related studies [123,125], models (5) and (6) are constructed to confirm the moderating effect of ESG on the first half of the mediation effect path, and Model (7) is constructed to confirm the direct moderating effect of ESG on the mediation effect path.

$$FC_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \beta_2 ESG_{i,t} + \beta_3 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{5}$$

$$FC_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \beta_2 ESG_{i,t} + \beta_3 ESG_{i,t} \times DT_{i,t} + \beta_4 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{6}$$

$$GI_{i,t} = \gamma_0 + \gamma_1 DT_{i,t} + \gamma_2 ESG_{i,t} + \gamma_3 FC_{i,t} + \gamma_4 ESG_{i,t} \times DT_{i,t} + \gamma_5 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \tag{7}$$

If in Model (6), the coefficient β_3 is significant, and it indicates that ESG moderates the mediating effect of FC caused by DT. If the coefficient γ_4 in Model (7) is significant, it means that ESG moderates the relationship between DT and GI not entirely through the mediating variable, FC. Based on the theoretical analysis, the predicted coefficient β_3 is significantly negative and γ_4 is significantly positive.

5. Results and Discussion

5.1. Regression Analysis of the Main Effect

Model (1) reveals that the coefficient for DT is negative and statistically significant at the 1% level (−0.0442), as shown in Table 3. This result confirms Hypothesis 1, indicating that digital transformation inhibits green innovation in Chinese mature, large-scale firms. These results align with the resource competition theory discussed earlier, highlighting the challenges of the twin transitions, further confirming the findings of Ardito et al. [15].

Table 3. Benchmark regression and endogeneity test.

	Model 1	First Stage		Second Stage
Variables	**GI**	**DT**	**DT**	**GI**
DT	−0.0442 ***			−0.5577 ***
	(−2.60)			(−2.75)
DEI		0.3986 ***		
		(5.05)		
DPA			0.0020 ***	
			(9.33)	
ROA	0.0010	−0.0019	−0.0017	0.0006
	(0.46)	(−1.00)	(−0.87)	(0.23)
Size	0.1179 ***	0.0943 ***	0.0932 ***	0.1946 ***
	(3.67)	(7.42)	(7.39)	(6.49)
Age	0.0546	0.0350 **	0.0386 ***	−0.0503 *
	(1.30)	(2.32)	(2.58)	(−1.76)
R&D	0.0062	0.0780 ***	0.0756 ***	0.1700 ***
	(0.44)	(8.85)	(8.55)	(8.60)
Lev	0.0130	0.1057 ***	0.1078 ***	0.894 **
	(0.30)	(4.35)	(4.45)	(2.18)
Growthrate	−0.0381	0.0041	0.0103	−0.0306
	(−1.05)	(0.10)	(0.26)	(−0.68)
Greenbonds	−0.0167	−0.0158	−0.0170	−0.0357
	(−0.97)	(−0.95)	(−0.97)	(−1.58)
TbQ	0.0002	0.0007	0.0005	0.0010
	(0.19)	(0.70)	(0.51)	(1.21)
Top1	−0.0032	−0.0004	−0.0008	−0.0011
	(−1.60)	(−0.54)	(−0.97)	(−0.79)
SOE	−0.1027	−0.2892 ***	−0.3098 ***	−0.0961
	(−1.14)	(−10.42)	(−11.14)	(−1.19)
Ind	−0.1140	0.0842	0.0950	−0.2602
	(−0.53)	(0.50)	(0.57)	(−0.89)
Constant	−0.4800	−0.5957 **	−0.5866 **	
	(−1.53)	(−2.53)	(−2.51)	
Year FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Observations	9521	9521	9521	9521
R-squared	0.0110	0.3666	0.3708	−0.0591
Kleibergen–Paap rk LM statistic				99.176
				[0.000]
Kleibergen–Paap rk Wald F statistic				49.544
Cragg–Donald Wald F statistic				49.272
Sargan test				1.635
				[0.2010]
Hansen J-test				1.714
				[0.1905]

Note: The T statistic is in parentheses; *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively; *p*-value in brackets.

5.2. Endogeneity Test

Although individual and time effects were included in the benchmark regression to account for heterogeneity in firms' green innovation capabilities, endogeneity concerns may persist owing to potential reverse causality and omitted variables. Both transitions require significant resource investments and face high risks of failure. This interdependence implies that increased investment in green innovation may divert resources away from digital transformation, introducing potential reverse causality. To mitigate this issue, the instrumental variable (IV) regression is used. Two instruments were selected: the Digital Economy Index (DEI) of cities and the Degree of Public Attention (DPA) to local digital transformation. Based on Tao et al. [128], a city-level DEI index was calculated with data drawn from the *China Urban Statistical Yearbook* and the *Local Statistical Yearbook* using the entropy weight method. The DPA measures the frequency of online searches for terms like "*digitalization*" and "*digital transformation*" in the Baidu Index to indicate the level of public attention to city-level digital transformation, following the method outlined by Li et al. [129].

These instrumental variables were chosen for the following reasons. Enterprise digital transformation heavily relies on the local digital infrastructure and environment [10]. Therefore, in regions where other enterprises have higher levels of digital transformation, individual companies are likely inclined to undergo digital transformation. For instance, cities like Shanghai, Shenzhen, Nanjing, Guangzhou, Beijing, and Hangzhou have advanced IT infrastructure, digital economy ecosystems, and innovation hubs, making companies in these cities more likely to adopt digital transformation [130]. The DEI signifies the general level of the digital economy within a city, while the online search frequency of digital-related terms reflects public awareness of and attention paid to digitalization, indicating the extent of regional digital transformation. These instrumental variables are strongly correlated with an enterprise's likelihood of pursuing digital transformation, meeting the relevance conditions for valid instruments. Moreover, these factors are unlikely to be directly related to an individual firm's green innovation performance. For example, the DEI measures a city's overall digital infrastructure and economy, but it does not directly impact how individual firms allocate resources for green innovation. Similarly, DPA to digital transformation captures general societal trends and awareness, which do not directly affect firm-specific green innovation outcomes. Thus, the exogeneity condition is reasonably satisfied.

Table 3 reports the estimation findings of the two-stage least squares (2SLS) approach. In Columns 2 and 3, the coefficients of DEI and DPA are both significant at the 1% level, indicating a high correlation between the IVs and DT. In Column (4), the Kleibergen–Paap rk LM statistic shows a p-value below 0.01, rejecting the null hypothesis of "under-identification of instrumental variables". Both the Cragg–Donald Wald F statistic and the Kleibergen–Paap Wald rk F statistic exceed the critical threshold at the 10% level (19.93), indicating no issue of weak instrumental variables. Furthermore, the p-values for both the Hansen J-test and Sargan test were greater than 0.1, confirming that there is no over-identification problem. In the second-stage regression, the effect of DT is negative and significant (-0.5577) at the 1% level. Moreover, the magnitude of the DT coefficient increases compared to the fixed-effects regression, indicating that the negative impact of DT on GI becomes more pronounced when endogeneity is addressed.

The limitations of the two instrumental variables (DEI and DPA) are that, as regional-level variables, they assume uniform influence across firms within a region, potentially overlooking heterogeneity in firms' responses due to size, industry, or strategy, and they may indirectly influence green innovation through unobserved pathways, such as regional policies or resource agglomeration effects. However, robustness checks, including the Hansen J-test and Sargan test, confirm the validity of the instruments, and given the sample's focus on mature, large firms, the risk of significant regional-level heterogeneity is likely minimal.

5.3. Mediating Effect Analysis

In Model (2) of Table 4, the coefficient of DT on the mediating variable (FC) is positive and significant at the 1% level (0.0039). This suggests that as DT intensifies, enterprises face heightened FCs. In Model (3), the coefficient of FC on GI is negative and significant at the 1% level (−0.9637), confirming that FC exerts a substantial negative effect on GI and further validating Hypothesis 2.

Table 4. Analysis of mediation effect.

