

Original Article



The Interaction of Digital Knowledge Stock, Financing Constraints, and ESG Performance: A PVAR Analysis of Panel Data from China's A-Share Listed Companies

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Abstract:

This study empirically examines the dynamic interactions among digital knowledge stock, financing constraints, and corporate ESG performance using panel vector autoregressive models based on data from China's A-share listed companies during 2014-2023. The findings reveal that all three variables exhibit self-reinforcing characteristics. Specifically, digital knowledge stock demonstrates an initial inhibitory effect followed by subsequent promotional influence on ESG performance, while ESG performance shows short-term resource crowding effects. Regarding financing constraints, digital knowledge stock manifests a dual impact of initial aggravation followed by eventual alleviation. Although financing constraints can temporarily stimulate digital knowledge accumulation, they simultaneously hinder ESG performance. Conversely, enhanced ESG performance consistently mitigates financing pressures. These findings provide valuable insights for enterprises worldwide in balancing digital transformation with ESG investments while alleviating financing constraints.

Keywords: Digital knowledge stock, Financing constraints, ESG performance, Panel vector autoregressions

1. Introduction

In the era of digital economy, Digital knowledge stock (Digistock) have become an important part of the core competitiveness of enterprises (Huang & Gao, 2025). The rapid development and wide application of digital technologies have not only promoted the innovation of enterprise productivity and business models but also provided a new impetus for the sustainable development of enterprises (Luo & Liu, 2024). However, enterprises generally face financing constraints (FC) in the process of digital transformation, especially in the construction of digital infrastructure and investment in R&D, which require a large amount of financial support (Wei & Li, 2024). At the same time, with the global focus on ESG performance (EPF) of firms has also become a focus of investors and policy makers (Arı & Sarioğlu, 2025). What is the dynamic relationship between Digistock, FC and

corporate EPF? How does this relationship evolve across regions and development conditions? How can the dynamic equilibrium of the three be achieved for long-term corporate development? These questions need to be explored in depth.

Existing studies have mostly focused on the unidirectional impact mechanisms of Digistock, FC, or corporate EPF performance, and have lacked systematic analysis of the complex interactions among the three (Xu & Yin, 2025). Especially in the context of regional heterogeneity, the variability of this dynamic relationship has not been fully revealed. In addition, the possible inhibitory effect of Digistock and EPF performance, the double-edged sword effect of FC, and the moderating effect of different regional policy environments are all important issues worthy of in-depth research. This paper aims to fill this research gap, reveal the

dynamic interaction mechanism between the three through empirical analysis, and provide theoretical basis for enterprises to optimize resource allocation and policy formulation.

Based on this, this paper selects the data of China's A-share listed companies from 2014-2023, and adopts the panel vector autoregressive model (PVAR), combining GMM estimation, impulse response analysis and variance decomposition to explore the following questions from the perspective of the whole country, as well as the eastern, middle and western regions: (1) What is the dynamic relationship between Digistock, FC and corporate EPF? (2) Is there regional heterogeneity in the dynamic relationship among the three? (3) How to realize the synergistic development of the three through

policy intervention? The marginal contributions of this paper are: first, it reveals the dynamic relationship among Digistock, FC, and EPF in the short and long term; second, it explores the sources of changes in Digistock, FC and EPF; and third, it puts forward differentiated policy recommendations by stage and region, which provide practical guidance for governments and firms.

The structure of the remaining paper is arranged as follows: the second part is the literature review and theoretical analysis; the third part introduces the research methodology and data sources; the fourth part is the empirical analysis; and the fifth part summarizes the research conclusions and puts forward the policy insights. Figure 1 is the research conceptualization of this paper.

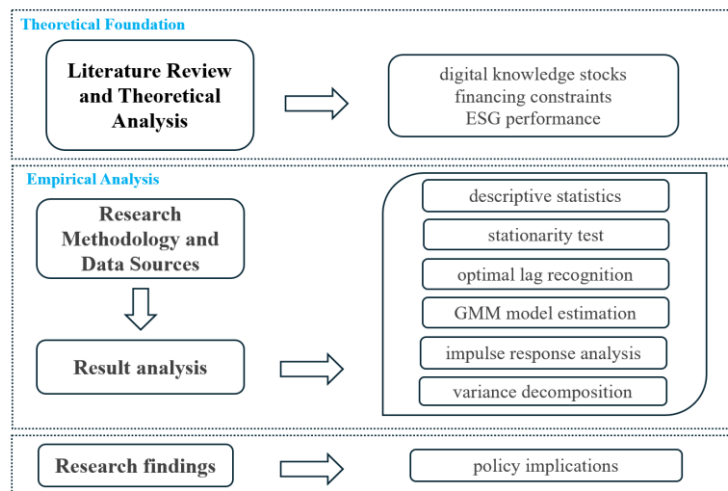


Figure 1 Research Framework Diagram

2. Literature Review and Theoretical Analysis

2.1 Literature Review

A relatively rich theoretical discussion on the definitions of corporate Digistock, FC and EPF performance has been developed in academia. In terms of defining Digistock, existing studies generally emphasize its attribute as a strategic resource formed in the process of enterprise digital transformation, with Brynjolfsson and McElheran (2016) taking the lead in systematically defining it as an aggregate of structured data, tacit knowledge, and intelligent analytical capabilities that an organization integrates through digital technologies, and subsequent scholars further differentiate between infrastructure-based different dimensions of

digital knowledge and application-based digital knowledge (Nambisan et al., 2019). The conceptual evolution of FC, on the other hand, has undergone a theoretical expansion from the measurement of financial indicators to the consideration of the institutional environment, which was pioneered by Kaplan and Zingales (1997) to be defined as “the gap between a firm's desired level of investment and its actual ability to raise capital”, and subsequent studies have supplemented with the theoretical perspective of information asymmetry to emphasize that its essence is the distortion of resource allocation due to the imperfections in the capital market (Hadlock and Pierce, 2010). The definitional development of EPF presents a paradigm shift from single responsibility to integrated value

creation, with early studies focusing on independent measures of environmental performance (Clarkson et al., 2008), and in recent years scholars have preferred to adopt an integrative framework, such as the three-dimensional interaction model proposed by Friede et al. (2015), which emphasizes that that environmental, social, and governance elements together constitute corporate sustainable value through synergistic effects. Environmental, Social, and Governance standards have now become a key tool for measuring a company's long-term value, risk management capabilities, and level of sustainable development (Wang et al., 2025). The evolution of the definition of these three core concepts reflects the paradigm shift of enterprise research from a static capability view to a dynamic system view in the digital economy era.

