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The power of financial support in accelerating digital transformation and corporate innovation in China: evidence from banking and capital markets

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Abstract

This study explores the role of financial support in the digital transformation of Chinese A-share-listed companies from 2001 to 2020. By utilizing the moderating effect model and threshold regression model, this study finds the following results: (1) Digital transformation positively impacts innovation, and the support of banking and capital markets further strengthens this impact. (2) With the development of banking and capital markets, the impact of digital transformation on innovation changes from negative to positive, which is also reflected in the subsamples of Eastern companies, small and medium-sized companies (SMEs), and non-SMEs. (3) The study reveals that only the capital market in the non-Eastern region has no threshold, and capital market support is effective only for non-SMEs when it reaches a higher level. These findings have important implications for policymakers in promoting digital transformation through financial support and help companies understand how to use financial support to improve competitiveness.

Keywords: Digital transformation, Banking sector, Capital market, Moderating effect model, Threshold regression model

Introduction

The twenty-first century is an age of digitalization. Currently, data resources are the core production factors. The United States,[1] Japan,[2] Germany,[3] and other countries have successively promulgated plans to promote digital transformation, compete to build a digital innovation ecosystem, and want to occupy the digital high ground. The Chinese government has repeatedly pointed out that China should firmly grasp the

[1] OFFICE OF SCIENCE AND TECHNOLOGY POLICY EXECUTIVE OFFICE OF THE PRESIDENT. Obama administration unveils"Big Data"initiative:announces$200 million in new R&D investments[EB/OL].(2012–03-29)[2018–10-01].https://www.cccblog.org/2012/03/29/obama-administration-unveils-200m-big-datard-initiative/.

[2] Japanese Cabinet. "The Fifth Science and Technology Basic Plan 2016–2020" [R]. http://www8.cao.go.jp/cstp/sogosenryaku/2016/honbun2016.pdf.

[3] THE FEDERAL GOVERNMENT. Digital agenda 2014–2017[R].Berlin:Federal Ministry for Economic Affairs and Energy, Federal Ministry of the Interior, Federal Ministry of Transport and Digital Infrastructure, 2014:30–36.

strategic opportunity of a scientific and technological revolution in digitalization and taken "accelerating digital development and building a digital China" as one of the goals and tasks of the "14th Five-Year Plan" period. Research on digital transformation is also becoming a hot topic, especially in digital innovation micro-companies. In recent years, Chinese companies have shown impressive performance in digital transformation; for example, Alibaba Cloud, the core technological carrier of Alibaba, has expanded from the initial Information Technology (IT) infrastructure to hardware fields such as chips, servers, and databases. In addition, it has integrated cutting-edge IT technologies such as big data, Artificial Intelligence (AI), Internet of Things (IoT), blockchain, and quantum computing. Alibaba Cloud has achieved breadth and depth in the IT industry and is at its forefront. Huawei regards digital transformation as a strategic focus for future development; invests in research and development in fifth-generation (5G) technology, IoT, and cloud computing; and promotes commercializing mobile devices and application scenarios. Investigating the impact of digital transformation on innovation and the role of digital transformation provides evidence for policymakers due to the vital role of innovation in economic development (Kamalaldin et al. 2021). China has been one of the countries with the fastest digital development in recent years,[4] and its financial market has remained stable during COVID-19 (Liu et al. 2020). Using China as a research object has important reference significance for other countries and regions to understand the digital impact trend and carry out financial reform.

Previous academic discussions on digital transformation have focused on defining it and its impact on industries or companies, with little discussion on how digital transformation is affected by the external financial environment. For example, some studies discuss the differences between intelligentisation and digitalization (Dengler and Matthes 2018) or the evolution process and different stages of digital transformation (Verhoef et al. 2021). Building on this foundation, the literature has further explored the impact of digital transformation on industries and companies from various perspectives, such as strategy, competitive pressure, intelligent technology, human resources, and marketing (Nasiri et al. 2020; Singh et al. 2021; Blanka et al. 2022). Specifically, current research indicates that digital transformation is becoming increasingly important in various industries, bringing challenges, such as the need to adapt to new technologies and digital talent, as well as opportunities, such as the emergence of new digital industries (Parida et al. 2019) and improved operational efficiency for businesses (Mourtzis 2020).

Research on the impact of digital transformation on innovation has yielded several key findings. Zhuo and Chen (2023) argued that digitalization can overcome the effective boundaries of innovation and enhance absorption and transformation capabilities to promote innovation, owing to the powerful cost-cutting and efficiency-boosting potential of digitalization (Bresciani et al. 2021; Peng and Tao 2022). However, scholars have different views. Corvello et al. (2023) believe that the effectiveness of digital innovation largely depends on the personal characteristics of managers, while Liu et al. (2023) suggest that, although digital transformation can achieve the integration of internal and external innovation elements, it only has innovation incentive effects during the lag period of 2 years. There are no such effects in the current year, next year, or lag period of

[4] World Intellectual Property Organization. Global Innovation Index Report 2022[EB/OL]. https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2022-section1-en-gii-2022-at-a-glance-global-innovation-index-2022-15th-edition.pdf

3 years. Although the existing literature has extensively discussed the positive or negative impacts and scope of the impact of digital transformation, most studies only focus on the internal impact of digital transformation on companies. It is unclear whether micro-companies are affected by external financial environments in the process of digital innovation and whether this effect varies under different levels of financial development. Furthermore, it is uncertain whether banks, capital markets, and their channels affect different companies differently. To fill this research gap, this study examines how financial development moderates the impact of a firm's digital transformation on innovation.

Changes in financial function are inevitable in the digital economy. Companies that rely on digital technologies as key production assets often exhibit asset-light operations (Bertani et al. 2021). However, digital assets pose challenges regarding their use as collateral for loans, as they are difficult to pledge (Brown et al. 2009; Czarnitzki and Hottenrott 2011). Moreover, equity financing can lead to crowding-out effects because of increased disclosure costs and agency problems (Gigler et al. 2014), which put forward higher requirements for the inclusiveness and efficiency of financial institutions. The prevailing view among most scholars is that financial development enhances loan opportunities for digital projects and reduces overall risk (Shan et al. 2023), thereby generating a positive impact on innovation. However, Iddrisu and Chen (2022) suggest that digitalization, conditional on financial sector development, does not necessarily promote economic growth in Africa, indicating that the impact of financial development could be negative. Ha et al. (2022) pointed out that companies can directly engage in online financial transactions, bypassing intermediary markets such as financial institutions, thereby potentially weakening the roles of banks and capital markets. Therefore, this study examined whether Chinese financial development can play a moderating role in the impact of digitalization on innovation. If so, does it enhance or diminish the impact of digitalization? This study also examines the threshold effect of digitalization on innovation across various levels of financial development. Furthermore, this study explored the differences in financial support across different regions and scales. Given China's vast land area and numerous companies, there are significant differences in investment styles, stock liquidity, market value, and other aspects among companies listed in different regions and on different stock exchange boards. For example, economically developed coastal regions in eastern China have higher market fairness and may experience different levels of financial support effectiveness than non-eastern regions (Wu et al. 2019). The People's Bank of China: The China Regional Financial Operations Report (2022) shows that in 2021, the proportion of new direct financing in China's eastern region accounted for 76.5% of the national total, and the balance of domestic and foreign currency loans exceeded the national average by 1.5%.[4] Huge regional differences in financial development make research in different regions significant. Companies listed on different boards have different entry thresholds and regulatory requirements, which may lead to differences in financing difficulty and preferential interest rates received. For companies of different sizes listed on the Science and Technology Innovation Board, the average price-to-earnings ratio of IPOs in the first year set a record in the Chinese stock market, reaching 71.05 times (Dong et al. 2022b). Based on this, tests are conducted by grouping companies according to their location and scale. The aim is to provide more detailed reference points for governments and companies in different regions. An important issue that

academics and policymakers need to pay attention to is understanding the moderating effect of finance on the impact of digital transformation and promoting the construction of a financial system that supports innovation so that the financial industry can better serve the digital economy.

Examining digital transformation in the external financial environment is crucial for governments and companies. As mentioned previously, internal financing cannot meet the massive funding needs of digital transformation (Nylund et al. 2019). Examining the effectiveness of external financial institutions in supporting digital transformation can help companies incorporate this easily overlooked external factor into their digital strategies, thereby avoiding discrepancies between actual outcomes and company decision expectations due to omitted factors (Wang and Du 2022). For the government, the country's scientific and technological development level is closely linked to the corporate technical level. Clarifying the support effect of financing on micro-subjects in digital transformation has important reference value for government policy guidance, preferential interest rate settings, and other aspects. This will help China to fully implement its strong digital country strategy and innovative development strategies.

The main contributions of this study are as follows: First, it extends the research on the impact of digital transformation on innovation by providing a new perspective. The macro financial environment heavily influences micro level corporate behavior, and this study creatively considers the influence of digital transformation on corporate innovation under the trend of financial development, making the effect of digital transformation more closely reflect real-world situations. Second, it clarifies the positive impacts of banking and capital markets on innovation promotion through digital transformation. The roles of the banking and capital markets in driving innovation have been debated. This study empirically examines the moderating effect of financial development on the impact of digital transformation on innovation, addressing these debates and providing directions for further reform and development of the financial industry. Third, this study overcomes the limitations of previous studies that overemphasize the positive effects of digital transformation and highlight the possibility of negative effects on innovation when financial development is imperfect. This finding reinforces the importance of considering the macro financial environment in research.

The rest of the paper is based on the research question of whether the development of banks and capital markets enhances or weakens the impact of digital transformation on innovation and what role it plays in different stages of financial development and types of companies. The second part discusses the mechanisms and hypothesis, theoretically explaining financial development's moderating and nonlinear effects in the digital transformation and innovation nexus. The third section comprises the model construction and data description. Using sample data from Chinese listed companies from 2001 to 2020, moderating effect and threshold regression models were constructed to examine the relationship between digital transformation, financial development, and innovation. The empirical results are presented in Section, along with a heterogeneity analysis of the companies. The fifth part is the conclusion.

Mechanisms and hypotheses

The impact of digital transformation on corporate innovation

Digital transformation involves the application of digital technologies, such as cloud computing and big data, to transform production, operations, and management processes (Frynas et al. 2018). This involves a shift in management paradigms from traditional analog or manual methods to digital systems and processes. Decisions made by the board of directors or top management mainly aim to leverage technology to improve efficiency, increase productivity, and drive intellectual and managerial innovations. First, digital transformation helps companies eliminate the ink "island phenomenon" in intellectual and technological innovation (Senyo et al. 2019). The "island phenomenon" refers to the information asymmetry and isolation phenomenon that exists in some market or economic systems (Mundell 1963). For example, a company may be isolated from other companies owing to geographical, political, and cultural factors, which makes it only able to trade in the local market and unable to obtain information elsewhere. This leads to a lack of effective price-discovery mechanisms in the market, causing companies to miss investment opportunities for innovative projects. Digitalization helps eliminate the barriers to information sharing and the "island phenomenon" among different business departments and different companies, establishes an information flow mechanism between companies and industries through interconnection means, promotes inter-industry technology spillovers, and promotes more open and collaborative innovation among companies (Pershina et al. 2019; Bresciani et al. 2021). Second, digital transformation significantly impacts managerial innovation. Efficient production management is achieved through data collection, analysis, and decision-making, which reduces market transaction costs, including search, transportation, and transmission costs (Peng and Tao 2022). This, in turn, enables greater capital investment in innovation activities. Moreover, in the digital era, most corporate production, operations, and customer-oriented operating systems are online, resulting in labor substitution and reduced human capital expenditure (Shakina et al. 2021). Third, big data and data analysis accelerate corporate business innovation decision-making processes (Li et al. 2022). Automated algorithmic decision-making facilitated by intelligent products and services improves operational efficiency and process management, thereby shortening the production cycle and supporting intellectual and managerial innovation (Newell and Marabelli 2015). In summary, the measures adopted in digital transformation lead to intellectual and managerial innovations, such as the board of directors or top management leveraging technology to improve efficiency, increase productivity, and drive innovation in both the intellectual and managerial domains. Accordingly, this study proposes the following hypothesis:

Hypothesis 1 Digital transformation has a positive impact on corporate innovation.

