



Research article

Research on the impact of finance on promoting technological innovation based on the state-space model

Mengxin Wang¹, Ran Gu^{2,*}, Meng Wang³ and Junru Zhang⁴

¹ Institute of Finance, Guangzhou University, Guangzhou Guangdong, China

² China Statistics Press, Beijing, China

³ Tangshan Branch, Agricultural Development Bank of China, Tangshan Hebei, China

⁴ Shenzhen Branch, Bank of Communications, Shenzhen Guangdong, China

* **Correspondence:** Email: guranqz@163.com.

Abstract: Finance has an important influence on technological innovation (TI). There are several stages of, as well as various financial constraints on, TI. In this article, we divide TI into four stages: the development, growth, maturity, and decline stages. Concurrently, we classify TI funding sources into five types: enterprise funds, government funds, venture capital funds, loans from financial institutions, and capital market funds. Based on the analysis of the stages and financing constraints of TI, this paper constructs a state-space model to study the effects of various funding sources on TI in Hebei Province, China, from 2005 to 2018. The results show a long-term equilibrium relationship between finance and TI, whereby different financial methods have different effects on each stage of TI. Enterprise funds play a primary role in the development, growth, and maturity stages. Government funds play a prominent role in the development and growth stages. Capital market funds and loans from financial institutions only play a role in the maturity period. The role of capital market funds was positive, while that of loans from financial institutions was negative. The effect of venture capital was not noticeable at any stage. Finally, we give our conclusions and put forward some countermeasures and suggestions to promote TI in Hebei Province.

Keywords: technological innovation (TI); financial methods; impact; state-space model; dynamic parameters

JEL Codes: E44, E47, G28, P34

1. Introduction

The Chinese economy has shifted from a rapid growth model to a stage of high-quality development. It is crucial that its development pattern is transformed, its economic structure is optimised, and transformation of the driving growth force occurs. In this process, technological innovation (TI) plays an important role. TI is a high-risk activity that promotes technical progress and faces a considerable risk of failure (Nanda et al., 2016). TI is the key to high-quality economic development, and finance will promote TI. Finance can guide the flow of innovation resources and promote the rational allocation of innovation elements. Schumpeter (1934) was the first to link finance and TI. He believed that innovation, as a decisive economic development factor, was essentially the result of the recombination of production factors. On the other hand, finance provides the necessary support for reallocating resources and promoting TI.

Based on Schumpeter's innovation theory, much literature has examined the interrelations and effects of the financial system and TI, believing that finance plays a driving role in TI. Greenwood and Jovanovic (1990) believed that financial institutions give full play to their advantages in information processing. While effectively reducing costs, they can screen the most promising innovative technologies, strengthen resource allocation, and promote TI. Levine (1991) and Saint-Paul (1992) believed that the uncertainty of the research and development (R&D) process exposes companies to huge intertemporal risks, and the existence of financial markets can diversify this risk, enable companies to choose more specialised technologies, and improve the success rate. King and Levine (1993) investigated the financial system and TI by constructing an endogenous growth model. They believed that a better financial system would improve the probability of successful innovation and accelerate economic development. Much evidence suggests that financial systems are important for productivity growth and economic development. Chowdhury et al. (2012) demonstrated the contrast between developed and emerging economies. They applied three distinct approaches: the ordinary least square method, cross-country instrumental variable regression approach, and panel regression method. They found that financial market development significantly contributes to the effectiveness of total R&D investment. Furthermore, this finding remains robust across different model specifications and individual estimation methods. Perez (2013) presented an alternative model of the emergence and propagation of technological revolutions. It proposed an explanation for the clustering and the spacing of technical change in successive revolutions. It provided arguments for the recurrence of clusters of bold financiers together with clusters of production entrepreneurs and an interpretation of major financial bubbles as massive episodes of credit creation, associated with the process of assimilation of each technological revolution. It concluded by demonstrating that financial capital plays a fundamental role in the articulation and propagation of technological revolutions. Many other scholars, such as Dosi (1990), Giudici et al. (2000), Andrew (2007), Zhu et al. (2008), Yu (2013), Zhang et al. (2015), and Audretsch (2016), have established the important role of various dimensions of financial development in TI. Some scholars also believe that the relationship between finance and innovation is more complicated. Law et al. (2018) examined the non-linear relationship between financial development and innovation using generalised method of moments (GMM) estimators for a panel data model for 75 developed and developing countries from 1996 to 2010. An inverted U-shaped non-linear relationship between finance and innovation was observed. This finding implies that finance enhances innovation only up to a certain level. Beyond that level, further development of finance tends to affect innovation adversely.

There are various financing methods in the financial market, which have various influences on TI. In the 1980s, the evidence suggested that venture capital not only played a significant role but that it was a unique kind of investment in terms of when, where, and how it was done (Economics, 1983). However, other research indicates that the “capital” in venture capital is the least important ingredient in fostering TI (Timmons et al., 1986). Since then, research has expanded on the effects of different financial modes on TI. Some scholars, such as Stulz (2000), Legrand et al. (2010), and Amore et al. (2013), have conducted studies on the banking system. Their results showed that banks could monitor loans to science and technology enterprises and promote scientific and technological progress, as well as economic growth, through regional diversification. Considering the financing difficulties of private enterprises, Zhu et al. (2021) studied the impact of financing methods on TI. The results show that internal financing can promote TI behaviour more than external funding. Among various external funding forms, bank loans have the most significant influence on TI among private enterprises. Rin et al. (2006), Atanassov et al. (2007), and Liao et al. (2019) studied capital markets. They believed that the second-board market was conducive to increasing investment in small- and medium-sized technological enterprises and innovative start-ups in the start-up stage. The development level of the capital market had a pronounced effect in promoting TI. Bejakovic (2002), Kaplan et al. (2003), Dushnitsky and Lenox (2005), and Zhang et al. (2020) studied the roles of venture capital in R&D and TI. They noted that venture capital can solve the information asymmetry, credit risk, and high financing costs inherent in TI. At the same time, it can provide financial support for scientific and technological enterprises in the development period and promote their rapid development. Lerner et al. (2020) recognised the role of venture capital in promoting innovation and analysed the limitations in promoting substantial technological changes. Zhang et al. (2019) compared the effects of equity financing and debt financing on TI. The findings showed that equity financing, which has higher risk tolerance, has a more positive impact on innovation than debt financing in terms of both economic uptrend and economic downtrend, and that government efficiency plays a significant role in supporting the performance of TI.

