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Does digital finance drive the green level of transportation companies? Coordination effects of governmental digital preference

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ABSTRACT

This paper examines the influence of digital finance (DF) on the green level of transportation companies (GLTC, $n = 112$) listed on the Chinese A-share market from 2011 to 2021 through moderation and mediation models. According to the conclusions, first, a significantly positive correlation exists between DF and GLTC. Second, DF indirectly promotes GLTC by enhancing corporate value and alleviating financing constraints. Both enterprise value and financing constraints have a chain mediation effect. Third, the government's digital preference can enhance the role of DF in promoting GLTC and alleviating financing constraints. In addition, governmental digital preference can moderate the impact of financing constraints on GLTC. Fourth, the effect of DF on GLTC exhibits regional, scale, and ownership heterogeneities. Drawing on the conclusions of the empirical analysis, several pertinent recommendations are proposed from micro and macro perspectives.

1. Introduction

Environmental problems have attracted global attention, making exploring a green and sustainable development path inevitable (Cheng and Ge, 2020). Although China's economic development mode has led to substantial economic progress over the past few decades, it has also resulted in severe environmental problems (Guo et al., 2022). To achieve the harmonious coexistence of economic growth and environmental sustainability in the global village, China has exerted efforts in many aspects. Examples are the introduction of environmental protection laws and the commitment to achieve a carbon peak (Shi et al., 2022). The effective governance of pollution sources is fundamental for countries to achieve harmonious coordination between their economy and environment (Zhou et al., 2022). As vital units of energy consumption, enterprises play a crucial role in the emissions of greenhouse gases (GHG) (Zhang and Kong, 2022). Enterprises in the transportation industry are among the primary sources of GHG, and transportation consumes roughly one-third of global energy (Li et al., 2019). For China, carbon emissions from the transportation sector account for nearly 14% of total emissions (Li and Yu, 2019).

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Existing studies generally suggested that increasing the proportion of China's tertiary industry can improve the quality of the environment (Zhuo et al., 2022). However, research on whether the transportation industry—which belongs to the tertiary industry—can benefit from green development lacks sufficient empirical evidence. Because of financial constraints, transportation companies often encounter considerable obstacles in advancing their green transformation and upgrading (Zhang and Graham, 2020). Without adequate financial support, enterprises cannot guarantee green technology research and transition to green production (Yu et al., 2021). Green technology innovation entails long research and development cycles and high risks, thus partially explaining the investment reluctance of traditional finance (Lin and Ma, 2022). In the absence of intervention by financial institutions and the government, enterprises often prioritize production efficiency over environmental protection, and transportation companies are no exception (Wang et al., 2019; Zhao et al., 2021).

To expedite progress towards carbon peaking, in the "Carbon Peaking Action Plan", China has clarified its commitment to implement green and low-carbon plans in the transportation sector. Concurrently, financial institutions are encouraged to offer enduring and consistent financing support for carbon-peaking actions (Zhang et al., 2023). As early as 2015, China implemented a comprehensive green financial policy system to empower green actions through targeted financial support (Lv et al., 2021). In contrast to traditional finance, green finance prioritizes ecological principles. It aims to foster green and low-carbon growth in both the economy and society; this aim is pursued by offering investment and financing support to environmental protection industries, clean energy, and related fields. This support is offered through diverse financial instruments such as green credit, green funds, and green insurance (Liu et al., 2023). Green finance can potentially enhance environmental quality and mitigate environmental risks (Zhang et al., 2021).

Throughout the support from green finance for green and low-carbon development, challenges such as information asymmetry, imperfect risk supervision, and inefficient resource allocation were encountered (Zhang et al., 2021; Lee and Lee, 2022). However, the evolution of digital finance (DF) has emerged as a crucial factor to address these issues within green finance. The core of DF is to utilize emerging information technologies to achieve the digitization, networking, and intelligence of financial services (Razzaq and Yang, 2023). The advantages of DF are reflected in the following aspects: First, DF can use big data and artificial intelligence technologies to comprehensively assess the environmental benefits, social impact, and economic benefits of green projects. Therefore, DF can provide very accurate information for investors while reducing the risks associated with information asymmetry (Wu and Huang, 2022). Second, DF can oversee the progress of green projects by establishing an early risk-warning model, which further aids investors in effectively managing associated risks and enhancing the benefits of green investments (Li et al., 2022b). Third, DF can achieve the automatic matching and flow of funds through technical means such as smart contracts and blockchain. Thus, DF can reduce transaction costs while enhancing the efficiency of fund utilization (Ding et al., 2023).

Within the academic area, scholars have conducted many valuable studies on how DF can contribute to green development. For example, Zhang and Liu (2022) examined DF's influence on Chinese cities' carbon emission efficiency. The findings demonstrate that DF can facilitate capital flow towards low-carbon industries and indirectly enhance carbon emission efficiency by promoting green technology innovation. This conclusion is also supported by Wang and Guo (2022), who identified industrial structure upgrading and economic growth as crucial mediators in the link between DF and carbon reduction. In addition, DF can potentially stimulate local carbon emissions while exerting an inhibitory effect on the carbon emissions of adjacent regions. Furthermore, in their critical study on Chinese cities, Lin and Ma (2022) found that DF can indirectly drive both the quantity and quality of green technology by mitigating constraints related to financing. Zhang et al. (2023) examined the correlation between provincial DF and consumption-based embodied carbon emissions in China. Their conclusions indicated that DF increases the consumption level and capacity of residents. However, this outcome amplifies the level of consumption-based embodied carbon emissions. Additionally, Zhang et al. (2023) suggested that industrial upgrading plays a negative moderating role in this relationship.

The literature above shows that while scholars have already examined the influence of DF on green development, the following research gaps persist: First, scholars have extensively examined the influence of DF on the green economy at the macro level. However, studies rarely explored the potential of DF to foster green development from the enterprise perspective, particularly for enterprises in the transportation industry. Second, while the influence of DF on green innovation has been explored by a few studies (Ding et al., 2023; Li et al., 2022c), the impact mechanism of DF on corporate green levels still requires in-depth examination. Third, as government departments pay increasing attention to digital technology, both financial institutions and enterprises have also started to emphasize the use of digital technology. However, existing research rarely considered the interference of these external factors on enterprises.