The impact of digital transformation on corporate innovation at different levels of financial development

The moderating effect of financial development

Internal and external environmental factors influence the impact of digital transformation on innovation. Previous literature has discussed internal factors mainly driven by the decision-making of the board of directors and strategic governance bodies, such as

top management, which play a crucial role in promoting digital transformation decisions (Chen and Hao 2022). As the formulators and implementers of corporate strategic decisions, their understanding and attitude toward digital transformation largely determine the effectiveness of the corporate digital transformation (Pan and Xu 2023). However, a research gap exists in exploring external macro-financial moderating effects.

According to Pecking Order Theory, companies first use internal financing to fund innovative investments, and when their funds become insufficient, they seek external financing channels (Myers and Majluf 1984). China's main external financing channels currently obtain credit funds from banks and financing capital markets (Backman and Wallin 2018). The extent to which banks and capital markets support the impact of digitization is a key question that must be examined in the digital age. Digital transformation is a high-risk project with a long return period. The development of digital transformation depends on a large amount of financial support, in which financial institutions play an important role. For example, Ullah et al. (2021) used the digitalization of intelligent real estate in Australia to point out that digital transformation involves high investment costs in software and hardware as well as the high complexity of digital technology, which together create risk and become an obstacle to innovation, and a lack of investment willingness is emphasized as the main reason for the failure of digital innovation. Digital technology requires a large amount of funding support for early research, product development, and later commercialization, but 80 percent of start-up companies fail to raise Series A financing (Hor et al. 2021). Therefore, how entrepreneurs can legally organize network relationships and find funding sources has been taken seriously by many scholars (Nigam et al. 2020). Maintaining good bank-company relationships and obtaining capital market financing support have become important factors in corporate digital transformation. First, financial development reduces financing constraints in digital transformation. The expansion of the financial scale means that financial institutions are more competitive, which is conducive to reducing loan interest rates, broadening loan channels (Leon 2015; Love and Martínez Pería 2015), and providing more financial support for corporate digital transformation. Since the twenty-first century, China has greatly improved the level of specialization and diversification of services by restructuring the financial services of large state-owned banks and completing shareholding transformation (Liu and Zhang 2020), which is conducive to providing more efficient financial services for digital transformation, thus promoting innovation. Third, the development of finance makes it easier for financial institutions to identify high-quality projects with investment value and facilitates their supervision and management. Financial technology provides intelligent support to financial institutions. Banks measure the default probability of customers through big data risk-control technology (He et al. 2023), and capital markets use big data to aggregate market information (Lee and Shin 2018), improving resource allocation efficiency and facilitating capital flow to digital transformation projects. Fourth, financial institutions and companies have become more closely connected with finance development. Banks and capital markets began to expand their business boundaries, and business links were constantly subdivided and outsourced to third-party institutions through a certain degree of standardization. Through this business link, banks became closer to companies (Boot 2000) and could provide a stable source of funds for digital projects.

Hypothesis 2 The development of banking and capital markets enhances the positive impact of digital transformation on innovation.

The threshold effect of financial development

The theory of financial development has been formed through constant exploration and development, from the study of financial functions to the proposal of the financial repression theory and then to the theory of financial deepening (Grubel and McKinnon 1974). According to the theory of financial deepening, Cole and Shaw (1974) believes that a sound financial system can accelerate economic growth in relatively poor areas. In contrast, distorted finance hinders technological progress and economic development. Digital transformation has different effects on innovation at different financial development levels. Trinugroho et al. (2021) believe that the financial development level has a strong threshold effect on regional technology catch-up, and only those regions with financial development levels beyond the threshold can have outstanding performance in technological innovation and technology catch-up. Some other scholars believe that the excessive expansion of the financial sector may produce a "financial curse" (Zhu et al. 2020). Frequent interbank lending activities, shadow banking, and securitization and regulatory arbitrage of bank assets increase the possibility of rent-seeking and market speculation and compress the living space of real high-quality digital transformation projects, thus hindering innovation. Therefore, at different stages of financial development, the impact of digital transformation on innovation may be nonlinear. In addition, the moderating effects of banks and capital markets differ and are mainly reflected in risk management and information processing (Liu et al. 2022a). Most studies believe that the capital market is significantly higher than traditional financial institutions, such as banks, in terms of risk tolerance and diversification ability (Purewal and Haini 2022). Regarding information processing, the centralized display of capital market information and the agility of information processing are also more advantageous than banks in supporting digital innovation (Hsu et al. 2014; Didier et al. 2021). Accordingly, this study proposes the following hypothesis:

Hypothesis 3 The impact of digital transformation on innovation changes from negative to positive under the moderating of financial development, which is more sensitive to the capital market.

The moderating effect of financial development in different companies

For various types of companies, the positive effects of digital transformation and the moderating effects of financial development exist; however, when considering the characteristics of different companies, the impacts of digital transformation and financial development are different.

China is a vast country with various natural resources in different regions and serious economic imbalances (Liang et al. 2021). The moderating effect of financial development has different manifestations. The "Aihui-Tengchong Line" is the dividing line of China's population development level and economic and social patterns. Digitalization in the eastern region has a more positive impact on innovation than in non-eastern regions because of the better development environment (Zhang and Zou

2012; Zheng et al. 2013; Xu et al. 2022a). Eastern cities have a better economic base, talent pool, complete infrastructure (Zheng et al. 2013) and innovation climate (Xu et al. 2022a, b), which can provide a better environment for digitalization. Moreover, non-Eastern regions depend more on the banking industry (Liu and Zhang 2020). Therefore, with the development of banking, the impact of digital transformation on innovation undergoes significant changes. As most of China's capital markets are distributed in the eastern region, there may be no threshold value for non-eastern capital markets. Based on this, we propose the following hypothesis:

Hypothesis 4 Digital transformation has a greater positive impact on innovation than in the eastern region, and the impact of change is higher in the non-eastern region.

In contrast, digitalization has provided unprecedented opportunities for small- and medium-sized entrepreneurial companies (SMEs) (Cenamor et al. 2019). Digital networks have enabled SMEs to compete with large-scale companies with lightweight assets; therefore, digital transformation has a greater impact on innovation. In addition, with the development of finance, banking competition is conducive to the adjustment of the credit structure and deregulation of credit, which helps alleviate the discrimination of financial ownership (Du et al. 2023), thereby reducing the cost of corporate loans, easing the financing constraints of SMEs, and improving the innovation quality of SMEs. Non-SMEs have abundant cash flow. When the capital market is imperfect, non-SMEs usually choose internal financing to fund innovative projects (Zhang et al. 2020). Therefore, digital transformation is not moderated if the capital market is underdeveloped. Accordingly, this study proposes the following hypothesis:

Hypothesis 5 For non-SMEs, the impact of digital transformation on innovation is smaller, and the capital market can only have a moderating effect when it develops to a higher level.

Methodology

Model specification

Moderating effect model

This study first constructs a moderation effect model to examine how financial development moderates the impact of digitalization on innovation. The moderation effect model proposes that when a third variable influences the relationship between the independent and dependent variables, it is referred to as the moderator variable. The moderator variable can affect both the direction and strength of the relationship between the independent and dependent variables (Baron and Kenny 1986; Toothaker 1994). Changes in the moderating variable can alter the marginal effect of the independent variable on the dependent variable. According to Eq. (2), $\partial PG/\partial DT = \beta_1 + \beta_3 FD$, the coefficient of β_3 represents that with an increase of one unit in financial development, the marginal effect of digital transformation on innovation increases by β_3 units. Therefore, the moderation effect model measures whether the external financial environment alters the impact of digital transformation on innovation.

$$PG_{it} = \alpha_0 + \alpha_1 DT_{it} + \alpha_2 X_{it} + \varepsilon_{it} \tag{1}$$

$$PG_{it} = \beta_0 + \beta_1 DT_{it} + \beta_2 FD_{it} + \beta_3 DT_{it} \times FD_{it} + \beta_4 X_{it} + \varepsilon_{it} \tag{2}$$

where PG_{it} represents the level of innovation in $i_{\text{-th}}$ corporation in year t, DT_{it} represents the level of digital transformation in $i_{\text{-th}}$ corporation in year t, FD_{it} represents the level of financial development in province i in year t and includes both banking (FD_b) and capital market dimensions (FD_c). $DT_{it} \times FD_{it}$ represents the interaction variable of digital transformation and financial development, and X_{it} represents the control variable, which includes five variables: the asset-liability ratio (*ALR*), the growth rate of operating income (*OI*), equity balance (*EB*), cash flow ratio (*CFR*), and whether the firm is audited by one of the four major accounting firms (*FA*).ε_{it} is the residual. If the DT_{it} in Eq. (1) and $DT_{it} \times FD_{it}$ in Eq. (2) are significant, it indicates that the impact of digital transformation on innovation is moderated by banking or the capital market. If the sign of DT_{it} in Eqs. (1) and $DT_{it} \times FD_{it}$ in Eq. (2) are the same: financial development enhances the effect of digital transformation on innovation, while the opposite sign indicates a weakened effect.

Threshold regression model

After estimating the moderating effect of financial development, we explored whether there is a turning point between the explanatory and explained variables when the level of financial development is at different stages. Some studies have adopted higher-order or dummy variable regression to deal with structural changes between the explanatory and explained variables (Brown 1968; Du and Lin 2022). However, this method may lead to high collinearity and difficulty determining grouping points, causing significant estimation errors. The threshold effect model proposed by Hansen (1999) can better avoid these issues and is widely used to estimate structural changes (Trinugroho et al. 2021; Shen and He 2022). This model is designed for non-dynamic panels with individual fixed effects, and the threshold value can be determined using a fixed-effect transformation. The regression slope can be obtained through least-squares estimation, and an unconventional asymptotic theory can be used for inference, allowing the construction of confidence intervals for hypothesis testing. This model has been widely applied in many research fields (Trinugroho et al. 2021). The threshold regression model was as follows:

$$\begin{aligned} PG_{it} = {} & \delta_0 + \delta_1 DT_{it} I(FD_{it} \le \gamma_1) + \delta_2 DT_{it} I(\gamma_1 < FD_{it} \le \gamma_2) \\ & + \cdots\cdots + \delta_{n+1} DT_{it} I(\gamma_n < FD_{it}) + \delta_{n+2} X_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

where DT_{it} is the regime-dependent variable, FD_{it} is the threshold variable, and γ is the threshold to be estimated. γ divides the studied provincial sample into different intervals, and the regression coefficients have different values for different sample intervals. $I(\bullet)$ is an indicator function with a value of one when the condition is met; otherwise, it is zero.

The interaction mechanism between digital transformation and innovation, with financial development as the moderator, is shown in Fig. 1.

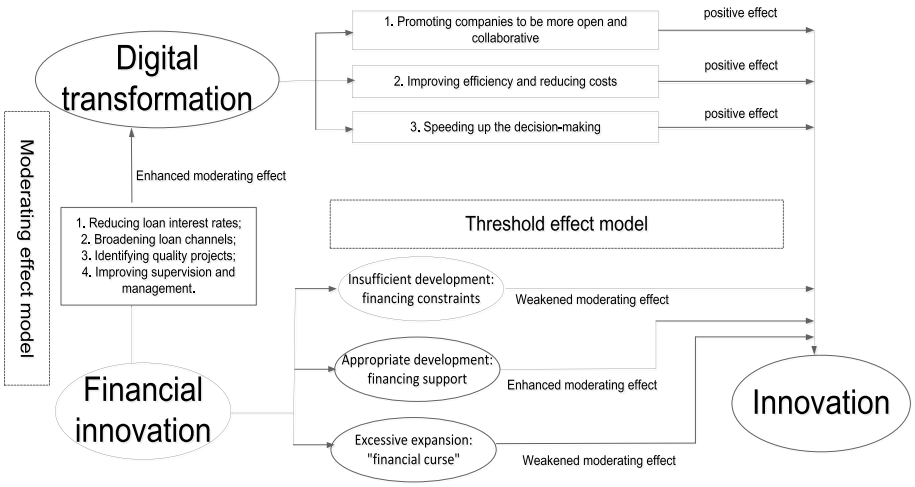

Fig. 1 The moderating effect of financial development

Variable selection

Dependent variable

Compared to non-invention patent innovation, invention patent innovation implies a higher level of technology, represents breakthrough creation (Gao and Yuan 2022), and is a concentrated expression of the quality of corporate innovation. Therefore, the logarithm of the number of invention patents granted was used as a proxy for the dependent variable.

