Journal of Information Economics

Homepage: https://anser.press/index.php/JIE

How does financial development environment affect regional innovation capabilities? New perspectives from digital finance and institutional quality

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ABSTRACT

Based on China's 30 provincial panel data from 2006 to 2018, this paper uses the spatial Durbin model to empirically study the influence path and transmission mechanism of financial development on regional technological innovation, and introduce digital finance environment, marketization degree, and government environmental management as an adjustment variable to verify its regulating effect on financial development and regional technological innovation. The study found that the overall promotion of digital finance to local technological innovation is not significant. Besides, the characteristics of ownership discrimination and weak risk appetite in the bank's medium and long-term credit market have led to its failure to promote regional technological innovation. In contrast, the stock market and bond market in direct financing channels have enhanced local innovation capabilities. When the external environmental system is used as the adjustment variable, the results show that an excellent digital finance development, marketization degree, and government environmental management can effectively and positively regulate the effect of financial development and technological innovation.

KEYWORDS

Institutional quality; R&D input; Regional innovation ability; Threshold effect

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ISSN 2972-3671
doi: 10.58567/jie01010003

Received 10 December 2022; Accepted 13 January 2023; Available online 16 January 2023

1. Introduction

Economic development is full of stage characteristics. In order to break through economic development, innovation has become an essential factor for China's economic growth and transformation (Khan et al.,2020). Under the continuing global economic downturn, the steady improvement of regional innovation capabilities will provide a valuable opportunity for China's new economic development and high-quality development (Wu et al., 2019). In recent years, China's scientific and technological development has been vigorous. The average annual investment in technological innovation has increased by more than 15%. The proportion of R&D investment in GDP far exceeds the EU average and is close to the average high-income countries (Peng et al., 2020). However, the continuous increase in scientific and technological innovation input has not yet manifested its effect on the improvement of China's total factor productivity, and the expansion of scientific and technological innovation input has reduced the contribution of total factor productivity to economic growth and has fallen into the dilemma of technological innovation (Shi et al., 2022). Nowadays, economic and political games are intensifying on the international stage, and the role of financial services in the real economy is especially critical for China to become an innovative country in 2035 (Mai et al., 2019). As the core of modern finance, a financial market is an important place for resource allocation. The availability of funds and the distribution efficiency of financial channels are different, which leads to different mechanisms for the influence of financial markets on economic growth and regional technological innovation capabilities (Zhu et al., 2020). China's financial development has now entered a new transitional period. There are long-term structural and institutional contradictions in the financial system, management operations, and rule-making, and the development of the financial market is in a slow and irregular state, which leads to the heterogeneity of the role of the financial market in promoting regional technological innovation (Xie et al., 2019). Therefore, this is an important way to break through China's current technological innovation dilemma by studying the impact of financial market development on regional technological innovation capabilities, and it is also a reliable guarantee for achieving high-quality development in China.

Due to problems such as structural mismatch, traditional financial services cannot effectively solve the financing problems faced by enterprise technology innovation (Li et al., 2022). In recent years, with the development of big data, blockchain, artificial intelligence and other technologies, whether the development of digital finance can improve the enterprise financing environment and promote technological innovation has become a new research topic (Hao et al., 2023; Wu et al., 2021a; Ren et al., 2022a). Inclusive finance provides financial services at affordable prices and helps to alleviate the conflict between supply and demand of finance (Cao and Zhang, 2022; Sarma and Pais, 2011; Turvey and Xiong, 2017). Digital inclusive finance further reduces operational costs, assessment difficulties, operating prices, and marketing costs (Du et al., 2022). Thus, by alleviating financing constraints and information asymmetries, digital inclusive finance contributes to firms' technological innovation. However, another group of scholars has put forward the opposite view, arguing that low-cost finance resources may lead firms to focus on the virtual economy and crowd out innovative innovation inputs. In order to avoid risks and resolve regulatory pressure, some financial institutions often detach from innovative business when engaging in digital inclusive financial services. These risk-averse behaviors squeeze out the inputs and outputs of technological innovation. So, what kind of impact does digital inclusive finance have on enterprise innovation? What is the moderating role of external institutional quality? The existing studies do not reach a consensus. Therefore, this paper develops a fixed effects model and a mediating effects model based on the digital inclusion finance index and inter-provincial panel data in China to empirically test the impact of digital finance on technological innovation and examine the moderating role of external institutional quality.

In summary, the main contributions of this study include the following aspects. Firstly, this article divides the financial market into three dimensions: the medium and long-term bank credit market, the stock market, and the bond market. Secondly, this paper explores the heterogeneous impact of the external institutional environment on

regional innovation capabilities from the finance ecological environment, the degree of marketization, and government environmental management. It makes up for the lack of previous studies that only consider a single channel. Finally, this article uses the spatial panel Durbin model and PVAR model, which reflects the spatial dependence of economic indicators on the regional distribution and identifies the long-term dynamic relationship between economic variables.