The primary purpose of this study is to explore how DF affects the green level of transportation companies (GLTC). Specifically, the following questions are addressed: First, has DF promoted GLTC? Second, what are the potential mechanisms through which DF influences GLTC? Third, does the preference for digital technology by government departments play a moderating role?

To address the aforementioned questions, the following analyses were conducted: First, a double-fixed effect panel regression approach was employed to examine the influence of DF on GLTC. Second, a chain intermediary model was constructed to examine the chain mediation effect of enterprise value and financing constraints in the benchmark path. Third, by utilizing text analysis tools, keywords related to digital technology were extracted from prefecture-level municipal government work reports, and a government digital preference index was developed. Moreover, a moderation model was constructed to inspect the moderating effect of governmental digital preference. Fourth, various heterogeneity analyses were performed, and targeted recommendations were proposed based on the empirical findings.

This study offers several potential contributions. First, it provides a comprehensive analysis concerning the impact of DF on GLTC from a micro-perspective within a specific industry type. Second, this paper identifies the mediating roles of corporate value and financing constraints in the pathway through which DF influences GLTC. This finding enriches the existing literature by elucidating the underlying mechanisms. Third, a review of existing literature shows an absence of empirical cases incorporating government digital preferences within a framework for analyzing the impact of DF on GLTC. Within a governance framework that integrates governmental macro-control and market regulation, the government's digital preference significantly propels the innovative development of DF (Szczygielski et al., 2017). Government preferences play a key role in substantially reducing information acquisition costs associated with corporate digital innovation, thus facilitating the efficient allocation of financial resources, and effectively addressing problems associated with information asymmetry (Feng et al., 2022). Therefore, this paper incorporates government digital preference into the baseline framework and employs a moderated mediation model to reveal a moderating effect of governmental digital preference. The conclusions and research findings that were obtained complement prior studies.

The remainder of this paper is structured as follows: Section 2 provides a theoretical analysis of the potential mechanism. Section 3 describes the model and data used in this study. Section 4 presents the empirical results and corresponding analyses. Finally, Section 5 summarizes the conclusions drawn from this study and provides several targeted recommendations.

2. Theoretical analysis

2.1. Digital finance and green development

DF represents the digitized evolution of traditional finance. DF offers customers inclusive and accurate financial services through advanced information technologies, such as artificial intelligence, big data, cloud computing, and blockchain (Lin and Ma, 2022). Such advanced technologies grant DF additional advantages over traditional finance. For example, DF can enhance financial efficiency, reduce financing costs (Liu et al., 2021), and help prevent resource misallocation (Wang and Guo, 2022). Scholars have conducted extensive research on DF at the macro level, and have led to the consensus that DF can indeed fulfill the requirements of sustainable economic development (Gomber et al., 2018).

However, researchers have rarely examined the impact of DF on green development, particularly from an enterprise perspective. DF may be an essential engine to guide heavily polluting industries towards green investment (Ding et al., 2023). DF can potentially mitigate market information asymmetry while substantially enhancing the efficiency of financial services (Demertzis et al., 2018). Moreover, DF can help to alleviate the risks associated with commitment costs and economies of scale losses enterprises may encounter in their green investments (Paramati et al., 2021). Furthermore, unlike traditional finance, which frequently exhibits credit discrimination towards small and medium-sized enterprises, DF has revolutionized the conventional paradigm of financial systems. It has expanded the scope of financial services and can provide financing services for tail enterprises not covered by traditional finance (Zhao and Yang, 2020). Using cutting-edge technology, DF can efficiently match and oversee green financing projects (Dong et al., 2022). Specifically, DF benefits from a kernel advantage in its ability to comprehensively leverage both internal and external information to establish a transparent information environment. Therefore, DF mitigates the reluctance of the financial industry to invest in corporate green development because of information asymmetry. Additionally, DF can generate enduring drive effects on enterprises' green innovation, thereby aligning with their internal requirement for sustainable development (Li et al., 2022c). Therefore, Hypothesis 1 is proposed as follows.

H1. DF can facilitate GLTC.

2.2. Enterprise value and financing constraints

The rapid advancement of DF has introduced additional avenues for corporate deleveraging. Thus, companies can leverage DF tools to restructure their debt structure and diminish corporate leverage. Increasing the self-investment efficiency and adjusting the debt ratio can improve enterprise value (Ding et al., 2023). Moreover, DF aids in enhancing the internal supervision mechanism of enterprises and fortifying internal governance capabilities, which foster a long-term appreciation of enterprise value (Salerno et al., 2022). Therefore, DF can increase corporate value by optimizing internal corporate governance and addressing inefficient investments (Lee et al., 2023). Once their value is increased, enterprises become highly willing to assume corresponding social responsibilities to fulfill stakeholder demands, thereby augmenting investments into green development to achieve sustainability (Le, 2022).

The primary challenge associated with the green development of enterprises is how the green transformation of production and operation methods can be realized (Lu et al., 2022). Green transformation necessitates substantial financial backing; notably, various aspects, such as green production equipment transformation and innovation in green technologies with prolonged cycles, substantial costs, and inherent risks, often impose financing barriers on enterprises (Yu et al., 2023). Additionally, substantial financing costs lead enterprises to prioritize economic benefits over environmental governance efforts. In particular, the transportation industry is witnessing a rise in the cost of pollution control, which further intensifies the financial strain on enterprises (Raza, 2020). However, DF ensures the efficacy of external financial markets by reducing financing thresholds, easing financing constraints, and lowering financing costs. Consequently, DF promotes both green investment and the development of enterprises (Feng et al., 2022). Moreover, DF facilitates the swift acquisition of various

forms of social capital, thus quickly providing funds for enterprises, enhancing their inclination to invest in environmental protection, and improving the efficiency of capital allocation (Lin and Ma, 2022). Therefore, DF alleviates financing constraints while internally stimulating the green development of enterprises (Li et al., 2022c).