Independent variable

Currently, the annual reports of listed companies in China do not include the degree of digital transformation. This has led some scholars to consider the proportion of network technology and software assets in intangible assets as the degree of digital transformation of companies (Jiang et al. 2022). However, this missing index data makes it prone to sample selection problems. Some studies use the number of robots as a measurement index of corporate digital transformation (Wang and Du 2022). Still, digitalization is a complex system, and artificial intelligence can only represent one aspect. Other scholars use questionnaire surveys to investigate the level of corporate digital development (Li 2022), but the data are significantly affected by interviewees' subjectivity.

The words managers use convey decision-making information (Jiang et al. 2019). By analyzing the documents issued by the company, it can be inferred whether the company is in the digital transformation process. Text analysis is widely used in top financial, accounting, and management journals (Ertugrul et al. 2017; Loughran and McDonald 2020). Based on the text analysis method, this study calculates the digitalization degree (*DIG*) of a listed company by dividing the total frequency of digital-related words by the length of the MD&A paragraph in its annual report of the listed company. The specific calculation method is as follows:

The first step is to build a digital glossary. By searching the websites of the Central People's Government of China and the Ministry of Industry and Information Technology,

31 important national digital economy-related policy documents released during 2012–2020 were manually screened to extract keywords related to company digitalization. After Python word segmentation and manual recognition, words related to company digitalization with a frequency greater than or equal to five times were selected. Words with a frequency greater than or equal to five were selected because they have a relatively high occurrence rate, indicating that they are more important and significant in corporate digitalization. This approach helps focus on the most relevant words and eliminates noise from less important words. Additionally, this ensures that the selected words are adequately represented in the data, increasing the analysis's accuracy. After manual comparison, a frequency of less than five makes some keywords unrepresentative, whereas selecting keywords with a frequency higher than five may miss important keywords. Based on these words, supplemented by the word frequency of digital transformation in Liu et al. (2022a, b), 239 digital transformation keywords were obtained, constituting this study's dictionary of digital terms. The second step was to import the digital dictionary into the Wingo database for word frequency statistics.[5] After extracting the word frequency of digitalization-related keywords, they were added, divided by the text length of the MD&A part of the corporate annual report (excluding numbers), and multiplied by 100 as the proxy variable for corporate digital transformation.

Mediator

Two main types of financial institutions exist in China's current financial market: the banking sector, which provides indirect financing, and the capital market, which provides direct financing. Financial development is reflected in both the level of development of the banking sector and the capital market. Referring to Hsu et al. (2014) and Brown et al. (2017), this study uses the ratio of loan balance to GDP of each province in the current year to measure the development level of the banking industry in China. It uses the ratio of stock market total value traded to GDP to represent the development level of China's capital market (Yue et al. 2019).

Control variables for innovation

To estimate the impact of digital transformation on innovation, other driving factors for innovation were controlled for, and all control variable indicators were based on a sample of Chinese A-share listed companies. (1) Capital structure: The asset-liability ratio can measure whether a company can innovate and the possibility of taking action (Myers and Majluf 1984). This study uses the asset-liability ratio to represent a company's capital structure. (2) Profitability capability: Profitability is positively related to corporate future innovation potential (Pham et al. 2021). This study uses operating profit margin to represent corporate profitability. (3) Equity balance: Equity checks and balances can reduce the self-interested behavior of major shareholders to a certain extent. In companies with a high degree of equity checks and balances, the decision-making of innovation activities is jointly decided by major shareholders and small and medium shareholders, which avoids the "short-sighted" behaviors of major shareholders to a certain extent and thus

[5] Wingo database provides analysis of exact word frequency, extended word frequency, exact sentence frequency and extended sentence frequency, as well as the total word count and total word count of the segment text of "Management Discussion and Analysis" (MD&A) in annual reports of listed companies.

has a positive impact on innovation (Li et al. 2018). The sum of the shareholding ratios of the second to fifth major shareholders/shareholding ratio of the first major shareholder is used to represent the equity balance. (4) Cash flow ratio: As a buffer against uncertainty, internal cash provides greater flexibility and error space for corporate innovation experiments (Atanassov and Liu 2020). This study uses net operating cash flow/current liabilities to represent the cash flow ratio. (5) Big4: If the audit institution is one of the four major accounting firms, we take 1; otherwise, we take 0. Lang and Maffett (2010) argue that while the use of the Big Four accounting firms does not necessarily indicate higher financial reporting quality, companies' choice to engage with these global providers can signify a certain willingness to commit to providing truthful and comprehensible accounting information, which can, in turn, attract more investors, provide more funding for innovation, and establish a foundation of trust.

Table 1 lists the variables used in this study. All the Abbreviations and their meanings are listed in Table 17 in "Appendix".

Research sample

The research sample consists of all A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2001 to 2020. The rationale for the sample selection is as follows: First, China's digitalization has developed rapidly in recent years, making Chinese companies a representative and valuable sample for study and reference. Second, the choice of listed companies for the research sample was based on data availability and effectiveness. Non-listed companies do not annually disclose information related to digital investments. Even if data for individual non-listed companies are available, they are not statistically significant because of the small sample size. Therefore, following Kong et al. (2021) and Yu et al. (2023), we selected a sample of listed Chinese companies from 2001 to 2020. This period coincides with the deepening of financial reforms in China (Petry 2021), making the discussion of different thresholds in finance more meaningful.

Company-level data were merged based on stock codes and years. The patent data of the companies were obtained from the China Research Data Services (CNRDS) database, and the digital word frequency data were obtained from the WinGo database. A combination of Python word segmentation and manual recognition was used to ensure the accuracy of the digitized word-frequency selection. Following manual checks, 239 keywords were obtained for digital transformation. The control variable data were obtained from the China Stock Market and Accounting Research (CSMAR) database. The sample excludes delisted companies and companies in the financial industry. Special treatment stocks (ST, *ST) and special transfer stocks (PT) are also excluded. The final sample consisted of 4035 companies with 39,982 observations.

Macroeconomic and company-level data are merged based on the year and province in which the listed companies are located. To obtain financial development indicators, the year-end loan balance and GDP data are collected from the "China Statistical Yearbook," and the stock trading volume data are obtained from the "China Securities and Futures Statistical Yearbook." No observations were made during the process. Therefore, an unbalanced panel dataset combining micro-level listed companies with macro-level financial development variables was obtained for the regression analysis. In the

Table 1 Variables description and selection

Variable type	Variable name	Symbol	Variable description	Indicator unit
Explained variable	Innovation output	*PG*	Ln (the number of invention patents granted + 1)	–
Independent variable	Digital transformation	*DT*	Digital related word frequency in annual reports of listed companies	%
Moderating variables	Banking sector	FD_b	Loan balance of financial institutions at the end of the year/GDP	%
	Capital market	FD_c	Stock market total value traded/GDP	%
Control variables	Capital structure	*CS*	Asset-liability ratio	%
	Profitability capability	*PC*	operating profit margin	%
	Equity balance	*EB*	The sum of the shareholding ratio of the second to fifth major shareholders/the shareholding ratio of the first major shareholder	%
	Cash flow ratio	*CF*	net operating cash flow/current liabilities	%
	Big4	*Big4*	audit institution is one of the four major accounting firms	0 or 1

regression analysis, individual and year-fixed effects were controlled for to ensure consistent and effective estimators.

Descriptive statistics

The descriptive statistics of the variables are shown in Table 2. According to the correlation coefficient test shown in Table 16 in the "Appendix", *DT*, FD_b, and FD_c were all positively correlated with *PG*, and FD_b and FD_c were also positively correlated with *DT*. According to the skewness characteristics in Table 2, the skewness of *PG*, *DT*, FD_b, and FD_c are all less than 3. Based on the kurtosis results, *PG* and FD_b exhibit a relatively flat data distribution. At the same time, *DT* and FD_c have a peak distribution, indicating that the value distribution of digital transformation and capital markets is mostly concentrated in the middle and less on both sides. The development levels of innovation, digitization, banking, and capital markets in the eastern regions are higher than those in the non-eastern regions, and the development levels of innovation, digitization, banking, and capital markets in non-SMEs are higher than those in SMEs.

Results

The estimated results of the moderating effect

To control for factors that do not change with time or individuals, the time and individual bidirectional fixed effects model was selected to eliminate the endogeneity problems caused by the correlation between the error term and the explanatory variables (Flannery and Rangan 2006). At the same time, before adding the interaction, the independent variables *DT* and the moderator *FD* are centralized to ensure the reliability of the coefficient results.

Table 3 presents the estimated results of the moderating effect. First, consistent with most existing studies (Pagani and Pardo 2017; Niu et al. 2023), this study found that digital transformation positively affects corporate innovation. In Model (1), the coefficient of digital transformation on innovation is positive and statistically significant at the 1%

Table 2 Descriptive statistics of variables

	Mean					Standard deviation (S.D.)	Minimum value (Min)	Maximum value (Max)	Skewness	Kurtosis
	National	Eastern	Non eastern	SMEs	Non SMEs					
PG	0.8572	0.9275	0.7109	0.7967	0.9611	1.1533	0.0000	8.0382	1.3247	4.1232
DT	0.6911	0.7700	0.5268	0.6343	0.7887	0.8267	0.0000	7.5693	2.1110	7.5557
FD_b	1.4871	1.6463	1.1556	1.4547	1.5425	0.4840	0.5499	2.9959	0.1753	1.9021
FD_c	1.6961	1.9890	1.0861	1.6710	1.7392	2.1252	0.0569	17.4183	2.7872	12.3886
CS	0.4352	0.4223	0.4620	0.4538	0.4032	0.2204	0.0071	9.6988	0.1251	2.2206
PC	4.0716	0.3561	11.8089	6.3015	0.2436	677.3623	− 1.3092	134,607.1000	3.0189	17.3118
EB	0.6720	0.6971	0.6198	0.6194	0.7624	0.6235	0.0000	4.0000	1.2169	4.1327
CF	0.0463	0.0463	0.0464	0.0466	0.0459	0.0805	− 1.9377	2.2216	− 0.1628	4.0195
Big4	0.0574	0.0682	0.0348	0.0602	0.0525	0.2325	0.0000	1.0000	3.8075	15.4974

Table 3 The regression results of moderating effects

Variables	(1)	(2)	(3)
	PG	*PG*	*PG*
DT	0.1655***	0.1424***	0.1642***
	(18.4967)	(15.2868)	(18.3307)
FD_b		−0.2259***	
		(−8.8129)	
$FD_b \times DT$		0.1199***	
		(7.6811)	
FD_c			0.0116***
			(3.9010)
$FD_c \times DT$			0.0068***
			(3.2260)
Control	Yes	Yes	Yes
Constant	−0.0470*	0.2131***	−0.0599**
	(−1.7945)	(5.2919)	(−2.2755)
Year	Yes	Yes	Yes
Id	Yes	Yes	Yes
Observations	39,982	39,982	39,982
Number of id	4035	4035	4035
R-squared	0.254	0.257	0.254

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

level. This result is consistent with the findings in intellectual innovation and organizational change. Through the adoption of advanced technologies and digital tools, digital transformation has revolutionized organizations' business models and processes. It enhances the efficiency of information acquisition and processing (Senyo et al. 2019), fostering intellectual innovation. During this process, organizational change can break traditional hierarchies and rigid structures (Chen and Hao 2022), foster the development of employees' digital skills, and ultimately positively influence innovation. Second, the higher the level of bank and capital market development, the greater the positive effect of digital transformation on innovation. As an important macro-financial variable, financial institutions play a significant financing role in companies' technological innovation. According to the coefficient estimation results of $FD_b \times DT$ in Model (2) and $FD_b \times DT$ in Model (3), both the banking and capital markets strengthened the positive impact of digital transformation on innovation, and the coefficients were statistically significant at the 1% level. This study again confirms the positive financial support effect, indicating that expanding the financial scale can reduce loan costs, broaden financing channels (Love and Martinez Peria 2012; Leon 2015), and provide more financial support for corporate digital transformation. Banks have a greater moderating effect than the capital market, which is related to the fact that China's financing structure is dominated by indirect financing provided by large state-owned banks (Allen et al. 2017; Nölke et al. 2019).

