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Digital Transformation and Corporate Environmental Green Innovation Nexus: An Approach towards Green Innovation Improvement

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Abstract: The impact of digital transformation on green innovation is widely discussed. However, existing studies mainly focus on the impact of the digital transformation of enterprises and fintech company development on environmental green innovation, while ignoring the effect of the digital transformation of commercial banks (DTCB) on corporate green innovation. Therefore, to fill the research gap, this paper explores the impact of DTCB on environmental green innovation in companies based on the data of listed companies from 2010 to 2019. This study finds that DTCB has significantly promoted enterprises' environmental green innovation. Mechanism analysis shows that DTCB can promote green environmental innovation by increasing R&D expenditures and reducing agency costs. The heterogeneity analysis indicates that DTCB can only promote the green environmental innovation of private enterprises and enterprises with a high degree of digital transformation, but it cannot promote the green environmental innovation of state-owned enterprises and enterprises with a low degree of digital transformation. From the perspective of DTCB, this paper enriches the research on the relationship between digital finance and enterprise environmental green innovation. The government should promote the digital transformation of enterprises to utilize the green innovation effect of DTCB.

Keywords: digital transformation; environmental green innovation; agency cost

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1. Introduction

As China's urbanization and industrialization continue to advance, green development is being challenged. As an essential player in the market economy, enterprises are responsible for coordinating economic growth with environmental protection [1]. Green innovation can reduce pollution emissions in the production process [2], which is critical to eliminating the conflict between China's economic growth and environmental pollution [3]. However, the high risk of green innovation poses some challenges to itself. Green technologies are more capital-intensive and risky than general innovations, making them more challenging to finance [4]. Since commercial banks are the primary source of external financing for most companies in China, exploring how to increase the credit of commercial banks for corporate green innovation is of great practical importance for developing a green economy.

The attitude of commercial banks toward corporate innovation has evolved from aversion to tolerance. Early studies concluded that commercial banks have an aversion to innovative corporate behavior [5]. On the one hand, commercial banks have an adversarial attitude toward risk, while corporate technology innovation is inherently high risk. On the other hand, commercial banks require companies to have stable cash flow that can repay principal and interest over a certain period, but technological innovation activities require continuous cash investment. However, many subsequent studies have found that

commercial banks do indeed finance corporate innovation [6]. Commercial banks are somewhat tolerant of this innovative behavior. In a fully competitive market environment, technological innovation becomes the key for enterprises to cultivate competitive advantages and eliminate the "homogenization trap" of products [7]. Commercial banks recognize that sustained growth through technological innovation is the only way for companies to obtain sufficient cash flow to repay debt and interest [8]. Commercial banks can identify with the practical logic of 'technological innovation for business growth', embrace the risk of innovation, and lend to innovative enterprises [6]. The sustainable growth of enterprises through technological innovation has become a common goal for banks and enterprises. This 'target binding effect' provides sufficient evolutionary motivation for the commercial bank attitude to change from 'innovation aversion' to 'innovation inclusion'. In the current context of advocating green development, achieving the green development of enterprises through green innovation has become a new common goal between enterprises and commercial banks [9]. However, although commercial banks can accommodate the innovative activities of enterprises, to some degree, many enterprises face credit rationing due to information asymmetry and lack of collateral [10].

The digital transformation of commercial banks (DTCB) is conducive to improving their ability to serve the real economy and can affect green innovation. DTCB refers to the application of digital technologies, such as big data, cloud computing, blockchain technology, the Internet of things, and artificial intelligence by commercial banks to realize the online, intelligent, scenario-based, and platform-based banking business [11]. Currently, commercial banks are beginning to implement digital transformation at a rapid pace [12]. National commercial banks implement digital transformation by setting up fintech subsidiaries, while urban and rural commercial banks implement digital transformation by cooperating with fintech companies [13]. DTCB can reduce information asymmetry and increase credit supply to enterprises [14]. So, can DTCB promote green innovation by increasing lending to enterprises? If DTCB can effectively promote the green innovation of companies, exploring the effect of the green innovation of DTCB is vital to improving the environment.

Studies have been conducted to explore the impact of digital transformation on green innovation at both the macro and micro levels, respectively. At the macro level, ref. [15] and ref. [16] have found that the development of the digital economy promotes green innovation using data from the city panel at the prefecture level in China. Ref. [17] has discovered that digital economy development can promote green innovation by promoting economic openness, optimizing the industrial structure, and expanding the market potential. From the micro level, ref. [18] has found that the digital transformation of enterprises promotes green innovation by optimizing the human capital structure and strengthening the cooperation between industry and academia. Ref. [19] has found that the digital transformation of enterprises promotes green innovation by enhancing the level of information sharing and resource allocation efficiency. Some studies focus on the green innovation effects of the digital transformation of financial institutions. Ref. [20] and ref. [21] have found that the development of fintech companies can significantly improve green innovation. The digital transformation of financial institutions includes the development of fintech companies and DTCB. In fact, fintech companies serve individual entrepreneurs and micro and small enterprises [22] and engage less in green innovation. DTCB can increase lending to enterprises, which may promote the green innovation of enterprises. However, the existing research has mainly studied the relationship between fintech companies and green innovation, ignoring the relationship between DTCB and green innovation.

In summary, from the micro level, studies on the effects of digital transformation on green innovation have mainly focused on exploring the impact of the digital transformation of enterprises and fintech companies on green innovation of enterprises, and little literature has focused on the impact of DTCB on green innovation. Therefore, this paper fills this gap by exploring the effect of DTCB on the green innovation of enterprises.

The marginal contributions of this study are as follows. First, the research object of digital finance is extended to the banking system, enriching the research on the effect of digital finance on green innovation. Current research focuses on exploring the effect of fintech companies on green innovation, while the impact of DTCB on green innovation is yet to be studied. Under China's bank-based financial system, ignoring the effect of DTCB on green innovation will make it difficult to clarify the effect of digital finance on green innovation. Second, it expands the research on the economic consequences of DTCB. The existing literature has mainly explored the impact of DTCB on the credit scale and credit structure, and the impact of DTCB on green innovation is yet to be studied. Hence, this paper further expands the economic consequences of DTCB. Third, the heterogeneity of DTCB affecting green innovation is explored. We have found that DTCB can only promote the green innovation of enterprises with a high degree of digital transformation, which provides a basis for government departments to further promote the digital transformation of enterprises to facilitate their green development.