Academic research has extensively examined the influence of financing constraints on corporate value (Jiang et al., 2018; Yao et al., 2021). Scholars widely acknowledged that reducing financing constraints can increase firm value (Zhao and Su, 2022). However, limited explorations within the academic community have focused on whether enterprise value can influence financing constraints. This paper examines this research question. Theoretically, increasing enterprise value implies the accumulation of both tangible and intangible assets by the enterprise. Financial institutions frequently evaluate the company value to ensure they only lend to promising enterprises. Shi et al. (2023) and Poncet et al. (2010) identified varying financing constraints among different types of enterprises in China. According to their findings, small and medium-sized private enterprises encounter substantial financing constraints, while state-owned and foreign-funded enterprises experience minimal constraints.

Therefore, the following three research hypotheses are proposed.

H2. DF can enhance corporate value and indirectly promote GLTC.

H3. DF can alleviate financing constraints and indirectly promote GLTC.

H4. DF can indirectly alleviate financing constraints by enhancing corporate value, thereby promoting GLTC.

2.3. Governmental digital preference

According to stakeholder theory, the stakeholders of an enterprise encompass not only its creditors but also other pressure groups, including government departments, society, and environmentalists. In addition to prioritizing the economic profit of enterprises, these stakeholders emphasize the focus of the enterprise on the well-being and responsibility of various stakeholders (Zhang et al., 2022). Among these stakeholders, the government plays a multi-faceted role. Government departments not only manage and regulate the economy (Graafland and Wells, 2021) but also provide industrial policy guidance, market supervision, infrastructure construction, and welfare security (Wu et al., 2016; Criscuolo et al., 2019; Agarwal et al., 2021; Lv and Qin 2023), thus promoting both economic development and social stability. Taking China as an example, the term "digital economy" was incorporated into the government work report for the first time in 2017 and has been emphasized many times across various documents since then. Currently, Chinese enterprises are accelerating their digital transformation, and various local governments are actively promoting both digital industrialization and industrial digitization (Wang et al., 2023). The value of China's digital economy surged from 27.2 trillion yuan in 2017 to 55 trillion yuan in 2023, securing its position as the world's second-largest digital economy. This magnitude indicates that the rapid development of both the economy and society is closely related to the accurate positioning and forward-looking strategic layout of the government.

The government has progressively recognized the importance of digital technology and increased financial support for digital infrastructure, personnel, and capital investment. This governmental behavior will not only facilitate the development of DF but also drive the digital transformation of enterprises. For instance, Tang et al. (2021) argued that the government's efforts in promoting digital infrastructure have enhanced energy efficiency and intensification; they further argued that it also facilitated the networked, intelligent, intensified, and green development of industries and enterprises. Moreover, under a powerful governmental framework, governmental actions can effectively steer DF to reduce the financing threshold and channel financial capital towards target companies (Feng et al., 2022; Li et al., 2023). As mentioned by Yu et al. (2023), governmental behavior can send a signal to both financial institutions and enterprises, thereby fostering an alignment of the development goals of financial institutions with the desired policy orientation. In turn, this alignment can assist enterprises in mitigating financing constraints. Therefore, the digital preference of the government can be an external moderation mechanism.

In summary, the following three research hypotheses are proposed.

H5. The government's digital preference can regulate DF and promote GLTC.

H6. The government's digital preference can regulate DF to further ease the financing constraints of transportation companies.

H7. The government's digital preference can regulate financing constraints and further promote GLTC.

The theoretical mechanism of the proposed research hypothesis is shown in Fig. 1.

3. Model and indicator

This study employed double-fixed-effects econometric, chained mediation, and moderated mediation models to test the seven research hypotheses proposed in Section 2.

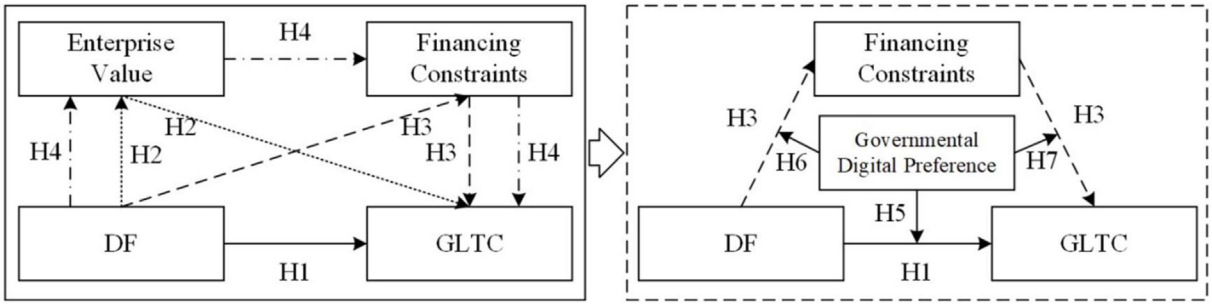

Fig. 1. Impact paths and associated hypotheses.

3.1. Benchmark Model

According to H1, Model 1 is constructed to examine the influence of DF on GLTC:

$$\mathrm{GLTC} = \alpha + \beta \mathrm{DF}_{it} + \gamma_j \mathrm{CONS}_{it,j} + v_i + u_t + \varepsilon_{it} \tag{1}$$

where the dependent variable is denoted as GLTC, DF serves as the main explanatory variable, and CONS_j encompasses a series of control variables. The subscripts i and t indicate firm and time, respectively. α denotes the constant term, β corresponds to the coefficient of DF, and γ_j denotes the coefficient associated with the control variable. Model 1 incorporates individual fixed effects (v_i) and time-fixed effects (u_j) to account for unobservable individual-level and time-related trends, respectively. ε_{it} denotes the error term. H1 can be tested by examining the significance level of the coefficient of DF (β). If β is significant at the 10% level, DF exerts an apparent influence on GLTC.