In recent years, some scholars have also begun to notice the stages of TI, studying the effects and functions of different financing methods on different TI stages. From the three stages of R&D input, achievement transformation, and industrial output, Zheng et al. (2015) established a variable parameter state-space model. They analysed the service path and examined the effectiveness of the financial sector for TI. Gao (2017) divided TI into three development stages: R&D, achievement transformation, and industrialisation. Using panel data from 2007 to 2016, he conducted an empirical test on science and technology finance and TI in Henan Province. His results showed that the impact was quite different. Pu et al. (2017) divided TI into three stages: TI, technological transformation, and high-tech industrialization, and also divided financial technology into two aspects: public financial technology and financial market technology. Then he analysed the impact of financing on technology in different TI stages.

To date, many researchers have mainly studied the one- or two-way interactions between finance and TI. In recent years, a few studies have noticed the stages of TI. Still, due to inconsistent divisions of TI stages, significant differences emerge in research results. Moreover, starting with the TI stages, it is rare to consider the effects of different sources of funds on the different stages of TI. In a relatively mature study on the stage division of technology innovation, Markard (2020) systematically analysed the stages of technology innovation system (TIS), introduced the key elements of the TIS life cycle framework, and distinguished between the four key stages: formation, growth, maturity, and decline.

TI consists of several stages. The activities in different stages have various financing constraints and suitable financing methods. This is an important entry point and provides space for writing this article.

TI consists of several stages, each of which often uses different financing methods. However, the literature on the effects of financial methods in various TI stages is scarce, which provided space for the analysis detailed in this paper. This paper's main contributions are as follows: first, based on analysing the financing methods in different stages of TI, this paper studies the effects of different financing methods in different stages of TI by establishing a state-space model; second, this paper chooses Hebei Province, which is relatively backward in terms of financial development and TI, as the research object, which is unique in the existing research.

China has a vast territory and a large population. Following 40 years of rapid development after reform and opening up, China is facing great pressure from the transformation of growth drivers and economic structure. We chose Hebei Province as the sample, as it has some economic characteristics that are similar to those of the whole country. Hebei Province is located in North China, surrounding the two municipalities of Beijing and Tianjin. Before 2015, Hebei Province had long been among the most prosperous provinces in China, ranking sixth for GDP. However, due to its historical conditions, Hebei has a relatively high proportion of steel, cement, and other enterprises with high energy consumption and pollution. With the increasing requirements for environmental protection in recent years, Hebei Province has experienced an intensified industrial structure adjustment, and, consequently, its economic growth has slowed. Its GDP ranking declined to thirteenth in 2018. Hebei Province is now facing tremendous pressure due to economic transformation. Therefore, Hebei must strengthen its TI, in order to promote industrial structure adjustment and transform its economic growth mode, which is very similar to China's overall economy. Taking Hebei Province as the study object thus reflects the current circumstances of China's high-quality development. This article has a certain referential role in exploring the use of finance to support TI and promote China's economic transformation.

The rest of this paper is structured as follows: the second part analyses the stages of TI, and the financing methods and applicability of TI, which provides the theoretical analysis of this paper; the third part constructs the evaluation index system and theoretical model of financing methods to promote TI; in the fourth part, combined with the data of Hebei Province from 2005 to 2018, the above theoretical model is empirically tested; the fifth part analyses the results of the empirical test; and the sixth part summarises the conclusions and makes corresponding suggestions.

2. TI stages and financing methods

2.1. Stages of TI

TI is a complex activity with greater uncertainty, and it is affected by many factors (Siming et al., 2019). Rosenberg (2009) believes that innovation is a complex and uncertain process in which many changes will occur. A model that describes innovation as a smooth linear process will give a seriously misleading picture of the nature and direction of the causality. In enterprises, technology and products are closely integrated, and TI is often concentrated in related product innovation. Therefore, based on the product life cycle theory (Vernon, 1966), and combined with the analysis of Markard (2020), this article divides TI into four stages according to the technological maturity of the products: development stage, growth stage, maturity stage, and decline stage. At each stage, the market performance of related technological products presents different characteristics.