2. Literature review

In the book "Economic Development Theory", Schumpeter (1982) first proposed the importance of capital for technological innovation and provided a theoretical basis for the mechanism of financial market development on industrial technological innovation. After the formation of the new growth theory, the research on financial development focused on the impact of technological innovation on economic growth, which provided theoretical support for subsequent discussions on financial markets and regional innovation capabilities (Romer, 1990; Coe and Helpman, 1995). The empirical results of many scholars show that financial markets play an important role in economic growth (Biosca, 2007). The financial market's support theory believes that technological innovation companies are difficult to obtain financial market support because of the high investment amount and high investment risk (Beck and Levine (2002). The financial markets with risk diversification and risk hedging mechanisms can effectively reduce the risk concerns of innovative companies and promote the continuous development of technological innovation activities (Allen and Gale, 1999; Tadesse, 2005; Shin and Buera, 2013). A sound financial market can not only guide financial investment in the field of technological innovation through financing prices but also provide financial owners with effective incentives and win-win opportunities, thus forming a virtuous circle of regional technological innovation activities (Brown et al., 2013). The scholars have compared and analyzed the support effect of the financial market on industrial technology innovation. The study found that there is a significant difference between equity financing and debt financing. The equity financing is more suitable for technical R&D investment projects with high-risk characteristics (Yeh et al., 2013).

Due to the obvious transformational characteristics of China's financial system, some scholars have conducted a series of empirical studies on the relationship between financial development and technological progress using China's financial market as the research object. The study found that there is a long-term equilibrium relationship between financial development and technical efficiency, which can not only solve financing constraints but also has a significant positive effect on regional innovation growth (Zhu et al., 2020; Guan and Yam, 2015). This promotion effect is related to the stage of economic development. The scholars analyzed the financial market's support effects on industrial technology innovation and concluded that banks provide very low lending funds for strategic high-tech industries because the assets of high-tech enterprises are mainly knowledge and technology that are difficult to use as collateral (Peng, et al., 2020).

The above research provides a theoretical framework and empirical analysis on the relationship between financial development and regional innovation, but there are still certain shortcomings. Firstly, the previous studies mainly discussed the relationship between financial system design or financial market and economic development, while the relationship between financial development and regional innovation was rarely involved. Secondly, the financial market measurement methods mostly use single indicators in the bank's medium and long-term credit market, stock market, and bond market, and few scholars incorporate the three into the same framework for careful consideration. Thirdly, China is in an active period of factor marketization reforms, and there are apparent differences in inter-regional external environments, which to a certain extent, will have a significant regulatory effect on financial development and regional innovation activities. However, existing research lacks a systematic analysis from the perspective of the external institutional environment. Finally, the current research methods ignore that local innovation may have spatial spillover effects.

3. Theoretical mechanism

The capital factors and traditional production factors have the same tendency to pursue the maximization of benefits. The uneven distribution of capital in space has caused differences in regional economic development (Mai, 2019). This feature has also promoted the cross-regional transfer of finance, which can promote the structural adjustment of existing stocks and optimize the configuration of financial industries, and therefore has become the main driving force for regional innovation and promotion (Wu et al., 2019). As a market-oriented risk transfer mechanism, the financial market has economic compensation and risk management functions, which can provide risk-sharing for the financial market to intervene in high-risk and high-tech industries and promote the development of strategic emerging industries and technological progress (Zhu et al., 2020).

The domestic reform and opening up of the financial sector have undoubtedly been the most drastic period of financial development and changes in China since the 21st century. There are significant irrational phenomena in China's financial market in terms of market pricing, market credit game system, basic norms, and governance mechanisms (Hirsch, 2011). This led to the failure of the competition mechanism and restraint mechanism of China's financial market. There is a non-market phenomenon, which obviously over-supports traditional industries and makes technological innovation activities into a difficult situation of financing, which has a transfer effect and crowding-out effect on many small and medium-sized emerging industries. Guan (2015) found that financial market distortion not only affects the resource allocation efficiency of incumbent enterprises and directly reduces economic efficiency, but also changes the entry and exit behavior of enterprises through monopoly, thereby indirectly reducing economic efficiency. The inefficient allocation of resources in the financial market has obviously been unable to meet the requirements of innovation-driven development, making it insufficient endogenous motivation to provide financial services to emerging industries, which indirectly hinders the improvement of China's regional innovation capabilities (Hsu et al., 2013). In summary, this paper proposes the following theoretical hypothesis 1.

Hypothesis 1: Due to the severe resource mismatch in China's financial development, the role of financial development in enhancing regional innovation capabilities is not significant.