3.2. Chain mediation model

Unlike the commonly employed multiple mediation model, the chain mediation model considers the influential relationships between mediating variables; this approach both enriches and extends the indirect influence pathway from the explanatory variable to the explained variable. As a result, the chain mediation model, which has been widely used, can unlock rich conclusions. For example, Wang and He (2022) constructed a chain mechanism model to consider the link between two mediating variables (e.g., retailer legitimacy and consumer trust). Chen et al. (2023) developed a chain influence mechanism to examine the influence of a healthy tourism experience on tourists' revisit intention. Using a chain intermediary model, Wu et al. (2023) found that DF can indirectly influence carbon emission efficiency through technological innovation and industrial structure upgrading. To examine H2, H3, and H4, four models were designed to assess the chain mediation effect of enterprise value and financing constraints using stepwise regression analysis. These four models are outlined in the following:

$$\mathrm{TQ} = \alpha + \beta_1 \mathrm{DF}_{it} + \gamma_j \mathrm{CONS}_{it,j} + v_i + u_t + \varepsilon_{it} \tag{2}$$

$$\mathrm{SA} = \alpha + \beta_2 \mathrm{DF}_{it} + \gamma_j \mathrm{CONS}_{it,j} + v_i + u_t + \varepsilon_{it} \tag{3}$$

$$\mathrm{SA} = \alpha + \beta_3 \mathrm{DF}_{it} + \delta_1 \mathrm{TQ}_{it} + \gamma_j \mathrm{CONS}_{it,j} + v_i + u_t + \varepsilon_{it} \tag{4}$$

$$\mathrm{GLTC} = \alpha + \beta_4 \mathrm{DF}_{it} + \delta_2 \mathrm{TQ}_{it} + \phi \mathrm{SA}_{it} + \gamma_j \mathrm{CONS}_{it,j} + v_i + u_t + \varepsilon_{it} \tag{5}$$

where TQ denotes enterprise value, SA represents financing constraints, and both δ and ϕ represent coefficients of their respective variables. Models (1), (2), (3), and (5) can assess the intermediary effect of enterprise value and financing constraints in the influence of DF on GLTC. β_4 quantifies the direct impact of DF on GLTC, $\beta_1\delta_2$ captures the mediating role of enterprise value, and $\beta_2\phi$ signifies the mediating influence of financing constraints. The total effect of DF on GLTC is denoted as β, satisfying the equation $\beta = \beta_4 + \beta_1\delta_2 + \beta_2\phi$. H2 is confirmed when all coefficients β, β_1, β_4, and δ_2 exhibit significance at the 10% level. Similarly, H3 is confirmed, when β, β_2, β_4, and ϕ are all significant at the 10% level.

Models (1), (2), (4), and (5) can be utilized to examine the chain mediation role of enterprise value and financing constraints in the impact of DF on GLTC. $\beta_1\delta_2$ and $\beta_3\phi$ represent the mediation effects of enterprise value and financing constraints, respectively. $\beta_1\delta_1\phi$ represents their chain mediation effect, while $\beta_1\delta_2 + \beta_3\phi + \beta_1\delta_1\phi$ reflects the total indirect effect. β satisfies the equation $\beta = \beta_4 + \beta_1\delta_2 + \beta_3\phi + \beta_1\delta_1\phi$. H4 is proven when the coefficients β, β_1, β_4, δ_1, δ_2, and ϕ are all significant at the 10% level. Given the inconsistencies in regression samples, the condition of "total effect = direct effect + indirect effect"

is subject to bias in this study. As a direct approach, the mediation and chain mediation effects are primarily assessed on the basis of the significance of the correlation coefficient obtained through stepwise regression analysis. This principle is also applied in the moderation model.

3.3. Moderated mediation model

Based on Model (1), the degree of government digital preference (DIG) and the interaction term of DF and DIG are introduced to test H5 as shown in Model (6):

$$GLTC = \alpha + \theta DF_{it} + \varphi DIG_{it} + \rho DF \times DIG_{it} + \gamma_j CONs_{it,j} + v_i + u_t + \varepsilon_{it} \quad (6)$$

Model (6) is employed to examine the potential moderating effect of DIG on the causal effect of DF on GLTC. If ρ is statistically significant, DIG exerts a significant moderating effect. If $\rho > 0$, the positive impact of DF on GLTC is strengthened with increasing DIG (or the negative impact diminishes with increasing DIG). If $\rho < 0$, the positive impact of DF on GLTC is weakened (or the negative impact increases with DIG). The same is true for the explanation of the moderating effect as follows.

Based on Model (3), Model (7) is constructed to test H6:

$$SA = \alpha + \theta DF_{it} + \varphi DIG_{it} + \rho DF \times DIG_{it} + \gamma_j CONs_{it,j} + v_i + u_t + \varepsilon_{it} \quad (7)$$

H7 was tested by the following models:

$$GLTC = \alpha + \theta DF_{it} + \phi SA_{it} + \gamma_j CONs_{it,j} + v_i + u_t + \varepsilon_{it} \quad (8)$$

$$GLTC = \alpha + \theta DF_{it} + \phi SA_{it} + \varphi DIG_{it} + \rho SA \times DIG_{it} + \gamma_j CONs_{it,j} + v_i + u_t + \varepsilon_{it} \quad (9)$$

3.4. Variable selection

3.4.1. Interpreted variable

In this study, the level of GLTC is the dependent variable. Yu and Van Luu (2021) noted that the concept of environmental, social, and governance (ESG) encompasses three dimensions with the same names (i.e., environment, society, and governance). ESG indicators contribute to careful decision-making considerations for investors and help to prevent investment losses resulting from inadequate attention to social and environmental responsibilities. Within Bloomberg's disclosed ESG performance scores for listed companies, sub-indicator E assesses an enterprise's environmental performance and reflects its green level. Bloomberg utilizes nine dimensions: air quality, climate exposure, ecological impact, energy management, environmental supply chain management, GHG emissions management, sustainable production, waste management, and water management. These nine dimensions were evaluated using 21 indicators to assess the corporate environmental performance score (Schiehll and Kolahgar, 2021). A high score in this sub-indicator indicates that the focal enterprise has an excellent green level. Hence, this study employs the environmental sub-indicators within Bloomberg's ESG score to assess GLTC.