2. Literature Review and Research Hypothesis

2.1. Impact Mechanism of DTCB on Green Innovation

2.1.1. Analysis of Innovation Resources Mechanism

Financing constraints lead to insufficient investment of companies in innovative resources [23]. The reason why green innovation by corporations often faces financing constraints is as follows. First, the traditional lending process is cumbersome, which may result in innovative projects missing the best research and development period due to the lack of timely financing. Second, companies are often reluctant to reveal specific details related to their innovative projects to avoid revealing trade secrets, which exacerbates information asymmetry, and further undermines the willingness of commercial banks to lend to these companies [24]. Third, many innovative enterprises have fewer fixed assets and lack collateral, making it difficult to obtain external financing in traditional lending models that value collateral. Next, the effect of DTCB on financing for green innovation is analyzed from the perspective of the above three explanations.

First, DTCB has simplified the credit approval process and reduced the possibility of innovative projects missing the best research and development period because they cannot obtain financing in time. The traditional credit approval process requires credit approval personnel to visit the enterprise to conduct on-site due diligence research. It includes explicitly assessing the business status of the enterprise, verifying the collateral and guarantors, etc. The whole process is long. Commercial banks have changed the credit-granting model, using big data and artificial intelligence. Commercial banks have implemented online lending operations based on firm-related information searched in many channels and intelligent risk control models [25]. Companies can apply for loans using the on-line platforms of commercial banks, avoiding the cumbersome approval process and reducing the time it takes to obtain loans.

Second, the DTCB improves the lending techniques of commercial banks based on soft information and increases the lending to innovative corporate projects. First, DTCB enhances the capabilities of commercial banks to search for and process soft information. Soft information refers to qualitative information, usually text, such as the quality of company managers and the competitiveness of enterprise products [26]. This soft information forms an important basis for commercial banks to grant loans [27]. As the digital economy develops rapidly, e-commerce, social networks, and credit platforms are accumulating a large amount of corporate data, which can capture the fundamental information of a company in detail. DTCB can efficiently connect to such data platforms, broaden information sources, and thus reduce the cost of soft information production [28]. At the same time, digital technology allows commercial banks to handle soft information more effectively [29]. Compared to the traditional manual information processing mode, commercial banks can apply big data, cloud computing, blockchain technology, and mathematical and statistical models to process soft information more rapidly and effectively [30]. A more comprehensive range

of soft information sources and more efficient soft information processing techniques have enabled commercial banks to improve their soft information-based lending techniques [31]. Moreover, digital technology enables commercial banks to achieve remote monitoring through the Internet of things and blockchain technology, thus supervising the granting of loans to enterprises more effectively [32]. It avoids the possible moral hazard of enterprises and improves the willingness of commercial banks to finance innovative projects.

2.1.2. Analysis of Debt Governance Mechanisms

The principal agent problem squeezes out green innovation activities. The separation of operation and ownership of the enterprise causes the principal–agent problem. In the case of business and ownership separation, managers often hold a portion of the company's equity. The utility of managers does not depend entirely on the value and profit of the company, giving managers an incentive to use the resources they control to satisfy their preferences [33]. Managerial preferences are expressed in three aspects. The first is the size preference of managers. In large companies, managers are paid more and have more power, so they tend to pursue growth in size to build their 'economic empire' [34]. The second is the spending preference of managers. Some of the expenditures in the company can directly or indirectly improve the utility of the manager [35]. The third is the manager's preference for a quiet life. Managers have only partial ownership of the company, making them reluctant to engage in activities they find difficult, such as green innovation [36]. The size preference and spending preference of managers lead to a flow of resources to fixed asset investment and the consumption of managers on the job, etc., which directly squeeze out green innovation activities. The preference of managers to enjoy a quiet life also conflicts with the high risk of green innovation activities. Therefore, the preferences of the three types of managers squeeze out the green innovation activities of the company.

Bank debt governance alleviates the principal agent problem, and thus improves managers' efforts to implement green innovation activities. According to organizational control theory, the important role of corporate governance is to constrain managers' preferences and make rational use of funding resources, such as investing in green innovation [37]. The economic theory of the agency indicates that bank debt governance mechanisms can alleviate the principal agent problem, affecting corporate managers' decision-making behavior and resource allocation efficiency [38]. First, the existence of liabilities requires companies to repay principal and interest to creditors within a specified period. It reduces the capital available to managers at their discretion and constrains managers' expansion and spending preferences. Second, in the event that the debtor is unable to repay the loan, the commercial bank can request the debtor to take out bankruptcy through legal procedures. Bankruptcy causes managers to lose their jobs and damages their reputations. Therefore, the threat of bankruptcy can force managers to work harder [39]. Third, to prevent debtors from investing borrowed capital in risky projects, commercial banks monitor the use of borrowed capital, constraining managers' private preferences [40]. In conclusion, commercial banks reduce the size and spending preferences of managers by exercising contractual restrictions and supervision, etc., and induce managers to work harder to implement green innovation activities.

The DTCB strengthens the role of commercial banks in debt governance, thus promoting corporate green innovation. First, the DTCB increases lending to companies, thus strengthening the governance role of contractual constraints. For companies, larger loans imply more pressure to repay debt and a greater threat of bankruptcy, which motivates managers to reduce their expansion and spending preferences and to work harder to implement green innovation activities. Second, the DTCB strengthens the supervision of the usage of loans. Through digital transformation, commercial banks can obtain information related to enterprises in real time and cross-verify the information obtained [41], making the information obtained by commercial banks more timely, accurate, extensive, and difficult to manipulate [42]. In this case, commercial banks can monitor the use of loans more effectively, limiting the use of loans for expansion and spending preferences. In general,

the mechanism of DTCB affecting green innovation is shown in Figure 1. Therefore, the following hypotheses are proposed.