	Model 1	**Model 2**	**Model 3**
Variables	**GI**	**FC**	**GI**
DT	−0.0442 ***	0.0039 ***	−0.0404 **
	(−2.60)	(4.50)	(−2.38)
FC			−0.9637 ***
			(−4.47)
ROA	0.0010	0.0003 ***	0.0013
	(0.46)	(2.94)	(0.61)
Size	0.1179 ***	−0.0340 ***	0.0851 ***
	(3.67)	(−20.55)	(2.59)
Age	0.0546	0.0407 ***	0.0938 **
	(1.30)	(18.77)	(2.19)
R&D	0.0062	−0.0048 ***	0.0016
	(0.44)	(−6.58)	(0.11)
Lev	0.0130	0.0116 ***	0.0242
	(0.30)	(5.21)	(0.56)
Growthrate	−0.0381	0.0046 **	−0.0337
	(−1.05)	(2.43)	(−0.93)
Greenbonds	−0.0167	−0.0050 ***	−0.0216
	(−0.97)	(−5.62)	(−1.25)
TbQ	0.0002	−0.0005 ***	−0.0003
	(0.19)	(−8.45)	(−0.22)
Top1	−0.0032	0.0006 ***	−0.0026
	(−1.60)	(5.71)	(−1.31)
SOE	−0.1027	0.0144 ***	−0.0889
	(−1.14)	(3.09)	(−0.99)
Ind	−0.1140	−0.0006	−0.1146
	(−0.53)	(−0.05)	(−0.53)
Constant	−0.4800	3.5206 ***	2.9126 ***
	(−1.53)	(218.23)	(3.55)
Year FE	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes
Observations	9521	9521	9521
R-squared	0.0110	0.7979	0.0134

Note: The T statistic is in parentheses; ** and *** represent significance levels of 5% and 1%, respectively.

As per Model (3) regression results, it was evident that the coefficient of DT on GI remains significant at the 5% level even after including the mediating variable, demonstrating that FC serves as a partial mediator in this model. When the mediating variable, FC, is included, the direct effect of DT on GI is reduced compared to the total effect observed in the baseline regression (with the coefficient of DT changing from −0.0442 in the total effect to −0.0404 in the direct effect). This indicates that the mediation model isolates the negative impact of FC from the baseline regression, thereby suggesting that part of the negative effect is due to increased FCs.

5.4. Moderating Effect and Moderated Mediation Effects Analysis

Table 5 presents the moderating effect of ESG. In Model (4), the coefficient of ESG × DT is significantly positive at the 1% level (0.0277), while the coefficient of DT remains negative. The opposite signs of the two indicate that ESG significantly mitigates the adverse effect of DT on GI. This finding emphasizes the economic and strategic implications of good ESG practices in buffering the challenges posed by digital transformation.

Table 5. Analysis of moderated effects and moderated mediation effects.

	Model 4	**Model 5**	**Model 6**	**Model 7**
Variables	**GI**	**FC**	**FC**	**GI**
DT	−0.1585 ***	0.0040 ***	0.0196 ***	−0.1404 ***
	(−3.36)	(4.54)	(8.06)	(−2.97)
ESG	−0.0392 *	−0.0019 **	0.0035 ***	−0.0359
	(−1.75)	(−2.33)	(3.07)	(−1.61)
ESG × DT	0.0277 ***		−0.0038 ***	0.0242 **
	(2.60)		(−6.89)	(2.27)
FC				−0.9264 ***
				(−4.28)
ROA	0.0008	0.0003 ***	0.0003 ***	0.0012
	(0.40)	(2.94)	(3.11)	(0.55)
Size	0.1170 ***	−0.0336 ***	−0.0335 ***	0.0859 ***
	(3.63)	(−20.22)	(−20.22)	(2.60)
Age	0.0479	0.0402 ***	0.0412 ***	0.0861 **
	(1.13)	(18.46)	(18.91)	(1.99)
R&D	0.0081	−0.0048 ***	−0.0050 ***	0.0034
	(0.57)	(−6.56)	(−6.91)	(0.24)
Lev	0.0114	0.0112 ***	0.0114 ***	0.0220
	(0.27)	(5.04)	(5.16)	(0.51)
Growthrate	−0.0356	0.0046 **	0.0042 **	−0.0317
	(−0.98)	(2.45)	(2.27)	(−0.87)
Greenbonds	−0.0172	−0.0050 ***	−0.0050 ***	−0.0218
	(−1.00)	(−5.66)	(−5.59)	(−1.26)
TbQ	0.0002	−0.0005 ***	−0.0005 ***	−0.0002
	(0.21)	(−8.47)	(−8.54)	(−0.19)
Top1	−0.0031	0.0006 ***	0.0006 ***	−0.0026
	(−1.56)	(5.71)	(5.64)	(−1.29)
SOE	−0.1047	0.0147 ***	0.0149 ***	−0.0909
	(−1.16)	(3.16)	(3.22)	(−1.01)
Ind	−0.1112	0.0000	−0.0004	−0.1116
	(−0.51)	(0.00)	(−0.04)	(−0.52)
Constant	−0.3109	3.5275 ***	3.5039 ***	2.9353 ***
	(−0.96)	(215.12)	(209.77)	(3.56)
Year FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Observations	9521	9521	9521	9521

Note: The T statistic is in parentheses; *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

Figure 3 illustrates the two-directional interaction effects. When ESG performance is low, the slope of DT's impact on GI is negative (−0.131). However, with high ESG performance, the slope turns positive (0.064), indicating that under higher ESG ratings, the adverse effect of DT on GI becomes positive. This indicates that under the management of ESG, a dual monitoring mechanism, firms allocate more resources to support GI, and, furthermore, the internal motivation and external incentives brought by ESG enable digital technologies to fulfill their potential to promote environmentally friendly innovation as well. This finding validates Hypothesis 3.

In Model (6) of Table 5, the coefficient of ESG × DT is significantly negative at the 1% level (−0.0038), showing that corporate ESG significantly mitigates the increase in FC due to DT, thereby validating Hypothesis 4. In Model (7), the coefficient of ESG × DT is significantly positive at the 5% level (0.0242), and this coefficient in the direct effect is smaller than in the total effect (0.0242 in Model (7) compared to 0.0277 in Model (4)), suggesting that ESG's moderating role is partly achieved through the mediator, FC. These findings confirm that ESG plays a dual role: directly mitigating the negative correlation between DT and GI while indirectly promoting GI by reducing the FC exacerbated by DT.

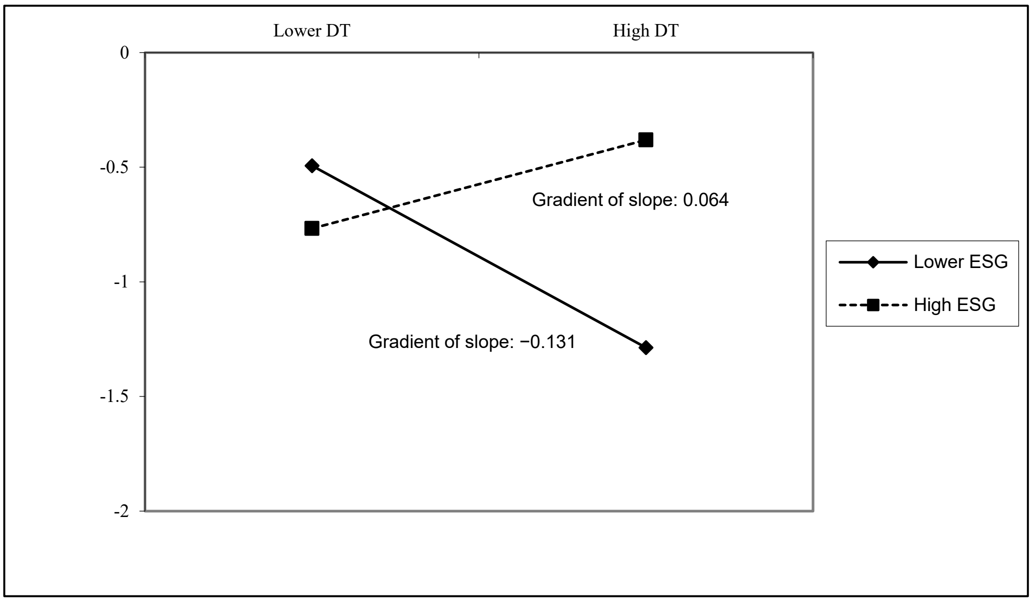

Figure 3. Two-way linear interaction effects for DT.

6. Further Analysis

6.1. Heterogeneity Analysis

The primary function of state-owned enterprises (SOEs) is usually focused on achieving public policy objectives [131]. Due to their unique role in China's economic and political landscape, SOEs frequently bear additional political missions [132] and are subject to heightened social responsibility pressures from both internal and external stakeholders, including employees, customers, the community, and government [133]. Consequently, SOEs are more incentivized to participate in socially responsible initiatives [134] and to pursue investments with dual externalities, like green innovation [135].

