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The Impacts of Technology Finance And Technological Innovation On Economic Growth of Jingjinji Region China

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Abstract: This study investigates the impact of technology finance and technological innovation on economic growth in the Beijing-Tianjin-Hebei (Jingjinji) region, while also exploring whether this relationship is nonlinear and moderated by technology finance. Using panel data from 2000 to 2021, the study constructs indices for technology finance and technological innovation through principal component analysis (PCA) and applies a threshold regression model. The findings reveal that technological innovation has a stronger positive effect on economic growth when the technology finance index is below or equal to a threshold of 1.459. Beyond this threshold, the impact of innovation diminishes. Additionally, financial development and financial openness positively influence growth, while higher college enrollment ratios have a negative effect. Comparing regional data, the study observes that Beijing has surpassed the technology finance threshold, reducing the positive impact of innovation, whereas Tianjin and Hebei remain below the threshold. The study recommends decreasing technology finance in Beijing and increasing it in Tianjin and Hebei to enhance growth in the region. It also advises the Chinese government to develop comprehensive policies to strengthen financial development and financial openness in the Jingjinji region.

Keywords: Technological Innovation, Technology Finance, Jingjinji Region, Threshold Regression

JEL Classification: G 38, O31, O32, O 33, O 34, O 38, O 43.

1. Introduction

The "14th Five-Year Plan" of China, introduced in 2020, proposes promoting the development of the real economy by constructing institutional mechanisms that effectively support it through technology finance. This integration of technological and financial innovation aims to guide the high-quality development of the real economy and provide the driving force for its growth. According to China's National 12th Five-Year Plan from 2010, technology finance refers to a systematic arrangement of policies and institutions that guide and promote various types of capital, such as banking, securities, insurance, venture capital, and human capital, through public investment. It focuses on innovating financial products, improving service models, and building service platforms. The goal is to integrate the technological innovation chain with the financial capital chain, providing financing support and services to technology enterprises at all stages of development, from start-up to maturity. Meanwhile, the "14th Five-Year Plan and 2035 Vision" also emphasizes enhancing innovation capability and improving the innovation system, with a focus on promoting collaborative innovation in the Beijing-Tianjin-Hebei (Jingjinji) region.

Innovation is the driving force behind high-quality economic and business development. In recent years, China has seen a high output of scientific and technological innovation, yet challenges related to efficiency and quality remain prevalent. For technological innovation to succeed, technology finance plays a crucial role. In response, the Chinese government and companies have allocated substantial resources to foster technological innovation, aiming to achieve high-quality economic growth. Between 1998 and 2019, China's investment in R&D increased from 0.65% to 2.24% of GDP, surpassing the European Union average of 2.12%. During this period, the number of patent applications granted rose from 68,000 to 2.457 million, marking a nearly 35-fold increase (Wang et al., 2022).

Despite significant investments in technology finance between 2007 and 2020, the Beijing-Tianjin-Hebei (Jingjinji) region has underperformed in terms of technological innovation efficiency and economic growth compared to other major regions in China, such as the Yangtze River Delta and the Pearl River Delta. Although Jingjinji's investment in technology finance was 1.2 times higher than that

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of the Yangtze River Delta and 1.1 times higher than that of the Pearl River Delta, its technological innovation efficiency and economic growth have lagged behind. This discrepancy raises concerns about the effectiveness of the region's technology finance strategy and whether its investment has surpassed a critical threshold that diminishes its marginal impact on economic growth. Additionally, these results do not align with the objectives of the 13th Five-Year Plan for National Economic and Social Development, which aimed to position Jingjinji as a key driver of innovation-driven economic growth. Therefore, it is essential to understand whether the current technology finance structure is hindering the desired outcomes and how it affects the region's economic growth and innovation potential, as illustrated in Figure 1.