Hypothesis 1: *DTCB can promote green innovation in enterprises.*

Hypothesis 2: *DTCB promotes green innovation by increasing the innovation resources of enterprises.*

Hypothesis 3: *DTCB promotes green innovation by enhancing the governance of debt by enterprises.*

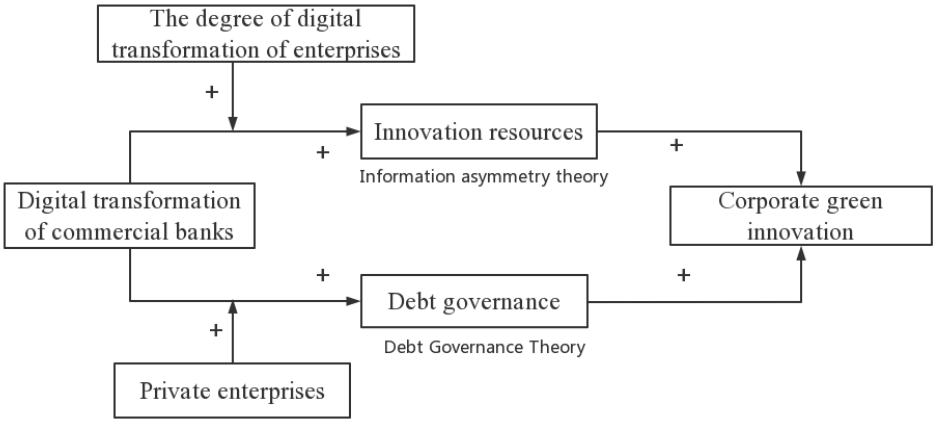

Figure 1. The mechanism of DTCB affecting green innovation.

2.2. Analysis of Heterogeneity

2.2.1. The Heterogeneity of the Degree of Enterprise Digital Transformation

When the digital transformation of enterprises reaches a certain level, DTCB can play a role in reducing information asymmetry. Digital technology empowers commercial banks to improve their ability to find information, but this is based on the accumulation of reliable data. When an enterprise accumulates reliable data, DTCB can play a role in reducing information asymmetry. If an enterprise completes the digital transformation, its information related to technological innovation, production and operation, internal control, and product sales can be made available. This information is open, transparent, shared, and verifiable [43], reflecting the enterprise's technological innovation, production, and sales. Commercial banks can access the data mentioned above to the credit tracking system through digital technology, which can better utilize DTCB in reducing information asymmetry. Since information asymmetry is an important mechanism by which DTCB affects green innovation, DTCB can only promote green innovation in enterprises with a high degree of digital transformation. Therefore, the following proposition is proposed.

Hypothesis 4: *DTCB can only promote green innovation in enterprises with a high degree of digital transformation, while it cannot promote green innovation in enterprises with a low degree of digital transformation.*

2.2.2. The Heterogeneity of Enterprise Ownership

In the case of "ownership discrimination" in the credit market, state-owned enterprises have invisible government guarantees and do not face credit rationing. In contrast, private enterprises face credit rationing and have difficulty obtaining loans from banks. This is because they are subject to "ownership discrimination" in the traditional financial market [44]. As DTCB promotes green innovation through increased financing. DTCB can only promote green innovation in private enterprises. Thus, the following proposition is proposed.

Hypothesis 5: *DTCB can only promote green innovation in private enterprises, while it cannot promote green innovation in state-owned enterprises.*

3. Data and Empirical Design

3.1. Data

This paper selects the data of listed companies from 2010 to 2019 for the empirical test. The deep integration of finance and technology originated in 2010 [14], so this paper chooses 2010 as the starting point. The outbreak of COVID-19 in 2020 has had a great impact on the operation and investment activities of private enterprises. In order to eliminate the interference of the impact of COVID-19 on the research results, this paper selects 2019 as the endpoint. The data come from the CSMAR (China Stock Market and Accounting Research Database). Samples from the financial sector are removed. All continuous variables were tailed by 1% before and after to remove outliers of continuous variables. A total of 7505 year-company observations were obtained. The variables are described as follows.

3.1.1. The Explained Variable

Green innovation (GI). Green innovation describes technological innovation that contributes to improving environmental quality. Referring to the research of ref. [45], the number of green invention patents granted is adopted to measure the level of green innovation of the enterprises. The World Intellectual Property Organization (WIPO) launched the Green List of International Patent Classifications in 2010. This list is used to determine whether each of the company's patents is a green patent.

3.1.2. The Core Explanatory Variable

DTCB at the enterprise level (DTCBE). DTCBE is measured by the level of digital transformation of commercial banks that lend to companies. This paper refers to the method of ref. [46] to construct DTCBE, including the following four steps. (1) The five most widely used digital technologies in commercial banks are selected as keywords, i.e., big data, artificial intelligence, cloud computing, blockchain technology, and the Internet of things. (2) Web-crawled technology is used to obtain news search results for the combination of commercial bank names and keywords (such as "China bank" + "big data") each year and to then calculate the total number of news search results for the combination in each year from 2010 to 2019. (3) The logarithm of the total number of news search results is used as the level of digital transformation of the commercial bank. (4) The weighted average level of digital transformation of a commercial bank's lending to an enterprise, DTCBE, is calculated. The weight used is the proportion of loans obtained by the enterprise in each commercial bank in the current year.

3.1.3. The Mechanism Variables

(1) R&D expenditure (RD). R&D expenditure is measured by the R&D expenditure of the enterprise in the current year.
(2) Agency cost (AC). Agency cost is measured by the ratio of the administrative expenses to the operating revenue.

3.1.4. The Control Variables

Referring to [47] and [48], a series of variables describing the important characteristics of enterprises or affecting enterprise green innovation are set as control variables. The control variables and their specific definitions are shown in Table 1.

The results of the descriptive statistics for the main variables are shown in Table 2. We can see that the standard deviations of green innovation, DTCBE, R&D expenditure, and agency cost are 0.377, 4.284, 1.402, and 0.083, respectively. The data show that the standard deviation of DTCBE is the highest, reflecting the large difference in the digital transformation of commercial banks lending to enterprises. To further reflect the distribution of DTCBE in different years, the nuclear density map of DTCBE over time is shown in Figure 2. The estimated peak nuclear density of DTCBE is increasing year by year, indicating an upward trend of DTCBE. The upward shift of the nuclear density curve indicates an

increase in the concentration of the BTCBE distribution. The accurate impact of DTCB on green innovation will be further studied using the subsequent econometric model.