Moreover, variations in resource endowments shape the responses of SOEs and non-state-owned enterprises (non-SOEs) to institutional pressures related to environmental responsibility [136]. While SOEs are under stricter government regulation and shoulder more social responsibility [136], they also enjoy substantial resources, like government subsidies and protection. However, prior studies often overlook state ownership as a critical institutional driver of green innovation [135]. Given these distinctions, digital transformation is likely to exert differing effects on green innovation depending on a firm's ownership structure. We hypothesize that in SOEs, either digital transformation does not adversely affect green innovation or its negative effects are offset by the influence of government resources and stakeholder-driven pressures. Conversely, non-SOEs, driven primarily by profit-maximization goals, may experience more pronounced challenges due to weaker institutional support. In addition, their social responsibility requires more internal and external supervision, so ESG performance may assume different roles in the digital transformation process among firms of different natures. To verify the differences between firms with different equity natures, we performed the following heterogeneity analysis.

The heterogeneity analysis in this study supports these theoretical expectations. Table 6 shows that DT does not have a significant effect on the GI in SOEs. By contrast, the coefficient for non-SOEs is significantly negative (−0.0755, significant at the 1% level), consistent with the conclusions drawn earlier. Mediating analysis further indicates that DT increases FC for both SOEs and non-SOEs, negatively affecting GI, suggesting that DT creates some degree of FC in both SOEs and non-SOEs. Table 7 shows that ESG does not moderate the relationship between DT and GI in SOEs, whereas it does exert a significant negative moderating effect in non-SOEs (coefficient of 0.0340, significant at the 5% level), aligning with previous findings. This may be because SOEs tend to rely on government support and enjoy a good social reputation, helping them navigate the challenges and threats of DT without negatively impacting their GI. Moreover, SOEs face greater institutional pressure [137] and inherently have a higher sense of responsibility toward the environment and society. They can utilize their abundant government resources and good social reputation to mitigate the negative impacts of the DT and have sufficient incentives to apply digital technologies to GI, thus the role of ESG is not significant. Moreover, ESG in both SOEs and non-SOEs alleviates the FC caused by DT, thereby mitigating its negative impact on GI. This suggests that the good signals that ESG sends to the market work across firms of different properties.

Table 6. Analysis of heterogeneity test—baseline regression and mediation effects.

	SOEs			Non-SOEs		
Variables	**GI**	**FC**	**GI**	**GI**	**FC**	**GI**
DT	−0.0160	0.0041 ***	−0.0124	−0.0755 ***	0.0028 **	−0.0716 ***
	(−0.66)	(3.21)	(−0.51)	(−3.09)	(2.50)	(−2.93)
FC			−0.8909 ***			−1.3786 ***
			(−2.94)			(−3.96)
ROA	−0.0001	0.0001	−0.0001	0.0011	0.0006 ***	0.0019
	(−0.02)	(0.26)	(−0.01)	(0.41)	(4.76)	(0.71)
Size	0.1200 ***	−0.0584 ***	0.0680	0.1353 ***	−0.0086 ***	0.1235 **
	(2.66)	(−24.95)	(1.40)	(2.70)	(−3.76)	(2.47)
Age	0.1338	0.0005	0.1342	0.0277	0.0415 ***	0.0850
	(1.46)	(0.10)	(1.46)	(0.51)	(16.86)	(1.53)
R&D	−0.0045	−0.0064 ***	−0.0101	0.0299	0.0013	0.0317
	(−0.25)	(−6.76)	(−0.56)	(1.23)	(1.19)	(1.30)
Lev	−0.0172	0.0301 ***	0.0096	0.0279	0.0011	0.0294
	(−0.23)	(7.81)	(0.13)	(0.51)	(0.44)	(0.54)
Growthrate	−0.0117	0.0020	−0.0099	−0.0662	0.0048 **	−0.0596
	(−0.21)	(0.68)	(−0.18)	(−1.34)	(2.10)	(−1.21)
Greenbonds	−0.0199	−0.0045 ***	−0.0239	0.0472	−0.0014	0.0453
	(−1.10)	(−4.76)	(−1.32)	(0.62)	(−0.40)	(0.60)
TbQ	0.0004	−0.0004 ***	0.0001	0.0001	−0.0004 ***	−0.0004
	(0.19)	(−3.21)	(0.04)	(0.08)	(−6.03)	(−0.30)
Top1	−0.0027	0.0003 **	−0.0024	−0.0021	0.0013 ***	−0.0004
	(−0.97)	(2.16)	(−0.87)	(−0.69)	(9.01)	(−0.12)
Ind	−0.1077	−0.0151	−0.1212	−0.1156	0.0106	−0.1009
	(−0.36)	(−0.98)	(−0.41)	(−0.36)	(0.72)	(−0.31)
Constant	−0.7890	3.9526 ***	2.7322 **	−0.6433	3.1685 ***	3.7246 ***
	(−1.54)	(148.89)	(2.10)	(−1.48)	(159.52)	(3.15)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4685	4685	4685	4836	4836	4836
R-squared	0.0096	0.7859	0.0117	0.0157	0.8364	0.0196

Note: The T statistic is in parentheses; ** and *** represent significance levels of 5% and 1%, respectively.

Table 7. Analysis of heterogeneity test—moderating effects and moderated mediation effects.

	SOEs		Non-SOEs	
Variables	**GI**	**FC**	**GI**	**FC**
DT	−0.0991	0.0166 ***	−0.2128 ***	0.0193 ***
	(−1.37)	(4.42)	(−3.31)	(6.58)
ESG	−0.0272	0.0041 **	−0.0585 *	0.0038 **
	(−0.86)	(2.51)	(−1.79)	(2.57)
ESG × DT	0.0196	−0.0030 ***	0.0340 **	−0.0041 ***
	(1.22)	(−3.55)	(2.31)	(−6.08)
ROA	0.0001	0.0000	0.0007	0.0006 ***
	(0.02)	(0.14)	(0.27)	(5.14)
Size	0.1183 ***	−0.0581 ***	0.1375 ***	−0.0081 ***
	(2.61)	(−24.76)	(2.73)	(−3.52)
Age	0.1310	0.0009	0.0141	0.0421 ***
	(1.43)	(0.19)	(0.26)	(16.92)
R&D	−0.0033	−0.0065 ***	0.0334	0.0009
	(−0.18)	(−6.94)	(1.37)	(0.84)
Lev	−0.0177	0.0302 ***	0.0250	0.0010
	(−0.24)	(7.82)	(0.45)	(0.38)
Growthrate	−0.0109	0.0018	−0.0624	0.0042 *
	(−0.20)	(0.64)	(−1.26)	(1.85)
Greenbonds	−0.0203	−0.0044 ***	0.0511	−0.0017
	(−1.12)	(−4.70)	(0.67)	(−0.49)
TbQ	0.0004	−0.0004 ***	0.0002	−0.0004 ***
	(0.16)	(−3.11)	(0.15)	(−6.25)
Top1	−0.0027	0.0003 **	−0.0019	0.0012 ***
	(−0.98)	(2.17)	(−0.62)	(8.98)
Ind	−0.1046	−0.0156	−0.1186	0.0111
	(−0.35)	(−1.01)	(−0.37)	(0.75)
Constant	−0.6585	3.9329 ***	−0.4229	3.1526 ***
	(−1.25)	(144.00)	(−0.94)	(154.06)
Year FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Observations	4685	4685	4836	4836
R-squared	0.0100	0.7866	0.0170	0.8382

Note: The T statistic is in parentheses; *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

6.2. Time-Dynamic Analysis of Digital Transformation and the Moderating Role of ESG

The impact of DT on GI, as well as the moderating role of ESG practices, is not static. Instead, it evolves over time due to dynamic adjustments driven by factors such as policy environments, resource availability, transformation stages, technological maturity, and firms' adaptive capacity. To capture this temporal heterogeneity, we conducted an in-depth analysis by introducing year dummy variables, interaction terms between DT and year dummies, and further interactions between ESG moderating effects ($ESG \times DT$) and year dummies, using 2022 as the baseline year.

The results in Table 8 reveal that, during 2013–2015, the coefficients of the interaction terms between DT and year dummies are significantly positive, indicating that the negative relationship between twin transitions was relatively weaker. This may be attributed to the early experimental and exploratory stage of digital transformation during that period, characterized by technical trials and relatively low resource demand, thus facing less resource allocation conflict. Meanwhile, the moderating role of ESG practices was stronger during this phase, effectively balancing resource allocation and promoting digital technologies to support green innovation.

Table 8. Time-dynamic analysis of digital transformation and the moderating role of ESG.