3.4.2. Core explanatory variable

DF is a crucial explanatory variable. In this paper, the digital financial inclusion index—established by the Digital Finance Research Center of Peking University—is adopted as a proxy variable to represent DF. This index is used to assess the level of digital financial development in Chinese cities across three dimensions: the breadth of digital financial coverage (DFbr), the depth of digital financial use (DFde), and the degree of digital financial digitization (DFdi) (Lin and Ma, 2022). For a comprehensive summary of the construction and introduction of this index, readers can refer to Guo et al. (2020).

3.4.3. Mediator variables

This study incorporates two intermediary variables, namely, firm value (TQ) and financing constraints (SA). Daines (2001) identified Tobin's Q value as an essential indicator to measure enterprise value, which has been extensively used in related research. Tobin's Q represents the ratio of the capital market value of a physical asset to the replacement cost of this asset. Additionally, the present paper employs the SA index proposed by Hadlock and Pierce (2010) to gauge financing constraints. The SA index typically carries a negative value, where small values correspond to strong financing constraints. Following the approach of Li et al. (2022c), this paper considers the absolute value of SA. Consequently, high values of SA indicate strong financing constraints.

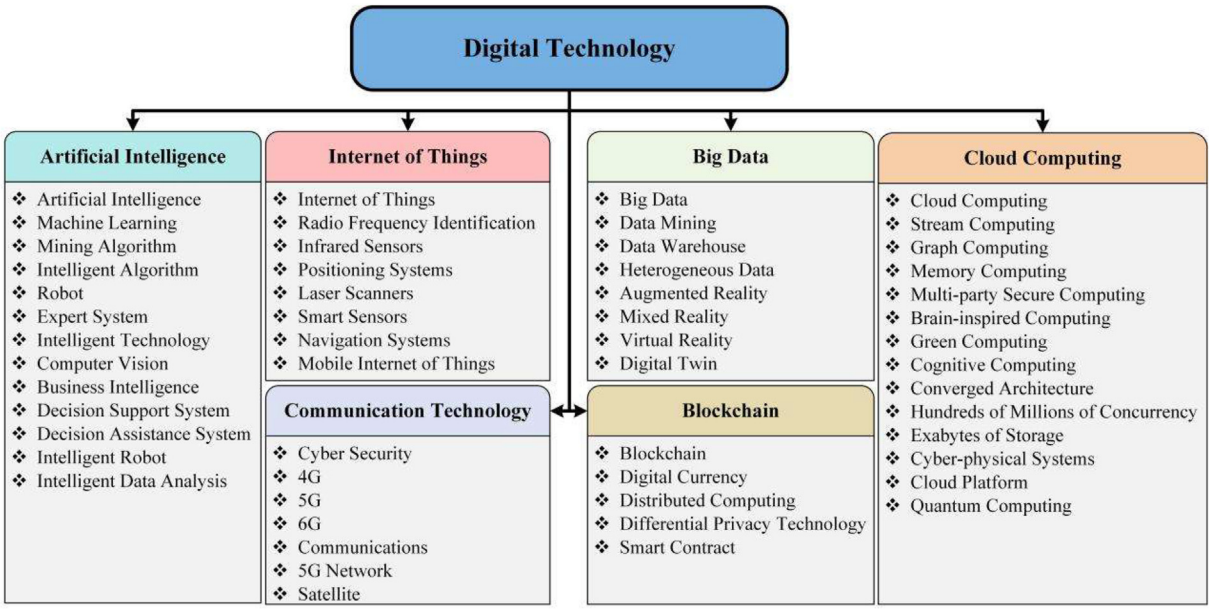

Fig. 2. Keywords related to digital technology.

3.4.4. Moderator variable

DIG is the moderator variable in this study. The government work report represents a comprehensive compilation of key activities undertaken by prefecture-level cities throughout the year, which is used to guide future work activities. Consequently, quantifying the extent of the government's digital preference within the work reports of each city is deemed scientific and reasonable. This quantification can be achieved by evaluating the proportion of word frequencies related to digital technology against the total word frequency. Digital technology keywords extracted by Wu et al. (2021) and in reference to the "China Digital Economy Development Report (2022)" and "Statistical Classification of Digital Economy and Its Core Industries (2021)" were incorporated for additional guidance. Fig. 2 presents the keywords associated with digital technology in the current study.

3.4.5. Control variables

Numerous other factors can influence the GLTC level. To mitigate the influence of significant factors, control variables were incorporated based on the research conducted by Li et al. (2022c) and Du et al. (2023). The following nine indicators were introduced into the model as control variables: (1) the age of the enterprise (AGE); (2) the shareholding ratio of the largest shareholder (TOP1); (3) the proportion of independent directors (IDP); (4) duality (DUA); (5) return on capital (ROA); (6) asset–liability ratio (ALR); (7) fixed assets ratio (FAR); (8) management costs (lnAC); and (9) regional economic level, which is measured by GDP per capita (lnPGDP). ln* means that the logarithm of the index is taken. Relevant data of the above-

Table 1
Descriptive statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max	VIF value
GLTC	571	0.10	0.13	0.00	0.51	–
DF	1177	218.41	76.68	59.70	351.53	2.33
SA	1174	3.72	0.32	2.89	4.48	8.19
TQ	946	1.42	0.73	0.75	5.77	1.15
DIG	1152	0.29	0.16	0	0.81	1.64
AGE	1232	16.73	6.95	1.00	34.00	7.55
TOP1	1084	44.92	17.26	13.89	100.00	1.39
IDP	1077	35.46	7.81	0.00	57.14	1.23
DUA	1232	0.13	0.33	0.00	1.00	1.16
ROA	1174	5.77	6.49	−26.66	24.38	1.65
ALR	1160	45.47	18.57	7.41	91.59	1.98
FAR	1174	37.35	22.78	0.00	86.60	1.22
lnAC	1160	18.98	1.34	16.04	22.37	2.66
lnPGDP	1232	11.48	0.44	10.18	12.22	1.75

mentioned listed companies were obtained from the WIND database, and the PGDP was obtained from the statistical yearbooks of each city.