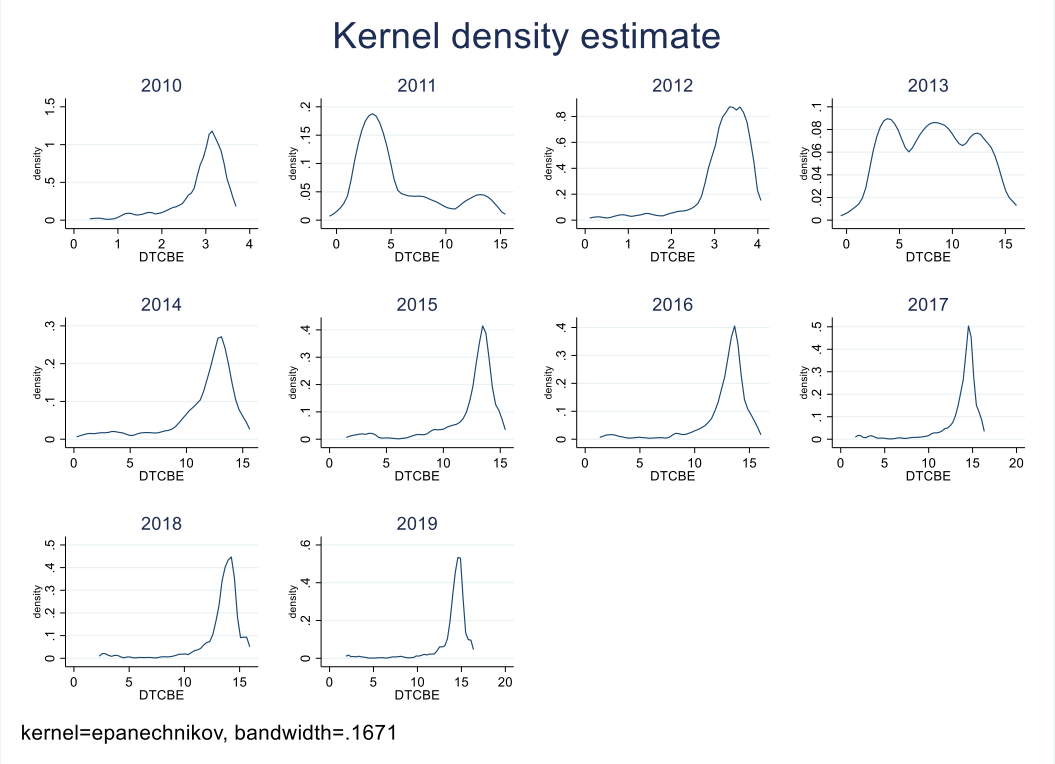

Figure 2. The nuclear density map of DTCBE.

Table 1. Variable descriptions.

	Variables	Index	Definition
Explained variable	GI	Green innovation	Logarithm of the number of green patents.
Explanatory variable	DTCBE	DTCB at the enterprise level	The digital transformation level of commercial banks that lend to companies.
Mechanism variable	RD	R&D expenditure	Logarithm of R&D expenditure.
Control variable	AC	Agency cost	The ratio of administrative expenses to operating revenue.
	CS	Company size	The logarithm of the number of employees in the company.
	SOE	State-owned enterprise	Set at 1 if it is a state-owned enterprise, 0 otherwise.
	ALR	Asset–liability ratio	Total liabilities divided by total assets.
	IRBR	Increasing rate of business revenue	Growth rate of current-period operating revenue relative to previous-period operating revenue.
	CLR	Capital–labor ratio	Net fixed assets divided by the number of employees, and followed by the application of the logarithm.
	DL	Dual leadership	Set at 1 if the CEO is also the board chairman.
	BS	Board Size	The logarithm of the number of board members.
	PID	Proportion of independent directors	The ratio of independent directors to all directors.
	GSC	Government subsidies changes	The change rate of government subsidies.
	ATBC	Actual tax burden changes	The change rate of the actual tax burden.

Table 2. Descriptive statistics of variables.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GI	7511	0.107	0.377	0	2.890
DTCBE	7511	11.24	4.284	0.223	16.21
RD	7511	17.75	1.402	11.78	22.09
AC	7511	0.107	0.0825	0.00644	0.772
CS	7511	7.679	1.112	3.829	11.29
SOE	7511	0.305	0.461	0	1
ALR	7511	0.458	0.200	0.0400	0.993
IRBR	7511	0.220	0.593	−0.674	8.507
CLR	7511	12.50	1.105	8.694	16.41
DL	7511	0.292	0.455	0	1
BS	7511	2.121	0.200	1.609	2.708
PID	7511	0.377	0.0564	0.273	0.667
GSC	7511	−0.0005	0.0197	−0.206	0.243
ATBC	7511	−0.0006	0.00695	−0.0450	0.0499

3.2. Empirical Design

This paper uses a fixed-effects model to test the impact of DTCB on green innovation. The model is set up as follows.

$$GI_{it} = C + \alpha_1 DTCBE_{it} + \alpha_2 \sum_m control\_m_{it} + \mu_i + u_t + \varepsilon_{it} \quad (1)$$

$$RD_{it} = C + \alpha_3 DTCBE_{it} + \alpha_4 \sum_m control\_m_{it} + \mu_i + u_t + \varepsilon_{it} \quad (2)$$

$$AC_{it} = C + \alpha_5 DTCBE_{it} + \alpha_6 \sum_m control\_m_{it} + \mu_i + u_t + \varepsilon_{it} \quad (3)$$

In Equation (1), GI_{it} is green innovation. $DTCBE_{it}$ is the level of digital transformation of commercial banks at the enterprise level. $\sum_m control\_m_{it}$ refers to a set of control variables including company size (CS), state-owned enterprise (SOE), asset–liability ratio (ALR), increase rate of business revenue (IRBR), capital–labor ratio (CLR), dual leadership (DL), board size (BS), proportion of independent directors (PID), government subsidies changes (GSC), and actual tax burden changes (ATBC). α is the parameter to be estimated, μ_i and u_t reflects the time fixed effects, and ε_{it} is the residual term. Additionally, due to the large differences in green innovation among industries, the fixed effects of the industry are controlled in Model (1).

In both Equations (2) and (3), RD_{it} and AC_{it} represent R&D expenditure and agency costs, respectively. The settings of other variables and parameters are consistent with Equation (1).