Existing studies have mainly explored the relationship between Digistock, FC and corporate EPF in terms of unidirectional impact mechanisms. In terms of Digistock and EPF, Li et al. (2024) find that digital transformation improves EPF by enhancing risk-taking capacity and optimizing governance structure, while Deng et al. (2025) point out that digitization has a U-shaped relationship with ESG, with the initial stage enhancing transparency but excessive digitization exacerbating FC. Regarding FC and EPF, Dyck et al. (2019) and El Ghouli et al. (2011) confirm that high ESG-rated firms are more likely to obtain low-cost financing, whereas Du et al. (2025) find that FC may push firms into adopting strategic ESG behaviors. In terms of Digistock and FC, studies have shown that digital transformation can alleviate financing pressures (Huang, 2023). Hu et al. (2025) find that digital inclusive finance significantly reduces corporate FC. Wang et al. (2025) explore the regulatory role of digitization of carbon assets. Du and Zhang (2025) point out that digital asset allocation reduces firms' cost stickiness. However, existing studies still lack systematic analysis on the dynamic path, nonlinear threshold and policy synergy effect of the synergistic evolution of the three, which will become an important research direction in the future.

2.2 Theoretical Analysis

2.2.1 Digital Knowledge Stock and Financing Constraints

The relationship between Digistock and FC of enterprises presents a dynamic non-linear relationship, and the mechanism of its action varies with the stage of development of enterprises. In the early stage of digital transformation, enterprises need to invest massively in digital infrastructure construction and other high-cost dedicated investments. These will significantly increase the enterprise's capital demand, while the uncertainty of digital technology makes it difficult for financial institutions to accurately assess the project risk, thus exacerbating the degree of the enterprise's FC in the short term. With the continuous accumulation of Digistock, enterprises gradually realize intelligent production processes, data-based management decisions, and business model innovation, and this transformational effect alleviates FC through two channels (Gao et al., 2024): first, the application of digital technology enhances the transparency and credibility of enterprises' financial information, and reduces information asymmetry (Zhang et al., 2024); Secondly, the construction of digital platform expands the financing channels of enterprises, enabling them to obtain more diversified sources of funds (Lu et al., 2024).

The impact of FC on Digistock presents a "double-edged sword" effect: on the one hand, the lack of funds will directly limit the investment of enterprises in the R&D and application of digital technology (Tiganasu & Lupu, 2023); on the other hand, under the pressure of competition in the market, FC may force enterprises to break the bottleneck of resources through the innovation of digital technology. This complex interaction is also regulated by multiple factors such as enterprise scale, industry characteristics and external policy environment. Therefore, an in-depth understanding of the mechanism of the interaction between Digistock and FC requires the examination of its short-term and long-term effects, direct and indirect paths, and the influence of various boundary conditions in the context of specific situations.

2.2.2 Digital Knowledge Stock and ESG Performance

There exists a complex dynamic interactive relationship between Digistock and corporate EPF, presenting significant time-varying characteristics. In the short term, the accumulation

of Digistock may have a dampening effect on corporate EPF, mainly because enterprises need to invest a large amount of resources in technology R&D, equipment upgrading and other digital construction at the initial stage of digital transformation, and this resource crowding-out effect temporarily weakens the ability of enterprises to invest in environmental governance. However, in the long run, corporations will enhance operational efficiency, optimize management processes through digital means, which will lay a solid foundation for the improvement of corporate EPF (Wu et al., 2025). The enabling effect of digital technology is mainly reflected in intelligent production to reduce energy consumption and emissions, big data analysis to optimize ESG decision-making, and blockchain technology to enhance the transparency of information disclosure (Jing et al., 2025).

On the contrary, the impact of EPF on Digistock is twofold: on the one hand, ESG inputs may crowd out the capital and human resources needed for digitalization; on the other hand, good EPF can enhance corporate reputation and reduce financing costs, thus providing more adequate resources for digital transformation, while ESG requirements may also push corporations to develop more sustainable digital technologies (Qi et al., 2024). The net effect of this two-way interaction depends on a variety of factors such as firms' resource endowment, strategic focus, and external institutional environment, which makes the interaction between the two non-linear.

2.2.3 Financing Constraints and ESG Performance

There is a two-way interaction mechanism between FC and corporate EPF. The improvement of corporate EPF can alleviate FC through multiple channels: on the one hand, good environmental performance and social responsibility fulfillment can help establish a green image of the enterprise, enhance the trust of stakeholders, and thus reduce the cost of financing (Li et al., 2024); on the other hand, a perfect corporate governance structure can improve the transparency of information, reduce the agency cost, and enhance the confidence of investors, thus widening the financing channels. Especially with the development of green finance, corporate EPF are more likely to obtain special financing

support such as green credit and green bonds.

Conversely, FC can have a dampening effect on corporate EPF (Wei & Xu, 2025): when a company faces a severe shortage of funds, management will often prioritize the protection of core businesses such as production and operation and cut back on investment in environmental protection, social responsibility and other EPF areas, and this short-term behavior of "survival" will lead to a decline in EPF. Therefore, a dynamic feedback system is formed between FC and EPF, which provides a new theoretical perspective to understand the relationship between corporate sustainable development and financing ability.