The development stage is the R&D phase of new technology, where there is no similar technology or related technical product on the market. In this stage, much money often needs to be invested into developing the new technology; thus, this is an investment stage without any return. The technology has not yet been transformed into products, and few enterprises are involved, with less competitive pressure in the market. In the latter part of this stage, new products are gradually created and introduced to the market, and then TI enters the next stage—the growth stage. In the growth stage, the new products featuring the latest technology are introduced into the market rapidly. These products are also updated quickly, with product models and specifications also changing. In this stage, the production, sales, and profits of new products multiply, while market awareness is gradually improved. In this period, the product technology has passed the development stage. However, as the new product forms progressively, it still needs research and development financing in order to meet market needs. Simultaneously, due to the rapid growth of the product market and profit, other manufacturers may also seize business opportunities and develop similar products, resulting in the emergence of market competitors. Otherwise, the product market expands vastly, such that there is less competitive pressure. At this stage, although the new product is profitable, the profit is small. Due to the high cost of early R&D investment, the overall profit is still low or even negative. After the growth period, TI enters the maturity stage. The market penetration rate of new products is relatively high, and both the technical specifications and sales volume of products are stable. The product technology becomes very mature, such that there is no need for significant technical improvement. Less research and lower development costs are needed to maintain the necessary technological advancement. Many manufacturers may be producing the product at this stage, their profit margins generally being low and decreasing. At this stage, the technology is relatively mature; the R&D cost is low; and the sales of new products are stable, so the overall profit is high.

In the decline stage of TI, products face problems such as obsolete models and outdated functions. The sales volume drops significantly, and the technology becomes outdated, gradually being eliminated and replaced by another new product. No extra capital will be invested in the product, but, instead, another new product will emerge to start a new round of TI. Considering the particularity of this stage, this paper will not conduct a later analysis of the decline stage of TI.

2.2. *Financing methods of TI*

Traditionally, there have been three main sources of funds for TI of Chinese enterprises: enterprise funds, government funds, and loans from financial institutions (Liang et al., 2009). With the development of the capital market, financing channels such as the GEM (Growth Enterprises Market), STAR Market (Science and Technology Innovation Board), New OTC (Over the Counter) Market are increasingly unimpeded. At the same time, venture capital in recent years has also expanded the funding sources of TI. At present, there are five main financing methods in China: enterprise funds, government funds, venture capital funds, loans from financial institutions, and capital market financing (Song et al., 2015).

Enterprise funds are the enterprise's capital that comes from its business profits. These can be used freely and at no additional cost. In recent years, enterprise funds have accounted for more than 70% of China's R&D spending,^① making them the most important TI capital source. By investing in

^①Annual statistical bulletin of national science and technology investment. On the website of National Bureau of Statistics: <http://www.stats.gov.cn/tjsj/tjgb/rdpcgb/qgkjjftrtjgb/>.

TI, enterprises have fewer restrictions and can apply in all stages. Therefore, in terms of quantity, enterprise funds are the primary source of funds. Government funds are financial resources allocated by the government to enterprises. Given their status as technology development projects encouraged by the government, the cost of funding through government funds is lower. Usually, government funds are much smaller than enterprise funds, making them not necessarily the primary funds. However, government funds reflect the government's policy guidance and guide other funds, making them a significant source of funds. Venture capital funds are private equity investment, whereby such funds mainly invest in the initial stage of enterprises and obtain their equity. Venture capital favours science and technology enterprises which grow rapidly. The cost of the funds is lower within the agreed period. In most cases, venture capital funds do not invest explicitly in TI. However, the target companies invested in are generally innovative and have high science and technology levels. Thus, these are also an essential capital source of funds. Loans from financial institutions are a traditional financing method for enterprises. To obtain such funds, enterprises need to meet certain conditions, such as stable production and operation, mature technology, mortgaged property, and so on. Many enterprises in the initial stage cannot meet strict financial supervision and guarantee conditions, so it is difficult to obtain the loans. The use of loans generally requires the payment of agreed-upon interest, as well as some other fees, such that the service cost is typically high. Capital market funds are a way to obtain funds from the securities market by issuing securities. At present, China's multi-level capital market system is becoming more and more mature. A multi-level capital market system has formed with the Shanghai and Shenzhen's main board as the main market and the Growth Enterprise Market, the New Third Board, and the Science and Technology Innovation Board as the auxiliary boards. The securities issued in Shanghai and Shenzhen's main board market are generally for enterprises with stable production and operation, mature technology, and standardised management, which is an important source of production and operation funds for modern enterprises. Since the GEM, New Third Board, and Science and Technology Innovation Board are mainly for financing of small and medium-sized and TI enterprises, they can effectively alleviate the lack of enterprise technology innovation funds, so they have become important sources of enterprise TI funds.

2.3. Financing methods in each stage

According to the above analysis, five financing funds are available for TI. There are different technological risks in different TI stages, which restrict the source of funds (Song et al., 2015; Sasidharan et al., 2015) and lead to the adoption of different financing methods in different stages.

TI is characterised by high risk and low return. In the development stage, TI faces a more significant risk of failure and requires more capital investment. The capital is required to achieve a lower cost and a more vital ability to resist threats. Therefore, enterprises mainly rely on their self-funds, government funds, and venture capital funds. In the growth stage, the market value of innovative products becomes apparent. In this stage, enterprises gradually normalise their operations, enhance their profitability, and expand their funding sources. These funds generally include enterprise funds, government funds, venture capital funds, and loans from financial institutions. As the technological products become more profitable, the proportion of loans from financial institutions may increase. Under certain conditions, capital markets such as the Growth Enterprise Market, the New Third Board, and the Science and Technology Innovation Board have also begun to provide financing for growth-stage enterprises, which has become an important financing method. In the mature stage of TI, the technical performance of products becomes stable

enough, the market share becomes higher; the profitability of products is stronger; and the enterprise management becomes more standardised. At this stage, venture capital and government funds gradually withdraw. The funding sources mainly include enterprise funds, loans from financial institutions, capital market funds, and so on.