4. Empirical Results and Discussion

4.1. Baseline Results

Table 3 reports the regression results. Model (1) only controls the fixed effects in time and individual, and Model (2) adds control variables that affect green innovation. Models (3) and (4) report the regression results, without controlling individual fixed effects for comparison. The coefficient of DTCBE is significantly positive in both Models (1)–(4), indicating that DTCB significantly promotes corporate green innovation, which supports Hypothesis 1. This is due to the following reasons. First, commercial banks increase loans to companies through digital transformation, allowing companies to invest in green innovation activities. Second, the use of digital technology by commercial banks can improve their ability to supervise enterprises. Under stronger external supervision, managers reduce self-interested behaviors, such as on-the-job consumption, and attach more importance to green innovation activities. In addition, the obtained loan signals operate in good condition, helping enterprises to obtain financing from other channels, thus promoting green innovation.

Table 3. Baseline regression results.

Variables	FE				RE			
	Model (1) GI		Model (2) GI		Model (3) GI		Model (4) GI	
	Coefficient	Std. Err	Coefficient	Std. Err				
DTCBE	0.004 ***	(3.59)	0.003 ***	(2.59)	0.004 ***	(4.12)	0.004 ***	(3.51)
CS			0.031 ***	(3.06)			0.029 ***	(5.13)
SOE			−0.014	(−0.40)			0.012	(0.80)
ALR			0.069 *	(1.84)			0.086 ***	(3.11)
IRBR			−0.011 *	(−1.89)			−0.014 ***	(−2.58)
CLR			0.020 ***	(2.65)			0.011 **	(1.99)
DL			−0.032 **	(−2.51)			−0.016	(−1.59)
BS			−0.060	(−1.41)			0.018	(0.59)
PID			−0.033	(−0.27)			0.050	(0.52)
GSC			−0.201	(−1.21)			−0.262 *	(−1.65)
ATBC			0.479	(0.98)			0.316	(0.67)
Constant	0.027	(0.16)	−0.314	(−1.24)	−0.023	(−0.29)	−0.470 ***	(−3.28)
Year FE	YES		YES		YES		YES	
Enterprise FE	YES		YES		No		No	
Industry FE	YES		YES		YES		YES	
N	7511		7511		7511		7511	
Adj. R-sq	0.0244		0.0298		0.0154		0.0189	

The values in parentheses are *t*-statistics. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2. The Robustness Test

4.2.1. Replace Core Explanatory Variables

(1) Replace the way DTCBE is constructed. This paper uses this method to replace the way DTCBE is constructed for the robustness test. Referring to [46], the news search results for the various keywords regarding commercial banks from 2010 to 2019 are obtained based on Web crawler technology. First, the log-value of the keyword news search results is calculated. Second, based on the news search results for each keyword each year, the factor analysis method is used to calculate the level of digital transformation of commercial banks. Finally, e the weighted average digital transformation level of commercial bank lending to an enterprise, DTCBE, is calculated.

(2) Use the digitalization of regional commercial banks as a proxy variable. This paper uses the digitalization of regional commercial banks as a proxy variable for the robustness test. This study follows the methods of studies in ref. [49] to measure the digitalization of regional commercial banks. The degree of the digitalization of regional commercial banks is constructed based on the degree of DTCB at the commercial bank level and the geographic distribution data of the commercial bank branches. Table 4 reports the regression results, and the DTCBE coefficient in Models (1) and (2) is significantly positive, indicating that the conclusion that DTCB significantly promotes green innovation is robust.

Table 4. Robust test with the alternative core explanatory variables and the alternative sample.

Variables	Model (1) GI (Replace the Way DTCBE Is Constructed)		Model (2) GI (Use the Digitalization of Regional Commercial Banks)		Model (3) GI (Delete the Sample of MDUCG)	
	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Err
DTCBE	0.022 ***	(3.23)	0.035 *	(1.85)	0.004 ***	(2.74)
Constant	−0.285	(−1.12)	−0.321	(−0.66)	−0.357	(−1.07)
Controlled variable	YES		YES		YES	
Enterprise FE	YES		YES		YES	
Year FE	YES		YES		YES	
Industry FE	YES		YES		YES	
N	7511		7511		6232	
Adj. R-sq	0.0304		0.0386		0.0345	

The values in parentheses are *t*-statistics. * $p < 0.1$ and *** $p < 0.01$.

4.2.2. Exclude Municipalities Directly under the Central Government

Referring to [50], the municipalities directly under the central government (MDUCG) were removed to carry out the robustness test. This is due to the high degree of DTCB in MDUCG, which may lead to the more significant impact of DTCB on green innovation in MDUCG. The regression results are shown in Model (3) in Table 4. It can be seen that the coefficient of DTCBE is still significantly positive after excluding the samples of MDUCG. This indicates that the core conclusions of this paper are robust.

4.2.3. Treatment of Endogeneity

The above regression results show that DTCB can promote green innovation. However, the above regression results may be challenged by endogeneity problems. Considering that enterprises' green innovation in the current period is often affected by the green innovation in the lag period, there may be a serial correlation in the time dimension. Therefore, this paper introduces the first-order lagged value of green innovation in the benchmark regression model to mitigate endogeneity problems, and the results are shown in column (1) in Table 5. The coefficient of the first-order lagged value of green innovation is significantly positive, indicating that the green innovation of enterprises in the current period is significantly affected by the green innovation in the previous period. The coefficient of DTCBE is significantly positive, indicating that DTCB still significantly promotes green innovation after considering the serial correlation in the time dimension of green innovation.

Table 5. Treatment of endogeneity with the first order lagged value of DTCBE and GI.

Variables	Model (1) GI (Use the First Order Lagged Value of GI)		Model (2) GI (Use the First Order Lagged Value of DTCBE)	
	Coefficient	Std. Err	Coefficient	Std. Err
L.GI	0.050 ***	(3.57)		
L.DTCBE			0.002 *	(1.92)
DTCBE	0.002 **	(1.99)		
Constant	−0.146	(−0.46)	−0.317	(−1.24)
Controlled variable	YES		YES	
Enterprise FE	YES		YES	
Year FE	YES		YES	
Industry FE	YES		YES	
N	6498		6498	
Adj. R-sq	0.0278		0.0265	

The values in parentheses are *t*-statistics. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The impact of DTCB on green innovation is usually a long-term cumulative process, which may have a certain lag. Therefore, referring to the method of [51], we use a first-order lagged value of DTCBE as a proxy for DTCBE to mitigate the underlying estimation error. The estimation results are displayed in column (2) in Table 5. The results indicate that the coefficient of the first-order lagged value of DTCBE is significantly positive, which once again confirms our conclusions.