3. Research Design

3.1 Model Construction

To reflect the interaction between variables more comprehensively, scholars usually adopt panel vector autoregression model, which is a kind of multivariate system equation and has become more mature after continuous development and improvement since it was put forward by Holtz-Eakin et al. The PVAR model combines the characteristics of the traditional vector autoregression model and panel data. advantages include: the ability to incorporate all variables into the endogenous system and reflect the dynamic influence relationship among multiple variables; the introduction of variable lag terms in the model, which in turn effectively solves the endogeneity problem; and the reduction of the requirement for the data time span compared with the traditional VAR model (Zhang & Yan, 2020; Liu et al., 2022). Therefore, this paper constructs a PVAR model to truly reflect the dynamic impact relationship between corporate Digistock, FC and EPF, and the model is set as follows:

$$Y_{it} = a_0 + \sum_{j=1}^p a_j Y_{i,t-j} + \mu_i + v_t + \varepsilon_{it} \quad (1)$$

In equation (1), i is an individual, denoting different firms; t is time, denoting different years; Y_{it} denotes a vector of endogenous variables consisting of Digistock, FC, and EPF; a_0 is a vector of intercept terms; p is a lagged order; a_j is a matrix of regression coefficients; μ_i and v_t denote the corporate fixed effects and the year fixed effects, respectively; and ε_{it} is a randomized perturbation term.

3.2 Variable Measurement

3.2.1 Digital Knowledge Stock

Digistock is an important indicator to measure the scale of digital knowledge elements accumulated by enterprises in the process of long-term digital technology innovation (Huang & Gao, 2025). In this paper, by identifying whether a patent belongs to the category of digital technology or not, and drawing on the research method of Wu and Shanley (2009), we calculate the sum of the number of digital technology patents filed by an enterprise in the three years from year $t-3$ to year $t-1$, and then add 1 and take the natural logarithm on the basis of this to measure the Digistock of an enterprise in year t , which is denoted as *DGS*.

3.2.2 Financing Constraints

Drawing on the research of Yang and Su (2025), this paper constructs the *WW* index to measure the FC faced by enterprises, denoted as *FCI*. The index reflects a firm's financing ability and the influence of external industry characteristics by weighing and summing multiple financial indicators. The larger the value of the *WW* index, the more severe the FC faced by the firm.

3.2.3 ESG Performance

Drawing on the research of Wang and Yang (2022), this paper divides the CSI EPF evaluation system into a total of nine grades, and assigns scores to corporate EPF performance using a nine-point scale, with higher scores representing better ESG performance. Meanwhile, the quarterly scores are averaged to measure annual EPF, denoted as *ESG*.

3.3 Data Source

The data used in this paper comes from patent database, CSMAR database and Wind database. The patent information comes from the patent database and CSMAR database, the sample of A-share listed companies including basic corporate information, financial status, performance indicators and other relevant fields come from the CSMAR database, and the rating results provided by the CSI ESG evaluation system come from the Wind database. After calculating the variables required in this paper will be part of the sample matching, in order to ensure the accuracy of the empirical results, delete the financial industry, ST category, there are a large number of missing data, delete the age of less than 1 and total assets less than the total liabilities of the enterprise samples, and ultimately get a total of 8,65 enterprise samples in the period from 2014 to 2023.

4. Empirical Analysis

4.1 Descriptive Statistics

The results of descriptive statistics show that the mean value of *DGS* in the national sample is 2.8222, with a standard deviation of 1.7043, indicating a large variation among corporations; the mean value of *FCI* is -1.0468, but the extreme values widen the standard deviation; and the mean value of *ESG* is 4.4374, with a relatively concentrated distribution. By region, the eastern region has the highest *DGS* and *ESG* mean values of 2.8868 and 4.4680 respectively, while the western region has the lowest *DGS* mean value and the central region has the least fluctuation in *FCI*. Overall, the eastern region performs better in terms of Digistock and EPF, while there are regional differences in the distribution of FC.

Table 1 Descriptive statistics

Regions	Variables	count	mean	sd	min	max
National	<i>DGS</i>	8650	2.8222	1.7043	0.0000	9.4785
	<i>FCI</i>	8650	-1.0468	0.5041	-33.9726	-0.7963
	<i>ESG</i>	8650	4.4374	0.8409	1.0000	7.2500
Eastern	<i>DGS</i>	6550	2.8868	1.7228	0.0000	9.4785
	<i>FCI</i>	6550	-1.0474	0.5471	-33.9726	-0.7986
	<i>ESG</i>	6550	4.4680	0.8291	1.0000	7.2500
Central	<i>DGS</i>	1280	2.6904	1.6683	0.0000	7.0353
	<i>FCI</i>	1280	-1.0355	0.0624	-1.3293	-0.8533
	<i>ESG</i>	1280	4.3401	0.8785	1.0000	7.0000
Western	<i>DGS</i>	820	2.5112	1.5616	0.0000	7.9241
	<i>FCI</i>	820	-1.0602	0.5324	-16.0670	-0.7963
	<i>ESG</i>	820	4.3445	0.8566	1.2500	6.7500

Figure 2 shows a box-and-line plot of corporate Digistock, FC and EPF in the national region,

from which we can clearly see the distributional characteristics of each variable.

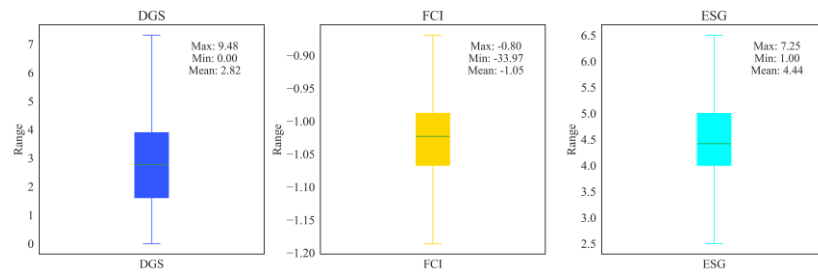


Figure 2 Variable box line diagram

4.2 Stationarity Test

To avoid the existence of errors in the regression results caused by the panel data not being smooth, this paper adopts four methods, namely, ADF-Fisher test, PP-Fisher test, IPS test and LLC test, to carry out the panel unit root test for each variable, and the results are shown in Table 2. The

test results show that the *DGS*, *FCI* and *ESG* in the whole country and in the eastern, central and western regions are rejecting the original hypothesis of the existence of unit root, indicating that all variables are smooth sequences, which satisfy the prerequisites of the subsequent panel regression analysis.