This study utilizes data on 112 A-share listed transportation companies from 2011–2021. All variables are winsorized at the 1% level to mitigate the influence of outliers. Descriptive statistics of variables are provided in Table 1. Furthermore, preliminary correlation tests were conducted among all variables. The correlation coefficients between variables are all below 0.8, indicating the absence of multicollinearity. Moreover, the variance inflation factor (VIF) values of each variable are assessed. All these values are below 10, with a mean VIF of 2.61, indicating the absence of multicollinearity (García et al., 2020).

4. Empirical analysis

4.1. Benchmark regression analysis

Benchmark Model (1) validates the direct impact of DF on GLTC. Table 2 presents the regression results. M1–M4 represent the results without including control variables, while M5–M8 incorporate control variables. The results of M1 and M5 indicate a significant positive impact of DF on GLTC at a significance level of 1%, thus providing support for H1. This conclusion can be attributed to the ability of DF to mitigate resource misallocation, waste, and constraints, thereby enhancing the production efficiency of enterprises. Moreover, DF facilitates enterprise transformation and upgrading, both of which foster high-quality and sustainable development (Lee et al., 2023). As highlighted by Zhou et al. (2022), the integration of finance and digital technology has amplified the volatility of green growth. DF contributes to the enhancement of green investment by improving green credit capabilities. Consequently, DF plays a key and direct role in promoting GLTC.

Among the numerous selected control variables in this study, AGE, IDP, ROA, and ALR exhibit a significant positive correlation with GLTC. First, older enterprises have a greater inclination to pursue green development aligned with policy guidance, thus ensuring their sustainable development (Yasir et al., 2020). Therefore, firm age positively contributes to the promotion of GLTC. Second, a higher IDP implies a decision-making level with comprehensive opinions during the corporate governance process, which facilitates effective guidance for the transformation and development of enterprises. As shown by Qiu and Yu (2023), an independent director network can foster corporate green innovation. Therefore, increasing IDP can also

Table 2
Benchmark regression results.

Variables	M1	M2	M3	M4	M5
	GLTC	GLTC	GLTC	GLTC	GLTC
DF	0.0014**				0.0020***
	(0.0006)				(0.0007)
DFbr		−0.0004			
		(0.0007)			
DFde			0.0012***		
			(0.0004)		
DFdi				0.0006**	
				(0.0003)	
AGE					0.0274**
					(0.0137)
TOP1					0.0002
					(0.0009)
IDP					0.0022**
					(0.0009)
DUA					−0.0050
					(0.0183)
ROA					0.0035***
					(0.0010)
ALR					0.0017***
					(0.0005)
FAR					0.0002
					(0.0004)
lnAC					0.0061
					(0.0096)
lnPGDP					−0.1062***
					(0.0401)
Constant	−0.0660	0.0761	−0.0486	0.0172	0.4142
	(0.0497)	(0.0588)	(0.0329)	(0.0162)	(0.4891)
Firm	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	557	557	557	557	552
Within *R*-sq	0.3317	0.3254	0.3367	0.3322	0.3810

Note: Standard errors are shown in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Same as below.

increase GLTC. Third, with increasing ROA, the company possesses additional capital that can be invested into green governance. Consequently, ROA significantly and positively impacts GLTC. Fourth, the higher ALR, the more urgently the company needs to transform and develop to find new ways to revitalize the capital chain (Li et al., 2022b). Therefore, the higher ALR, the more enterprises need to pursue green and sustainable development. Conversely, the regional economic level demonstrates a significant negative correlation with GLTC. This observation can be attributed to the increased frequency of economic activities, which leads to a sustained growth in transportation volume. However, China's transportation industry predominantly relies on petroleum energy, which produces substantial GHG emissions (Yin et al., 2015). Therefore, economic improvement adversely affects the green development of the transportation industry.

4.2. Robustness test

The robustness of the results regarding the significant positive impact of DF on GLTC, as observed under M1 and M5, is further confirmed following the gradual addition of control variables. Further, various methods were employed to assess the reliability of the results. Table 3 details the outcomes.

First, considering that the implementation of the low-carbon city pilot policy will affect GLTC, this study introduces a constructed low-carbon city dummy variable into the model as a control variable. This dummy variable comprises the product of the city dummy variable and the time dummy variable. If the city is low-carbon, the city dummy variable value is 1; otherwise, it is 0. The time dummy variable before the policy pilot is 0; otherwise, it is 1. The regression results are shown in M6. Second, this study considers that the stricter the environmental policy, the higher the tendency of enterprises to engage in green development. Therefore, based on M6, this study introduces the intensity of environmental regulation. This indicator reflects the proportion of words related to environmental protection in the total number of words in the work reports of each municipal government. The result is shown in M7. Third, this study uses Bloomberg's ESG composite index and the environmental dimension score of the ESG index published by the WIND database to replace explained variables. The results are shown in M8 and M9. Fourth, following the approach employed by Zhou et al. (2022), in this study, DFbr, DFde, and DFdi are individually substituted as explanatory variables. The results of M10–M12 indicate that DFde and DFdi both significantly and positively affect GLTC. The findings presented in Table 3 align with baseline regression results, further confirming the robustness of the conclusion.

To address potential endogeneity issues arising from omitted variables and interactions between explained and explanatory variables, instrumental variables (IVs) are employed, and two-stage least squares analyses are conducted for further examination. This approach allows to mitigate endogeneity concerns and strengthens the validity of the findings. In reference to the idea of Chong et al. (2013), this study uses the average level of FinTech in neighboring cities (IV1) as one of the IVs. FinTech is generated by the Baidu News Advanced Search Index (Li et al., 2020), and a high FinTech level implies a solid foundation for the development of DF. The selection of this IV1 complies with correlation and exogeneity constraints. First, the economic modes and development levels of neighboring cities are similar; therefore, the development of FinTech is also similar. Second, because of the geographical fragmentation of credit financing, it is difficult for FinTech and DF in neighboring cities to influence local GLTC through financing channels. In addition, the one-lagged DF index (IV2) was also chosen as an IV to address potential endogeneity problems. Table 4 presents the results estimated from this adjustment. The results indicate that even after addressing endogeneity, the hypothesis regarding DF's significant promotion of GLTC remains valid, and all results are significant at the 5% level. The under-identification test for IV is significant at the 1% level. The F statistic for the weak identification test for IV exceeds 19.93 (corresponding to a 10% maximum IV size). These test outcomes affirm the appropriateness of the selection of IVs.