China's financial system currently has apparent characteristics of transformation. The distribution of the financial system implies government guarantees, ownership discrimination, and weak risk appetite, which makes capital concentrated in the real estate industry (Ge, 2007; Amin et al., 2022). This is an important reason for the inefficient allocation of resources in the financial sector. Lu (2012) studied the discrimination of property rights credit in China and concluded that bank credit often implements higher-level risk control on private enterprises, and clearly favors state-owned enterprises in terms of loan term structure and loan interest rates. This will hinder fair competition between companies with different property rights. Most banks are still at the exploratory stage in the field of risk appetite. They have not established a complete risk management system and a mature risk appetite system framework, and banks have a robust risk appetite, which has triggered a hesitation in credit investment in high-input technological innovation projects (Haque, 2013; Hsu et al., 2014). Due to the preference of banks in low-risk and mature industries, it is difficult for innovative enterprises to obtain support from the formal financial system for their innovation activities, and direct financing provides a convenient channel to promote industrial technological innovation (Park, 2022). The stock market provides long-term investment in technological innovation for small and medium enterprises, and equity financing channels are beneficial to support regional technological innovation. In summary, this paper proposes the following theoretical hypothesis 2.

Hypothesis 2: Due to the long-term structural, institutional contradictions, and development heterogeneity of the financial market, the influence of the financial development on regional innovation capabilities is also heterogeneous.

Digital finance has made creative improvements to the traditional financial services model (Ketterer, 2017). It forces the digital transformation of the traditional sector as a way to improve credit mismatch, increase wind

resistance, and weaken border constraints. Digital finance can transfer more capital elements to highly efficient real enterprises and improve the efficiency of traditional financial capital allocation (Ozili, 2018). At the same time, with the help of big data and digital technology, digital finance can enhance information transparency, reduce the risk of financial mismatch in the capital market, optimize the allocation of capital market factors, improve the efficiency of capital use, and stimulate the innovative vitality of high-quality enterprises (Ren et al., 2022b; Li et al., 2020). On the other hand, with the help of big data, cloud computing and other emerging information technologies, digital finance can effectively reduce the information asymmetry between banks and enterprises in real time and solve the problem of difficult and expensive financing for enterprises to promote green innovation. In summary, this paper proposes the following theoretical hypothesis 3.

Hypothesis 3: The digital finance affects the effect of financial development on technological innovation, and a good digital finance environment can positively regulate the effect of financial development on regional technological innovation.

The degree of marketization reflects the market's effect on resource allocation and forms a unified market operation mechanism and market system (Wang et al., 2022). The imperfect market mechanism will cause financial development to inhibit innovation ability of enterprises, which objectively weakens the possibility of cooperation between financial owners and entrepreneurs, and hinders the efficient flow of finance from owners to demanders (Khan et al., 2020). This has aggravated the difficulty for companies to raise funds in the local area, indirectly increased operating costs, and curbed output efficiency. When the market power is weak, the market's ability to determine prices and the efficiency of resource allocation is weaker, and it cannot effectively encourage enterprises to build a suitable flow mechanism of innovative elements, thus hindering enterprise technological innovation (Lu, 2012). This means that companies will face higher R&D costs and cause higher R&D risks. The regions with a higher degree of marketization have more liberalized financial markets, which can not only promote the allocation of resources in the financial market according to market prices but also effectively expand the financing channels for enterprises' original technology innovation, which is more conducive to enterprises to reduce R&D risks and improve regional technology levels (Peng, 2020). Therefore, the restraining effect of financial development on regional technological innovation has an optimal adjustment effect on the degree of marketization. In summary, this paper proposes the following theoretical hypothesis 4.

Hypothesis 4: The effect of financial development on technological innovation is affected by the degree of marketization, and a good degree of marketization can positively regulate the effect of financial development on regional technological innovation.

All economic activities in a market economy are autonomously adjusted to maximize benefits under the condition of price equilibrium, but autonomous adjustment will also cause some enterprises to have unethical and even illegal behaviors out of a profit-seeking mentality (Shin, 2007). China has distinctive institutional characteristics. Although the government's adjustment of resource allocation and market imbalance is conducive to restoring market order, the government's excessive administrative intervention in the factor market has led to a misallocation of financial market resources (Guan, 2015). The government's intangible preference for state-owned enterprises has caused more capital to flow to state-owned enterprises with lower innovation efficiency and distorted the allocation of funds in the financial market (Brown, 2013). Therefore, government efficiency and financial market supervision can help the financial market allocate resources based on price signals to promote technological innovation to the optimal boundary (Hirsch, 2011). This paper proposes the following theoretical hypothesis 5.

Hypothesis 5: The effect of financial development on regional technological innovation is affected by government environmental control. A good government management can positively regulate the effect of financial development on regional technological innovation.