Table 2 Smoothness test

Regions	Variables	ADF-Fisher test	PP-Fisher test	IPS test	LLC test
National	<i>DGS</i>	-9.7855***	-5.6949***	-2.0193**	-50.3057***
	<i>FCI</i>	-40.9485***	-45.0451***	-32.0120***	-58.0046***
	<i>ESG</i>	-31.8545***	-21.2004***	-12.0950***	-56.1471***
Eastern	<i>DGS</i>	-11.6883***	-5.4814***	-2.1749**	-44.3616***
	<i>FCI</i>	-34.8236***	-38.1172***	-25.6721***	-45.1679***
	<i>ESG</i>	-29.9416***	-19.6890***	-11.8697***	-51.5161***
Central	<i>DGS</i>	-9.0583***	-2.4314***	-1.5130***	-22.2668***
	<i>FCI</i>	-17.9067***	-20.2341***	-8.8087***	-22.7292***
	<i>ESG</i>	-9.3556***	-5.9194***	-3.0297***	-19.0344***
Western	<i>DGS</i>	-4.5860***	-1.6071*	-1.3111*	-14.3959***
	<i>FCI</i>	-12.2488***	-13.3405***	-3.8415***	-18.7076***
	<i>ESG</i>	-7.1364***	-5.8085***	-1.3248*	-14.0002***

4.3 Optimal Lag Recognition

To ensure the accuracy of PVAR model estimation, this paper selects the optimal lag based on the three criteria of AIC, BIC and HQIC. As shown in Table 3, the optimal lags for the whole country, the east, the central and the west regions are 1st order, 1st order, 2nd order and 1st order, respectively, and the values of AIC, BIC and HQIC are all minimized in the optimal lag period, which indicates that the model setting is reasonable.

In terms of regional differences, the optimal lags of the East and the whole country are all of order 1, indicating that the dynamic interactions among

the variables are more rapid, which may be related to the region's high economic activity, fast policy response, and lower data volatility. The optimal lags in the central region are of order 2, indicating that there is a certain time lag in the interaction between the variables, which may be affected by the industrial structure adjustment or policy transmission efficiency. The optimal lag in the western region is of the 1st order, but the absolute value of its statistics is relatively low, indicating that although the dynamic relationship between variables exists in this region, it may be limited by the quality of the data or the characteristics of the regional economy, and the intensity of the influence is weak.

Table 3 Optimal lags of the PVAR model

Regions	Lag order	AIC	BIC	HQIC
National	1	3.8106*	6.3853*	4.6983*
	2	4.0027	6.8978	5.0076
	3	4.4750	7.7863	5.6334
	4	4.6656	8.5420	6.0342
Eastern	1	3.7841*	6.2569*	4.6487*
	2	3.9565	6.7376	4.9355
	3	6.1479	9.3292	7.2766
	4	6.9881	10.7115	8.3214
Central	1	0.4308	2.3234	1.1493
	2	-0.4750*	1.6777*	0.3475*
	3	1.9547	4.4398	2.9111
	4	0.6295	3.5573	1.7659
Western	1	4.8721*	6.616*	5.5483*
	2	5.0192	7.0211	5.8000
	3	5.5347	7.8644	6.4495
	4	5.6264	8.3887	6.7192

4.4 GMM Model Estimation

Table 4 reports the results of GMM estimation of Digistock, FC and corporate EPF at the national level and in the East, Central and West regions. At the national level, the lagged period of Digistock has a significant positive effect on itself, indicating that the accumulation of Digistock has a strong self-reinforcing effect. At the same time, there is a significant promotion effect of digital knowledge stock on corporate EPF, indicating that the enhancement of digital technology in the short term can promote the enhancement of corporate EPF. However, the short-term effects of FC on both Digistock and corporate EPF are not significant, which may reflect that the current financial system still needs to strengthen its support for digital technology transformation and corporate green transformation. It is worth noting that corporate EPF has a significant negative impact on Digistock in the short term, a phenomenon that may be related to the higher initial investment costs of sustainable development and the crowding out of digital technology R&D resources in the short term.

The GMM estimation results reveal significant regional differences in characteristics: in the eastern region, Digistock exhibits stronger self-reinforcing effects, but does not contribute significantly to EPF, which may stem from the diminishing marginal benefits of digital

technology due to the higher level of development in the region, or corporations are more inclined to invest their digital resources in short-term economic benefits. It is worth noting that there is a significant negative effect of EPF on FC in the eastern region, thanks to its well-developed financial market mechanism and social responsibility awareness, where ESG-leading corporate EPF obtains more green financial support by upgrading their credit ratings (El Ghoul *et al.*, 2011; Kwilinski *et al.*, 2025). Although the Digistock in the central region shows self-reinforcement in the short term, negative autocorrelation occurs in the lag two period, reflecting the pressure of resource reorganization and insufficient integration with traditional industries after excessive digital investment (Guan & Zhou, 2025); EPF faces the challenge of unsustainable inputs despite the initial formation of a virtuous cycle. The coefficients of FC are negative but do not pass the significance test, indicating that the current financial system has not yet been able to provide effective support for digital transformation and EPF in the central region. In the western region, Digistock remains self-reinforcing, but there is a short-term inhibitory effect of ESG on digitization, and the link between the two is not significant, highlighting the disconnect between digitization and sustainable development (Sun *et al.*, 2024), indicating that different regions face differentiated challenges in coordinating the goals

of the digital economy and ESG.

The GMM estimation results show that Digistock presents self-reinforcing effects in the short term at the national level and in all regions, but with significant regional differences: sustained positive development in the eastern region, fluctuating characteristics in the central region, and obvious base effects in the western region. The interaction between digital technology and EPF is complex; digital technology promotes ESG development at the national level, but there is a general short-term crowding-out effect of ESG on digital technology. Regional development imbalance is prominent (Eva et al., 2022), the east has formed a virtuous cycle of digital-financial-ESG, the center faces the

dual challenges of unsustainable digital applications and fluctuating ESG inputs, and the west is still in the stage of digital infrastructure construction. Insufficient financial support is a common problem, and only eastern EPF can significantly alleviate FC. These findings suggest that differentiated regional policies need to be implemented: the east promotes the deep integration of digital and ESG, the center addresses the issues of digital sustainability and ESG stability, the west strengthens its digital foundation, and financial support for transformation needs to be strengthened at the national level.