	First Period	**Second Period**
Variables	**GI**	**GI**
DT	−0.093 ***	−0.176 ***
	(−3.22)	(−3.67)
ESG		−0.041 *
		(−1.81)
ESG × DT		0.021 *
		(1.80)
DT × $Year_{2013}$	0.105 **	
	(2.32)	
DT × $Year_{2014}$	0.118 ***	
	(2.72)	
DT × $Year_{2015}$	0.113 ***	
	(2.81)	
DT × $Year_{2016}$	0.034	
	(0.90)	
DT × $Year_{2017}$	0.058 *	
	(1.68)	
DT × $Year_{2018}$	0.031	
	(0.92)	(−0.99)
DT × $Year_{2019}$	−0.007	−0.023
	(−0.21)	(−1.32)
DT × $Year_{2020}$	0.042	0.000
	(1.28)	(0.21)
DT × $Year_{2021}$	0.061 *	−0.002
	(1.91)	(−0.74)
ESG × *DT* × $Year_{2013}$		0.019 *
		(1.87)
ESG × *DT* × $Year_{2014}$		0.026 ***
		(2.72)
ESG × *DT* × $Year_{2015}$		0.022 **
		(2.52)
ESG × *DT* × $Year_{2016}$		0.006
		(0.74)
ESG × *DT* × $Year_{2017}$		0.012
		(1.59)
ESG × *DT* × $Year_{2018}$		0.008
		(1.17)
ESG × *DT* × $Year_{2019}$		−0.003
		(−0.36)
ESG × *DT* × $Year_{2020}$		0.011
		(1.63)
ESG × *DT* × $Year_{2021}$		0.015 **
		(2.16)
Control variables	Yes	Yes
Year dummy	Yes	Yes
Constant	−0.317	−0.158
	(−0.95)	(−0.46)
Observations	9521	9521
R-squared	0.013	0.014

Note: The T statistic is in parentheses; *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

However, during the 2016–2020 period, the interaction terms became insignificant, except for a weakly significant one at the 10% level in 2017, suggesting that the negative influence of digital transformation stabilized, while the moderating effect of ESG weakened noticeably. This shift can be explained by the large-scale, high-intensity, and increasingly competitive digital transformation implementation stage following China's issuance of the *13th Five-Year Plan for National Informatization* and the *Cybersecurity Law* in 2016 [138]. This stage intensified internal resource-allocation conflicts within firms. Furthermore, although macroeconomic shocks like the 2018 China–US trade war [139] were absorbed by the year fixed effects, these factors likely intensified internal competition for limited resources, indirectly shaping corporate strategies. Consequently, firms prioritized digital transformation to drive product innovation and marketing innovation for competitive advantages, often at the expense of green innovation efforts.

In 2021, the negative effect of DT on GI was once again alleviated, and the moderating role of ESG practices also strengthened. This suggests a promising trend: as investments in digital transformation increased and improved, and green development strategies were reinforced, firms achieved a better balance between twin transitions.

7. Conclusions and Implications

7.1. Summary of the Findings

This study explores how digital transformation impacts green innovation within mature, large-scale enterprises in China by investigating its effects and mechanisms, with particular consideration for ESG performance as a moderating influence. By conducting an empirical analysis on the data of main board-listed companies on the Shanghai Stock Exchange from 2013 to 2022, the following key conclusions are drawn:

Firstly, digital transformation is found to negatively impact green innovation. Building on the traditional perspective that views digital transformation as a straightforward accelerator of innovation (e.g., Ning et al. [12] and Rao et al. [11]), our study provides a deeper analysis through the "crowding-out" effect. It highlights how both digital transformation and green innovation require substantial resource investment, leading to intensified internal competition. This finding enriches the understanding of resource allocation dynamics within large enterprises, especially those with entrenched structures and complex interdepartmental interactions. It is consistent with the discussions of the challenges of cross-functional collaboration in larger firms [18]. Furthermore, it underscores the inherent tension between the short-term performance goals of digital transition and the long-term sustainability objectives of green transition. The research highlights how digital transformation's inherent risks—high failure rates, slow returns, and competitive pressures—divert managerial focus and financial resources away from green innovation. This provides a novel explanation for the misalignment between short- and long-term goals, expanding the discourse on the dual transformation challenge faced by contemporary enterprises.

Secondly, digital transformation is shown to exacerbate financing constraints, subsequently hindering green innovation. Our finding is consistent with the fact that over half of Chinese firms are in the early stages of digital transformation, as well as with studies that highlight the increased financing needs and constraints firms face at this stage [24,25]. Moreover, unlike previous studies that often emphasize the potential of digital transformation to enhance information transparency and reduce financing barriers [140], our findings highlight a less explored dimension: the adoption of new technologies also amplifies information asymmetry, thereby increasing external supervision costs and limiting firms' access to external financing, extending Fazzari et al.'s [141] theory that information asymmetries trigger financing constraints. Moreover, the study challenges the prevailing assumption in the literature that digital transformation efforts are uniformly successful or beneficial. By considering the high failure rates, long payback periods, and regulatory compliance risks associated with digital transformation, we offer a nuanced perspective on its impact on green innovation, extending the "digital paradox" [30] in green transformation.

Thirdly, this study reveals that ESG, encompassing both "internal governance" and "external supervision", moderates the relationship between the twin transitions, addressing the limitations of prior research focused on a single perspective [31–33]. Good ESG allows firms to address the challenges of digital transformation, providing both external pull and internal push for green innovation, thus promoting synergies between digital technologies and environmental goals and improving green innovation. Our study further reveals the role of ESG in mitigating the financing constraints induced by digital transformation, finding that good ESG performance can increase support of the capital market, secure sufficient financing, and direct limited capital toward green innovation with long-term developmental value. Unlike studies on the direct effect of ESG [36,38], the contribution of this study is a systematical investigation of how ESG plays a positive role during digital transformation from a moderating-effect perspective, supplementing the existing literature on ESG's impact on corporate long-term sustainability.

Moreover, research highlights the varying relationship between twin transitions and its mechanisms across firms with different equity ownership. SOEs benefit from government resources and institutional pressures, and the downside from digital transformation is not significant. In contrast, non-SOEs face more pronounced challenges, with ESG mitigating the negative impacts. Moreover, digital transformation creates some degree of financing constraints on firms of different natures, and ESG significantly mitigates the financing constraints caused by digital transformation across different firms. It suggests that the good sustainability signals ESG sends to the market can lead to more external financing in both SOEs and non-SOEs, expanding on the studies about the direct impact of ESG on financing constraints [83,142]. This distinction provides a deeper understanding of how ownership structure influences the dual-transformation process.

Finally, our findings highlight that the relationship between twin transitions evolves dynamically over time, and the moderating role of ESG practices aligns with this dynamic pattern. Specifically, the ESG effect becomes more pronounced during periods when the negative influence of digital transformation weakens. This dynamic analysis provides valuable insights that can be applied to future research and offers a reference for policymakers and firms to optimize the role of ESG practices in promoting digital technology-driven green transformation.

These discoveries provide valuable theoretical contributions and empirical implications for mature, large enterprises seeking to balance digital and green transformations in the pursuit of sustainable development.

7.2. Theoretical Implication

This study extends Resource-Based Theory [69] by introducing the concept of the resource crowding-out effect, which explains how the resource-intensive nature of digital transformation generates internal competition for scarce resources, such as funding and talent, particularly in large firms with overlapping functional departments. This contribution highlights that both digital and green transformations require substantial and sustained resource investments but often face trade-offs between conflicting strategic objectives. These challenges are notable in mature, large-scale firms, where organizational inertia and structural complexity exacerbate the difficulty of resource allocation.

Additionally, the study advances Information Asymmetry Theory [59] by identifying how the complexity, high failure rates, and compliance risks of digital transformation introduce significant uncertainties for investors. These uncertainties increase decision-making challenges, leading to stricter financing conditions and higher capital costs. By linking information asymmetry to technological and regulatory factors, this research contributes to theory's application in the domains of digital technology adoption and innovation management.

This study also enriches the Resource-Based Theory [69] framework by incorporating ESG performance as a moderating factor, demonstrating how firms with superior ESG capabilities can alleviate resource competition and financing constraints during twin transitions. ESG encourages long-term investment in green innovation while minimizing short-term decision-making biases, thereby aligning technological transformation with environmental objectives. This finding underscores ESG's role as a strategic resource for optimizing resource allocation and balancing competing priorities.

Furthermore, the study contributes to Stakeholder Theory [80] by examining its role in twin transitions. Superior ESG performance attracts external stakeholder support, such as government subsidies and green financing, while establishing stakeholder-driven accountability mechanisms. These mechanisms compel firms to optimize resource allocation, actively integrate digital technologies into green innovation processes, and meet sustainability benchmarks aligned with stakeholder expectations.