Once TI enters the decline stage, the product's performance starts to lag; its function gradually ages; the market share declines; and it faces elimination. TI focuses on developing new products in this stage; that is, another round of new technologies and new products begins. Considering the case, the analysis of this paper does not take the decline stage into account. It only studies the development, growth, and maturity stages of TI.

Table 1. The stages of TI and the financing methods.

Stages of TI	Financing methods
Development stage	Enterprise Funds, Government Funds, Venture Capital Funds
Growth stage	Enterprise Funds, Government Funds, Venture Capital Funds, Loans from Financial Institutions, Capital Market Funds
Mature stage	Enterprise Funds, Loans from Financial Institutions, Capital Market Funds

From the above theoretical analysis combined with Table 1, it can be seen that the different characteristics affect the choice of financing methods. Generally, enterprise funds can be applied to all stages of TI; government funds, venture capital, and some capital market funds will play a role in the development and growth stages; loans from financial institutions and capital market funds are mainly invested in the growth and maturity stages. However, whether the various sources of funds for TI in Hebei Province have played their due role requires testing through an empirical model.

3. Evaluation index system and model

3.1. Evaluation index system

This article focuses on analysing the effects of different financing methods on TI, so we need to choose indicators according to two aspects. One is the source of funds, and the other is TI output. For the sources of funds, on the basis of the previous analysis, we selected five indicators: enterprise funds, government funds, venture capital funds, loans from financial institutions, and capital market funds. For the outputs of TI, each stage has different characteristics and various achievements. New technologies are developing in the development phase, such that there is no product and no profitability. The achievements are usually in R&D projects. Therefore, we selected the number of R&D projects as the achievements. During the growth stage, innovation results began to emerge, and new products come out. However, due to the large investment required in the early stage, the product profit is still insufficient. The innovation output is usually in the form of intellectual property. Thus, we take the number of patent applications as innovation results. In the mature stage, innovative products are produced with higher market share and better profitability. Therefore, innovation achievement was assessed as the product's economic value, that is, the sales revenue of a new product.

According to the above analysis, the indicators of financial development and TI achievements selected for this paper are shown in Table 1.

Table 2. The evaluation index system.

Category	Indicators	Unit	Symbol	Symbol after the logarithm
Financial Methods	Enterprise Funds		X1	LX1
	Government Funds		X2	LX2
	Venture Capital Funds	ten thousand	X3	LX3
	Loans from Financial Institutions	yuan	X4	LX4
	Capital Market Funds		X5	LX5
TI achievements	Number of R&D Projects	item	Y1	LY1
	Number of Patent Applications	item	Y2	LY2
	Sales Revenue of New Product	ten thousand yuan	Y3	LY3

In Table 2, the indicators X1 (enterprise funds), X2 (government funds), and X4 (loans from financial institutions) were obtained from the data on the amount of funding for science and technology in the annual *Hebei Economic Yearbook*. X3 (venture capital funds) was replaced by the venture capital scale managed in Hebei, appropriately sorted, and calculated: these data were from the annual *China Venture Capital Yearbook*. X5 (capital market funds) came from the data of technology companies in Hebei, as listed on the Shanghai and Shenzhen stock exchanges. This included the technology companies on the main board and all companies listed on the GEM board. The financing amount was adjusted, according to the *High-tech Industries Catalog* published by the National Bureau of Statistics. The three indicators of achievements (Y1, Y2, and Y3) were obtained from the *Hebei Statistics Yearbook of Science and Technology* and *China Statistics Yearbook of Science and Technology*. Since China's venture capital industry was not developed at the start of this century, according to the existing statistics, the earliest year for which venture capital data can be collected is 2005. So the time interval of all the above indicators was from 2005 to 2018.

3.2. Descriptive analysis of variables

Table 3. Variable descriptive statistics.

	Means	Min.	Max.	Standard deviation	Coefficient of variation
X1	1,345,606.12	295,861.76	3,134,186.90	896,009.26	0.6659
X2	30,665.01	3,592.08	68,903.27	20,489.58	0.6682
X3	190,981.52	12,224.85	1,655,287.60	435,929.45	2.2826
X4	13,181.05	2,440.89	31,851.85	9,072.55	0.6883
X5	261,441.23	10,290.55	692,546.03	225,298.84	0.8618
Y1	6,342.00	1,952.13	11,295.00	3,063.37	0.4830
Y2	6,977.44	847.87	16,707.00	5,360.66	0.7683
Y3	17,869,040.97	3,981,710.01	43,647,419.69	12,208,908.09	0.6832

Through descriptive analysis, we can have a preliminary understanding and grasp of variables. Table 3 shows the descriptive statistics of each variable after eliminating the price factor. In terms of the explanatory variables, the average value of enterprise funds is the largest, which is much larger than other types of funds; the average values of government funds (X2) and financial institution credit

funds (X4) are small, at only 2.88% and 0.98% of enterprise funds, respectively. The data in the table also show that the volatility of venture capital funds (X3) is relatively large, and the coefficient of variation exceeds 2. The volatility of other variables is relatively small.

3.3. Evaluation model

This paper mainly studies the effect of different sources of financing on TI. Based on the foregoing analysis, it can be seen that every financing method has restriction conditions, and the financing methods that can be adopted at each stage are also different. With the development of technology, the stage of TI will change, and the effects of every financing method will not be the same. In order to reflect the changing effect, the variable parameter state space model can be used for research. By studying the changes of model parameters over time, the effects of every financing method on TI stages can be reflected.