4. Methodology and data

4.1. Econometric Methodology

The existing research shows that financial development has strong spatial correlation characteristics, and ignoring its inherent spatial spillover effects will lead to biased estimation results (Coe, 1995). The regional innovation may have path-dependent characteristics and may have a two-way causal relationship with financial development and R&D investment, leading to endogenous problems. Therefore, the lagging period of regional technological innovation variables is included in the analysis framework. Since the spatial Durbin model introduces both endogenous and exogenous interactions, it can control the spatial spillover effects and endogeneity between variables (Wu et al., 2021b; Yang et al., 2021). Therefore, this paper constructs the dynamic space Durbin model as formula (1).

$$lninno_{it} = \beta_0 + \rho \sum_{j=1}^{n} w_{it} lninno_{it} + \beta_1 lninno_{it-1} + \beta_2 \sum_{j=1}^{n} w_{it} lncmd_{it} + \beta_2 lnX_{it} + \varepsilon_{it} \quad (1)$$

i represents the province, t represents the year, $lninno_{it}$ is the regional innovation capability, and $lninno_{it-1}$ is the lagging one-phase item of the regional innovation capability. $\mathrm{cmd_{it}}$ represents the financial development indicators, which mainly include stock market development indicators (stock), bond market development indicators (bond), and mid- and long-term bank credit development indicators (bank). X is a series of control variables, including industrial structure adjustment index (ind_{it}), R&D personnel input (rdp_{it}), R&D capital input (rd_{it}), human capital (hum_{it}). ρ is the spatial spillover coefficient of technological innovation, β_0, β_1, β_2, … , β_n are the parameters to be estimated, W_{it} is the N×N-order spatial weight matrix, ε_{it} is the random disturbance term, which is the heteroscedasticity and collinearity of the control model, all indicators are logarithmic.

4.2. Explanation of variables

4.2.1. Regional innovation capability

The regional innovation capability is a multi-dimensional concept, including innovation input, innovation output, innovation capability diffusion, and innovation environment support. The existing studies mostly choose a single indicator to measure regional innovation capabilities, which cannot fully reflect its connotation. Therefore, this article draws on Kosajan (2018) research and adopts the full array polygon index method for index synthesis. This method not only reflects the principle of system integration but also avoids the problem of overlapping information between multiple index variables. A comprehensive review was done on the development status of innovation capabilities. The evaluation method's basic principle is to set n indicators and use the maximum value of these indicators as the radius to construct (n-1)!/2 irregular center n polygons whose vertices are connected from the beginning to the end of the n indicators Full arrangement. The composite index is the ratio of the mean value of all irregular polygons to the area of the central polygon. The specific calculation process is formula (2).

$$F(x) = \frac{a}{bx + c} \quad (2)$$

a, b, and c respectively represent the parameters of the hyperbolic function.

The hyperbolic standardized function F(x) is constructed to satisfy: F(U)=1, F(T)=0, F(L)=-1, where U is the upper limit of index x, and L is the index of x the lower limit, T is the critical value of index x, and the critical value can be expressed by the average value of the index. Formula (3) can be obtained from the above conditions.

$$F(x) = \frac{(U - l)(x - T)}{(U + L - 2T)x + UT + LT - 2UT} \quad (3)$$

It can be seen from formula (2) that the standardization function F(x) maps the index value located in [L, U] to [-1, 1]. The standardization process will cause the index value to show a fast-slow-fast non- Linear growth trend.

Corresponding to the i index, the standardized formula is formula (4).

$$S_i(x) = \frac{(U_i - I_i)(x_i - T_i)}{(U_i + L_i - 2T_i)x + U_iT_i + L_iT_i - 2UT} \tag{4}$$

The vertices of the n-sided shape are composed of values under the condition of S_i=1, and the center point is composed of values under the condition of S_i=-1. The critical value that constitutes the polygon index is when S_i=0, when it is above the critical value, each index value is positive, and when it is below the index value, each index value is negative.

The comprehensive index of full array polygon is as formula (5).

$$S(x) = \frac{\sum_{i\neq j}^{i,j}(S_i + 1)(S_j + 1)}{2n(n-1)} \tag{5}$$

S is a comprehensive index, and S_i is a single index.

Table 1. Index system of regional innovation capability.

First indicator	Secondary indicators	three indicators	unit
Regional innovation capability	Innovation investment	Total number of people engaged in R&D	Million
		R&D project investment funds	100 million yuan
		Internal expenditure of R&D expenses	100 million yuan
		outside expenditure of R&D expenses	100 million yuan
		R&D project personnel input	Million
	Innovation output	Three types of patent applications accepted per 10,000 people	Million
		Three types of patent applications approved per 10,000 people	Million
		Number of scientific papers published per 10,000 people	Million
	Diffusion of innovation	Technical market transaction amount	100 million yuan
		The amount of foreign technology contracts introduced by region	100 million yuan
		Large and medium-sized industrial enterprises introduce technology funds	100 million yuan
	Innovative environment support	The average number of students in colleges and universities per 10,000 people	Million
		The average road ownership per 10,000 people	Km
		The number of health technicians per 10,000 people	Million
		Total investment in fixed assets of the whole society by region	100 million yuan
		Education expenditure per capita	Yuan