Finally, this study applies the Signaling Theory [81] to the context of sustainability, demonstrating how superior ESG performance signals corporate sustainability efforts, robust risk management, and long-term value creation. By reducing the perceived risks of digital transformation and alleviating external stakeholders' uncertainties, this signal enhances firms' access to external financing. This contribution emphasizes the pivotal role of ESG in shaping stakeholder perceptions and fostering confidence in firms undergoing complex transitions.

7.3. Practical Implication

To ensure long-term sustainability, companies must strategically balance internal resources during digital transformation, avoiding an overemphasis on investments in digital technologies at the expense of other initiatives. Mature, large enterprises undergoing structural change generate significant organizational inertia and resource demand, so we recommend that enterprises set up dedicated funds for green innovation to safeguard these projects from the financial strain caused by competing priorities. Large conglomerates with several departments that have overlapping functions should foster interdepartmental collaboration to promote the sharing of resources and information. Dynamically adjusting resource allocation based on real-time needs and implementing robust monitoring mechanisms can minimize resource competition among departments. Furthermore, encouraging IT and environmental departments to jointly develop green technologies maximizing synergies. Develop a comprehensive project evaluation framework that considers potential returns, risks, and resource requirements to ensure that management does not overlook projects with long-term strategic significance due to a focus on short-term gains. This approach helps synchronize digital transformation with green innovation.

Moreover, companies should actively engage in ESG management, regularly disclosing ESG performance to enhance transparency and credibility. Strong ESG performance can attract government subsidies, green funds, and strategic investors aligned with sustainability goals. Managing ESG aspects within the supply chain by working with upstream and downstream partners can build trust with suppliers and increase customer satisfaction and loyalty. For example, aligning sustainability practices with major suppliers can reduce carbon footprints and build a resilient supply chain, thereby improving corporate reputation and risk management capabilities. In addition, good ESG performance can be utilized to access green funds and loans linked to sustainability to finance the long-term transformation of green projects.

In summary, effectively balancing resource allocation, embracing robust ESG management practices, and expanding financing avenues enable enterprises to reconcile their twin transitions, fostering sustainable development.

7.4. Limitations and Future Research Prospects

While our research provides critical insights into the interplay between digital transformation and green innovation, there are certain limitations. First, macroeconomic control variables with significant influence on green innovation were not included, which future research should incorporate to enhance robustness. Second, the study does not address the heterogeneity of the relationship between dual transitions across industries. Considering industry-specific differences is essential, as these could substantially affect outcomes, and future research shall explore these dynamics in depth. Third, while the mediating role of financing constraints is comprehensively analyzed, potential biases in measuring these constraints warrant attention. Future studies should explore alternative methodologies to validate the mediating mechanism more rigorously.

Author Contributions: Conceptualization, Y.W.; methodology, Y.W., G.B. and C.L.; software, Y.W. and C.L.; validation, Y.W., I.I. and G.B.; formal analysis, Y.W., I.I. and G.B.; data curation, Y.W. and C.L.; writing—original draft preparation, Y.W.; writing—review and editing, I.I. and G.B.; supervision, I.I. and G.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the China Scholarship Council (CSC), grant numbers 202208090691 and 202308091342.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The Stata codes for this study can be provided by the author upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Kiron, D.; Kane, G.C.; Palmer, D.; Phillips, A.N.; Buckley, N. Aligning the organization for its digital future. *MIT Sloan Manag. Rev.* **2016**, *58*, 1–27.
2. Bianchini, S.; Damioli, G.; Ghisetti, C. The environmental effects of the "twin" green and digital transition in European regions. *Environ. Resour. Econ.* **2023**, *84*, 877–918. [CrossRef] [PubMed]
3. Le, T.T. How do corporate social responsibility and green innovation transform corporate green strategy into sustainable firm performance? *J. Clean. Prod.* **2022**, *362*, 132228. [CrossRef]
4. Tu, Y.; Wu, W. How does green innovation improve enterprises' competitive advantage? The role of organizational learning. *Sustain. Prod. Consum.* **2021**, *26*, 504–516. [CrossRef]
5. Miao, C.; Fang, D.; Sun, L.; Luo, Q. Natural resources utilization efficiency under the influence of green technological innovation. *Resour. Conserv. Recycl.* **2017**, *126*, 153–161. [CrossRef]
6. Song, W.; Yu, H. Green innovation strategy and green innovation: The roles of green creativity and green organizational identity. *Corp. Soc. Responsib. Environ. Manag.* **2018**, *25*, 135–150. [CrossRef]
7. Butt, J. A conceptual framework to support digital transformation in manufacturing using an integrated business process management approach. *Designs* **2020**, *4*, 17. [CrossRef]
8. Tian, M.; Chen, Y.; Tian, G.; Huang, W.; Hu, C. The role of digital transformation practices in the operations improvement in manufacturing firms: A practice-based view. *Int. J. Prod. Econ.* **2023**, *262*, 108929. [CrossRef]
9. Warner, K.S.; Wäger, M. Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. *Long Range Plan.* **2019**, *52*, 326–349. [CrossRef]
10. Xue, L.; Zhang, Q.; Zhang, X.; Li, C. Can digital transformation promote green technology innovation? *Sustainability* **2022**, *14*, 7497. [CrossRef]
11. Rao, S.; Pan, Y.; He, J.; Shangguan, X. Digital finance and corporate green innovation: Quantity or quality? *Environ. Sci. Pollut. Res.* **2022**, *29*, 56772–56791. [CrossRef]