Based on the Cobb-Douglas production function, the form of the variable parameter state-space model is as follows:

$$LY_{it} = c + \sum_{j=1}^5 \alpha_{jt} LX_{jt} + u_t \quad (1)$$

$$\alpha_{it} = \alpha_{it-1} + \varepsilon_{it}, \quad u_t \sim (0, \sigma^2), \quad \varepsilon_{it} \sim (0, 1) \quad (2)$$

where $i = 1, 2, 3$ represents the development stage, growth stage, and maturity stage of TI, respectively; t is the time, with value range of 2005–2018; LY_{it} ($i = 1, 2, 3$) represents the achievements of the three stages of TI each year—namely, the number of R&D projects, the number of patent applications, and the sales revenue of new products; LX_{jt} ($j = 1, 2, \dots, 5$) represents enterprise funds, government funds, venture capital, loans from financial institutions, and capital market funds, respectively; α_{it} is a variable parameter, indicating the effect of different forms of investment on TI in each stage (namely, the effective coefficient)—the larger the value is, the better the financial support effect will be; and u_t and ε_{it} are the corresponding random error terms.

4. Empirical test of the model

4.1. Stationarity and co-integration test

The variables selected were all time-series data. Heteroscedasticity was eliminated by taking the logarithm. The ADF unit root test was performed on the variables, in order to avoid false regression. The results of the stationarity test are shown in Table 4.

The test results indicate that only LY3 was a stationary series among all the eight variables, while the other variables were first-order integral series. Then, we used the Johansen co-integration test to determine the long-term equilibrium relationships between TI variables and financial variables. The test results are shown in Table 5.

Table 4. Stationarity test.

Variables	Test form	ADF statistics	5% critical value	Stationarity
LX1	(C, N, 0)	-2.8239	-3.0810	No
Δ LX1	(C, T, 0)	-5.6778	-3.7912	Yes
LX2	(C, T, 0)	-1.6767	-3.7597	No
Δ LX2	(N, N, 0)	-2.9936	-1.9684	Yes
LX3	(C, N, 1)	-1.4562	-3.0989	No
Δ LX3	(N, N, 0)	-2.2677	-1.9684	Yes
LX4	(C, N, 1)	-2.3256	-3.0989	No
Δ LX4	(N, N, 0)	-2.1784	-1.9684	Yes
LX5	(C, N, 1)	-1.8031	-3.0989	No
Δ LX5	(C, N, 0)	-7.2057	-3.0989	Yes
LY1	(C, T, 0)	-2.4127	-3.7597	No
Δ LY1	(C, N, 3)	-2.8689	-2.7290*	Yes
LY2	(C, T, 0)	-2.0013	-3.7597	No
Δ LY2	(N, N, 0)	-3.7684	-1.9684	Yes
LY3	(C, N, 0)	-2.9483	-3.0810	Yes

Note: The test forms (C, T, K) mean that the test equation includes constant term (C), time trend (T), and the order of the lag term. N means no C or T, respectively. Δ is the difference operator.

Table 5. Co-integration test of output variables and financial variables.

Variables	Hypothesised No. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.
	None*	0.988848	140.6625	95.75366	0.0000
LY1	At most 1*	0.901636	73.21989	69.81889	0.0261
	At most 2	0.812776	38.43371	47.85613	0.2834
LY2	None*	0.992396	140.2445	95.75366	0.0000
	At most 1	0.834754	67.05821	69.81889	0.0814
LY3	None*	0.994823	146.1508	95.75366	0.0000
	At most 1	0.871422	67.19824	69.81889	0.0795

Note: * indicates significance at the 5% level.

The results in Table 3 indicate that there was at least one co-integration relationship between each output variable and the financial variables, indicating that finance has a significant long-term effect on TI. However, the analysis only shows that different TI stages are affected by financial variables; we established the state-space model to analyse the influences of the financial variables on TI.

4.2. Empirical results of the model

It will take some time for finance to play a role in TI. In this paper, state-space models were established, where the lag-periods were set as one year. In each equation, LY1, LY2, and LY3 were the explained variables and the financial variables-namely, X1, X2, X3, X4, and X5-were the explanatory variables. We use Eviews11.0 to get the estimation and test results of each model. After multiple

operations and adjustments, each model's estimation and test results are shown in Table 6. The initial models gave the estimated results with all five financial variables, while the final model gave the estimated results after removing the insignificant variables. In the table, C(1) are the coefficients of constant terms, and C(2) are the exponential values of random error term variance. SV(1)–SV(5) are the dynamic parameter values of the five variables (i.e. LX1, LX2, LX3, LX4, and LX5). Only the parameter values of the last year (2018) are listed in Table 6, and all the dynamic parameter values of each final model in every year are shown in Table 7.

The results in Table 6 show that compared with the initial model, the effect of each final model has been significantly improved; the Log likelihood has been significantly improved; and the statistics of AI, SC, and HQ have also been significantly reduced. C(2) of each model and C(1) of LY2 and LY3 models passed the significance test. Although C(1) of model LY1 did not pass the test, it did not affect the analysis. The state equation of each initial model has one or more dynamic parameters that failed the test; the final model was obtained after removing insignificant variables; each parameter passed the significance test at the level of 0.01. Overall, the effects of each final model are very good.

To ensure the robustness of the model and reduce the impact of sample time selection as much as possible, the two-year samples in 2005 and 2018 are removed and the time interval from 2006 to 2017 is re-estimated. The results indicate that the estimation results are basically consistent with the above conclusions, indicating that the research conclusions in this paper are relatively robust.

Table 6. The estimated results of the models.