4.2.2. Financial Development (CMD)

Drawing on Caprio's (1999) research on financial development, this article mainly composed of three sub-markets: the stock market, the bank's mid- and long-term credit market, and the bond market. This article uses the ratio of each province's stock market value to GDP to measure the stock market's development indicators. The ratio of bond financing to each province's GDP is used to measure the bond market's development indicators. The medium- and long-term credit development indicators of the banks are measured by the ratio of the medium and long-term credit of the banks of each province to GDP. This paper uses the full array polygon index method to

synthesize the three sub-markets to form the financial development index.

4.2.3. External institutional environment

The degree of marketization (market) is measured by Beck's (2002) research on China's marketization index. The Digital Inclusive Finance Index (FE), jointly compiled by the Institute of Digital Finance of Peking University and Ant Financial Services Group, is used to measure the overall development level of digital finance in China (Li et al. 2020). Government environmental management (gov). This paper constructs a government environmental management indicator system from four dimensions: judicial protection, administrative protection, government services, and corruption control to comprehensively reflect the level of regional government environmental management, as shown in table 2.

Table 2. Government environmental management measurement indicators.

First indicator	Secondary indicators	three indicators	unit
Government environmental management	judicial protection	The number of regional lawyers as a percentage of the total population of the region	%
	administrative protection	The percentage of closed cases of infringement cases, closed cases of other patents, and closed cases of passing off others as a percentage of patent authorizations	%
	government services	The non-tax revenue as a percentage of total government revenue The ratio of fiscal revenue to fiscal expenditure	%
	corruption control	The number of public officials involved per 10,000 people	%

4.2.4. Control variables

This paper selects human capital (HUM), R&D investment (RD), R&D personnel investment (RDP), and industrial structure adjustment index (IND) as control variables to avoid the unobservable factors' biases on the measurement results as much as possible. The human capital uses the weighted average of the years of education of people aged six and above in each region (Wang et al., 2022; Hao et al., 2020). R&D personnel investment is fully measured by R&D personnel. The intensity of R&D investment is measured by the ratio of regional R&D investment to regional GDP (Zhou et al., 2022). The industrial structure adjustment index is measured by the ratio of the added value of the tertiary industry to the secondary industry in each province (Liu et al., 2022). The data comes from the "China Statistical Yearbook" and "China Finance Yearbook." The missing data of related variables are calculated using linear regression to calculate the fitting coefficients to obtain extrapolated values.

Table 3. The statistical description of variables.

Variable	Definition	Obs	Mean	Std.	Min	Max	Unit
Inno	Regional innovation capability	390	5.728	0.534	2.126	7.345	-
rd	R&D investment	390	0.015	0.011	0.002	0.060	%
hum	human capital	390	8.574	0.966	6.594	12.028	-
ind	industrial structure adjustment	390	0.476	0.009	0.333	0.809	%
rdp	R&D personnel investment	390	10.93	1.175	7.14	13.21	-
cmd	Financial Development	390	0.123	0.112	0.000	1.000	-
bank	the bank's mid- and long-term credit market	390	0.641	0.277	0.240	1.855	%
stock	the stock market	390	0.565	1.182	0.041	10.535	%
bond	the bond market	390	0.041	0.111	0.000	0.949	%
market	The degree of marketization	390	7.889	2.191	3.250	13.930	-
gov	Government environmental management	390	0.866	0.143	0.353	1.238	-

5. Empirical Results

5.1. Spatial correlation test

Referring to the research of Hao et al. (2022) and Yang et al. (2022), this paper uses Stata14.0 to calculate the Moran index of the variable to check whether there is a spatial correlation between the explained variable and the explanatory variable, and uses the geographical proximity weight matrix and the geographical distance weight matrix for comparison to reflect the robustness of the spatial correlation relationship. Table 3 presents the Moran index test results. Based on the two spatial weight matrices of geographic distance and economic distance, the Moran index of regional technological innovation is positive and has passed at least a 10% significance test, indicating that China's regional innovation capability is significant Spatial dependence, which shows that the use of spatial measurement analysis is more appropriate.

Table 4. The regional innovation Moran index test results.