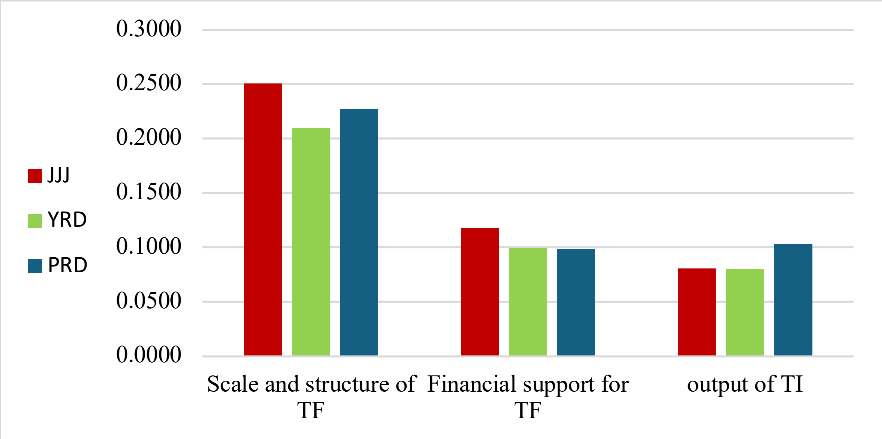

Figure 1: Comprehensive Evaluation of the Development of TF and TI in Three Regions(Average value 2007-2020). Source: Drawn by the author using data from Yaopeng et.al (2022)

To ensure the successful implementation of a coordinated development mechanism in the Jingjinji region, it is crucial to examine how technology finance can enhance technological innovation, thereby fostering regional economic integration and transforming the area into a new driver of national economic growth. Additionally, it is important to explore whether there is a nonlinear relationship between technological innovation and regional economic growth at varying levels of technology finance. Understanding this relationship will provide valuable insights for effectively implementing technology finance policies in the coordinated development of the Jingjinji Mega-City Cluster. Therefore, this paper focuses on two key objectives: studying how technology finance and technological innovation impact economic growth in the Jingjinji region and investigating whether the relationship between technological innovation and economic growth is nonlinear, as shown in Figure 2.

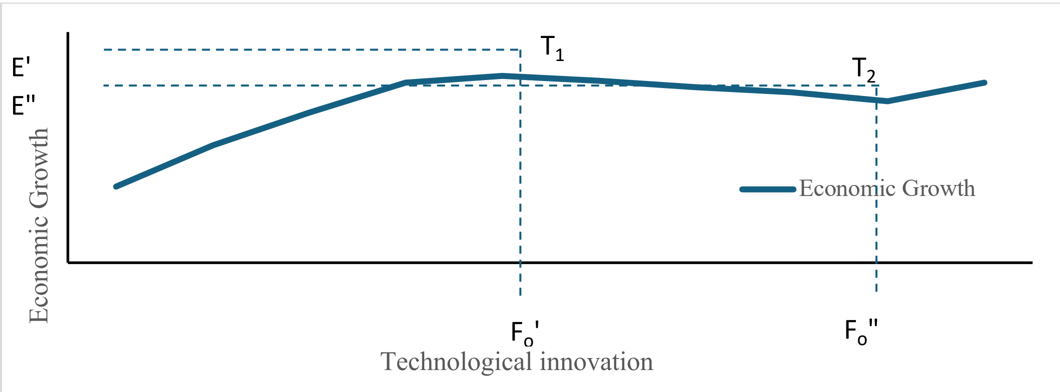

Figure 2: Non-linear relationship between economic growth and technological innovation

Figure 2 illustrates that the impacts of technological innovation on economic growth are nonlinear. Initially, economic growth may increase with the enhancement of technological innovation. However, after reaching threshold level F0', economic growth starts to decline in response to further increases in technological innovation. This could be due to the law of diminishing marginal returns or the concept of decreasing returns to scale. Therefore, the main objectives of this research are as follows:

1. To examine the impact of technology finance on technological innovation efficiency in the Beijing-Tianjin-Hebei (Jingjinji) region. This will involve measuring how effectively technological innovation has translated into economic growth relative to the scale of financial investments in the region.
2. To investigate whether the relationship between technology finance and economic growth in Jingjinji is nonlinear. The study aims to determine whether the region has crossed a threshold level of technology finance that has altered its marginal impact on economic growth.