Heterogeneity analysis

Heterogeneity of eastern and non-eastern region

The regression results in Table 4 show that digital transformation in the eastern region has a greater impact on innovation. In Model (4), the coefficient of *DT* is 0.1789, which is

Table 4 Regression results of the eastern and non-eastern region

Variables	Eastern			Non-eastern		
	(4)	(5)	(6)	(7)	(8)	(9)
	PG	*PG*	*PG*	*PG*	*PG*	*PG*
DT	0.1789***	0.1643***	0.1781***	0.1197***	0.0926***	0.1190***
	(16.7752)	(14.8572)	(16.6832)	(7.1723)	(5.4360)	(7.1322)
FD_b		−0.2651***			−0.2805***	
		(−7.4453)			(−7.0678)	
$FD_b \times DT$		0.0991***			0.2310***	
		(5.0008)			(5.3903)	
FD_c			0.0108***			0.0054
			(3.1656)			(0.6359)
$FD_c \times DT$			0.0050**			0.0296***
			(2.2600)			(3.0875)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.1004***	0.2174***	−0.1129***	0.0017	0.2807***	−0.0039
	(−2.8606)	(3.8283)	(−3.2046)	(0.0438)	(5.0999)	(−0.0985)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27,011	27,011	27,011	12,971	12,971	12,971
Number of id	2920	2920	2920	1115	1115	1115
R-squared	0.255	0.258	0.256	0.256	0.261	0.256

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

significant at the 1% level and greater than 0.1197 in the non-eastern regions. The deeper the digital transformation, the higher the requirement for a long-term research and development atmosphere and highly skilled talent. As confirmed in previous studies, the eastern region has greater advantages (Kamble et al. 2018). Therefore, digital transformation in the Eastern region has a greater positive impact on innovation. Second, the moderating effects of banking and capital markets are greater in non-eastern regions than in eastern regions. $FD_b \times DT$ of Model (5) was 0.0991, which was smaller than 0.2310 of Model (8). $FD_c \times DT$ of Model (6) is 0.0050, smaller than 0.0296 in Model (9). The reason is that, on the one hand, financial development can provide better services for corporate financing, so the moderating effects of banking and capital markets in both regions are positive. However, the non-eastern regions of China started their economic development later, and their growth potential has not yet been fully realized. Financial development in these regions gives companies better opportunities to expand their markets. In contrast, the eastern region, although well-developed (Dong et al. 2022a), may experience diminishing returns from further financial development. While financial development remains important, according to the law of diminishing marginal returns, its incremental effect on supporting digital transformation and innovation may be less pronounced than in non-eastern regions.

Heterogeneity of SMEs and non-SMEs

According to Table 5, first, the digital transformation of both SMEs and non-SMEs has a positive effect on innovation, and the effect of the digital transformation of SMEs is

Table 5 Regression results of the SMEs and Non-SMEs

Variables	SMEs			Non-SMEs		
	(10)	(11)	(12)	(13)	(14)	(15)
	PG	*PG*	*PG*	*PG*	*PG*	*PG*
DT	0.2230***	0.1903***	0.2210***	0.0643***	0.0534***	0.0647***
	(19.2880)	(15.7027)	(19.0834)	(4.6146)	(3.7169)	(4.6406)
FD_b		−0.2164***			−0.2287***	
		(−6.8261)			(−5.2909)	
$FD_b \times DT$		0.1631***			0.0563**	
		(8.1223)			(2.2973)	
FD_c			0.0093**			0.0176***
			(2.5319)			(3.4847)
$FD_c \times DT$			0.0069***			0.0053
			(2.6727)			(1.4622)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.0980***	0.1512***	−0.1084***	0.2724***	0.5428***	0.2524***
	(−3.3115)	(3.1569)	(−3.6377)	(4.2693)	(6.5784)	(3.9441)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,265	25,265	25,265	14,717	14,717	14,717
Number of id	1993	1993	1993	2042	2042	2042
R-squared	0.294	0.298	0.294	0.173	0.176	0.174

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

greater than that of non-SMEs. In Model (10), the coefficient of *DT* is 0.2230, which is significant at the 1% significance level and greater than 0.0643 in non-SMEs. Unlike previous studies that emphasized the inherent weaknesses of SMEs and had a negative view of their digital transformation (Giotopoulos et al. 2017; Zhang et al. 2022), this study shows that, compared to non-SMEs, digital transformation has a more positive impact on innovation for SMEs because a large number of high-tech companies and new start-ups are concentrated on Small and Medium-sized Board and the Growth Enterprise Board. These companies place greater emphasis on digital investment and transformation. Second, developing both banking and capital markets positively moderates SMEs. In contrast, the capital market has no significant moderating effect on non-SMEs, and the moderating effect of banking on SMEs is greater than that on non-SMEs. $FD_b \times DT$ of Model (11) is 0.1631, which is smaller than 0.0563 of Model (14). $FD_c \times DT$ of Model (12) was 0.0069. The positive moderating effect of banks may be related to the market competition mechanism in the process of bank development. The higher the level of banking development, the more intense the market competition, and the lower the credit threshold and credit interest rate. Financial discrimination is reduced to gain more market share (Beck et al. 2005; Du et al. 2023). Therefore, SMEs benefit more from bank development. As for the insignificant results for the capital market, the reason may be that the capital market has an impact only under certain circumstances. This is due to the inadequate development of China's capital market in the initial stage (Li 2017), which has been subject to strict regulations (Hu et al. 2021). More positive financial functions were achieved until several capital market reforms were implemented (Petry

2021). Combined with the threshold regression results in Table 11, the capital market can moderate the impact of digital transformation on innovation only when it develops at a higher level.

The estimated results of the threshold regression model

This study uses the threshold model to test for the existence of the threshold effects of banking and capital markets and to determine the threshold value. This approach provides a more comprehensive understanding of the impact of financial development on the relationship between digitization, transformation, and innovation. Therefore, this study considers the development level of the banking and capital markets as a threshold variable and determines whether there is a structural breakpoint in the impact of digital transformation on innovation. Table 6 shows the F-values obtained by analyzing the threshold effect and the *p* values obtained by repeated sampling 300 times using the bootstrap method under Hypothesis 3. Both the banking and capital markets passed the significance test of the double threshold. The two thresholds are 0.8857 and 1.0478 for banking and 0.2297 and 1.4559 for the capital market, all within the 95% confidence interval.

Figure 2 shows the likelihood ratio function graphs of the estimated threshold values in the 95% confidence intervals of FD_b and FD_c. In the figure, the lowest point of the LR statistic is the true threshold, and the dotted line represents the critical value corresponding to the 95% confidence interval. Because the critical value of 7.35 is significantly larger than the threshold, the threshold can be considered true and effective.

Table 7 presents the threshold regression results. First, the impact of digital transformation on innovation changed from negative to positive at various financial

Table 6 Financial development threshold value test

Threshold variable	Threshold number	F-statistics	Prob	Threshold value [Confidence interval]	Critical value (F test)		
					10%	5%	1%
FD_b	Single	297.68***	0.000	0.8857 [0.8813 0.8924]	12.009	13.785	17.780
	Double	54.13***	0.000	1.0478 [1.0393 1.0504]	12.314	14.337	18.700
FD_c	Single	370.69***	0.000	0.2297 [0.2217 0.2418]	10.889	12.706	17.150
	Double	16.79**	0.030	1.4559 [1.4346 1.4850]	11.821	14.229	18.129

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

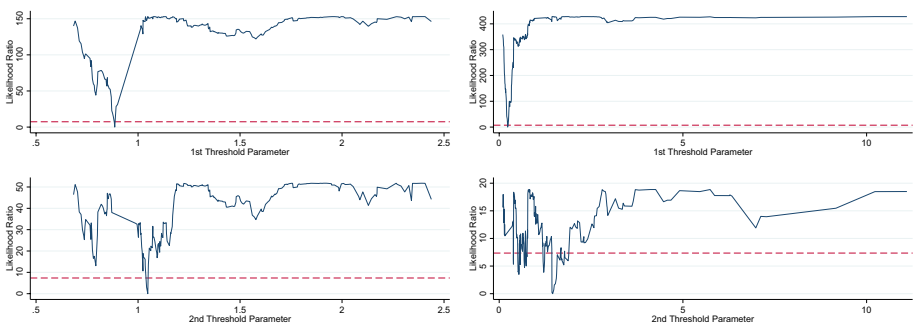

Fig. 2 Likelihood ratio function of the threshold regression model (Left: FD_b; Right: FD_c)

Table 7 Financial development threshold regression results

Variables	(16)	(17)
	PG	*PG*
$DTI(FD_b\ it \le \gamma_1)$	−0.3608***	
	(−11.0865)	
$DTI(\gamma_1 < FD_b\ it \le \gamma_2)$	0.2306***	
	(10.4761)	
$DTI(\gamma_2 < FD_b\ it)$	0.5281***	
	(54.9052)	
$DTI(FD_c\ it \le \gamma)$		−0.5431***
		(−14.7498)
$DTI(\gamma_1 < FD_c\ it \le \gamma_2)$		0.5144***
		(48.7860)
$DTI(\gamma < FD_c\ it)$		0.5388***
		(45.7158)
Control	Yes	Yes
Constant	0.3288***	0.3015***
	(17.6055)	(16.2936)
Observations	33,950	33,950
Number of id	3119	3119
R-squared	0.131	0.133

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

development levels. In Model (16), the coefficient of *DT* is −0.3608 before the banking crosses the first threshold, while all coefficients are positive after the first threshold and significant at the 1% level. It indicates that with the improvement of banking development, the marginal impact of digital transformation on innovation increases. Similarly, at different levels of capital market development, the impact of digital transformation on innovation changes from negative to positive, and the marginal impact of digital transformation on innovation increases. Developing countries are prone to cost-related obstacles in the process of digital transformation (Bogoviz et al. 2019). When the development levels of banking and capital markets are low, there is insufficient financial support for digital transformation. Digital transformation without adequate external financing is almost impossible, considering the high cost of digitalization. Moreover, because of the long investment return cycle (Ullah et al. 2021), the positive impact of digitalization on cost reduction and efficiency increase cannot be fully exerted at the initial stage of digital investment, which has a negative impact on corporate production, operations, and innovation. Second, compared with banking, when the capital market is the threshold variable, the impact of digital transformation on innovation changes over a larger range. In Model (16), with the development of banking, the impact of digital transformation on innovation gradually increases from −0.3608 to 0.5281. In Model (17), with the development of the capital market, the impact of digital transformation on innovation gradually increases from a smaller value of −0.5431 to a larger value of 0.5388. Over the past 10 years, China's capital markets have developed rapidly (Petry 2021), and its financial system has gradually transitioned to market-oriented finance (Gabor 2018; Petry 2020). Recent studies confirm that, compared to banks, capital markets are becoming increasingly

important for the real economy (Liu and Zhang 2020; Wen et al. 2021). Therefore, with the increasing influence of the capital market, the impact of digital transformation on innovation is broader than that of banking development.

Heterogeneity of eastern and non-eastern region

Banking and capital markets in the eastern and non-eastern regions were tested using triple, double, and single thresholds. According to the test results in Table 8, the banking and capital markets in the eastern region passed the double-threshold test. In contrast, only the banking industry in the non-eastern region passed the double-threshold test, and there was no threshold in the capital market.

Figure 3 shows the likelihood ratio function graphs of the estimated threshold values in the 95% confidence intervals of FD_b and FD_c in the eastern region. Figure 4 shows the likelihood ratio function graphs of the threshold-estimated FD_b value of the FD_b in the non-eastern region. Because the critical value of 7.35 is significantly larger than these thresholds, the thresholds can be considered true and effective.