Year	Geographic distance matrix		Economic distance matrix	
	Moran's I	P-value	Moran's I	P-value
2006	0.157**	0.038	0.215***	0.000
2007	0.168***	0.005	0.221**	0.018
2008	0.203***	0.000	0.224**	0.026
2009	0.215*	0.076	0.186***	0.002
2010	0.171***	0.000	0.172**	0.035
2011	0.224***	0.003	0.131**	0.027
2012	0.132**	0.041	0.217**	0.034
2013	0.213**	0.018	0.226***	0.001
2014	0.237**	0.039	0.135**	0.041
2015	0.215***	0.001	0.167**	0.029
2016	0.226*	0.083	0.141***	0.000
2017	0.214**	0.027	0.207***	0.003
2018	0.187***	0.006	0.132**	0.041

*Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels.*

5.2. Spatial panel model estimation and result analysis

In order to obtain more robust regression results, this paper also reports the regression analysis of the non-spatial panel model OLS and the non-spatial dynamic panel system GMM. The second and third columns in Table 4 respectively present the estimation results of the non-spatial panel model OLS linear panel model and the dynamic panel model GMM. The columns 4-7 respectively present the parameter regression results of the dynamic spatial Durbin model under the two spatial weight matrices. The Hausman test of the spatial weight of geographic distance and the spatial weight of economic distance both passed the 5% significance test. Therefore, the non-spatial panel model and static spatial Doberman model in this article are both suitable for regression with fixed effects.

Table 5. Spatial panel model estimation and setting form test.

Variables	OLS	SYS-GMM	Geographic distance matrix			Economic distance matrix				
lninnoit-1		0.326***	0.334***	0.386***	0.340***	0.444***	0.084***	0.097***	0.317	0.333***
		[92.52]	[111.37]	[187.81]	[262.96]	[11.16]	[42.22]	[12.25]	[77.15]	[71.13]
lnrd	-0.111	-0.137	1.113***	0.007	-0.139**	0.090***	0.249***	0.008*	0.085***	-0.131**

	**	**			*					*
	[-1.97]	[-2.29]	[16.19]	[1.14]	[-3.02]	[3.39]	[11.38]	[1.72]	[7.27]	[-2.86]
lnhum	1.090***	0.171***	-0.125	0.254***	0.074	-0.127	1.936***	1.845***	1.396***	0.886
	[19.61]	[2.98]	[-1.16]	[8.46]	[0.33]	[-1.43]	[22.66]	[8.43]	[25.13]	[1.48]
lnind	0.025***	0.034	-0.033***	-0.015***	0.031***	-0.096**	-0.021	0.005	0.035***	0.011
	[5.12]	[0.52]	[-9.59]	[-11.15]	[16.94]	[-2.37]	[-0.85]	[0.05]	[21.76]	[0.07]
lnrdp	-0.047**	0.031**	-0.462**	0.002	0.006	-0.030***	-0.344***	-0.799***	-0.223***	-0.194*
	[-2.30]	[2.07]	[-2.39]	[0.83]	[0.39]	[-3.03]	[-23.46]	[-13.55]	[-35.71]	[-1.88]
lncmd	0.045		0.033				0.052			
	[1.22]		[0.92]				[0.87]			
lnbank		-0.247*		-0.063**				-0.030*		
		[-1.89]		[-2.21]				[-1.76]		
lnstock		0.158**			0.051**				0.194**	
		[2.55]			[1.83]				[2.03]	
lnbond		0.043***				0.032**				0.045***
		[10.72]				[2.49]				[17.04]
ρ			0.274***	0.202***	0.048*	0.030**	0.155*	0.118***	0.024***	0.036**
			[8.93]	[8.29]	[1.86]	[2.10]	[1.80]	[4.45]	[51.72]	[2.06]
W*lncmd			-0.261**	0.130***	-0.049*	0.384***	-0.093**	0.122***	-0.307*	0.014**
			[-2.21]	[6.01]	[-1.89]	[66.51]	[-2.39]	[5.98]	[-1.86]	[1.99]
Log-likelihood			209.013	127.225	148.558	163.175	107.352	114.602	174.233	122.406
R2	0.721	0.895	0.904	0.711	0.807	0.830	0.785	0.744	0.865	0.843
Obs	390	390	390	390	390	390	390	390	390	390

*Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels.*

Table 4 shows the estimation results of the spatial panel model under the two spatial weight matrices. The coefficient of regional technological innovation is positive at the 1% significance level, indicating that regional technological innovation has a strong path dependence in the time dimension, which may be related to the time lag in factor input. The Durbin model's regression results under the two spatial weight matrices are positive at least at a confidence level of 10%, indicating that regional technological innovation is closely related to innovation activities in regions with similar geographic or economic development levels. This is because innovative elements flow more frequently in regions with similar geographic or economic development levels, strengthening the regional division of labor and collaboration, leading to convergence of innovative elements in the process of technological development between regions (Peng et al., 2020). In addition, there is a competitive relationship between Chinese governments, and local governments imitate each other in their behaviors to promote technological development. The regions with similar geographic or economic development levels will learn from each other's development and

experience methods to form spatial interactions for technological innovation (Mai, 2019). The ρ value of the geographic weight matrix is larger than that of the economic weight matrix, indicating that the spatial effect of the geographic weight matrix on regional technological innovation is greater than the economic weight matrix. The spatial factors are an important factor affecting the distribution of technological innovation performance. The interdependence of the innovation performance of adjacent regions has resulted in the spatial agglomeration of regions with similar innovation performance levels due to the spatial spillover effects of geographical proximity. The regression coefficients of the spatial panel model are basically consistent with the regression coefficients of the non-spatial model and the non-dynamic model, indicating that the spatial panel model has strong stability.