Table 4 GMM model estimation results

Regions	Variables	h_{DGS}	h_{FCI}	h_{ESG}
National	L1. h_{DGS}	0.7606***	-0.0056	0.0394*
	L1. h_{FCI}	0.0559	0.3036	-0.0414
	L1. h_{ESG}	-0.1449***	-0.0176	0.7533***
Eastern	L1. h_{DGS}	0.7631***	-0.0048	0.0340
	L1. h_{FCI}	0.0624	0.3443	-0.0399
	L1. h_{ESG}	-0.1491***	-0.0323**	0.7521***
Central	L1. h_{DGS}	0.8176***	-0.0161	-0.7620
	L1. h_{FCI}	-5.1417	0.1696	-15.4763
	L1. h_{ESG}	-0.0064	0.0002	0.6786***
	L2. h_{DGS}	-0.2107***	0.0014	0.1196
	L2. h_{FCI}	-3.4087	0.0733	-9.4448
	L2. h_{ESG}	0.0218	-0.0005	-0.1151**
Western	L1. h_{DGS}	0.7732***	-0.0023	0.0631
	L1. h_{FCI}	-0.0093	0.1062	0.0175
	L1. h_{ESG}	-0.1781*	0.1013	0.7008***

4.5 Impulse Response Analysis

The GMM estimation results only show the static relationship among the variables of the model, to further analyze the interaction of Digistock, FC and corporate EPF dynamically, this paper carries out impulse response analysis of the variables by conducting 200 Monte Carlo simulations with a time span of 10 periods. Figures 1-4 show the synthesized impulse response curves at the national level and in the eastern, central and western regions, respectively, showing the interaction mechanism among Digistock, FC and corporate EPF.

As shown in figure 3, at the national level, the effects of Digistock, FC, and corporate EPF on

themselves show a gradual weakening trend, indicating that the self-reinforcing effects of the variables diminish over time. Regarding Digistock and corporate FC, subfigures (2) and (4) show that in the short term, the increase in Digistock will temporarily exacerbate FC due to the high resource investment in corporate digital transformation, but with the deeper application of digital technology to improve corporate transparency and operational efficiency, FC will be effectively mitigated in the long term; at the same time, FC significantly contribute to the digital knowledge at the initial stage by forcing the allocation of capital for digital knowledge accumulation, but as the market adapts and technology becomes saturated, this facilitating effect will gradually weaken (Yao et al., 2022);

Regarding the Digistock and EPF, as shown in sub-figures (3) and (7), in the short term, EPF inhibits the accumulation of Digistock due to the resource crowding-out effect, but as corporations gradually balance the allocation of resources and the digital technology empowers the ESF, the inhibition will gradually weaken; at the same time, the digital knowledge constraints will be effectively alleviated in the long term by forcing the allocation of capital; meanwhile, Digistock may be negatively impacted by technology investment crowding out ESG resources at the initial stage, but in the long run, it will eventually significantly contribute to EPF improvement by enhancing operational efficiency and digital management capabilities (Wang & Hou, 2024). Regarding the relationship between corporate EPF

and FC, as shown in subfigures (6) and (8), on the one hand, the enhancement of EPF can sustainably alleviate FC thanks to positive effects such as the improvement of corporate image and the enhancement of governance, on the other hand, FC significantly inhibit ESG inputs at the initial stage but, as firms optimize their financing strategies and adapt to the environment, this inhibiting effect will gradually weaken. This suggests that ESG construction and improvement of financing environment can form a virtuous circle, which is consistent with the estimation results of the GMM model. These results reveal the complex interactions between Digistock, FC, and corporate EPF, providing new perspectives for understanding how these variables affect long-term corporate development.

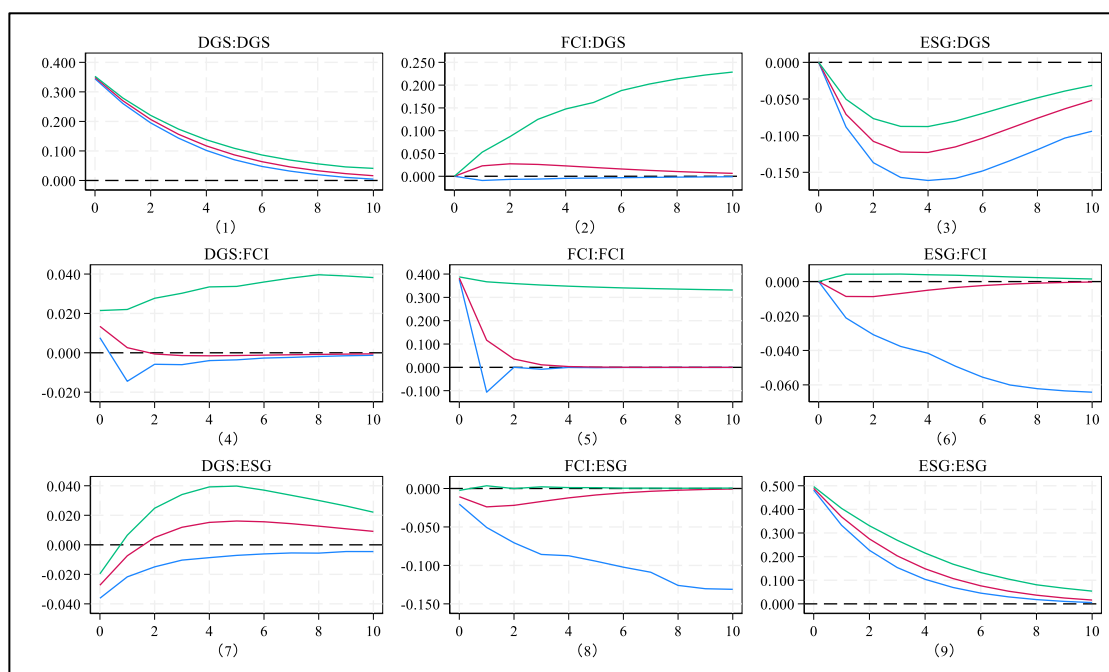


Figure 3 National impulse response map

As shown in figure 4, the results of the impulse response analysis in the eastern region are consistent with those at the national level, where Digistock, FC and corporate EPF all have self-reinforcing effects, but gradually weaken over time. FC promotes the accumulation of Digistock in the early stage, mainly because in the eastern region, FC force firms to optimize resource allocation and prioritize investment in digital technologies that can rapidly improve competitiveness (Yuan et al., 2022), but the effect

diminishes with technological maturity; the Digistock exacerbates FC in the short term but mitigates them slightly in the long term. Digistock and EPF initially inhibit each other, but in the long run, digital technology promotes EPF by improving management efficiency and transparency. FC and EPF consistently inhibit each other, reflecting the well-developed financial market environment and stronger sense of social responsibility in the eastern region.