4.3. Mechanism Analysis

Theoretical analysis shows that DTCB can promote green innovation by increasing the expenditures of enterprises on R&D and strengthening the governance of debts for enterprises. Therefore, this paper next examines the impact of DTCB on R&D expenditures and agency costs, and the regression results are shown in Table 6. The coefficient of DTCBE is significantly positive in Model (1), indicating that DTCB can significantly increase the R&D expenditure. The coefficient of DTCBE is significantly negative in Model (2), indicating that DTCB can strengthen the governance of debt of the enterprises, thus reducing agency costs. Therefore, Hypothesis 2 and Hypothesis 3 are supported.

Table 6. Mechanism test results.

Variables	Model (1)		Model (2)	
	RD		AC	
	Coefficient	Std. Err	Coefficient	Std. Err
DTCBE	0.018 ***	(5.81)	−0.001 **	(−2.33)
CS	0.681 ***	(29.78)	−0.003 **	(−2.04)
SOE	−0.063	(−0.93)	0.003	(0.65)
ALR	−0.178 **	(−2.28)	0.020 ***	(3.48)
IRBR	0.042 ***	(2.83)	−0.016 ***	(−16.76)
CLR	0.197 ***	(11.63)	0.003 ***	(2.74)
DL	0.028	(1.04)	−0.002	(−1.01)
BS	0.219 **	(2.46)	−0.011	(−1.64)
PID	0.224	(0.86)	−0.009	(−0.50)
GSC	0.399	(1.15)	0.124 ***	(4.75)
ATBC	0.045	(0.04)	−0.408 ***	(−5.47)
Constant	9.982 ***	(15.76)	0.027	(0.68)
Enterprise FE	YES		YES	
Year FE	YES		YES	
Industry FE	YES		YES	
N	7511		7511	
Adj. R-sq	0.4317		0.1212	

The values in parentheses are *t*-statistics. ** $p < 0.05$ and *** $p < 0.01$.

4.4. Heterogeneity Analysis

4.4.1. Heterogeneity of Ownership

The theoretical analysis shows that the influence of DTCB on corporate green innovation is only significant in private enterprises. Therefore, this paper explores whether there is ownership heterogeneity in the impact of DTCB on green innovation. Enterprises are divided into state-owned and private enterprises, and the regression is conducted by group. The regression results are reported in Table 7. The results show that DTCB can significantly promote green innovation in private enterprises, but it is unable to promote green innovation in state-owned enterprises. This verifies Hypothesis 4.

Table 7. Results based on the heterogeneity of the degree of enterprise digital transformation.

Variables	Model (1) GI (Enterprises with a Low Degree of Digital Transformation)		Model (2) GI (Enterprises with a High Degree of Digital Transformation)	
	Coefficient	Std. Err	Coefficient	Std. Err
DTCBE	0.003	(1.61)	0.005 **	(2.04)
Constant	−0.204	(−0.63)	−0.103	(−0.29)
Controlled variable	YES		YES	
Enterprise FE	YES		YES	
Year FE	YES		YES	
Industry FE	YES		YES	
N	3894		3617	
Adj. R-sq	0.0365		0.0376	

The values in parentheses are *t*-statistics. ** $p < 0.05$.

4.4.2. Heterogeneity of the Degree of Digital Transformation of Enterprises

Theoretical analysis shows that only when enterprises have realized a certain degree of digital transformation can DTCB promote green innovation. Therefore, this paper examines whether the effect of DTCB on green innovation is heterogeneous between enterprises with different degrees of digital transformation. This paper uses the method of [52–55] to construct the indicators reflecting the degree of enterprise digital transformation. The specific steps are as follows. Firstly, with the help of the semantic expression of national policies related to the digital economy, 197 words related to enterprise digital transformation, with a frequency of more than or equal to 5 times, are selected to form a digital dictionary. Then, the machine learning-based text analysis method is used to analyze the text of the 'management discussion and analysis' part of the annual report of listed companies, and the frequency of 197 words related to the digital transformation of the enterprise is obtained from the annual report. Finally, a comprehensive indicator is constructed reflecting the degree of enterprise digital transformation based on the above frequency data. According to the median of the degree of enterprise digital transformation, we divide the samples into the group with a high digital transformation degree and the group with a low digital transformation degree. Then the regression is conducted by groups. The regression results are shown in Table 8. The results show that DTCB can only promote green innovation in enterprises with a high degree of digital transformation, but it is unable to promote green innovation in enterprises with a low degree of digital transformation. This verifies Hypothesis 5.

Table 8. Results based on the heterogeneity of firm ownership.

Variables	Model (1) GI (State-Owned Enterprise)		Model (2) GI (Private Enterprise)	
	Coefficient	Std. Err	Coefficient	Std. Err
DTCBE	0.001	(0.10)	0.005 ***	(3.06)
Constant	−0.363	(−0.88)	−0.405	(−1.61)
Controlled variable	YES		YES	
Enterprise FE	YES		YES	
Year FE	YES		YES	
Industry FE	YES		YES	
N	2330		5181	
Adj. R-sq	0.0344		0.0345	

The values in parentheses are *t*-statistics. *** $p < 0.01$.

5. Conclusions

The development of digital finance has changed the way financial services are provided and improved the ability of the financial system to serve the real economy. Many scholars

have focused on the impact of digital finance on green innovation and have drawn some useful conclusions. However, existing studies only discuss the impact of the development of fintech companies on green innovation, ignoring the impact of the digital transformation of commercial banks (DTCB) on green innovation. Therefore, this paper fills this gap and explores the impact of DTCB on corporate green innovation. Based on the data of listed companies from 2010 to 2019, this study explores the impact of DTCB on enterprise green innovation. We find that DTCB has significantly promoted enterprise green innovation. Mechanism analysis shows that DTCB can promote green innovation by increasing R&D expenditures and reducing agency costs. The heterogeneity analysis indicates that DTCB can only promote green innovation in private enterprises and enterprises with a high degree of digital transformation, but it cannot promote green innovation in state-owned enterprises and enterprises with a low degree of digital transformation.