Parameter	LY1 (development stage)		LY2 (growth stage)		LY3 (maturity stage)		
	Initial model	Final model	Initial model	Final model	Initial model	Final model	
Coefficient values	C(1)	2.3591 (0.9317)	1.5878 (0.7975)	-4.0103 (-4.4421)*	-4.1364 (-5.5004)*	3.4850 (6.8625)*	3.7282 (12.7510)*
	C(2)	-3.7168 (-10.4641)*	-3.8986 (-9.8832)*	-5.0390 (-8.1404)*	-4.9115 (-8.5220)*	-5.4609 (-6.7240)*	-5.6389 (-13.4142)*
Final value of dynamic parameter	SV(1)	0.1875 (1.4410)	0.2423 (3.7790)*	0.5557 (8.2735)*	0.6351 (11.3461)*	0.9507 (17.4790)*	0.9306 (799.8982)*
	SV(2)	0.3502 (1.7952)**	0.3766 (4.2495)*	0.3893 (3.8652)*	0.3216 (3.2761)*	0.0057 (0.0697)	—
	SV(3)	0.0156 (0.3114)	—	0.0399 (1.5460)	—	0.0225 (1.0772)	—
	SV(4)	-0.059674 (-0.8305)	—	-0.1562 (-4.2115)*	-0.1370 (-3.6404)*	-0.0233 (-0.7768)	—
	SV(5)	0.054959 (0.7202)	—	0.1773 (4.4997)*	0.1732 (4.1240)*	-0.0095 (-0.2967)	—

Note: The figures in square brackets under the estimated coefficients are the corresponding Z-statistics. *, **, and *** indicate that the coefficient is significant at the significance level of 0.01, 0.05, and 0.10, respectively.

Table 7. Dynamic parameters of the final models at every stage.

Year	Development stage		Growth stage				Mature stage
	SV(1)	SV(2)	SV(1)	SV(2)	SV(4)	SV(5)	SV(1)
2005	0.3383	0.2395	0.3411	0.2414	0.2619	0.2441	0.9358
2006	0.4247	0.1175	0.3576	0.2098	0.2463	0.2692	0.9336
2007	0.3011	0.2814	0.3605	0.2520	0.1889	0.2849	0.9319
2008	0.2328	0.3882	0.3840	0.2052	-0.1010	0.2567	0.9327
2009	0.2178	0.4108	0.5130	0.5145	-0.1041	0.1285	0.9318
2010	0.2214	0.4051	0.5216	0.5090	-0.1074	0.1246	0.9301
2011	0.1993	0.4378	0.5150	0.5143	-0.1150	0.1357	0.9300
2012	0.1703	0.4805	0.5082	0.5038	-0.0979	0.1382	0.9303
2013	0.1731	0.4763	0.5066	0.5058	-0.1001	0.1406	0.9301
2014	0.1962	0.4429	0.5621	0.4267	-0.1103	0.1485	0.9301
2015	0.2214	0.4060	0.5739	0.4027	-0.1113	0.1555	0.9298
2016	0.2523	0.3616	0.6188	0.3683	-0.1339	0.1487	0.9295
2017	0.2422	0.3766	0.6158	0.3655	-0.1308	0.1525	0.9298
2018	0.2424	0.3766	0.6351	0.3216	-0.1370	0.1732	0.9306

5. Analysis of results

5.1. Variable parameter analysis of the development stage

In the development stage, innovation achievements were represented by the number of R&D projects (LY1). The estimation results showed that, in the initial model, only the variable parameter of government funds (SV2) passed the significance test. After the insignificant variables (LX3, LX4, and LX5) were removed, the parameters SV1 (enterprise funds) and SV2 (government funds) passed the significance test in the final model. These results indicate that, in the development stage of TI in Hebei Province, enterprise funds and government funds play prominent roles. Figure 1 shows the changes in the parameters with respect to time.

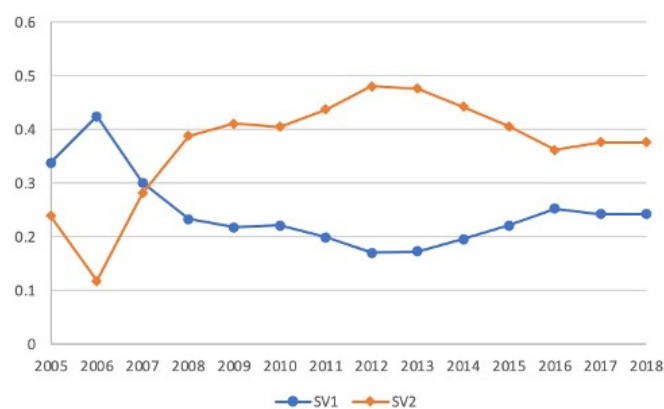
**Figure 1.** Dynamic parameter chart of enterprise funds and government funds.

Figure 1 shows that, in the development period, enterprise funds and government funds significantly promoted output, while the elasticity coefficient was remarkably positive. In the early part of the sample period (2005–2007), the elasticity coefficients of enterprise funds were greater than those of government funds. In 2008, the elasticity coefficients of government funds began to surpass those of enterprise funds.

The reasons for this are closely related to China's national technology innovation policy. In 2005, the State Council of China issued the *Outline of the National Medium- and Long-term Plan for Scientific and Technological Development (2006–2020)*, proposing that China should become an innovation-oriented country by 2020 and a global scientific and technological power by the middle of the 21st century. The government has increased its support for TI, such that government funding invested in TI of enterprises has increased significantly, which played a vital guiding role. Furthermore, government funding for TI has a clear purpose and strict requirements, such that their effects are better than enterprise funds. In addition, industrial enterprises above a designated size in Hebei are dominated by heavy industries, such as steel, cement, and chemical industries, which have low profit margins. The Chinese government has implemented many environmental protection policies, such as production transformation, energy conservation, emissions reduction, and other requirements in recent years, which decreased enterprise profits and, thus, TI funds. Therefore, the dynamic parameters SV2 were significantly higher than the parameters SV1.