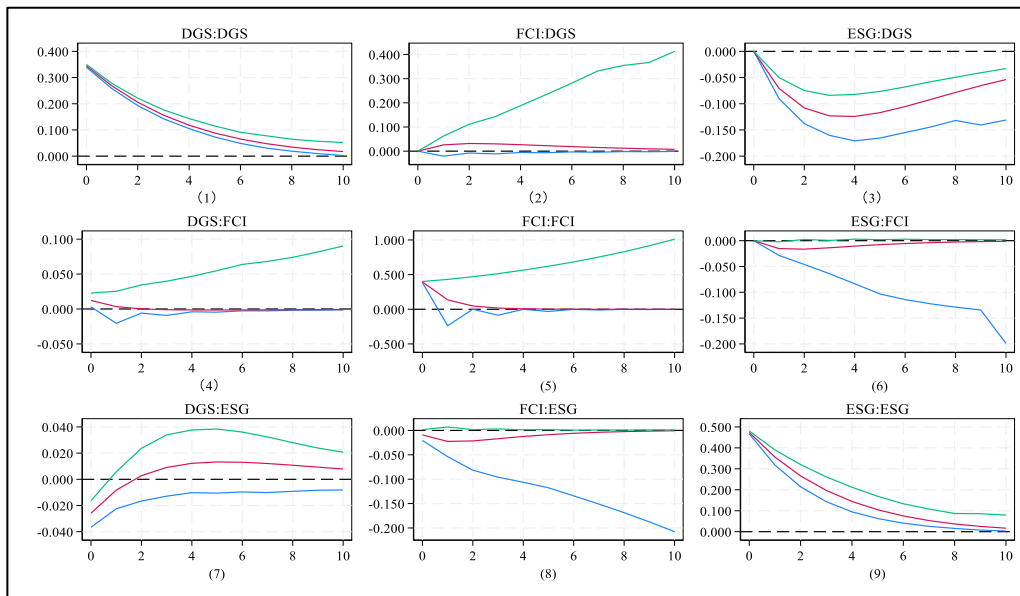


Figure 4 Impulse response map for eastern region

As shown in figure 5, impulse response analysis in the central region shows that although there is a self-enhancing effect of Digistock and EPF, the effect is weak, reflecting the relative lag in the development of digital technology and ESG practices in the region (Tang et al., 2021). The disappearance of the enhancing effect of FC may stem from the lack of maturity of financial markets leading to their limited binding effect on firms. Digistock has only a weak short-term inhibitory effect on FC and fades quickly, which contrasts with the eastern region and suggests that the marginal contribution of digital technology to the improvement of the financing environment in the center is low. It is worth noting that unlike in the East, central EPF does not inhibit digital

knowledge accumulation, which may benefit from a more balanced resource allocation (Wu et al., 2025); however, Digistock instead inhibits EPF, suggesting that corporate EPF are more inclined to prioritize allocation of their limited resources to digitization rather than to ESG areas. The insignificant mitigating effect of EPF on FC reflects that the ESG rating system is imperfect resulting in its financing function not being fully utilized; and FC significantly inhibits ESG inputs, suggesting that firms cut ESG expenditures to protect core operations under financial pressure. These findings reveal the unique challenges faced by the Central Region in reconciling digital transformation, financing optimization, and sustainable development.

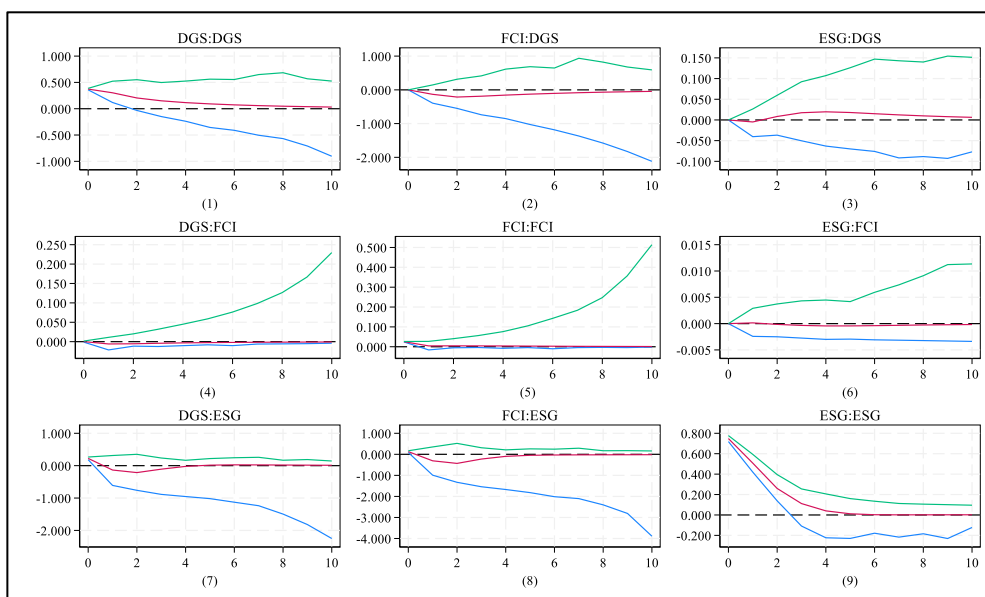


Figure 5 Impulse response map for central region

Impulse response analysis in the western region shows that Digistock, FC and corporate EPF all exhibit self-enhancing characteristics, which is mainly due to the government's policy support in recent years. The insignificant interaction between Digistock and FC reflects both the fact that the western region is still in the early stage of digital transformation (Liu *et al.*, 2024), where the application of digital technology has not yet fully penetrated, and the limited moderating effect of FC on digital investment due to the lagging development of the local financial market. Notably, Digistock significantly contributes to corporate EPF, suggesting that digital technology helps to enhance sustainable management; however, EPF inhibits digital knowledge accumulation, which stems from the policy-driven

nature of resource allocation, where firms prioritize the allocation of resources to ESG projects to satisfy policy requirements (Li & Hu, 2025). The insignificant effect of FC on EPF suggests that local ESG investments are mainly driven by policies rather than market financing conditions; while the failure of EPF to mitigate FC reflects both the imperfections of the ESG rating system and reveals the peculiar phenomenon that ESG investments may exacerbate short-term financing pressures due to upfront costs instead. These findings highlight the unique challenges faced by the Western region in harmonizing policy-driven and market mechanisms and balancing digital transformation and sustainable development.