According to the regression results in Table 9, the impact of digital transformation on innovation in the Eastern and Non-Eastern regions is negative before banking crosses the second threshold. With the development of banking, in Model (18), the

Table 8 Financial development threshold value test of eastern and non-eastern region

Sample	Threshold variable	Threshold number	F-statistics	Prob	Threshold value [Confidence interval]	Critical value (F test)		
						10%	5%	1%
Eastern	FD_b	Single	39.52***	0.000	0.7834 [0.7763 0.7857]	12.449	13.709	17.419
		Double	335.91***	0.000	0.9202 [0.9157 0.9313]	11.819	13.269	17.924
	FD_c	Single	464.98***	0.000	0.2297 [0.2248 0.2419]	11.612	14.954	21.474
		Double	18.90***	0.003	1.4850 [1.4414 1.5002]	11.915	13.966	17.109
Non-eastern	FD_b	Single	8.35*	0.060	0.7346 [0.7292 0.7612]	7.503	8.576	13.682
		Double	22.76***	0.000	0.8582 [0.8158 0.8857]	9.201	11.283	13.900
	FD_c	–						

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

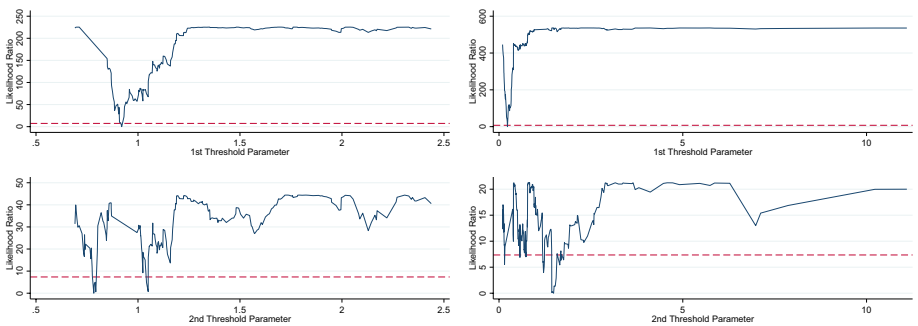

Fig. 3 Likelihood ratio function of eastern region (Left: FD_b in the eastern region; Right: FD_c in the eastern region)

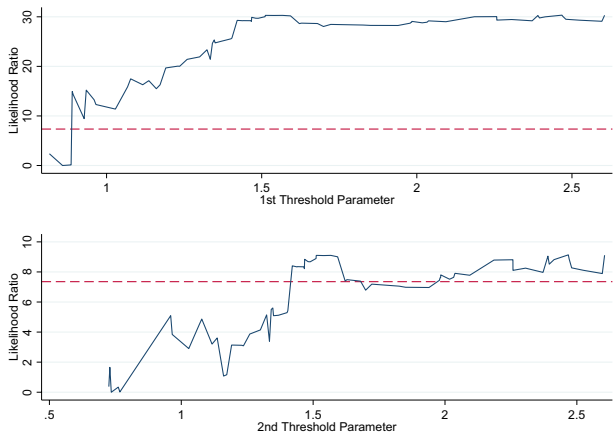

Fig. 4 Likelihood ratio function of FD_b in the non-eastern region

Table 9 Financial development threshold regression results of eastern and non-eastern regions

Variables	Eastern		Non-Eastern
	(18)	(19)	(20)
	PG	*PG*	*PG*
$DTI(FD_b\ it \le \gamma_1)$	−0.4714***		−1.4568**
	(−9.7293)		(−2.5204)
$DTI(\gamma_1 < FD_b\ it \le \gamma_2)$	−0.1054***		−3.3469***
	(−3.3951)		(−4.5181)
$DTI(\gamma_2 < FD_b\ it)$	0.5164***		0.5526***
	(52.9095)		(5.0776)
$DTI(FD_c\ it \le \gamma)$		−0.5522***	
		(−14.6606)	
$DTI(\gamma_1 < FD_c\ it \le \gamma_2)$		0.5105***	
		(47.6832)	
$DTI(\gamma < FD_c\ it)$		0.5357***	
		(44.7272)	
Control	Yes	Yes	Yes
Constant	0.3243***	0.3167***	0.8701***
	(16.9272)	(16.6300)	(4.7139)
Observations	32,394	32,394	511
Number of new id	3004	3004	84
R-squared	0.130	0.134	0.152

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

impact of digital transformation on innovation in the eastern region gradually changes from −0.4714 to 0.5164. In the non-eastern region, it gradually changes from −1.4568 to 0.5526 in Model (20), which is larger than that in the eastern region, reflecting the deeper dependence of enterprises in the non-eastern region on the banking industry (Liu and Zhang 2020). Second, the estimated results of the eastern region subsample are the same as those of the national sample; that is, the impact coefficient of digital transformation on innovation is negative before the capital market crosses the first threshold, and then the marginal impact increases. There is no threshold value in the capital market of the non-eastern region, indicating that the impact of digital transformation

on innovation remains unchanged under the moderating effect of the capital market. The uneven development of China's regional economies indirectly leads to imbalances in capital market development. Some studies have shown that the capital markets in economically developed regions along the eastern region are significantly more mature than those in non-eastern regions (Hu et al. 2021). This is reflected in the fact that the impact of digitalization on innovation changes from negative to positive with the development of the capital market in the eastern regions. However, capital markets in non-eastern regions cannot provide the same support for digitalization. The descriptive statistics in Table 2 also show that the average development of capital markets in the eastern region is much higher than in non-eastern regions.

Heterogeneity of SMEs and non-SMEs

According to the test results in Table 10, the banking and capital markets of SMEs and non-SMEs passed the double-threshold test.

Figures 5 and 6 show the likelihood-ratio function graphs of the threshold estimated values for SMEs and non-SMEs, respectively. Because the critical value of 7.35

Table 10 Financial development threshold value test of SMEs and non-SMEs

Sample	Threshold variable	Threshold number	F-statistics	Prob	Threshold value [Confidence interval]	Critical value (F test)		
						10%	5%	1%
SMEs	FD_b	Single	294.74***	0.000	0.8858 [0.8846 0.8924]	13.044	15.307	19.724
		Double	54.62***	0.000	1.0478 [1.0386 1.0504]	12.288	14.183	18.489
	FD_c	Single	15.78**	0.023	0.1499 [0.1469 0.1552]	11.718	13.647	17.501
		Double	559.68***	0.000	0.2331 [0.2277 0.2418]	14.014	17.051	20.503
Non-SMEs	FD_b	Single	93.26***	0.000	0.9057 [0.9005 0.9113]	11.592	14.421	17.886
		Double	26.86***	0.000	2.0874 [2.0681 2.1018]	11.197	12.895	17.199
	FD_c	Single	38.73***	0.000	1.6585 [1.5436 1.6719]	10.550	12.087	16.495
		Double	15.51**	0.013	0.2418 [0.2046 0.2554]	9.914	10.984	18.632

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

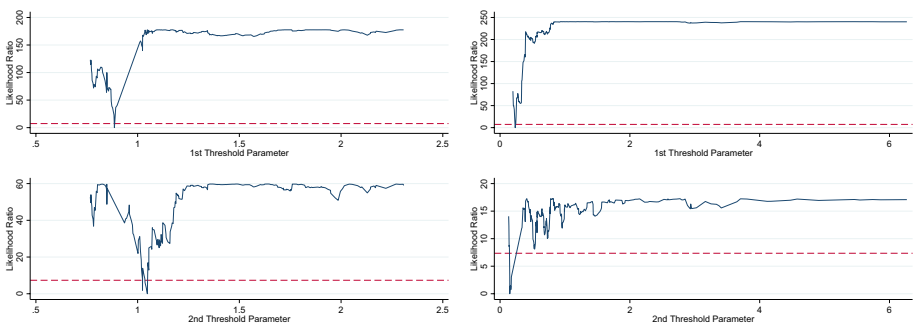

Fig. 5 Likelihood ratio function of SMEs (Left: FD^b; Right: FD^c)

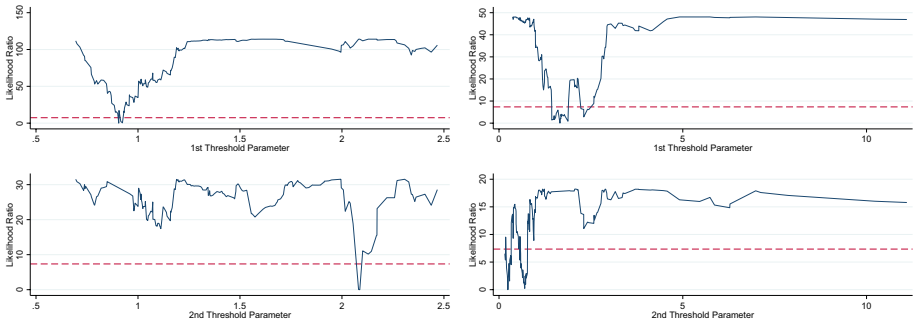

Fig. 6 Likelihood ratio function of non-SMEs (Left: FD_b; Right: FD_c)

Table 11 Financial development threshold regression results for SMEs and non-SMEs

Variables	SMEs		Non-SMEs	
	(21)	(22)	(23)	(24)
	PG	*PG*	*PG*	*PG*
$DTI(FD_b\ it \le \gamma_1)$	−0.3269***		−0.2299***	
	(−8.1826)		(−4.4714)	
$DTI(\gamma_1 < FD_b\ it \le \gamma_2)$	0.2852***		0.3526***	
	(10.2364)		(22.4891)	
$DTI(\gamma_2 < FD_b\ it)$	0.6243***		0.3196***	
	(49.9548)		(13.3133)	
$DTI(FD_c\ it \le \gamma)$		−0.6634***		−0.0442
		(−11.8398)		(−0.4715)
$DTI(\gamma_1 < FD_c\ it \le \gamma_2)$		−0.4068***		0.3640***
		(−7.4945)		(22.5858)
$DTI(\gamma < FD_c\ it)$		0.6131***		0.3235***
		(49.6211)		(17.6410)
Control	Yes	Yes	Yes	Yes
Constant	0.2412***	0.2301***	0.5329***	0.5092***
	(10.2126)	(9.8603)	(17.4958)	(16.7261)
Observations	21,463	21,463	12,487	12,487
Number of new id	1627	1627	1492	1492
R-squared	0.160	0.170	0.084	0.074

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

is significantly larger than the thresholds, the thresholds can be considered true and effective.

According to the threshold regression results in Table 11, first, with the development of banking, the impact of the digital transformation of SMEs and non-SMEs on innovation changes from negative to positive. According to Model (21), SMEs' changing scope of impact is larger, from −0.3269 to 0.6243, while the non-SMEs in Model (23) change from −0.2299 to 0.3196. This means there is enormous potential for SMEs; as long as the global problem of difficulty in SME financing can be resolved (Liang and Qi 2013; Harrison et al. 2022), innovation output can be more effectively improved. Second, in model (22), with the development of the capital market, the impact of SMEs' digital transformation on innovation changes from negative to positive, from −0.6634 to −0.4068 and then to 0.6131. In model (24), before the capital

market crosses the first threshold, the negative impact of digital transformation on innovation is insignificant. After crossing the first threshold, the significant impact of digital transformation was always positive. This result further explores why Model (15) in Table 5 is not significant. It is not that there is no moderating effect in the capital market but that the digital transformation of non-SMEs has only a positive impact on innovation when capital markets develop to a specific stage.

Robustness test

Robustness test of moderating effect

To ensure the robustness of the results, we tested the robustness of the moderating effect model. In robustness test 1, the loans/GDP of prefecture-level cities is used to replace provincial loans/GDP as an indicator of banking development, and the stock turnover/GDP of prefecture-level cities is used to replace provincial stock turnover/GDP as an indicator of the development level of the capital market. Robustness test 2 replaces the explained variable from the logarithm of invention patents granted to the logarithm of invention patent applications by replacing the moderators. Robustness Test 3 replaces the digital word frequency ratio with the ratio of intangible assets to total assets, as the proportion of intangible assets to total assets may increase when a company undergoes digital transformation, reflecting corporate core competitiveness and value-creation ability in the knowledge-based economy. Table 12 presents the results. Digital transformation has a positive impact on innovation, and the development of banking and capital markets has a positive moderating effect on the impact of digital transformation. The conclusions of this study are robust.