3. To compare the technological innovation efficiency and economic growth performance of the Jingjinji region with the Yangtze River Delta and Pearl River Delta. This comparison will highlight the reasons behind Jingjinji's underperformance despite higher investment levels.
4. To assess the role of financial development, financial openness, and other factors such as human capital (e.g., college enrollment) in influencing the relationship between technology finance, innovation, and economic growth in Jingjinji. This will help identify additional factors that may be affecting the region’s innovation-driven growth.
5. To provide policy recommendations for optimizing technology finance allocation in the Jingjinji region to enhance innovation efficiency and stimulate sustained economic growth. The study will offer insights on how to adjust current financial and innovation strategies to better align with the region’s growth objectives outlined in the '13th Five-Year Plan.'

This paper is structured into six sections for systematic analysis and discussion. Section 1 provides an introduction along with the research objectives. Section 2 offers a comprehensive literature review and examines the current state of research on the subject. In Section 3, the study area is described alongside the data sources and research methodologies employed. Section 4 presents the empirical results and engages in a detailed discussion. Section 5 concludes the study, followed by sections dedicated to acknowledgments and references.

2. Literature review

Technology finance plays a crucial role in driving technological innovation, which, in turn, fuels efficient economic growth. By leveraging technology finance, economies can achieve high-quality development. This relationship has been extensively studied by scholars. For example, Hus et al. (2014) analyzed panel data from developed and emerging economies and found that financial markets positively impact patent grants, thereby fostering technological innovation. Beck et al. (2016) argue that credit loans from commercial banks provide sufficient capital to society, boosting enterprise productivity and technological innovation, which subsequently influences economic growth. Additionally, Shujuan & Shen (2021) suggest that science and technology financial institutions can support technology innovation companies by providing investment and financing, alleviating issues such as insufficient funds and financing constraints. This creates a favorable environment for research and development activities, ultimately enhancing innovation and production capabilities.

Similarly, Lei & Degong (2020) and Xueyan & Xiaoyang (2021) highlight that technology finance represents the synergy between technological innovation and capital investment. This combination enhances financial resources for China's high-tech small and medium-sized enterprises (SMEs), addressing their financing challenges, promoting basic research, and driving innovation through the effective transformation of research outcomes.

Provincial-level studies have yielded various insights. Alessandra & Stoneman (2006), focusing on the Financial Progress Index in the Jingjinji region, argue that finance significantly boosts technological advancement, with financial value increasing as technological achievements are transferred and transformed. Hendrikse et al. (2020) examined vocational resources, showing how financial centers in less developed areas seek growth opportunities by merging technology and finance, thereby enriching theoretical research. Xinlei's (2022) study in Guizhou Province reveals a long-term equilibrium between financial technology and high-tech industries, where financial investment and technological development mutually reinforce each other, while financial loans alone only promote technology unilaterally.

Likewise, Pingxiong & Zhen's (2022) research in Hebei Province discusses the coupling coordination between technology finance and economic development, noting that while coordination has improved, openness still requires attention. Lijun's (2022) broader analysis in the Jingjinji region shows that while the coordination between science, technology finance, and high-quality economic development has improved, internal disparities persist, especially after 2016 in Tianjin. The study emphasizes the need for enhanced collaboration and highlights that while technology finance promotes efficiency, green, and innovation-driven development, its impact on green development remains limited.

However, Z. Lei & Weike (2018) conducted a study using threshold models to analyze the relationship between technology finance and technological innovation in China. They utilized panel data from 29 provincial-level administrative regions, spanning from 2005 to 2015, and used regional economic development as the threshold variable. Their research aimed to explore the nonlinear relationship between technology finance and technological innovation. The findings revealed a significant threshold effect, indicating a U-shaped relationship. Specifically, at lower levels of economic development, technology finance negatively impacts the enhancement of technological innovation capabilities. However, once economic development reaches a certain level, technology finance begins to positively influence and promote technological innovation.

Similarly, Shao-hua & Han-xiang (2023) analyzed the relationship between digital finance, technological innovation, and regional economic growth using panel data from 31 provinces between 2011 and 2020. The findings reveal three key insights: (1) Digital finance significantly and directly enhances regional economic growth, particularly in the eastern and central regions. (2) Digital finance also indirectly boosts economic growth by promoting regional technological innovation. (3) A detailed causal chain is identified, where digital finance increases R&D investment, which in turn leads to more innovation output and broader technological progress. This technological progress serves as a crucial driver for regional economic growth.