According to the previous theoretical analysis, funding sources in the development stage were mainly enterprise funds, government funds, and venture capital. Little access is available to loans from financial institutions or funds from the capital market. Thus, their effects were not significant, consistent with the theoretical analysis in this paper. The empirical study here also shows that the role of venture capital was not significant; the reason why will be specifically analysed later when it comes to venture capital.

5.2. Variable parameter analysis of the growth stage

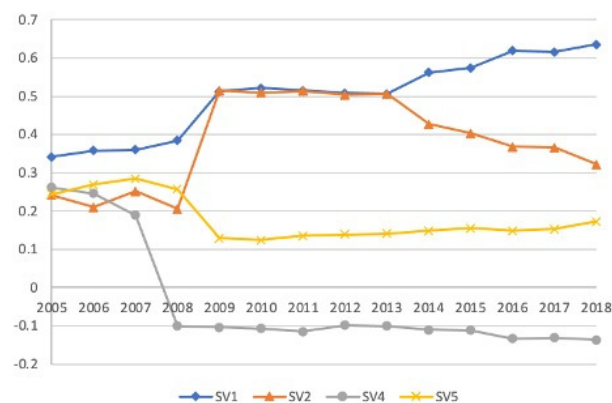


Figure 2. Dynamic parameter charts in the growth stage.

In the growth stage, innovation achievements are represented by the number of patent applications (LY2). The initial model estimation result shows that only the parameter of venture capital (SV3) failed the significance test. After it was removed, the final model included four variables, with every

parameter being highly significant. The results indicate that enterprise funds (SV1), government funds (SV2), loans from financial institutions (SV4), and financing in the capital market (SV5) play significant roles. However, the effect of each variable was different (see Figure 2).

Considering Figure 2, the sample period can be divided into three stages:

(1) Before 2008, the four financial methods all had a noticeable effect on the TI output. SV1 was the highest, between 0.35 and 0.4; meanwhile, the others showed little difference, almost all between 0.2 and 0.3.

(2) From 2008 to 2013, the effects of various financial methods diverged. SV1 and SV2 increased significantly, both exceeding 0.5. However, SV5 and SV4 decreased significantly, the former dropping to around 0.15 and the latter stabilising after dropping to below -0.1 .

(3) After 2014, SV1 and SV2 also began to diverge. SV1 improved further, from 0.5 to more than 0.6. SV2 began to decline gradually, from around 0.5 to about 0.3. During this period, the roles of financing in the capital market and loans from financial institutions were relatively stable.

During this period, there were many reasons for the variation in the effects of financial modes. First, during the growth period, the impact of TI begins to appear, and the innovation achievements—the number of patent applications (LY2)—increase rapidly. At the same time, with the rise of new products and profits, enterprises will also have more money to invest in TI, promoting their funding effect. Second, the *Outline of The National Medium- and Long-term Scientific and Technological Development Plan (2006–2020)*² was promulgated in 2005. After several years, the implementation effect began to emerge, and the elasticity coefficients of SV1 and SV2 were improved. Third, to deal with the outbreak of the subprime mortgage crisis in the United States in 2008, the Chinese government offered greater convenience and preferential treatment to enterprises with respect to bank loans and capital market funds. The amount of the loans exceeded the needs of the businesses. Further, limited by data sources, the data of capital market funds (Y5) used in this paper were the total enterprise funds from the capital market. Although the enterprises were all TI-oriented enterprises, only some of the funds are generally used for TI. Therefore, the effect was lower than that of the enterprise funds and government funds. Fourth, taking loans from financial institutions (X4) is a traditional way to obtain funds. In China, the innovation environment in Hebei Province is not advanced, and so science and technology loan policies are not perfect. For risk control, fewer loans are applied to TI, and more restrictive conditions are required, such as requiring collateral or guarantees. This leads to a squeeze on enterprise resources and may be another important reason for the negative effect observed (SV4). Fifth, after 2014, the output elasticity of government funds (SV2) dropped significantly, which may be related to the financial strain caused by the economic transformation of Hebei Province. Under the pressure of environmental protection policies, the economic growth of Hebei Province began to slow. The average annual GDP growth rate was above 10% before 2012, dropping to 6.5% in 2018. Its GDP ranking fell from 6th in 2012 to 13th in 2018. This slowing of economic growth led to a sharp decrease in fiscal revenue. The funds applied to TI dropped from 918 million yuan in 2015 to 550 million yuan in 2018. Before 2014, government funds typically accounted for less than 3% of enterprise funds, then decreased rapidly to 1.48% in 2018. The proportion of government funds to enterprise funds is relatively low. In the face of such large fluctuations, the effect of government funds declined and was significantly lower than that of enterprise funds.

²The Chinese Central People's Government: http://www.gov.cn/gongbao/content/2006/content_240244.htm.

5.3. Variable parameter analysis of the mature stage

Only the enterprise funds (X1) in the initial model passed the significance test in the maturity stage (see Table 1). After insignificant variables were eliminated, the final model retained the independent variable (X1). Figure 3 shows the variation of the parameter SV1.