12. Ning, J.; Jiang, X.; Luo, J. Relationship between enterprise digitalization and green innovation: A mediated moderation model. *J. Innov. Knowl.* **2023**, *8*, 100326. [CrossRef]
13. He, Q.; Ribeiro-Navarrete, S.; Botella-Carrubi, D. A matter of motivation: The impact of enterprise digital transformation on green innovation. *Rev. Manag. Sci.* **2024**, *18*, 1489–1518. [CrossRef]
14. Ghasemaghaei, M.; Calic, G. Assessing the impact of big data on firm innovation performance: Big data is not always better data. *J. Bus. Res.* **2020**, *108*, 147–162. [CrossRef]
15. Ardito, L.; Raby, S.; Albino, V.; Bertoldi, B. The duality of digital and environmental orientations in the context of SMEs: Implications for innovation performance. *J. Bus. Res.* **2021**, *123*, 44–56. [CrossRef]
16. Usai, A.; Fiano, F.; Petruzzelli, A.M.; Paoloni, P.; Briamonte, M.F.; Orlando, B. Unveiling the impact of the adoption of digital technologies on firms' innovation performance. *J. Bus. Res.* **2021**, *133*, 327–336. [CrossRef]
17. Cicerone, G.; Faggian, A.; Montresor, S.; Rentocchini, F. Regional artificial intelligence and the geography of environmental technologies: Does local AI knowledge help regional green-tech specialization? *Reg. Stud.* **2023**, *57*, 330–343. [CrossRef]
18. Aliane, N.; Al-Romeedy, B.S.; Agina, M.F.; Salah, P.A.M.; Abdallah, R.M.; Fatah, M.A.H.A.; Khababa, N.; Khairy, H.A. How job insecurity affects innovative work behavior in the hospitality and tourism industry? The roles of knowledge hiding behavior and team anti-citizenship behavior. *Sustainability* **2023**, *15*, 13956. [CrossRef]
19. Li, H.; Zhang, Y.; Li, Y. The impact of digital inputs on pollution reduction in Chinese manufacturing enterprises. *J. Clean. Prod.* **2023**, *428*, 139393. [CrossRef]
20. Zhang, W.; Zhao, J.; Li, H.; Chen, S. Does digital transformation empower green innovation? Evidence from listed companies in heavily polluting industries in China. *Financ. Res. Lett.* **2024**, *66*, 105685. [CrossRef]
21. Wang, X.; Ma, C.; Yao, Z. The double-edged sword effect of digital capability on green innovation: Evidence from Chinese listed industrial firms. *Econ. Anal. Policy* **2024**, *82*, 321–339. [CrossRef]
22. Saarikko, T.; Westergren, U.H.; Blomquist, T. Digital transformation: Five recommendations for the digitally conscious firm. *Bus. Horiz.* **2020**, *63*, 825–839. [CrossRef]
23. Zhang, H.; Wu, J.; Mei, Y.; Hong, X. Exploring the relationship between digital transformation and green innovation: The mediating role of financing modes. *J. Environ. Manag.* **2024**, *356*, 120558. [CrossRef] [PubMed]
24. Yaya, S.; Deming, Y. Business model innovation and earnings management in the era of digital economy. *Sci. Res. Manag.* **2021**, *42*, 170.
25. Du, Z.-Y.; Wang, Q. Unveiling the time-lag effects of digital transformation on financing constraints in Chinese listed enterprises: A study of automation and network technology. *Technol. Anal. Strateg. Manag.* **2024**, *36*, 4202–4216. [CrossRef]
26. Xiang, X.; Liu, C.; Yang, M. Who is financing corporate green innovation? *Int. Rev. Econ. Financ.* **2022**, *78*, 321–337. [CrossRef]
27. Bai, Y.; Song, S.; Jiao, J.; Yang, R. The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *J. Clean. Prod.* **2019**, *233*, 819–829.
28. Rolland, K.-H.; Hanseth, O. Managing path dependency in digital transformation processes: A longitudinal case study of an enterprise document management platform. *Procedia Comput. Sci.* **2021**, *181*, 765–774. [CrossRef]
29. Sebastian, I.M.; Ross, J.W.; Beath, C.; Mocker, M.; Moloney, K.G.; Fonstad, N.O. How big old companies navigate digital transformation. In *Strategic Information Management*; Routledge: Oxfordshire, UK, 2020; pp. 133–150.
30. Gebauer, H.; Fleisch, E.; Lamprecht, C.; Wortmann, F. Growth paths for overcoming the digitalization paradox. *Bus. Horiz.* **2020**, *63*, 313–323. [CrossRef]
31. Wu, S.; Cheng, P.; Yang, F. Study on the impact of digital transformation on green competitive advantage: The role of green innovation and government regulation. *PLoS ONE* **2024**, *19*, e0306603. [CrossRef]
32. He, J.; Su, H. Digital transformation and green innovation of Chinese firms: The moderating role of regulatory pressure and international opportunities. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13321. [CrossRef] [PubMed]
33. Huang, Y.; Lau, C.-W. Can digital transformation promote the green innovation quality of enterprises? Empirical evidence from China. *PLoS ONE* **2024**, *19*, e0296058. [CrossRef]
34. Hanf, K. Implementing international environmental policies. In *Environmental Policy in an International Context*; Elsevier: Amsterdam, The Netherlands, 2003; Volume 3, pp. 197–221.
35. Sun, Y.; He, M. Does digital transformation promote green innovation? A micro-level perspective on the Solow Paradox. *Front. Environ. Sci.* **2023**, *11*, 1134447. [CrossRef]
36. Tan, Y.; Zhu, Z. The effect of ESG rating events on corporate green innovation in China: The mediating role of financial constraints and managers' environmental awareness. *Technol. Soc.* **2022**, *68*, 101906. [CrossRef]
37. Zhao, X.; Fang, L.; Zhang, K. Online search attention, firms' ESG and operating performance. *Int. Rev. Econ. Financ.* **2023**, *88*, 223–236. [CrossRef]
38. Tan, X.; Liu, G.; Cheng, S. How does ESG performance affect green transformation of resource-based enterprises: Evidence from Chinese listed enterprises. *Resour. Policy* **2024**, *89*, 104559. [CrossRef]

39. Wang, J.; Ma, M.; Dong, T.; Zhang, Z. Do ESG ratings promote corporate green innovation? A quasi-natural experiment based on SynTao Green Finance's ESG ratings. *Int. Rev. Financ. Anal.* **2023**, *87*, 102623. [CrossRef]
40. Wang, F.; Sun, Z. Does the environmental regulation intensity and ESG performance have a substitution effect on the impact of enterprise green innovation: Evidence from China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 8558. [CrossRef] [PubMed]
41. Yang, C.; Zhu, C.; Albitar, K. ESG ratings and green innovation: AU-shaped journey towards sustainable development. *Bus. Strategy Environ.* **2024**, *33*, 4108–4129. [CrossRef]
42. Rau, P.R.; Yu, T. A survey on ESG: Investors, institutions and firms. *China Financ. Rev. Int.* **2024**, *14*, 3–33. [CrossRef]
43. Liu, L.; Nemoto, N. Environmental, social and governance (ESG) evaluation and organizational attractiveness to prospective employees: Evidence from Japan. *J. Account. Financ.* **2021**, *21*, 14–29.
44. McCahery, J.A.; Pudschedl, P.C.; Steindl, M. Institutional investors, alternative asset managers, and ESG preferences. *Eur. Bus. Organ. Law Rev.* **2022**, *23*, 821–868. [CrossRef]
45. Fu, T.; Li, J. An empirical analysis of the impact of ESG on financial performance: The moderating role of digital transformation. *Front. Environ. Sci.* **2023**, *11*, 1256052. [CrossRef]
46. Alkaraan, F.; Albitar, K.; Hussainey, K.; Venkatesh, V. Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). *Technol. Forecast. Soc. Chang.* **2022**, *175*, 121423. [CrossRef]
47. Triguero, A.; Moreno-Mondéjar, L.; Davia, M.A. Drivers of different types of eco-innovation in European SMEs. *Ecol. Econ.* **2013**, *92*, 25–33. [CrossRef]
48. Han, Y.; Li, Z.; Feng, T.; Qiu, S.; Hu, J.; Yadav, K.K.; Obaidullah, A.J. Unraveling the impact of digital transformation on green innovation through microdata and machine learning. *J. Environ. Manag.* **2024**, *354*, 120271. [CrossRef] [PubMed]
49. Hall, B.H.; Lerner, J. The financing of R&D and innovation. In *Handbook of the Economics of Innovation*; Elsevier: Amsterdam, The Netherlands, 2010; Volume 1, pp. 609–639.
50. Rajan, R.; Servaes, H.; Zingales, L. The cost of diversity: The diversification discount and inefficient investment. *J. Financ.* **2000**, *55*, 35–80. [CrossRef]
51. Vial, G. Understanding digital transformation: A review and a research agenda. In *Managing Digital Transformation*; Routledge: Oxfordshire, UK, 2021; pp. 13–66.
52. Tabrizi, B.; Lam, E.; Girard, K.; Irvin, V. Digital transformation is not about technology. *Harv. Bus. Rev.* **2019**, *13*, 1–6.
53. Cennamo, C.; Dagnino, G.B.; Di Minin, A.; Lanzolla, G. Managing digital transformation: Scope of transformation and modalities of value co-generation and delivery. *Calif. Manag. Rev.* **2020**, *62*, 5–16. [CrossRef]
54. Cozzolino, A.; Verona, G.; Rothaermel, F.T. Unpacking the disruption process: New technology, business models, and incumbent adaptation. *J. Manag. Stud.* **2018**, *55*, 1166–1202. [CrossRef]
55. McGrath, R. *The End of Competitive Advantage: How to Keep Your Strategy Moving as Fast as Your Business*; Harvard Business Review Press: Brighton, MA, USA, 2013.
56. Ghisetti, C.; Mancinelli, S.; Mazzanti, M.; Zoli, M. Financial barriers and environmental innovations: Evidence from EU manufacturing firms. *Clim. Policy* **2017**, *17*, S131–S147. [CrossRef]
57. Lee, I. Big data: Dimensions, evolution, impacts, and challenges. *Bus. Horiz.* **2017**, *60*, 293–303. [CrossRef]
58. McAfee, A.; Brynjolfsson, E. *Machine, Platform, Crowd: Harnessing Our Digital Future*; WW Norton & Company: New York, NY, USA, 2017.
59. Akerlof, G.A. The market for "lemons": Quality uncertainty and the market mechanism. In *Uncertainty in Economics*; Elsevier: Amsterdam, The Netherlands, 1978; pp. 235–251.
60. Wu, K.; Fu, Y.; Kong, D. Does the digital transformation of enterprises affect stock price crash risk? *Financ. Res. Lett.* **2022**, *48*, 102888. [CrossRef]
61. Reddy, S.K.; Reinartz, W. Digital transformation and value creation: Sea change ahead. *NIM Mark. Intell. Rev.* **2017**, *9*, 10–17. [CrossRef]
62. Carcary, M.; Doherty, E.; Conway, G. A dynamic capability approach to digital transformation: A focus on key foundational themes. In Proceedings of the European Conference on Information Systems Management, Evora, Portugal, 8–9 September 2016; pp. 20–28.
63. Brekke, T.; Lenka, S.; Kohtamäki, M.; Parida, V.; Solem, B.A.A. Overcoming barriers to transformation in manufacturing firms. A path-dependence perspective of digital servitization. *Rev. Manag. Sci.* **2024**, *18*, 385–412. [CrossRef]
64. Forcadell, F.J.; Aracil, E.; Úbeda, F. The impact of corporate sustainability and digitalization on international banks' performance. *Glob. Policy* **2020**, *11*, 18–27. [CrossRef]
65. Valencia, F. Aggregate uncertainty and the supply of credit. *J. Bank. Financ.* **2017**, *81*, 150–165. [CrossRef]
66. Buttel, F.H. Ecological modernization as social theory. *Geoforum* **2000**, *31*, 57–65. [CrossRef]
67. Wu, D.; Jia, W.; Xie, Y. The impact of environmental information disclosure on green innovation in extractive enterprises: Promote or crowd out? *Extr. Ind. Soc.* **2023**, *14*, 101247. [CrossRef]