Table 3
Robustness test results.

Variables	M6	M7	M8	M9	M10	M11	M12
	GLTC	GLTC	GLTC	GLTC	GLTC	GLTC	GLTC
DF	0.0017**	0.0015**	0.0634*	0.0633***			
	(0.0007)	(0.0007)	(0.0363)	(0.0231)			
DFbr					−0.0002		
					(0.0007)		
DFde						0.0014***	
						(0.0004)	
DFdi							0.0007**
							(0.0003)
Constant	0.7229	0.6661	73.0607***	−4.3158	−0.1050	0.268	0.3159
	(0.4922)	(0.4902)	(24.7353)	(11.5325)	(0.4691)	(0.4679)	(0.4857)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	552	522	554	373	552	552	552
Within *R*-sq	0.3958	0.4033	0.7082	0.1174	0.3711	0.3837	0.3784

Table 4
Endogeneity test results.

Variables	2SLS first stage	2SLS second stage
	DF	GLTC
DF		0.0026**
		(0.0013)
IV1	0.0078***	
	(0.0021)	
IV2	0.5378***	
	(0.0304)	
Control variables	Yes	Yes
Firm	Yes	Yes
Year	Yes	Yes
N	509	509
Centered *R*-squared		0.3714
Under identification test		209.627***
Weak identification test		187.500[19.93]

4.3. Chain mediation analysis

In this section, stepwise regression analysis is employed to examine the mediation effect of firm value and financing constraints as well as their chain mediation effect. According to the regression results presented in Table 5, the following findings can be summarized: First, models M15 and M16 show that DF has a significant positive impact on enterprise value, at a significance level of 1%. Additionally, DF exhibits a negative effect on financing constraints. This finding aligns with the conclusions drawn by Wu and Huang (2022) and Lin and Ma (2022). DF can reduce corporate leverage, improve the efficiency of external financial markets, and reduce financing barriers. Consequently, DF promotes corporate value while alleviating financing constraints.

Second, the regression results of M18 indicate that financing constraints significantly hinder GLTC, whereas an enhancement in corporate value significantly promotes GLTC. The combined results of M15, M16, and M18 provide evidence of the mediating roles of both firm value and financing constraints in the pathway of the influence of DF on GLTC. These findings support both H2 and H3, and align with the findings of Le (2022) and Li et al. (2022b). DF continues to increase corporate value, thus prompting companies to embrace increased responsibility towards achieving green and sustainable development. Furthermore, by alleviating financing constraints, DF intrinsically encourages enterprises to prioritize green project investment and green project development.

Third, M15, M17, and M18 results demonstrate that DF can alleviate financing constraints by enhancing enterprise value, thereby indirectly promoting GLTC. This finding provides support for H4, indicating the presence of a chain mediation effect of firm value and financing constraints in the pathway through which DF influences GLTC.

4.4. Moderated mediation analysis

Table 6 summarizes the relevant moderation model regression results, reflecting the following findings: First, the results obtained from M19 demonstrate that DF significantly promotes GLTC. The coefficient is significantly positive when introducing the cross product of DF and governmental digital preference, as indicated in M20. This result indicates that the positive impact of DF on GLTC increases with increasing levels of governmental digital preference. Second, the results of M21 and M22

Table 5
Results of chain mediation regression.

Variables	M15	M16	M17	M18
	TQ	SA	SA	GLTC
DF	0.0102***	−0.0016***	−0.0010***	0.0015**
	(0.0029)	(0.0004)	(0.0003)	(0.0007)
SA				−0.4836***
				(0.0926)
TQ			−0.0209***	0.0190*
			(0.0036)	(0.0111)
Constant	4.1952**	2.9517***	3.3087***	2.0102***
	(2.0172)	(0.2447)	(0.2045)	(0.5838)
Control variables	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	896	991	896	541
Within *R*-sq	0.2490	0.8126	0.8723	0.4312

Table 6
Regression results of the moderated analysis.

Variables	M19	M20	M21	M22	M23	M24
	GLTC	GLTC	SA	SA	GLTC	GLTC
DF	0.0020***	0.0006	−0.0016***	−0.0011***	0.0018***	0.0021***
	(0.0007)	(0.0008)	(0.0004)	(0.0004)	(0.0007)	(0.0007)
SA					−0.5482***	−0.4269***
					(0.0792)	(0.0946)
DIG		−0.3460***		0.1021*		0.6635**
		(0.1157)		(0.0604)		(0.3018)
DF × DIG		0.0014***		−0.0005**		
		(0.0005)		(0.0002)		
SA × DIG						−0.1794**
						(0.0803)
Constant	0.4142	0.3329	2.9517***	3.0038***	2.4418***	2.1383***
	(0.4891)	(0.5012)	(0.2447)	(0.2551)	(0.5508)	(0.5783)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	552	546	991	969	552	546
Within *R*-sq	0.3810	0.3971	0.8126	0.8069	0.4381	0.4449

show that DF can alleviate financing constraints for enterprises. This mitigating effect is further amplified with increasing governmental digital preference. Third, the results of M23 and M24 imply that the adverse effect of financing constraints on GLTC intensifies with increasing governmental digital preference. This finding suggests that when DF further alleviates financing constraints, the GLTC level increases even further because the government places additional emphasis on digital topics. Overall, the findings support the effectiveness of the government's external behavioral factors as moderating variables. Therefore, H5, H6, and H7 are corroborated.