The estimated coefficient of the core explanatory variable financial development is positive, but it has not passed the significance test, indicating that the promotion of regional innovation by financial development is not obvious. It may be because the scale discrimination and ownership discrimination in the financial market have an adverse effect on the accumulation of innovation capital of enterprises (Lu et al., 2012), resulting in the regional technological innovation dilemma, which also verified Hypothesis 1. The development coefficient of the stock market and the bond market has a significant role in promoting regional technological innovation (Hsu et al., 2013). The main reason is that the stock market and bond market are more flexible and proactive than other financing methods, and their operating efficiency is also higher than the bank's medium and long-term credit market (Khan, 2020). The estimated coefficient of the bank's medium and long-term credit market is significantly negative, indicating that the medium and long-term credit market has restrained the regional innovation level. This is because bank credit has high liquidity requirements and prefers conservative investment, and the fund recovery time of innovative enterprises is relatively uncertain, and it is difficult to meet the requirements of bank credit. Therefore, bank credit fails to provide greater support for regional innovation (Hirsch, 2011). The above results also verify the theoretical hypothesis 2 that the stock market, bond market, and medium- and long-term credit in financial development have significant heterogeneity in the influence of regional innovation capabilities.

5.3. Further analysis

The spatial Durbin model can only reflect the dynamic simulation process between variables in a macroscopic view, but it is not enough to reflect the long-term dynamic relationship between economic variables. In order to further verify the effect of the external institutional environment on regional innovation capabilities, this paper introduces the crossover terms of financial development and three external environmental variables as new variables into the PVAR model to examine the dynamic transmission mechanism of regional innovation capabilities.

The unsteady variables can easily lead to spurious regression. The three stationarity test methods of LLC, IPS, and Fisher-ADF selected in this paper are tested, and the results all show that the relevant variables are stationary series. AIC test, BIC test, and HQIC test choose the lag order. The optimal lag order of the crossover variable of the financial market and the financial ecological environment is all 1, and the crossover variable of the financial market and the marketization process and the government environment management are all 2. At the same time, the forward difference Hermlet transformation method is used to eliminate the endogeneity, individual effect, and time effect of each variable. This article refers to the pioneering study of Cameron and Miller (2010), repeating the simulation 1000 times to obtain an impulse response graph in the 95% confidence interval with a lag of 6 periods.

Figure 1 (a) is the impulse response diagram of innovation ability to itself; Figures (b), (c), and (d) are the impulse response diagrams of financial development and three external environmental variables to regional innovation ability. The technological innovation has a positive impact on its impact, indicating that technological innovation has a time lag effect. The positive impact response of financial development and digital finance environment, marketization process, and government management efficiency to technological innovation is mainly manifested in the early stage. After the first period, the response peak is quickly reached and gradually decreased,

and after the fourth period, the impulse response gradually revolves around the zero-scale line and tends to converge to the zero-scale line. The interaction term between financial development and digital finance environment and government management efficiency has a short-term negative value, but the overall positive impact is dominant, indicating that a good digital finance environment and government management efficiency will affect financial development. A good external environment not only improves the efficiency of financial allocation and reduces market operating costs, but also stimulates market players' enthusiasm for technological innovation, which has a positive regulatory effect on technological innovation. The above results also confirmed the hypotheses (3)-(5) that the digital finance environment, the degree of marketization, and government management efficiency have a positive regulatory effect on financial development and regional technological innovation.

Why does financial development and the external institutional environment affect regional innovation? The possible reasons for this analysis are the following. Firstly, the R&D investment has a large scale and long cycle characteristics, and it is difficult to continue relying solely on internal financial resources (Hsu et al., 2014). A good external digital finance can not only provide companies with broader financing channels and social resources but also significantly ease the information asymmetry between technology companies and external investors through corporate information disclosure, thereby breaking the barriers to the flow of innovative resources (Guan and Yam, 2015). Secondly, the fittest mechanism's market-oriented survival can play the role of the financial market in optimizing capital allocation. It not only enables various innovative elements to break through geographical restrictions and realize the free flow of elements but also reduces information asymmetry and enables innovative companies to obtain resources more efficiently (Ge and Qiu, 2007). Thirdly, to improve the distortion of financial development, it is necessary not only to rely on market mechanisms but also to give full play to the government's macro adjustment role. The government can reduce the technological and market risks in technological innovation by implementing technological system reforms and improving the financial market's external management environment (Brown et al., 2013).