The following recommendations can be derived from our study, based on the above conclusions. First, the government should focus on solving the problem of the inadequate sharing of enterprise-related information. The mechanism analysis shows that the DTCB increases loans to enterprises by reducing information asymmetry, thus promoting green innovation. At present, enterprise-related information is scattered, so the government should broaden the information sources of commercial banks by building enterprise-related information sharing platforms and allowing DTCB to play a full role in promoting green innovation. The information sharing platform can collect and share the information within the purview of local governments, such as enterprise tax payment information, real estate information, compulsory administrative information, and water and electric fee payment information. Second, the government should guide and support the digital transformation of enterprises. The heterogeneity analysis shows that only when the digital transformation of enterprises reaches a certain level can DTCB significantly promote green innovation. Therefore, the government should guide and support enterprises to implement digital transformation. The government can give full play to the guiding role of central financial funds and encourage local governments to provide preferential support to the digital transformation of these enterprises. In addition, the government can build some platforms to provide enterprises with digital services, such as transformation consulting and software applications.

This paper clarifies the impact of DTCB on environmental green innovation. However, due to the difficulty in obtaining the digital transformation level of commercial banks that provide loans to unlisted companies, this paper does not explore the impact of DTCB on unlisted companies. In the future, if we obtain the digital transformation index of commercial banks that provide loans to unlisted companies, we will further test to determine the impact of DTCB on green environmental innovation in unlisted companies to deepen and expand our findings.

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References

1. Ba, S.; Li, N.; Zhang, J. Digital Finance and Corporate Green Innovation: Exclusion or Integration? *Res. Financ. Econ. Issues* **2022**, 57–68.
2. Wang, C.H. An environmental perspective extends market orientation: Green innovation sustainability. *Bus. Strategy Environ.* **2020**, *29*, 3123–3134. [CrossRef]
3. Sahoo, S.; Kumar, A.; Upadhyay, A. How do green knowledge management and green technology innovation impact corporate environmental performance? Understanding the role of green knowledge acquisition. *Bus. Strategy Environ.* **2023**, *32*, 551–569. [CrossRef]
4. Yu, C.-H.; Wu, X.; Zhang, D.; Chen, S.; Zhao, J. Demand for green finance: Resolving financing constraints on green innovation in China. *Energy Policy* **2021**, *153*, 112255. [CrossRef]
5. Opler, T.C.; Titman, S. Financial Distress and Corporate Performance. *J. Financ.* **1994**, *49*, 1015–1040. [CrossRef]
6. Wang, X. From innovation aversion to innovation tolerance: A study of influence of bank debt governance towards technological innovation. *Sci. Res. Manag.* **2015**, *36*, 184–192.
7. Yu, C.; Zhang, Z.; Lin, C.; Wu, Y.J. Knowledge Creation Process and Sustainable Competitive Advantage: The Role of Technological Innovation Capabilities. *Sustainability* **2017**, *9*, 2280. [CrossRef]
8. David, P.; O'Brien, J.P.; Yoshikawa, T. The Implications of Debt Heterogeneity for R&D Investment and Firm Performance. *Acad. Manag. J.* **2008**, *51*, 165–181.
9. Yu, D.; Tao, S.; Hanan, A.; Ong, T.S.; Latif, B.; Ali, M. Fostering Green Innovation Adoption through Green Dynamic Capability: The Moderating Role of Environmental Dynamism and Big Data Analytic Capability. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10336. [CrossRef]
10. Stiglitz, J.; Weiss, A. Credit Rationing in Markets with Imperfect Information. *Am. Econ. Rev.* **1981**, *71*, 393–410.
11. Wang, S.; Xie, X. Economic Pressure or Social Pressure: The Development of Digital Finance and the Digital Innovation of Commercial Banks. *Economist* **2021**, *1*, 100–108.
12. Omarini, A. The Digital Transformation in Banking and The Role of FinTechs in the New Financial Intermediation Scenario. *Int. J. Financ. Econ. Trade (IJFET)* **2017**, *1*, 1–6.
13. Wang, X.; Huang, Y.; Xun, Q.; Qiu, H. How Digital Technologies Change Financial Institutions: China's Practice and International Implications. *Int. Econ. Rev.* **2022**, 70–85+6.
14. Hu, B.; Ren, X. The Development of FinTech: Characteristics, Challenges and Regulatory Strategies. *Reform* **2021**, 82–90.
15. Wang, X.; Sun, X.; Zhang, H.; Xue, C. Digital Economy Development and Urban Green Innovation CA-Pability: Based on Panel Data of 274 Prefecture-Level Cities in China. *Sustainability* **2022**, *14*, 2921. [CrossRef]
16. Xiao, Y.; Wu, S.; Liu, Z.Q.; Lin, H.J. Digital economy and green development: Empirical evidence from China's cities. *Front. Environ. Sci.* **2023**, *11*, 1124680. [CrossRef]
17. Luo, S.; Yimamu, N.; Li, Y.; Wu, H.; Irfan, M.; Hao, Y. Digitalization and sustainable development: How could digital economy development improve green innovation in China? *Bus. Strategy Environ.* **2022**. [CrossRef]
18. Guo, F.; Yang, S.; Chai, Z. Does Digital Transformation of Enterprises Improve the Quantity and Quality of Green Technology Innovation? Text Analysis Based on Annual Reports of Chinese Listed Companies. *South China J. Econ.* **2023**, *401*, 146–162.
19. Yang, Y.; Yang, C.; Cai, X. Enterprise Digital Transformation and Green Innovation Capability Development: Analysis Based on Network Effect. *Mod. Financ. Econ.* **2023**, *43*, 3–19.
20. Wang, Z.; Zhu, W.; Han, C. Does Digital Finance affect corporate green technology Innovation —Empirical evidence from listed companies in China. *Forum Sci. Technol. China* **2022**, 52–61.
21. Han, X.; Song, W.; Li, B.; Jiang, Z. Heterogeneous nonlinear regulation effect of digital finance empowerment on green innovation. *China Popul. Resour. Environ.* **2022**, *32*, 65–76.
22. Zhang, M.; Xie, S.; Qiang, H.; Zheng, L. Digital Financial Inclusion and Export of SMEs: Timely Help or Additional Improvement. *J. World Econ.* **2022**, *45*, 30–56.
23. Zhang, X.; Liu, B.; Wang, T.; Li, C. Credit Rent-seeking, Financing Constraint and Corporate Innovation. *Econ. Res. J.* **2017**, *52*, 161–174.
24. Tang, J.; Tang, Q. R&D Investment and Frictions of R&D Resource Acquisition of Enterprise: Based on a Questionnaire Research. *Contemp. Econ. Manag.* **2010**, *32*, 20–27.
25. Nie, X.; Wu, Q. Research on the Driving Effect of Digital Finance on the Technological Innovation of SMEs. *East China Econ. Manag.* **2021**, *35*, 42–53.
26. Berger, A.N.; Udell, G.F. The institutional memory hypothesis and the procyclicality of bank lending behavior. *J. Financ. Intermediation* **2004**, *13*, 458–495. [CrossRef]
27. Qian, X.; Tang, Y.; Fang, S. Does Reform of the Security Interests System Reduce the Cost of Corporate Debt? Evidence from a Natural Experiment in China. *J. Financ. Res.* **2019**, *7*, 115–134.
28. Khandani, A.E.; Kim, A.J.; Lo, A.W. Consumer credit-risk models via machine-learning algorithms. *J. Bank. Financ.* **2010**, *34*, 2767–2787. [CrossRef]
29. Frost, J.; Gambacorta, L.; Huang, Y.; Shin, H.S.; Zbinden, P. BigTech and the changing structure of financial intermediation. *Econ. Policy* **2019**, *34*, 761–799. [CrossRef]