Table 12 Robustness test of moderating effect

Variables	Robustness test 1		Robustness test 2			Robustness test 3		
	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
	PG	*PG*	*PG*	*PG*	*PG*	*PG*	*PG*	*PG*
DT	0.1442***	0.1559***	0.2128***	0.1992***	0.1999***	0.4086***	0.4395***	0.4372***
	(15.0049)	(16.5144)	(19.9086)	(17.4056)	(17.7939)	(4.5065)	(4.8186)	(4.8090)
FD_b	−0.0591***			−0.0646***			−0.2657***	
	(−3.4496)			(−3.1650)			(−10.3470)	
$FD_b \times DT$	0.0725***			0.0279**			0.4007**	
	(6.3238)			(2.0417)			(2.4939)	
FD_c		−0.0001***			−0.0003***			−0.0057
		(−3.6843)			(−6.1933)			(−1.3122)
$FD_c \times DT$		0.0001***			0.0001***			0.2080***
		(3.0789)			(3.2261)			(3.9617)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0242	−0.0595**	0.1181***	0.2330***	0.1422***	0.0285	0.3404***	0.0308
	(0.6760)	(−2.1769)	(3.7728)	(5.4591)	(4.3736)	(1.0981)	(8.5265)	(1.1798)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Id	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	39,982	39,982	39,982	39,982	39,982	39,982	39,982	39,982
Number of id	4035	4035	4035	4035	4035	4035	4035	4035
R-squared	0.246	0.245	0.286	0.274	0.275	0.247	0.249	0.247

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

Robustness test of threshold regression model

As with the moderating effect model, the threshold regression tests were conducted again by replacing the explained variable with the number of invention patents applied for that year and replacing the independent variable with the proportion of intangible assets. The test results are presented in Robustness Test 1 in Table 13. Robustness test 2 in Table 13 uses the financial development index (FD_t) as the threshold variable for regression, uses the entropy weight method to assign weights to the two indicators of the bank and the capital market, and obtains the FD_t according to the weighted sum. The results of this study are robust, with a double threshold for both the banking and capital markets. Figure 7 shows that the thresholds can be considered true and effective.

According to the results of robustness test 1 in Table 14, with the development of the banking and capital markets, the impact of digital transformation on innovation changes from negative to positive. Before crossing the first threshold, the impact of digital transformation on innovation was negative. Between the first and second thresholds and after crossing the second threshold, the impact of digital transformation on innovation is positive, and the impact range of capital markets is broader. According to the results of robustness test 2 in Table 14, with an increase in FD_t, the impact of digital transformation on innovation changes from negative to positive, and the marginal impact increases.

Table 13 Financial development threshold value robustness test

	Threshold variable	Threshold number	F-statistics	Prob	Threshold value [Confidence interval]	Critical value (F test)		
						10%	5%	1%
Robustness test 1	FD_b	Single	477.44***	0.000	0.9238 [0.9119 0.9313]	9.030	10.508	15.672
		Double	232.32***	0.000	1.9479 [2.9294 2.9492]	8.675	10.779	13.700
	FD_c	Single	478.70***	0.000	0.2402 [0.2297 0.2419]	11.965	14.341	22.998
		Double	45.50***	0.000	0.7003 [0.6845 0.7173]	10.204	11.852	14.086
Robustness test 2	FD_t	Single	380.13***	0.000	0.0447 [0.0444 0.0449]	11.597	13.286	16.080
		Double	114.43***	0.000	0.2127 [0.2116 0.2162]	11.102	12.845	18.987

Note: $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$

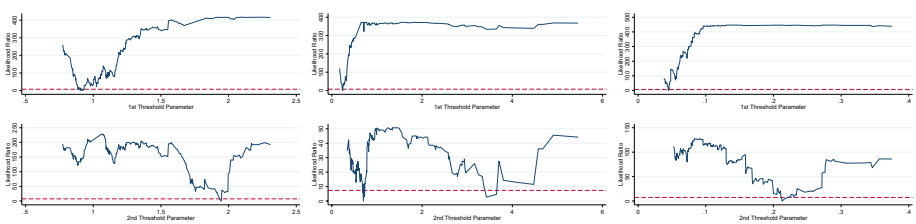

Fig. 7 Likelihood ratio function of robustness test (Left: FD_b; Middle: FD_c; Right: FD_t)

Table 14 Financial development threshold regression results of the robustness test

Variables	Robustness test 1		Robustness test 2
	(33)	(34)	(35)
	PG	*PG*	*PG*
$DT\,I(FD_b\,it \le \gamma_1)$	−4.1830***		
	(−14.7483)		
$DT\,I(\gamma_1 < FD_b\,it \le \gamma_2)$	3.1920***		
	(17.8163)		
$DT\,I(\gamma_2 < FD_b\,it)$	7.7840***		
	(27.2326)		
$DT\,I(FD_c\,it \le \gamma)$		−5.8466***	
		(−16.8952)	
$DT\,I(\gamma_1 < FD_c\,it \le \gamma_2)$		1.5487***	
		(7.9571)	
$DT\,I(\gamma < FD_c\,it)$		2.6868***	
		(18.3217)	
$DT\,I(FD_t\,it \le \gamma)$			−0.5180***
			(−12.2459)
$DT\,I(\gamma_1 < FD_t\,it \le \gamma_2)$			0.6219***
			(51.9724)
$DT\,I(\gamma < FD_t\,it)$			0.6335***
			(39.8033)
Control	Yes	Yes	Yes
Constant	0.6726***	0.8742***	0.6363***
	(28.0040)	(39.9384)	(29.6786)
Observations	33,950	33,950	33,950
Number of id	3119	3119	3119
R-squared	0.072	0.050	0.131

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. To save space, we do not list the regression results for the controls separately

Endogenous test

To solve the possible reverse causality between digital transformation and innovation, this study uses the lag of the independent variable as an instrumental variable in the endogenous test. The results in Table 15 show that the instrumental variables (*IVDT*) and independent variables (*DT*) are significantly positively correlated. The second-stage regression results showed that the coefficients of the interaction variables ($IVDT \times FD_b$ and $IVDT \times FD_c$) were positive and significant at the 1% level. The *p* value of the *LM* and *Wald-F* statistics passed the test. This shows that digital transformation has a positive effect on innovation, and banking and capital markets enhanced the positive impact of digital transformation on innovation.

Discussion and conclusion

This study examined the role of financial development in the impact of digital transformation on innovation. The impact of digital transformation on innovation has garnered significant attention from scholars (Kolloch and Dellermann 2018; Nambisan et al. 2019; Kamalaldin et al. 2021). However, this study adopts a unique perspective by focusing on the influence of financial development. We emphasize that the impact of digital

Table 15 Endogenous test

Variables	(36) First stage	(37) Second stage	(38) First stage	(39) Second stage	(40) First stage	(41) Second stage
	DIG	*PG*	*DIG*	*PG*	*DIG*	*PG*
IVDT	1.1736***	0.5226***	1.4850***	0.7627***	1.5036***	0.4130***
	(24.8842)	(9.4397)	(14.4863)	(7.8545)	(21.1899)	(6.1251)
FD_b			−0.0551**	−0.1832***		
			(−2.3268)	(−6.1176)		
$IVDT \times FD_b$			−0.4867***	0.2851**		
			(−3.7785)	(2.2111)		
FD_c					−0.0364***	−0.0187***
					(−6.5732)	(−3.2353)
$IVDT \times FD_c$					0.0298	0.1125***
					(1.5023)	(5.6672)
	(−6.6979)	(17.0751)	(−6.6383)	(17.3188)	(−6.6041)	(17.1355)
Constant	0.6610***	0.2424***	0.7241***	0.2814***	0.6601***	0.3205***
Control	Yes	Yes	Yes	Yes	Yes	Yes
F Value	130.55***	54.13***	112.98***	45.57***	116.04***	47.49***
LM statistic		602.357***		228.251***		415.766***
Cragg-Donald Wald F statistic		619.224		115.262		211.806
Observations	21,649	21,649	21,649	21,649	21,649	21,649
R-squared	0.068	0.023	0.068	−0.098	0.070	−0.026

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. The regression results of the controls are not listed separately to save space

transformation on corporate innovation changes from negative to positive at different stages of financial development. This finding enriches the theory of digital innovation and enhances the understanding of financial development in the digital era.

Due to the importance of digitalization in economic development and international competitiveness, China has introduced several financial policies to increase support for the digital economy, including, but not limited to, special subsidies, tax incentives, and the establishment of guidance funds. This study uses a moderating effects model to examine how support from banks and capital markets for digital strategies in China is reflected in innovation. This study argues that the rapid development of China's digital transformation, which has become the second largest economy in the scale of the digital economy after the United States,[6] is largely attributable to the credit support of the banking industry and the foresight investment vision of the capital market under the guidance of the policy. China's financial institutions have gradually increased their support for digital projects along with their own development levels and market trends. Therefore, this study further discusses whether different stages of financial development limit the impact of digital transformation on innovation through constructing a threshold regression model and presents a piecewise influenced trend. Based on unique data from China's macro finance and micro companies, this study discusses whether China's current financial support is conducive to digital innovation, provides an empirical reference for financial supply-side reform, and helps countries around the world understand the nonlinear impact of digitalization and the critical role of financial support.

[6] China Academy of Information and Communications, White Paper on the Global Digital Economy (2022), July 29, 2022.

Research conclusion

This study has important implications for two broader research fields, digital innovation ecosystems, financial development, and their cross-sectoral interaction.

First, according to Model (1) in Table 3, the coefficient of digital transformation on innovation is 0.1655. It is statistically significant at the 1% level, indicating that digital transformation and distributed collaboration are new driving forces for innovation. According to Models (4) and (7) in Table 4, the coefficient of digital transformation is positive and statistically significant at the 1% level in both eastern and non-eastern regions. Models (10) and (13) in Table 5 show that this positive impact also exists in the subsamples of SMEs and non-SMEs. This represents that China's digital transformation has penetrated all regions and types of companies, forming a good cycle of further tilting innovation and financial resources. This result is consistent with the findings of previous research, suggesting that successful digital transformation represents a decrease in information asymmetry, an increase in intellectual capital and organizational knowledge management (Mingaleva et al. 2020), and improvements in board policy decision-making (Chen and Hao 2022), all of which have a positive impact on innovation.

Second, according to the moderating effect of financial development in Table 3, the coefficients of banks and capital markets are positive and significant, indicating that financial development enhances the positive impact of digital transformation on innovation. This is also a key factor in digital transformation that existing research has overlooked, apart from intellectual innovation and organizational change (Mingaleva et al. 2020; Pan and Xu 2023). China's policy guidance and financial institutions' pursuit of high returns enhance the impact of banks and capital markets on digital transformation.

Third, according to Models (16) and (17) in Table 7, the effect of digital transformation does not follow a static linear trend. At different financial development levels, the impact of digital transformation on innovation is piecewise linear and changes from negative to positive. This also means that in the company's digital transformation process, financial institutions are the macro variables that must be considered, as they significantly impact digital innovation.

Managerial implications

According to the research conclusion, this paper puts forward several policy recommendations.

First, countries should strengthen their policies that support digital transformation and cultivate an external environment for corporate digital transformation. Based on the significant role of digital transformation in innovation, governments worldwide should encourage and support the development of the digital economy, seize the digital highland by injecting state-owned capital, set up guidance funds, seize the development opportunities of the new generation of the digital revolution, and effectively solve the problems of unclear strategies and inconsistent standards in the digital transformation of enterprises.

Second, it promotes the structural reform of the financial supply side and provides the necessary support for digitalization. The characteristics of digitalization, such as high risk and lack of collateral, are contrary to banks' robust business objectives. The banking industry needs to focus on promoting "intellectual property pledge financing"

and avoid obstacles to digital transformation caused by difficulties in evaluation, realization, and risk control. The initial stages of scientific and technological companies require equity financing, but most developing countries have an imperfect multilevel capital market system. Countries should promote the normalization of IPOs and refinancing based on their actual financial market conditions, strengthen the supervision of the use of raised funds, and guide long-term capital toward truly valuable digital projects.