Additionally, Zhang et al. (2024) explored the effect of digital finance on corporate innovation, focusing on Chinese A-share listed companies from 2011 to 2017. The findings indicate that digital finance significantly enhances corporate innovation, leading to an increase in patent applications and approvals. The promotion of corporate innovation occurs through two key channels: (1) Digital finance intensifies competition among banks and improves credit access, which fosters innovation; and (2) it reduces financing constraints and costs for companies, further supporting innovation. Robustness tests confirm the consistency of these results.

Similarly, Liu et al. (2024) examined the long-term relationship between digital finance and the real economy in China, using panel data from 31 provinces between 2011 and 2020. Various statistical methods, including cross-sectional dependence, CADF unit root, panel co-integration tests, and the PMG method, confirm a co-integration relationship between digital finance and the real economy. The findings reveal that digital finance promotes short-term economic growth but has detrimental effects in the long run. In the eastern regions, digital finance has no short-term impact and a negative long-term effect on the real economy. In non-eastern regions, digital finance positively influences short-term growth but fails to sustain this impact over the long term. Overall, the study shows that while digital finance supports short-term economic progress, it is insufficient for long-term development.

Additionally, Liu et al. (2022) investigated the impact of digital finance on corporate green innovation, using data from Chinese listed firms between 2011 and 2018. The findings reveal that digital finance positively influences green innovation, a result confirmed by robustness tests. Further analysis indicates that digital finance promotes green innovation by easing financial constraints and boosting R&D investment. The effect is particularly strong in economically underdeveloped regions and high-pollution industries. The research offers practical insights for advancing financial development and enhancing environmental sustainability.

3. Empirical Model, Methodology, and Data

3.1. Data Source and Variables Description

This study compiles a panel data set covering one province (Hebei) and two municipalities (Beijing and Tianjin) for the period from 2000 to 2021. The time frame is selected based on the availability of relevant data, including variables such as the number of technology professionals, technology expenditure loans issued by financial institutions, and research funding investments. The data is sourced from the *Beijing Statistical Yearbook*, *Tianjin Statistical Yearbook*, *Hebei Provincial Statistical Yearbook*, and its *Financial Yearbook*, as well as the *China Statistical Yearbook on Science and Technology*.

Technology finance is assessed using three indicators: the number of technology professionals, the number of financial industry professionals, and loans for technology expenditures from financial institutions. The choice of these indicators is based on the availability of data and support from previously conducted research studies that have included these indicators in their research. An increase in research personnel indicates an expanding research scale and a growing need for financial services to support economic growth, establishing a positive link between research input and technology finance. This correlation is supported by studies such as those by Sicheng & Lihua (2022), Qian (2022), Guohua & Lu (2022), and Xinming et al. (2022). Additionally, a rise in financial professionals and loans for technology suggests stronger financial backing for technology enterprises, aligning with the findings of scholars like Qian (2022), Z. Lei & Weike (2018), Honglan (2020), and Lijun (2022).

Technological innovation is measured using both input-based and output-based methods. For input, research funding investment is used, while for output, the volume of patent applications is considered, drawing on methodologies from Feng et al. (2022), Lv et al. (2021), and Z. Lei & Weike (2018). The inclusion of these indicators to develop an index for technological innovation through PCA is also based on the availability of data and evidence from existing literature.

The dependent variable in this study is economic growth, measured by per capita gross domestic product (GDP) at the local level, as referenced by Bekaert et al. (2005), Chinn & Ito (2006), Rousseau & Wachtel (2011), Zhang et al. (2012), Estrada et al. (2015b), Nasreen et al. (2020), and Li & Wei (2021). The analysis includes standard control variables such as financial development, financial openness, and the gross enrollment rate in higher education. Financial development is proxied by the amount of credit in the financial system, reflecting the strong link between credit scale and economic growth (Cheng et al., 2021; Osei & Kim, 2020). Financial openness is represented by foreign direct investment (FDI), which introduces advanced technologies and experiences, enhancing technological innovation and economic growth (Boqiang Lin, 2022). The gross enrollment rate in higher education is included as it represents the availability of high-end talent, contributing to regional economic development, as suggested by Botev et al. (2019), Ehigiamusoe (2017), and Erdoğan et al. (2020). Detailed definitions and descriptions of these variables are provided in Table 1.