68. Wang, P.; Dong, C.; Chen, N.; Qi, M.; Yang, S.; Nnenna, A.B.; Li, W. Environmental regulation, government subsidies, and green technology innovation—A provincial panel data analysis from China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11991. [CrossRef]
69. Barney, J. Firm resources and sustained competitive advantage. *J. Manag.* **1991**, *17*, 99–120. [CrossRef]
70. Albinger, H.S.; Freeman, S.J. Corporate social performance and attractiveness as an employer to different job seeking populations. *J. Bus. Ethics* **2000**, *28*, 243–253. [CrossRef]
71. Skare, M.; de Obesso, M.d.l.M.; Ribeiro-Navarrete, S. Digital transformation and European small and medium enterprises (SMEs): A comparative study using digital economy and society index data. *Int. J. Inf. Manag.* **2023**, *68*, 102594. [CrossRef]
72. Gomez-Valencia, M.; Gonzalez-Perez, M.A.; Gomez-Trujillo, A.M. The "Six Ws" of sustainable development risks. *Bus. Strategy Environ.* **2021**, *30*, 3131–3144. [CrossRef]
73. Boutin-Dufresne, F.; Savaria, P. Corporate social responsibility and financial risk. *J. Invest.* **2004**, *13*, 57–66. [CrossRef]
74. Giese, G.; Lee, L.-E.; Melas, D.; Nagy, Z.; Nishikawa, L. Foundations of ESG investing: How ESG affects equity valuation, risk, and performance. *J. Portf. Manag.* **2019**, *45*, 69–83. [CrossRef]
75. Benlemlih, M.; Shaukat, A.; Qiu, Y.; Trojanowski, G. Environmental and social disclosures and firm risk. *J. Bus. Ethics* **2018**, *152*, 613–626. [CrossRef]
76. Scholz, R.W. Digital threat and vulnerability management: The SVIDT method. *Sustainability* **2017**, *9*, 554. [CrossRef]
77. Agina, M.F.; Khairy, H.A.; Abdel Fatah, M.A.; Manaa, Y.H.; Abdallah, R.M.; Aliane, N.; Afaneh, J.; Al-Romeedy, B.S. Distributive Injustice and Work Disengagement in the Tourism and Hospitality Industry: Mediating Roles of the Workplace Negative Gossip and Organizational Cynicism. *Sustainability* **2023**, *15*, 15011. [CrossRef]
78. Zhang, X.; Zhang, J.; Feng, Y. Can companies get more government subsidies through improving their ESG performance? Empirical evidence from China. *PLoS ONE* **2023**, *18*, e0292355. [CrossRef] [PubMed]
79. Wang, Y.; Yang, Y.; Fu, C.; Fan, Z.; Zhou, X. Environmental regulation, environmental responsibility, and green technology innovation: Empirical research from China. *PLoS ONE* **2021**, *16*, e0257670. [CrossRef]
80. Fernando, S.; Lawrence, S. A theoretical framework for CSR practices: Integrating legitimacy theory, stakeholder theory and institutional theory. *J. Theor. Account. Res.* **2014**, *10*, 149–178.
81. Spence, M. Signaling in retrospect and the informational structure of markets. *Am. Econ. Rev.* **2002**, *92*, 434–459. [CrossRef]
82. Kotsantonis, S.; Pinney, C.; Serafeim, G. ESG integration in investment management: Myths and realities. *J. Appl. Corp. Financ.* **2016**, *28*, 10–16. [CrossRef]
83. Raimo, N.; Caragnano, A.; Zito, M.; Vitolla, F.; Mariani, M. Extending the benefits of ESG disclosure: The effect on the cost of debt financing. *Corp. Soc. Responsib. Environ. Manag.* **2021**, *28*, 1412–1421. [CrossRef]
84. Hu, A.; Yuan, X.; Fan, S.; Wang, S. The impact and mechanism of corporate ESG construction on the efficiency of regional green economy: An empirical analysis based on signal transmission theory and stakeholder theory. *Sustainability* **2023**, *15*, 13236. [CrossRef]
85. Wang, S.; Wang, D. Exploring the relationship between ESG performance and green bond issuance. *Front. Public Health* **2022**, *10*, 897577. [CrossRef]
86. Hornuf, L.; Stenzhorn, E.; Vintis, T. Are sustainability-oriented investors different? Evidence from equity crowdfunding. *J. Technol. Transf.* **2022**, *47*, 1662–1689. [CrossRef]
87. Huang, Y.; Bai, F.; Shang, M.; Ahmad, M. On the fast track: The benefits of ESG performance on the commercial credit financing. *Environ. Sci. Pollut. Res.* **2023**, *30*, 83961–83974. [CrossRef] [PubMed]
88. Zheng, J.; Jiang, Y.; Cui, Y.; Shen, Y. Green bond issuance and corporate ESG performance: Steps toward green and low-carbon development. *Res. Int. Bus. Financ.* **2023**, *66*, 102007. [CrossRef]
89. Liu, M.; Li, C.; Wang, S.; Li, Q. Digital transformation, risk-taking, and innovation: Evidence from data on listed enterprises in China. *J. Innov. Knowl.* **2023**, *8*, 100332. [CrossRef]
90. Feng, H.; Wang, F.; Song, G.; Liu, L. Digital transformation on enterprise green innovation: Effect and transmission mechanism. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10614. [CrossRef] [PubMed]
91. Wang, J.; Liu, Y.; Wang, W.; Wu, H. How does digital transformation drive green total factor productivity? Evidence from Chinese listed enterprises. *J. Clean. Prod.* **2023**, *406*, 136954. [CrossRef]
92. Tang, M.; Liu, Y.; Hu, F.; Wu, B. Effect of digital transformation on enterprises' green innovation: Empirical evidence from listed companies in China. *Energy Econ.* **2023**, *128*, 107135. [CrossRef]
93. Tang, L.; Jiang, H.; Hou, S.; Zheng, J.; Miao, L. The Effect of Enterprise Digital Transformation on Green Technology Innovation: A Quantitative Study on Chinese Listed Companies. *Sustainability* **2023**, *15*, 10036. [CrossRef]
94. Liu, X.; Liu, F.; Ren, X. Firms' digitalization in manufacturing and the structure and direction of green innovation. *J. Environ. Manag.* **2023**, *335*, 117525. [CrossRef]
95. Wu, S.; Li, Y. A study on the impact of digital transformation on corporate ESG performance: The mediating role of green innovation. *Sustainability* **2023**, *15*, 6568. [CrossRef]