Finally, for small and medium-sized companies, the positive impact of digital transformation is greater, but financing it is more difficult. This study suggests establishing a special incentive policy through the initial transformation of the "pain period." In addition, to address the problem of uneven digital development among regions and avoid the continuation and widening of the digital divide in the digital economy era, fiscal resources should be tilted towards supporting digital projects in less-developed regions.

Limitations and further research

Although this study provides important insights into the relationship between financial development and digital innovation, it acknowledges the need for further research to address certain limitations. This study did not consider the spatial moderating effect of financial development. The most significant feature of digitalization is its boundlessness; however, it is difficult to research spatial spillover from a micro-level perspective. Future research could discuss how to carry out cooperation or spatial spillovers between different industries or regions.

Appendix

See Tables 16 and 17.

Table 16 Correlation coefficient between variables

	PG	*DT*	FD_b	FD_c	*CS*	*PC*	*EB*	*CF*	*Big4*
PG	1.000								
DT	0.800***	1.000							
FD_b	0.370***	0.491***	1.000						
FD_c	0.493***	0.422***	0.372***	1.000					
CS	− 0.504***	− 0.562***	− 0.504***	− 0.460***	1.000				
PC	− 0.240***	− 0.097	0.440***	0.104	− 0.320***	1.000			
EB	0.862***	0.716***	0.464***	0.454***	− 0.519***	− 0.076	1.000		
CF	− 0.266***	− 0.117*	− 0.267***	− 0.134*	0.230***	0.118*	− 0.380***	1.000	
Big4	0.385***	0.277***	− 0.127*	0.114*	0.056	− 0.635***	0.222***	− 0.067	1.000

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 17 Abbreviations

Abbreviations	Meaning
SMEs	Small and medium-sized companies
non-SMEs	Large companies
IT	Information Technology
AI	Artificial Intelligence
5G	Fifth-generation
IoT	Internet-of-Things
PG	Innovation output
DT	Digital transformation
FD_b	Banking sector
FD_c	Capital market
FD_t	Financial development index
CS	Capital structure
PC	Profitability capability
EB	Equity balance
CF	Cash flow ratio
Big4	Big4
ST, **ST*	Special Treatment Stock
PT	Particular Transfer Stock
CNRDS	Chinese Research Data Services
CSMAR	China Stock Market & Accounting Research Database
S.D	Standard Deviation
Min	Minimum value
Max	Maximum value

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Availability of data and materials
Data can be requested from the first author.

Declarations

Competing interests
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References

Allen F, Qian J, Gu X (2017) An overview of China's financial system. Annu Rev Financ Econ 9:191–231. https://doi.org/10.1146/annurev-financial-112116-025652
Atanassov J, Liu X (2020) Can corporate income tax cuts stimulate innovation? J Financ Quant Anal 55:1415–1465. https://doi.org/10.1017/S0022109019000152

Backman M, Wallin T (2018) Access to banks and external capital acquisition: perceived innovation obstacles. Ann Reg Sci 61:161–187. https://doi.org/10.1007/s00168-018-0863-8
Baron RM, Kenny DA (1986) The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J Pers Soc Psychol 51:1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173
Beck T, Demirgüç-Kunt A, Maksimovic V (2005) Financial and legal constraints to growth: does firm size matter? J Finance 60:137–177. https://doi.org/10.1111/j.1540-6261.2005.00727.x
Bertani F, Ponta L, Raberto M et al (2021) The complexity of the intangible digital economy: an agent-based model. J Bus Res 129:527–540. https://doi.org/10.1016/j.jbusres.2020.03.041
Blanka C, Krumay B, Rueckel D (2022) The interplay of digital transformation and employee competency: a design science approach. Technol Forecast Soc Change 178:121575. https://doi.org/10.1016/j.techfore.2022.121575
Bogoviz AV, Osipov VS, Chistyakova MK, Borisov MY (2019) Comparative analysis of formation of industry 4.0 in developed and developing countries. In: Popkova EG, Ragulina YV, Bogoviz AV (eds) Industry 4.0: industrial revolution of the 21st century. Springer, Cham, pp 155–164
Boot AWA (2000) Relationship banking: what do we know? J Financ Intermed 9:7–25. https://doi.org/10.1006/jfin.2000.0282
Bresciani S, Ciampi F, Meli F, Ferraris A (2021) Using big data for co-innovation processes: mapping the field of data-driven innovation, proposing theoretical developments and providing a research agenda. Int J Inf Manag 60:102347. https://doi.org/10.1016/j.ijinfomgt.2021.102347
Brown KC (1968) The significance of dummy variables in multiple regressions involving financial and economic data. J Finance 23:515–517. https://doi.org/10.1111/j.1540-6261.1968.tb00824.x
Brown JR, Fazzari SM, Petersen BC (2009) Financing innovation and growth: cash flow, external equity, and the 1990s R&D boom. J Finance 64:151–185. https://doi.org/10.1111/j.1540-6261.2008.01431.x
Brown JR, Martinsson G, Petersen BC (2017) Stock markets, credit markets, and technology-led growth. J Financ Intermed 32:45–59. https://doi.org/10.1016/j.jfi.2016.07.002
Cenamor J, Parida V, Wincent J (2019) How entrepreneurial SMEs compete through digital platforms: the roles of digital platform capability, network capability and ambidexterity. J Bus Res 100:196–206. https://doi.org/10.1016/j.jbusres.2019.03.035
Chen P, Hao Y (2022) Digital transformation and corporate environmental performance: the moderating role of board characteristics. Corp Soc Responsib Environ Manag. https://doi.org/10.1002/csr.2324
Cole DC, Shaw ES (1974) Financial deepening in economic development. J Finance 29:1345. https://doi.org/10.2307/2978421
Corvello V, Belas J, Giglio C et al (2023) The impact of business owners' individual characteristics on patenting in the context of digital innovation. J Bus Res 155:113397. https://doi.org/10.1016/j.jbusres.2022.113397
Czarnitzki D, Hottenrott H (2011) R&D investment and financing constraints of small and medium-sized firms. Small Bus Econ 36:65–83. https://doi.org/10.1007/s11187-009-9189-3
Dengler K, Matthes B (2018) The impacts of digital transformation on the labour market: substitution potentials of occupations in Germany. Technol Forecast Soc Change 137:304–316. https://doi.org/10.1016/j.techfore.2018.09.024
Didier T, Levine R, Llovet Montanes R, Schmukler SL (2021) Capital market financing and firm growth. J Int Money Finance 118:102459. https://doi.org/10.1016/j.jimonfin.2021.102459
Dong B, Guo Y, Hu X (2022a) Intellectual property rights protection and export product quality: evidence from China. Int Rev Econ Finance 77:143–158. https://doi.org/10.1016/j.iref.2021.09.006
Dong X, Xu S, Liu J, Tsai F-S (2022b) Does media sentiment affect stock prices? Evidence from China's STAR market. Front Psychol 13:1040171. https://doi.org/10.3389/fpsyg.2022.1040171
Du L, Lin W (2022) Does the application of industrial robots overcome the Solow paradox? Evid China Technol Soc 68:101932. https://doi.org/10.1016/j.techsoc.2022.101932
Du J, Li C, Wang Y (2023) Shadow banking of non-financial firms: arbitrage between formal and informal credit markets in China. J Financ Intermed 55:101032. https://doi.org/10.1016/j.jfi.2023.101032
Ertugrul M, Lei J, Qiu J, Wan C (2017) Annual report readability, tone ambiguity, and the cost of borrowing. J Financ Quant Anal 52:811–836. https://doi.org/10.1017/S0022109017000187
Flannery MJ, Rangan KP (2006) Partial adjustment toward target capital structures. J Financ Econ 79:469–506. https://doi.org/10.1016/j.jfineco.2005.03.004
Frynas JG, Mol MJ, Mellahi K (2018) Management innovation made in China: Haier's Rendanheyi. Calif Manag Rev 61:71–93. https://doi.org/10.1177/0008125618790244
Gabor D (2018) Goodbye (Chinese) shadow banking, hello market-based finance: debate: shadow banking or market-based finance? Dev Change 49:394–419. https://doi.org/10.1111/dech.12387
Gao K, Yuan Y (2022) Government intervention, spillover effect and urban innovation performance: empirical evidence from national innovative city pilot policy in China. Technol Soc 70:102035. https://doi.org/10.1016/j.techsoc.2022.102035
Gigler F, Kanodia C, Sapra H, Venugopalan R (2014) How frequent financial reporting can cause managerial short-termism: an analysis of the costs and benefits of increasing reporting frequency: frequent financial reporting. J Account Res 52:357–387. https://doi.org/10.1111/1475-679X.12043
Giotopoulos I, Kontolaimou A, Korra E, Tsakanikas A (2017) What drives ICT adoption by SMEs? Evidence from a large-scale survey in Greece. J Bus Res 81:60–69. https://doi.org/10.1016/j.jbusres.2017.08.007
Grubel HG, McKinnon RI (1974) Money and capital in economic development. Can J Econ 7:333. https://doi.org/10.2307/134177
Ha LT, Huong TTL, Thanh TT (2022) Is digitalization a driver to enhance environmental performance? An empirical investigation of European countries. Sustain Prod Consumption 32:230–247. https://doi.org/10.1016/j.spc.2022.04.002
Hansen BE (1999) Threshold effects in non-dynamic panels: estimation, testing, and inference. J Econom 93:345–368. https://doi.org/10.1016/S0304-4076(99)00025-1