4.5. Heterogeneity analysis

This section presents the heterogeneity analysis, which is presented in Table 7. This analysis distinguishes heterogeneities among transportation companies in the eastern and central regions, large and medium-sized companies, and state- and non-state-owned companies. The following findings are obtained:

First, DF significantly promotes GLTC in the eastern region, where financing constraints negatively affect GLTC. However, the central region has no substantial relationship with DF, financing constraints, and GLTC. Given that DF originated in the eastern region of China, its impact on transportation enterprises is stronger and more direct (Li et al., 2022a). In addition, the transportation industry exhibits higher development levels in the eastern region than in the central region. According to life cycle theory, enterprises prioritize sustainable development as they mature. Therefore, transportation companies in the eastern region of China tend to support green development through financing, and the impact of financing constraints on their green level may be substantial.

Second, DF substantially promotes large-scale GLTC, whereas financing constraints significantly impede the progress of GLTC across different GLTC extents. However, DF does not exert a notable influence on medium-sized GLTC. This can be

Table 7
Results of heterogeneity analysis.

Variables	Regional heterogeneity		Scale heterogeneity		Ownership heterogeneity	
	Eastern	Central	Large	Middle	State-owned	Non-state-owned
	GLTC	GLTC	GLTC	GLTC	GLTC	GLTC
DF	0.0020***	0.0003	0.0018**	0.0005	0.0007	0.0033*
	(0.0008)	(0.0017)	(0.0007)	(0.0009)	(0.0008)	(0.0018)
SA	−0.4340***	−0.1344	−0.4299***	−2.5242***	−0.3900***	−0.3406
	(0.1011)	(0.2266)	(0.1027)	(0.6970)	(0.1052)	(0.2594)
TQ	0.0210	−0.0104	0.0186	0.0091	0.0165	0.0381
	(0.0131)	(0.0149)	(0.0123)	(0.0113)	(0.0133)	(0.0275)
Constant	2.2511***	−3.1592**	1.8651***	8.0642***	1.5526**	4.0762**
	(0.6366)	(1.4480)	(0.6385)	(2.4249)	(0.6467)	(1.9180)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	438	92	495	44	480	61
Within *R*-sq	0.4744	0.4506	0.4471	0.7375	0.4440	0.7094

attributed to these companies' current lack of emphasis on green development, as they primarily focus on corporate profitability and scale expansion (Li et al., 2021).

Third, DF is significantly positively correlated with non-state-owned GLTC. This outcome can be attributed to the closer political ties and better financial support state-owned transportation companies receive (Liu et al., 2022); consequently, DF support does not significantly impact state-owned GLTC. Nevertheless, non-state-owned transportation companies require substantial external financial support to invest in green development projects and technology development to fulfill their environmental responsibilities. Therefore, DF exerts a significant promotional effect on non-state-owned GLTC.

5. Conclusions and recommendations

This paper utilizes a sample of A-share listed transportation companies from 2011 to 2021. The double fixed effect panel model, the chain mediation model, and the moderated mediation model are employed to explore the impact mechanism of DF on GLTC from a micro perspective. The following research findings have been obtained: First, DF significantly promotes GLTC. Among the dimensions of GLTC, DFde and DFdi display significant positive effects. Second, in the indirect path through which DF influences GLTC, both enterprise value and financing constraints play multiple intermediary and chain intermediary roles. Third, the digital preference of the government exerts a significant moderating effect. Specifically, it amplifies DF's positive impact on GLTC and strengthens DF's ability to alleviate financing constraints. In addition, the government's digital preference can moderate the impact of financing constraints on GLTC. Fourth, DF affects GLTC and shows regional, scale, and ownership heterogeneity. Building upon the conclusions above, several policy recommendations are presented in the following:

First, DF offers direct green benefits for transportation companies while indirectly fostering their green development by alleviating financing constraints and enhancing corporate value. Thus, enterprises should be encouraged to diversify their financing channels and leverage DF to overcome limitations associated with traditional finance. By utilizing digital financial services, transportation companies can stimulate green innovation, bolster investment in and construction of eco-friendly projects, and propel their sustainable development.

Second, financial institutions can significantly enhance their DF service capabilities by seamlessly integrating digital technology and financial services. To achieve such a seamless integration, financial institutions must expedite their digital transformation efforts and harness cutting-edge technologies (such as artificial intelligence, blockchain, and big data) to deliver outstanding financial services. Furthermore, financial institutions should prioritize maximizing the depth of utilization and digitization of DF while fully capitalizing on its inherent green attributes.

Third, the government exercises an important role in guiding the development of financial institutions and enterprises. The digital preference of the government assumes a crucial moderating role in both the direct and indirect paths of the impact of DF on GLTC. Therefore, local governments should not only emphasize digital development but also promote the development and construction of local digital infrastructure and digital platforms. Governments should establish incentives and reward mechanisms to encourage financial institutions and enterprises to invest and innovate in green transportation. In addition, governments need to strengthen regulation and guidance in DF and green transportation to ensure the safety and sustainability of provided investment and financing.

Fourth, DF exhibits substantial heterogeneity in its impact on GLTC. In terms of regional considerations, the central and western regions of China must persistently foster the advancement of DF to enhance its capacity, bolster the economy, and support resident enterprises. Regarding enterprise scale, the scope of DF services must be expanded to broaden their reach and depth. Regarding ownership types, non-state-owned enterprises can harness DF to infuse long-term and sustainable momentum.

This study has the following shortcomings. First, future research could analyze the role environmental policies play in DF's impact on enterprises' green development. Second, this study examined the impact of DF on the green development of A-share listed transportation companies. However, the green development of unlisted enterprises is also of profound importance in achieving dual carbon goals. Therefore, DF's impact mechanism on unlisted enterprises' green development can be further explored in the future.

Ethics statement

Not applicable because this work does not involve the use of animal or human subjects.

CRediT authorship contribution statement

Ruizeng Zhao: Writing – original draft, Formal analysis, Data curation. **Jie Wu:** Writing – review & editing, Formal analysis, Conceptualization. **Jiasen Sun:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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