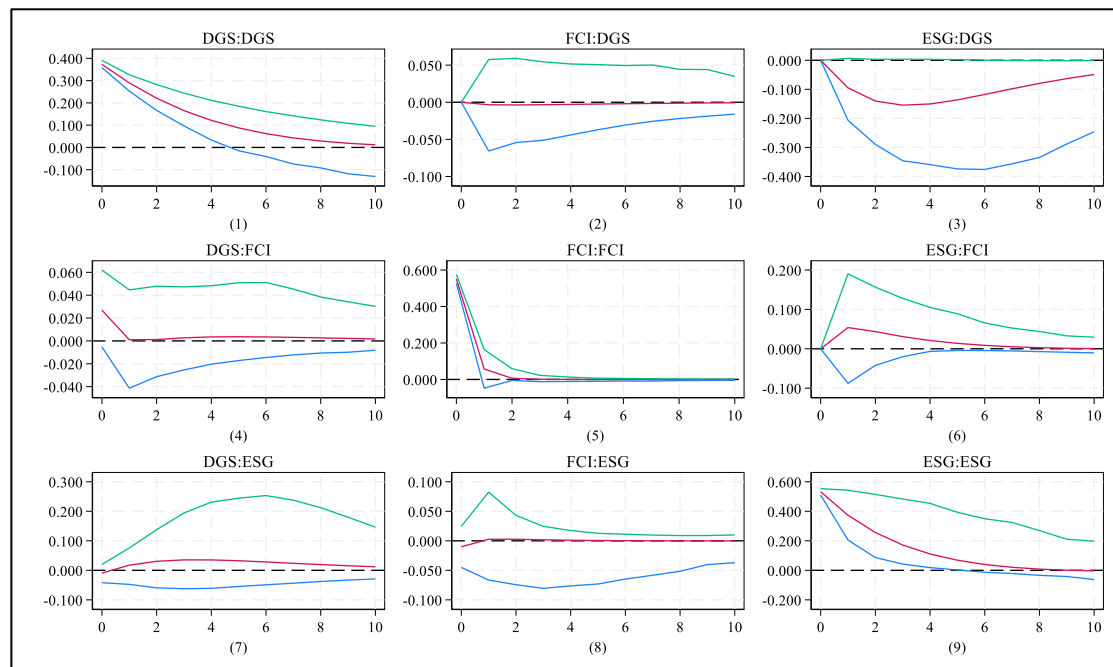


Figure 6 Impulse response map for western region

4.6 Variance Decomposition

The results of the variance decomposition show that the fluctuations in Digistock mainly originate from its own factors, and its explanatory strength gradually decreases from 100% to 74.6% over time, while the explanatory strength of EPF on the fluctuations in the Digistock rises from zero to 24.5%, indicating that the extent of the influence of EPF on the development of digitization is increasing. The fluctuations of FC are almost entirely explained by self-factors, with an explanatory strength of more than 99.7% in all periods, showing a high degree of independence.

The fluctuations of EPF are also mainly dominated by self-factors, with an explanatory strength of more than 99.2% maintained. The explanatory strength of Digistock on EPF fluctuations increases slightly from 0.3% to 0.4%, suggesting that digitization's influence on EPF is small but persistent exists. Overall, the explanatory strength of EPF on Digistock is increasing, the explanatory strength of Digistock on EPF is relatively limited, and the fluctuation of FC is relatively independent.

The variance decomposition results reveal the differentiated characteristics of Digistock, FC and

corporate EPF in different regions. In the eastern region, changes in Digistock are mainly driven by its own factors, with a contribution rate of 0.736, showing obvious path-dependence characteristics, while corporate EPF has a gradually increasing impact on it, with a long-run contribution rate of 0.252, which may be derived from ESG-oriented technological input and policy support effects. Changes in FC and corporate EPF, on the other hand, are almost entirely self-determined, with contribution rates as high as 0.994 and 0.993, respectively, and the influence of external factors is minimal. The central region shows a different pattern, with Digistock being jointly influenced by its own factors and FC, with contribution rates of 0.661 and 0.336, respectively; FC, although still dominated by its own adjustments, with a contribution rate of 0.872, have an explanatory power of 0.127 for Digistock that is significantly higher than that of the eastern region; and corporate EPF is affected by both its own factors

and FC, with a The endogenous characteristics of the variables are most prominent in the western region, where the stock of digital knowledge mainly relies on self-accumulation, with a contribution rate of 0.713, and only weakly influences the EPF; the FC and the corporate EPF are almost completely determined by themselves, with a contribution rate of 0.977 and 0.987, respectively, and the explanatory power of both Digistock and FC is less than 0.03. These findings are sufficiently high. are less than 0.03. These findings fully reflect the imbalance of China's regional economic development, with the eastern region having initially formed a benign interaction mechanism between digital technology and EPF, the central region presenting an interactive characterization of digital development and FC, and the development of each element in the western region still in a relatively independent state.