Harrison R, Li Y, Vigne SA, Wu Y (2022) Why do small businesses have difficulty in accessing bank financing? Int Rev Financ Anal 84:102352. https://doi.org/10.1016/j.irfa.2022.102352
He C, Geng X, Tan C, Guo R (2023) Fintech and corporate debt default risk: influencing mechanisms and heterogeneity. J Bus Res 164:113923. https://doi.org/10.1016/j.jbusres.2023.113923
Hor SC, Chang A, Torres de Oliveira R, Davidsson P (2021) From the theories of financial resource acquisition to a theory for acquiring financial resources: how should digital ventures raise equity capital beyond seed funding. J Bus Ventur Insights 16:e00278. https://doi.org/10.1016/j.jbvi.2021.e00278
Hsu P-H, Tian X, Xu Y (2014) Financial development and innovation: cross-country evidence. J Financ Econ 112:116–135. https://doi.org/10.1016/j.jfineco.2013.12.002
Hu GX, Pan J, Wang J (2021) Chinese capital market: an empirical overview. Crit Finance Rev 10:125–206. https://doi.org/10.1561/104.00000097
Iddrisu AG, Chen B (2022) Economic growth through digitalization in Africa: does financial sector development play a mediating role? IJOEM. https://doi.org/10.1108/IJOEM-02-2022-0278
Jiang F, Kim KA, Ma Y et al (2019) Corporate culture and investment-cash flow sensitivity. J Bus Ethics 154:425–439. https://doi.org/10.1007/s10551-017-3444-3
Jiang K, Du X, Chen Z (2022) Firms' digitalization and stock price crash risk. Int Rev Financ Anal 82:102196. https://doi.org/10.1016/j.irfa.2022.102196
Kamalaldin A, Sjödin D, Hullova D, Parida V (2021) Configuring ecosystem strategies for digitally enabled process innovation: a framework for equipment suppliers in the process industries. Technovation 105:102250. https://doi.org/10.1016/j.technovation.2021.102250
Kamble SS, Gunasekaran A, Sharma R (2018) Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. Comput Ind 101:107–119. https://doi.org/10.1016/j.compind.2018.06.004
Kolloch M, Dellermann D (2018) Digital innovation in the energy industry: The impact of controversies on the evolution of innovation ecosystems. Technol Forecast Soc Change 136:254–264. https://doi.org/10.1016/j.techfore.2017.03.033
Kong X, Si D-K, Li H, Kong D (2021) Does access to credit reduce SMEs' tax avoidance? Evidence from a regression discontinuity design. Financ Innov 7:18. https://doi.org/10.1186/s40854-021-00235-3
Lang M, Maffett M (2010) Economic effects of transparency in international equity markets: a review and suggestions for future research. Found Trends Account 5:175–241. https://doi.org/10.1561/1400000016
Liang D, Qi X (2013) Comparative analysis on financing models of innovative small and medium enterprises in France and in China. In: 2013 International conference on management science and engineering 20th annual conference proceedings. IEEE, Harbin, China, pp 1915–1921
Lee I, Shin YJ (2018) Fintech: ecosystem, business models, investment decisions, and challenges. Bus Horiz 61:35–46. https://doi.org/10.1016/j.bushor.2017.09.003
Leon F (2015) Does bank competition alleviate credit constraints in developing countries? J Bank Finance 57:130–142. https://doi.org/10.1016/j.jbankfin.2015.04.005
Li X-M (2017) New evidence on economic policy uncertainty and equity premium. Pac Basin Finance J 46:41–56. https://doi.org/10.1016/j.pacfin.2017.08.005
Li L (2022) Digital transformation and sustainable performance: the moderating role of market turbulence. Ind Mark Manag 104:28–37. https://doi.org/10.1016/j.indmarman.2022.04.007
Li J, Xia J, Zajac EJ (2018) On the duality of political and economic stakeholder influence on firm innovation performance: theory and evidence from Chinese firms. Strateg Manag J 39:193–216. https://doi.org/10.1002/smj.2697
Li L, Lin J, Ouyang Y, Luo X (2022) Evaluating the impact of big data analytics usage on the decision-making quality of organizations. Technol Forecast Soc Change 175:121355. https://doi.org/10.1016/j.techfore.2021.121355
Liang L, Chen M, Luo X, Xian Y (2021) Changes pattern in the population and economic gravity centers since the reform and opening up in China: the widening gaps between the South and North. J Clean Prod 310:127379. https://doi.org/10.1016/j.jclepro.2021.127379
Liu G, Zhang C (2020) Does financial structure matter for economic growth in China. China Econ Rev 61:101194. https://doi.org/10.1016/j.chieco.2018.06.006
Liu D, Sun W, Zhang X (2020) Is the Chinese economy well positioned to fight the COVID-19 pandemic? The financial cycle perspective. Emerg Mark Finance Trade 56:2259–2276. https://doi.org/10.1080/1540496X.2020.1787152
Liu C, Fan Y, Xie Q, Wang C (2022a) Market-based versus bank-based financial structure in China: from the perspective of financial risk. Struct Change Econ Dyn 62:24–39. https://doi.org/10.1016/j.strueco.2022.03.013
Liu C, Zhang W, Zhu X (2022b) Does digital transformation promote enterprise development? Evidence from Chinese A-share listed enterprises. J Organ End User Comput 34:1–18. https://doi.org/10.4018/JOEUC.307156
Liu M, Li C, Wang S, Li Q (2023) Digital transformation, risk-taking, and innovation: Evidence from data on listed enterprises in China. J Innov Knowl 8:100332. https://doi.org/10.1016/j.jik.2023.100332
Loughran T, McDonald B (2020) Textual analysis in finance. Annu Rev Financ Econ 12:357–375. https://doi.org/10.1146/annurev-financial-012820-032249
Love I, Martinez Peria MS (2012) How Bank Competition Affects Firms' Access to Finance. SSRN Journal. https://doi.org/10.2139/ssrn.2144888
Love I, Martínez Pería MS (2015) How bank competition affects firms' access to finance. WorldBank Econ Rev 29:413–448. https://doi.org/10.1093/wber/lhu003
Mingaleva Z, Deputatova L, Starkov Y (2020) Management of organizational knowledge as a basis for the competitiveness of enterprises in the digital economy. In: Antipova T (ed) Integrated science in digital age. Springer, Cham, pp 203–212
Monetary Policy Analysis Group of the People's Bank of China (2023) China Regional Financial Operations Report (2022). People's Bank of China.http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/5127467/20231109165451725 32.pdf.
Mourtzis D (2020) Simulation in the design and operation of manufacturing systems: state of the art and new trends. Int J Prod Res 58:1927–1949. https://doi.org/10.1080/00207543.2019.1636321

Mundell RA (1963) Capital mobility and stabilization policy under fixed and flexible exchange rates. Can J Polit Sci 29:475–485. https://doi.org/10.2307/139336
Myers SC, Majluf NS (1984) Corporate financing and investment decisions when firms have information that investors do not have. J Financ Econ 13:187–221. https://doi.org/10.1016/0304-405X(84)90023-0
Nambisan S, Wright M, Feldman M (2019) The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. Res Policy 48:103773. https://doi.org/10.1016/j.respol.2019.03.018
Nasiri M, Ukko J, Saunila M, Rantala T (2020) Managing the digital supply chain: the role of smart technologies. Technovation 96–97:102121. https://doi.org/10.1016/j.technovation.2020.102121
Newell S, Marabelli M (2015) Strategic opportunities (and challenges) of algorithmic decision-making: a call for action on the long-term societal effects of 'datification.' J Strat Inf Syst 24:3–14. https://doi.org/10.1016/j.jsis.2015.02.001
Nigam N, Benetti C, Johan SA (2020) Digital start-up access to venture capital financing: what signals quality? Emerg Mark Rev 45:100743. https://doi.org/10.1016/j.ememar.2020.100743
Niu Y, Wen W, Wang S, Li S (2023) Breaking barriers to innovation: the power of digital transformation. Finance Res Lett 51:103457. https://doi.org/10.1016/j.frl.2022.103457
Nölke A, ten Brink T, May C, Claar S (2019) State-permeated capitalism in large emerging economies, 1st edn. Routledge, New York
Nylund PA, Arimany-Serrat N, Ferras-Hernandez X et al (2019) Internal and external financing of innovation: sectoral differences in a longitudinal study of European firms. Eur J Innov Manag 23:200–213. https://doi.org/10.1108/EJIM-09-2018-0207
Pagani M, Pardo C (2017) The impact of digital technology on relationships in a business network. Ind Mark Manag 67:185–192. https://doi.org/10.1016/j.indmarman.2017.08.009
Pan X, Xu G (2023) The impact of managers' IT experience on the enterprises' digital transformation: empirical evidence from China. Appl Econ. https://doi.org/10.1080/00036846.2023.2207813
Parida V, Sjödin D, Reim W (2019) Reviewing literature on digitalization, business model innovation, and sustainable industry: past achievements and future promises. Sustainability 11:391. https://doi.org/10.3390/su11020391
Peng Y, Tao C (2022) Can digital transformation promote enterprise performance? From the perspective of public policy and innovation. J Innov Knowl 7:100198. https://doi.org/10.1016/j.jik.2022.100198
Pershina R, Soppe B, Thune TM (2019) Bridging analog and digital expertise: cross-domain collaboration and boundary-spanning tools in the creation of digital innovation. Res Policy 48:103819. https://doi.org/10.1016/j.respol.2019.103819
Petry J (2020) Financialization with Chinese characteristics? Exchanges, control and capital markets in authoritarian capitalism. Econ Soc 49:213–238. https://doi.org/10.1080/03085147.2020.1718913
Petry J (2021) Same same, but different: varieties of capital markets, Chinese state capitalism and the global financial order. Compet Change 25:605–630. https://doi.org/10.1177/1024529420964723
Pham TTT, Nguyen KS, Nguyen HH et al (2021) Dynamic entrepreneurship, planned innovation, and firm profitability: evidence from a Southeast Asian country. Heliyon. https://doi.org/10.1016/j.heliyon.2021.e07599
Purewal K, Haini H (2022) Re-examining the effect of financial markets and institutions on economic growth: evidence from the OECD countries. Econ Change Restruct 55:311–333. https://doi.org/10.1007/s10644-020-09316-2
Senyo PK, Liu K, Effah J (2019) Digital business ecosystem: literature review and a framework for future research. Int J Inf Manag 47:52–64. https://doi.org/10.1016/j.ijinfomgt.2019.01.002
Shakina E, Parshakov P, Alsufiev A (2021) Rethinking the corporate digital divide: the complementarity of technologies and the demand for digital skills. Technol Forecast Soc Change 162:120405. https://doi.org/10.1016/j.techfore.2020.120405
Shan S, Mirza N, Umar M, Hasnaoui A (2023) The nexus of sustainable development, blue financing, digitalization, and financial intermediation. Technol Forecast Soc Change 195:122772. https://doi.org/10.1016/j.techfore.2023.122772
Shen L, He G (2022) Threshold effect of financial system on high-quality economic development. J Math 2022:e9108130. https://doi.org/10.1155/2022/9108130
Singh S, Sharma M, Dhir S (2021) Modeling the effects of digital transformation in Indian manufacturing industry. Technol Soc 67:101763. https://doi.org/10.1016/j.techsoc.2021.101763
Toothaker LE (1994) Multiple regression: testing and interpreting interactions. J Oper Res Soc 45:119–120. https://doi.org/10.1057/jors.1994.16
Trinugroho I, Law SH, Lee WC et al (2021) Effect of financial development on innovation: roles of market institutions. Econ Model 103:105598. https://doi.org/10.1016/j.econmod.2021.105598
Ullah F, Sepasgozar SME, Thaheem MJ, Al-Turjman F (2021) Barriers to the digitalisation and innovation of Australian Smart Real Estate: a managerial perspective on the technology non-adoption. Environ Technol Innov 22:101527. https://doi.org/10.1016/j.eti.2021.101527
Verhoef PC, Broekhuizen T, Bart Y et al (2021) Digital transformation: a multidisciplinary reflection and research agenda. J Bus Res 122:889–901. https://doi.org/10.1016/j.jbusres.2019.09.022
Wang Q, Du Z-Y (2022) Changing the impact of banking concentration on corporate innovation: the moderating effect of digital transformation. Technol Soc 71:102124. https://doi.org/10.1016/j.techsoc.2022.102124
Wen S, Lin B, Zhou Y (2021) Does financial structure promote energy conservation and emission reduction? Evidence from China. Int Rev Econ Finance 76:755–766. https://doi.org/10.1016/j.iref.2021.06.018
Wu M, Zhao M, Wu Z (2019) Evaluation of development level and economic contribution ratio of science and technology innovation in eastern China. Technol Soc 59:101194. https://doi.org/10.1016/j.techsoc.2019.101194
Xu A, Qiu K, Jin C et al (2022a) Regional innovation ability and its inequality: measurements and dynamic decomposition. Technol Forecast Soc Change 180:121713. https://doi.org/10.1016/j.techfore.2022.121713
Xu P, Xu X, Bai G (2022b) Corporate environmental responsibility, CEO's tenure and innovation legitimacy: evidence from Chinese listed companies. Technol Soc 70:102056. https://doi.org/10.1016/j.techsoc.2022.102056
Yu H, Wang J, Hou J et al (2023) The effect of economic growth pressure on green technology innovation: do environmental regulation, government support, and financial development matter? J Environ Manag 330:117172. https://doi.org/10.1016/j.jenvman.2022.117172
Yue S, Lu R, Shen Y, Chen H (2019) How does financial development affect energy consumption? Evidence from 21 transitional countries. Energy Policy 130:253–262. https://doi.org/10.1016/j.enpol.2019.03.029

Zhang Q, Zou H-F (2012) Regional inequality in contemporary China. Annal Econ Finance 13:113–137
Zhang Y, Uchida K, Dong L (2020) External financing and earnings management: evidence from international data. Res Int Bus Finance 54:101275. https://doi.org/10.1016/j.ribaf.2020.101275
Zhang X, Gao C, Zhang S (2022) The niche evolution of cross-boundary innovation for Chinese SMEs in the context of digital transformation: case study based on dynamic capability. Technol Soc 68:101870. https://doi.org/10.1016/j.techsoc.2022.101870
Zheng X, Li F, Song S, Yu Y (2013) Central government's infrastructure investment across Chinese regions: a dynamic spatial panel data approach. China Econ Rev 27:264–276. https://doi.org/10.1016/j.chieco.2012.12.006
Zhu X, Asimakopoulos S, Kim J (2020) Financial development and innovation-led growth: is too much finance better? J Int Money Finance 100:102083. https://doi.org/10.1016/j.jimonfin.2019.102083
Zhuo C, Chen J (2023) (2023) Can digital transformation overcome the enterprise innovation dilemma: Effect mechanism and effective boundary. Technol Forecast Soc Change 190:122378. https://doi.org/10.1016/j.techfore.2023.122378

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