30. Cornee, S. The Relevance of Soft Information for Predicting Small Business Credit Default: Evidence from a Social Bank. *J. Small Bus. Manag.* **2019**, *57*, 699–719. [CrossRef]
31. Li, H.; Wu, F. Bank Institution Size, Loan Technology and Small Business Financing. *Financ. Trade Econ.* **2019**, *40*, 84–101.
32. Kshetri, N. Blockchain's roles in meeting key supply chain management objectives. *Int. J. Inf. Manag.* **2018**, *39*, 80–89. [CrossRef]
33. Jensen, M.C.; Meckling, W.H. Theory of the firm: Managerial behavior, agency costs and ownership structure. *J. Financ. Econ.* **1976**, *3*, 305–360. [CrossRef]
34. Jensen, M.C. Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers. *Am. Econ. Rev.* **1986**, *76*, 323–329.
35. Williamson, O.E. Managerial Discretion and Business Behavior. *Am. Econ. Rev.* **1963**, *53*, 1032–1057.
36. Hicks, J.R. Annual Survey of Economic Theory: The Theory of Monopoly. *Econometrica* **1935**, *3*, 1–20. [CrossRef]
37. O'Connor, M.; Rafferty, M. Corporate Governance and Innovation. *J. Financ. Quant. Anal.* **2012**, *47*, 397–413. [CrossRef]
38. Allen, F. Do Financial Institutions Matter? *J. Financ.* **2001**, *56*, 1165–1175. [CrossRef]
39. Grossman, S.; Hart, O. Corporate Financial Structure and Managerial Incentives. *Econ. Inf. Uncertain.* **1983**, 107–140.
40. Harris, M.; Raviv, A. Capital Structure and the Informational Role of Debt. *J. Financ.* **1990**, *45*, 321–349. [CrossRef]
41. Rowan, N.J.; Murray, N.; Qiao, Y.; O'Neill, E.; Clifford, E.; Barceló, D.; Power, D.M. Digital transformation of peatland eco-innovations ('Paludiculture'): Enabling a paradigm shift towards the real-time sustainable production of 'green-friendly' products and services. *Sci. Total Environ.* **2022**, *838*, 156328. [CrossRef] [PubMed]
42. Berg, T.; Burg, V.; Gombović, A.; Puri, M. On the Rise of FinTechs: Credit Scoring Using Digital Footprints. *Rev. Financ. Stud.* **2020**, *33*, 2845–2897. [CrossRef]
43. Zhang, X.; Wu, Y. Advances in Empirical Asset Pricing Research Based on Web-based Big Data Mining. *Econ. Perspect.* **2018**, 129–140.
44. Brandt, L.; Li, H. Bank discrimination in transition economies: Ideology, information, or incentives? *J. Comp. Econ.* **2003**, *31*, 387–413. [CrossRef]
45. Lv, C.; Shao, C.; Lee, C.-C. Green technology innovation and financial development: Do environmental regulation and innovation output matter? *Energy Econ.* **2021**, *98*, 105237. [CrossRef]
46. Zhang, J.; Li, K.; Zhang, J. How does Bank FinTech Impact Structural Deleveraging of Firms? *J. Financ. Econ.* **2022**, *48*, 64–77.
47. Li, H.; Tang, H.; Zhou, W.; Wan, X. Impact of enterprise digitalization on green innovation performance under the perspective of production and operation. *Front. Public Health* **2022**, *10*, 971971. [CrossRef]
48. 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]
49. Li, X.; Wang, C.; Fang, J. Bank Fintech, commercial credit and Private enterprise export: An empirical analysis based on panel data of prefecture-level cities in China. *Financ. Econ. Res.* **2022**, *37*, 1–18.
50. Song, M.; Zhou, P.; Si, H. Financial Technology and Enterprise Total Factor Productivity—Perspective of "Enabling" and Credit Rationing. *China Ind. Econ.* **2021**, *4*, 138–155.
51. Meng, L.; Huang, B. Shaping the Relationship Between Economic Development and Carbon Dioxide Emissions at the Local Level: Evidence from Spatial Econometric Models. *Environ. Resour. Econ.* **2018**, *71*, 127–156. [CrossRef]
52. Yuan, C.; Xiao, T.; Geng, C.; Sheng, Y. Digital Transformation and Division of Labor between Enterprises: Vertical Specialization or Vertical Integration. *China Ind. Econ.* **2021**, *9*, 137–155.
53. Hu, G.; Wang, J.; Fahad, S.; Li, J. Influencing factors of farmers' land transfer, subjective well-being, and participation in agri-environment schemes in environmentally fragile areas of China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 4448–4461. [CrossRef]
54. Fahad, S.; Bai, D.; Liu, L.; Dagar, V. Comprehending the environmental regulation, biased policies and OFDI reverse technology spillover effects: A contingent and dynamic perspective. Environ. *Sci. Pollut. Res.* **2022**, *29*, 33167–33179. [CrossRef]
55. Fahad, S.; Su, F.; Wei, K. Quantifying households' vulnerability, regional environmental indicators, and climate change mitigation by using a combination of vulnerability frameworks. *Land Degrad. Dev.* **2023**, *34*, 859–872. [CrossRef]

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