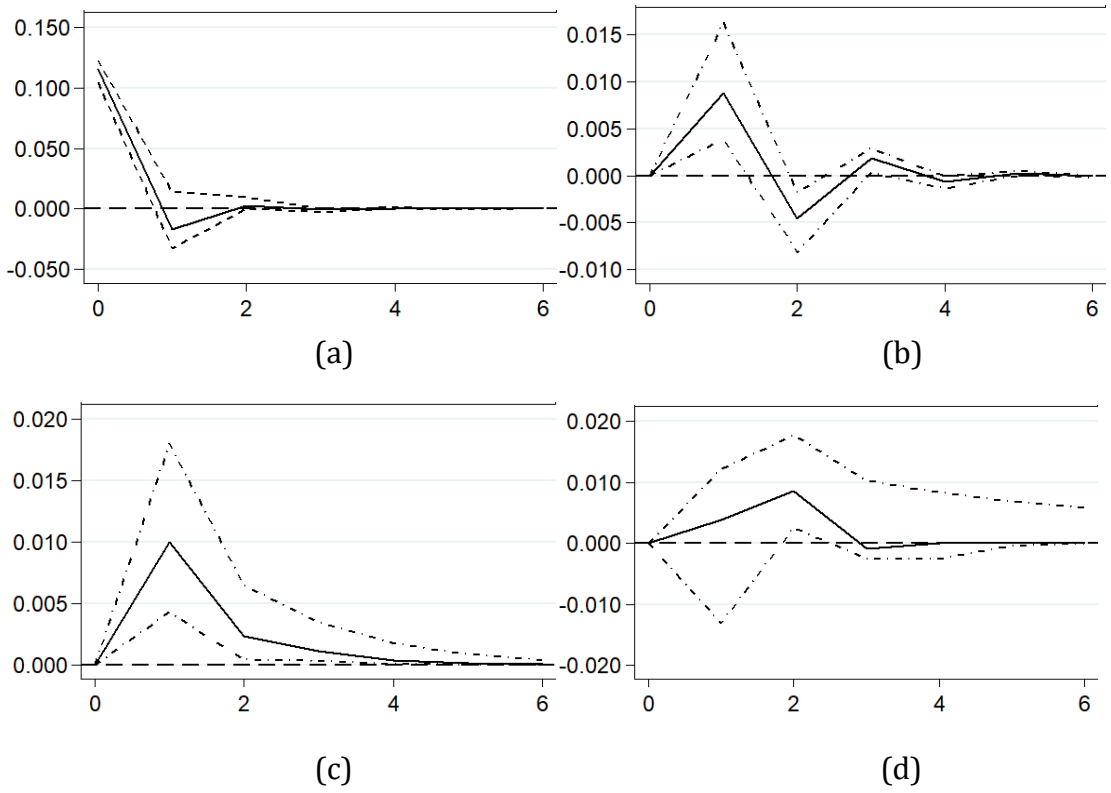

Figure 1. Impulse response function results.

6. Conclusion and policy recommendations

An excellent external environment is a foundation for promoting regional innovation and development, and it is necessary that should be fully utilized the role of the financial market and external institutional environment on the development of technological innovation. This paper uses the spatial Durbin model to test the mechanism of financial development on innovation capabilities empirically and discusses the regulatory role of the external institutional environment on regional innovation. The study found that the development of financial markets did not significantly promote regional innovation capabilities. The medium and long-term bank credit hinder regional innovation capabilities. The stock market and bond market have enhanced regional innovation capabilities. A good digital financial environment, a marketization degree, and government management efficiency can promote the adjustment of the development of the financial market to regional innovation capabilities, in order to promote the development of regional innovation and solve the financing problems of innovative enterprises. The article proposes the following countermeasures.

Firstly, in order to relieve the predicament of technological innovation and support the rapid development of China's high-tech industries, it is necessary to establish and improve a multi-level financial market and expand the financing scale and openness of the financial market. Local governments and banks should strengthen financial support for innovative local companies, accelerate the development of stock and bond markets, and break the funding monopoly of banking institutions to promote healthy competition among financing institutions to alleviate financing problems in emerging economies. Secondly, local governments should create a systematic financial ecosystem and promote the construction of financial service infrastructure to solve financing problems in regional innovation. It is necessary to strengthen the construction of the financial legal system and strengthen the legal protection of the financial ecological environment to protect the legitimate rights and interests of innovative enterprises. Thirdly, in order to create a fair competitive external financing environment. It is necessary to pay attention to market-oriented reforms on the development of financial markets and establish a fair and reasonable price formation mechanism. Finally, the government should deepen institutional reforms and reduce excessive intervention in the capital factor market and market price discrimination to ensure that high-tech industries can receive a capital injection in a fair environment.

Funding Statement

This research received no external funding.

Declaration of Competing Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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