Table 5 Variance Decomposition

Variable	S	National			Eastern			Central			Western		
		DGS	FCI	ESG	DGS	FCI	ESG	DGS	FCI	ESG	DGS	FCI	ESG
DGS	1	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000
	5	0.849	0.008	0.144	0.843	0.010	0.147	0.716	0.283	0.002	0.807	0.000	0.193
	10	0.760	0.009	0.231	0.751	0.012	0.237	0.666	0.330	0.003	0.721	0.000	0.279
	15	0.747	0.009	0.244	0.737	0.012	0.251	0.661	0.335	0.003	0.713	0.000	0.287
	20	0.746	0.009	0.245	0.736	0.012	0.252	0.661	0.336	0.004	0.713	0.000	0.287
FCI	1	0.001	0.999	0.000	0.001	0.999	0.000	0.000	1.000	0.000	0.002	0.998	0.000
	5	0.001	0.997	0.001	0.001	0.995	0.005	0.114	0.886	0.000	0.002	0.978	0.020
	10	0.001	0.997	0.002	0.001	0.994	0.005	0.125	0.874	0.001	0.003	0.977	0.021
	15	0.001	0.997	0.002	0.001	0.994	0.005	0.127	0.872	0.001	0.003	0.977	0.021
	20	0.001	0.997	0.002	0.001	0.994	0.005	0.127	0.872	0.001	0.003	0.977	0.021
ESG	1	0.003	0.000	0.996	0.003	0.000	0.997	0.081	0.027	0.893	0.000	0.000	0.999
	5	0.002	0.003	0.995	0.002	0.003	0.995	0.092	0.257	0.651	0.007	0.000	0.993
	10	0.004	0.003	0.993	0.003	0.003	0.993	0.093	0.259	0.648	0.013	0.000	0.987
	15	0.004	0.003	0.992	0.004	0.003	0.993	0.093	0.260	0.647	0.013	0.000	0.987
	20	0.004	0.003	0.992	0.004	0.003	0.993	0.093	0.260	0.647	0.013	0.000	0.987

5. Research Conclusions and Policy Implications

5.1 Research Conclusion

Using panel data of 865 A-share listed companies in China from 2014-2023, this paper conducts an empirical study by building a PVAR model, utilizing GMM estimation, impulse response analysis, and variance decomposition, and based

on the whole country as well as the eastern, central, and western regions, it explores the interaction between Digistock, FC, and EPF, and draws the following conclusions.

First, there is a self-enhancing effect between Digistock, FC and corporate EPF. Digistock and EPF show a synergistic evolution of inhibition followed by promotion, but ESG inputs may crowd out digital R&D resources in the short

term; Digistock and FC show a U-shaped relationship of exacerbation followed by alleviation; FC force the accumulation of digital knowledge in the short term, but the long term effect is diminishing, and at the same time inhibit EPF, while ESG improvement can continue to alleviate FC. These relationships reflect the dynamic equilibrium character of resource allocation in the transition process.

Second, the fluctuation of Digistock mainly originates from its own factors, but the influence of EPF on it gradually increases; the fluctuation of FC is highly independent and almost entirely self-determined; and the fluctuation of EPF is also dominated by its own factors, with the limited influence of Digistock. Overall, the interaction between Digistock and EPF is deepening, but still dominated by its own driving force.

Third, there are significant regional differences in the dynamic relationships between variables. The long-term dynamic relationship of the variables in the eastern region is consistent with the national level, but the promotion effect of digital knowledge stock on corporate EPF in the short term does not pass the significance test. EPF has a significant negative impact on corporate FC, indicating that a virtuous digital-financial-ESG cycle has been formed in this region; in the central region, both the Digistock and corporate EPF show short-term fluctuation characteristics. There is a mutual inhibitory relationship between the Digistock and FC in this region, while EPF can promote the accumulation of digital knowledge but has a more limited impact on alleviating FC. In the western region, the interrelationship between Digistock and FC and the impact of FC on corporate EPF are not obvious, while the improvement of EPF will exacerbate corporate FC due to the resource appropriation effect.

5.2 Policy Implications

5.2.1 Digital-ESG Synergistic Development to Ease Financing Constraints

In view of the dynamic relationship between Digistock and EPF, it is recommended that the government implement a phased support policy. In the short term, tax incentives or special subsidies can be used to alleviate the crowding out of digital R&D resources due to ESG investment; in the medium and long term, the in-depth integration of digitalization and ESG management

systems should be promoted, for example, the formulation of industry standards for the application of digital technology in ESG areas such as environmental monitoring and supply chain transparency improvement. At the same time, we should give full play to the mitigating effect of EPF on FC, establish a mechanism linking EPF and financing costs, and provide policy support such as green credit preferences and bond issuance facilitation to corporations with excellent EPF. It is recommended to establish a cross-sectoral “digital-EPF” synergistic development fund to support enterprises in realizing the double enhancement of technological application and social benefits, and to improve the corporate financing environment by enhancing corporate EPF.

5.2.2 Improve Differentiated Regional Policy Systems

Based on the virtuous circle already formed in the east, it can be encouraged to explore the innovative application of digital financial tools; the central region needs to focus on solving the dilemma of mutual inhibition of “digital-financing”, and it is recommended to set up a regional guarantee fund for digital transformation and carry out a pilot project on ESG disclosure in order to enhance the accessibility of financing; and the western region should prioritize the solution to the contradiction of resource occupation of ESG inputs, and can establish a fund through the central financial transfer payment to support enterprises to achieve both technological application and social benefits.

5.2.3 Strengthen Market Self-Regulation Capacity Building

The policy design should focus on cultivating the endogenous power of the market. Establish a nationally unified digital knowledge sharing platform to reduce the cost of repeated inputs for corporate digital transformation; improve the mechanism linking the ESG rating system and FC, so that top-performing corporate EPF can automatically obtain financing facilities; and develop a dynamic monitoring system to provide real-time early warnings on the interactions between the application of digital technology, the financing environment and ESG performance, so as to provide data support for policy adjustments. Eventually, a new pattern of market-led and

government-guided sustainable development will be formed.

5.3 Research Weaknesses and Future Prospects

Although this study systematically explores the dynamic relationship between Digistock, FC and corporate EPF, there are still limitations: the sample is limited to Chinese A-share listed companies, which restricts the generalizability of the conclusions; the measure of Digistock based on patent data may be biased; and the impact of industry heterogeneity has not been analyzed in depth. Future research can expand the sample, optimize variable measures, and subdivide industries; introduce moderating variables such as policy environment and market competitiveness to explore the threshold effect of nonlinear relationships, analyze strategic adjustments in combination with case studies, and pay attention to the impact of emerging technologies such as blockchain and artificial intelligence.

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