96. Li, J.; Lian, G.; Xu, A. How do ESG affect the spillover of green innovation among peer firms? Mechanism discussion and performance study. *J. Bus. Res.* **2023**, *158*, 113648. [CrossRef]
97. Lian, G.; Xu, A.; Zhu, Y. Substantive green innovation or symbolic green innovation? The impact of ER on enterprise green innovation based on the dual moderating effects. *J. Innov. Knowl.* **2022**, *7*, 100203. [CrossRef]
98. Zhang, D.; Rong, Z.; Ji, Q. Green innovation and firm performance: Evidence from listed companies in China. *Resour. Conserv. Recycl.* **2019**, *144*, 48–55. [CrossRef]
99. Hao, X.; Fu, W. Innovation with ecological sustainability: Does corporate environmental responsibility matter in green innovation? *J. Econ. Anal.* **2023**, *2*, 21–42. [CrossRef]
100. Lian, Y.; Li, Y.; Cao, H. How does corporate ESG performance affect sustainable development: A green innovation perspective. *Front. Environ. Sci.* **2023**, *11*, 1170582. [CrossRef]
101. Wu, F.; Hu, H.; Lin, H.; Ren, X. Enterprise digital transformation and capital market performance: Empirical evidence from stock liquidity. *Manag. World* **2021**, *37*, 130–144.
102. Guo, X.; Li, M.; Wang, Y.; Mardani, A. Does digital transformation improve the firm's performance? From the perspective of digitalization paradox and managerial myopia. *J. Bus. Res.* **2023**, *163*, 113868. [CrossRef]
103. Hadlock, C.J.; Pierce, J.R. New evidence on measuring financial constraints: Moving beyond the KZ index. *Rev. Financ. Stud.* **2010**, *23*, 1909–1940. [CrossRef]
104. Kaplan, S.N.; Zingales, L. Do investment-cash flow sensitivities provide useful measures of financing constraints? *Q. J. Econ.* **1997**, *112*, 169–215. [CrossRef]
105. Lamont, O.; Polk, C.; Saaá-Requejo, J. Financial constraints and stock returns. *Rev. Financ. Stud.* **2001**, *14*, 529–554. [CrossRef]
106. Whited, T.M.; Wu, G. Financial constraints risk. *Rev. Financ. Stud.* **2006**, *19*, 531–559. [CrossRef]
107. Xiaosheng, J.; Di, L.; Yihua, Y. Financing constraints, working capital management and corporate innovation sustainability [J]. *Econ. Res.* **2013**, *48*, 4–16.
108. Xu, G.; Li, G.; Sun, P.; Peng, D. Inefficient investment and digital transformation: What is the role of financing constraints? *Financ. Res. Lett.* **2023**, *51*, 103429. [CrossRef]
109. Zhang, Y.; Xing, C.; Wang, Y. Does green innovation mitigate financing constraints? Evidence from China's private enterprises. *J. Clean. Prod.* **2020**, *264*, 121698. [CrossRef]
110. Zhang, J.; Li, Y.; Xu, H.; Ding, Y. Can ESG ratings mitigate managerial myopia? Evidence from Chinese listed companies. *Int. Rev. Financ. Anal.* **2023**, *90*, 102878. [CrossRef]
111. Fang, M.; Nie, H.; Shen, X. Can enterprise digitization improve ESG performance? *Econ. Model.* **2023**, *118*, 106101. [CrossRef]
112. Chang, K.; Cheng, X.; Wang, Y.; Liu, Q.; Hu, J. The impacts of ESG performance and digital finance on corporate financing efficiency in China. *Appl. Econ. Lett.* **2023**, *30*, 516–523. [CrossRef]
113. Deng, X.; Li, W.; Ren, X. More sustainable, more productive: Evidence from ESG ratings and total factor productivity among listed Chinese firms. *Financ. Res. Lett.* **2023**, *51*, 103439. [CrossRef]
114. Wang, T.; Liu, X.; Wang, H. Green bonds, financing constraints, and green innovation. *J. Clean. Prod.* **2022**, *381*, 135134. [CrossRef]
115. Li, J.; Ji, L.; Zhang, S.; Zhu, Y. Digital technology, green innovation, and the carbon performance of manufacturing enterprises. *Front. Environ. Sci.* **2024**, *12*, 1384332. [CrossRef]
116. Ye, F.; Ouyang, Y.; Li, Y. Digital investment and environmental performance: The mediating roles of production efficiency and green innovation. *Int. J. Prod. Econ.* **2023**, *259*, 108822. [CrossRef]
117. Liao, Z. Corporate culture, environmental innovation and financial performance. *Bus. Strategy Environ.* **2018**, *27*, 1368–1375. [CrossRef]
118. Riva, F.; Magrizos, S.; Rubel, M.R.B. Investigating the link between managers' green knowledge and leadership style, and their firms' environmental performance: The mediation role of green creativity. *Bus. Strategy Environ.* **2021**, *30*, 3228–3240. [CrossRef]
119. Wang, S.; Abbas, J.; Sial, M.S.; Álvarez-Otero, S.; Cioca, L.-I. Achieving green innovation and sustainable development goals through green knowledge management: Moderating role of organizational green culture. *J. Innov. Knowl.* **2022**, *7*, 100272. [CrossRef]
120. Adamopoulos, T.; Brandt, L.; Leight, J.; Restuccia, D. Misallocation, selection, and productivity: A quantitative analysis with panel data from China. *Econometrica* **2022**, *90*, 1261–1282. [CrossRef]
121. Cheng, H.; Li, Y.; Pang, Y.; Zhao, J.; Fu, K. Can digital transformation change a firm's green innovation strategy? Evidence from China's heavily polluting industries. *Heliyon* **2024**, *10*, e24676. [CrossRef] [PubMed]
122. Baron, R.M.; Kenny, D.A. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Personal. Soc. Psychol.* **1986**, *51*, 1173. [CrossRef] [PubMed]
123. Xu, N.; Lv, W.; Wang, J. The impact of digital transformation on firm performance: A perspective from enterprise risk management. *Eurasian Bus. Rev.* **2024**, *14*, 369–400. [CrossRef]
124. Wen, Z.; Ye, B. Analyses of mediating effects: The development of methods and models. *Adv. Psychol. Sci.* **2014**, *22*, 731. [CrossRef]

125. Li, Y.; Dai, J.; Cui, L. The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. *Int. J. Prod. Econ.* **2020**, *229*, 107777. [CrossRef]
126. Muller, D.; Judd, C.M.; Yzerbyt, V.Y. When moderation is mediated and mediation is moderated. *J. Personal. Soc. Psychol.* **2005**, *89*, 852. [CrossRef] [PubMed]
127. Edwards, J.R.; Lambert, L.S. Methods for integrating moderation and mediation: A general analytical framework using moderated path analysis. *Psychol. Methods* **2007**, *12*, 1. [CrossRef]
128. Tao, Z.; Zhang, Z.; Shangkun, L. Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. *Front. Econ. China* **2022**, *17*, 393.
129. Li, X.W.; Li, N.; Xie, Y.F. Digital Economy, Manufacturing Agglomeration and Carbon Productivity. *J. Zhongnan Univ. Econ. Law* **2022**, *6*, 131–145. (In Chinese)
130. Zhai, H.; Yang, M.; Chan, K.C. Does digital transformation enhance a firm's performance? Evidence from China. *Technol. Soc.* **2022**, *68*, 101841. [CrossRef]
131. Cunningham, P.H. State-owned enterprises: Pursuing responsibility in corporate social responsibility. *Manag. Commun. Q.* **2011**, *25*, 718–724. [CrossRef]
132. Lu, Y.; Xu, C.; Zhu, B.; Sun, Y. Digitalization transformation and ESG performance: Evidence from China. *Bus. Strategy Environ.* **2024**, *33*, 352–368. [CrossRef]
133. Córdoba-Pachón, J.R.; Garde-Sánchez, R.; Rodríguez-Bolívar, M.P. A systemic view of corporate social responsibility (CSR) in state-owned enterprises (SOEs). *Knowl. Process Manag.* **2014**, *21*, 206–219. [CrossRef]
134. Hu, M.; Xiong, W.; Xu, C. Analyst coverage, corporate social responsibility, and firm value: Evidence from China. *Glob. Financ. J.* **2021**, *50*, 100671. [CrossRef]
135. Wang, K.; Jiang, W. State ownership and green innovation in China: The contingent roles of environmental and organizational factors. *J. Clean. Prod.* **2021**, *314*, 128029. [CrossRef]
136. Jiang, W.; Wang, A.X.; Zhou, K.Z.; Zhang, C. Stakeholder relationship capability and firm innovation: A contingent analysis. *J. Bus. Ethics* **2020**, *167*, 111–125. [CrossRef]
137. Huang, S.; Yu, J. The nature, objectives and social responsibility of state-owned enterprises. *China Ind. Econ.* **2006**, *2*, 68–76.
138. Hong, Y. Reading the 13th five-year Plan: Reflections on China's ICT policy. *Int. J. Commun.* **2017**, *11*, 1755–1774.
139. Li, C.; He, C.; Lin, C. Economic impacts of the possible China–US trade war. *Emerg. Mark. Financ. Trade* **2018**, *54*, 1557–1577. [CrossRef]
140. Yang, Y.; Han, J. Digital transformation, financing constraints, and corporate environmental, social, and governance performance. *Corp. Soc. Responsib. Environ. Manag.* **2023**, *30*, 3189–3202. [CrossRef]
141. Fazzari, S.; Hubbard, R.G.; Petersen, B.C. *Financing Constraints and Corporate Investment*; National Bureau of Economic Research: Cambridge, MA, USA, 1987. [CrossRef]
142. Bai, X.; Han, J.; Ma, Y.; Zhang, W. ESG performance, institutional investors' preference and financing constraints: Empirical evidence from China. *Borsa Istanb. Rev.* **2022**, *22*, S157–S168. [CrossRef]