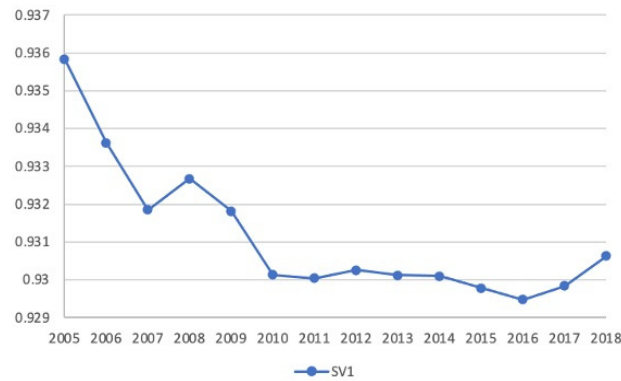


Figure 3. Dynamic parameter chart during the maturity period.

In this stage, the technology is mature; the product sales volume is large; and the profit is relatively stable. In this period, significant investment in TI is not required; expenses are to cover the cost of providing technical support for functional stability. The elasticity coefficient fluctuated at a high level (around 0.93) during this period.

5.4. Comprehensive evaluation

From the previous analysis, it can be seen that at different TI stages, the roles of the financial methods are not the same. Enterprise funds (X1) play an essential role in all three phases, while government funds (X2) were important in the development and growth stages. Loans from financial institutions (X4) and capital market funds (X5) played a role only in the growth stage. Figure 4 shows the changes of SV1 and SV2. The underlined numbers 1, 2, and 3 represent the development, growth, and maturity stages, respectively.

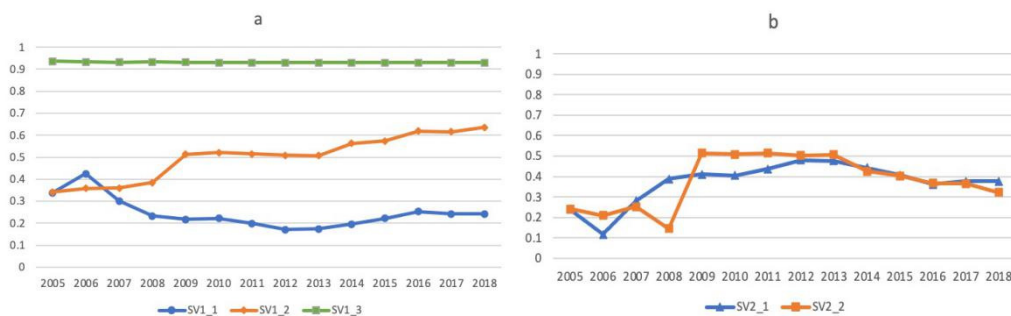


Figure 4. Dynamic parameter charts of enterprise funds and government funds.

Figure 4(a) shows that SV1, in the maturity stage, was stably above 0.9, significantly higher than in the development and growth stages. Except for in 2006, the SV1 of the growth period was higher than in the development period. SV1 was the lowest and fluctuated during the development period. This indicates that enterprise funds play different roles according to the TI stage. The elasticity coefficient increases from development to maturity, and the effect becomes more and more significant. Figure 4(b) shows that the effects of government funds (X2) were noticeable in both the development and growth stages. The trend was nearly the same, except that it fluctuated slightly in the growth period. The results also showed that venture capital funds did not play a significant role in the three stages. The venture capital industry in Hebei is undeveloped. The venture capital scale in Hebei accounts for less than 1% of the whole country's venture capital. In 2018, the scale was 19.83 billion yuan, only 0.22% of the total national scale of 89,969.55 billion yuan. In addition, in the sample period, venture capital funds accounted for less than 8% of the total funds, on average, with significant fluctuation year by year. It can be seen that venture capital had not become the main fund for TI in Hebei and that its effect on TI was not significant.

6. Conclusions and recommendations

By constructing a state-space model, we took Hebei Province as an example, in order to study the influence of five financial methods on three stages of TI. In terms of economic strength, Hebei Province is a mid-ranking Chinese province, but its TI ability is weak. Hebei has also faced significant pressures in recent years, such as structural adjustment and economic transformation. Thus, Hebei Province serves as a microcosm of China. Making Hebei Province the object of inquiry allows for a representative picture of the role of different financing methods on TI under the pressure of economic transformation in contemporary China.

Subsequent to our analysis, we can draw the following main conclusions: (1) Different financial methods in Hebei Province have various effects in every TI stage. These differences were clearly noticeable in the research results. (2) In the development stage, enterprise funds and government funds played essential roles. The effect of government funds was more significant than that of the enterprise funds. (3) In the growth stage, enterprise funds, government funds, and capital market funds all play important roles. Their effect decreased successively. Affected by various factors, the impact of loans from financial institutions was negative. (4) In the maturity stage, only enterprise funds played an important role. (5) Among all five financial methods, only enterprise funds, being the primary capital source, played an important role in all stages. Government funds played important roles in the development and growth stages, which are crucial to support TI. Capital market funds only played a role in the growth period, with their function being smaller than that of enterprise funds and government funds. Loans from financial institutions only played a role in the growth stage; however, the effect was negative. Venture capital was not an influential fund source, and its role in each step was not apparent.

On the basis of the above research conclusions, in order to promote TI in Hebei Province, we propose the following suggestions: (1) Promote the development of a multi-level financial market system. The multi-level and diversified financial market system can meet the financing needs and effectively promote the development of TI. (2) Pay attention to the difference in the effects of financing methods on TI and suggest that different financing methods should be adopted for TI at different stages. (3) Promote the integrated development of the financial market and the TI market and enhance the effect of TI.

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Conflicts of interest

The authors declare no conflict of interest.

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