Table 1: Descriptions of the Variables and Statistical Sources

Region	Variables	Description of Data	Measurement	Source
Jing-Jin-Ji region(including Beijing, Tianjie and Hebei province)	PGDP- dependent variable	Domestic product per capita	logarithmized	Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Provincial Statistical Yearbook and its Financial Yearbook, and China Statistical Yearbook on Science and Technology
	TF	technology finance	PCA of three indicators: the number of technology professionals(NoT), the number of financial industry professionals(NoF), and loans for technology expenditure issued by financial institutions(LfT).	
	TI	technological innovation	PCA of two indicators: research funding investment (CfT) and the volume of patent applications received(Patent)	
	FOFDI-Control variable(CV)	foreign direct investment	logarithmized	
	FDLFIN -CV	the credit in the financial system	logarithmized	
	ERHE -CV	The gross enrollment rate of higher education	logarithmized	

Source: by the author

3.2. Empirical model

Our model is based on Pagano's (1993) well-known AK model, utilizing endogenous economic growth theory to examine the relationship between finance and economic growth. It also draws on the works of Chinn & Ito (2006), Guo & Peng (2016), Yang et al. (2020), Liang (2020), and Okunade (2022). The equation can be represented as follows:

$Y = f(TF, TI, K, L)$----------------1

Where Y, TF, TI, K, and L denote GDP, technology finance, technological innovation, capital stock, and human resources respective.

To examine the impact of technological innovation on economic growth, we can rewrite the equation as follows:

$PGDP_{it} = \alpha_0 + \beta_1' TI_{it} + \beta_2' \chi_{it} + \varepsilon_{it}$------------------2

where $PGDP$ is GDP per capita, which is the dependent variable technological Innovation (TI) is the main independent variable, x_{it} indicates an i dimensional vector of explanatory regressors that include threshold variable Technology Finance (TF), and control variables: Financial development $(FDLFIN)$, Financial Openness $(FOFDI)$, and $(ERHE)$. i represents different provinces or municipalities within the scope of the cross-section (i = 1, ..., N), t indicates the time-series dimension for each unit (t = 1,..., T),. $\alpha_0$is the specific fixed effect, $\varepsilon_{it} \approx (0, \sigma^2)$ is the independently and identically distributed error term.

In this paper, the main independent variable TI and the threshold variable TF are developed by applying principal component analysis. we first extracted the technology finance component from its original three indicators namely technology professionals(NoT), the number of financial industry professionals(NoF), and loans for technology expenditure issued by financial institutions(LfT). The choice for selecting these indicators of technology finance is purely based on the availability of data and support from previously conducted research studies that have also included these indicators in their research. Afterwards, we extracted the technological innovation component from its original two indicators namely research funding investment (CfT) and the volume of patent applications received(Patent). The inclusion of these indicators to develop an index for technological innovation through PCA is also based on the availability of data and supportive evidence from existing literature.

The concept of principal components was proposed by Pearson (1901) and later extended to random variables by Hotelling (1933). Principal component analysis is a mathematical procedure that transforms correlated variables into a smaller number of uncorrelated ones. This method is more efficient in establishing optimal weights for variables compared to other methods that assign equal or subjective weights (Ozkok, 2015). By addressing the collinearity of independent variables, PCA extracts the majority of the information while simultaneously solving the collinearity problem, thereby eliminating potential issues arising from different measurement scales or units.

To check the nonlinear relationship between economic growth and technological innovation, moderated by technology finance, the following equation will be estimated by including the square term of technology finance multiplied by technological innovation, along with control variables. If the coefficient of the square term is significant, it indicates a nonlinear relationship moderated by technology finance.

$PGDP_{it} = \alpha_0 + \beta_1 TF_{it}{}^2 TI_{it} + \beta_2 \chi_{it} + \varepsilon_{it}$-----------------p3

Borrowing from Hansen's (1999) non-dynamic panel threshold regression model, and following former scholars' studies (Yang et al., 2020), if we consider technology finance (TF) as a threshold variable, we can write our threshold regression model with a single threshold as::

$PGDP_{it} = \alpha_0 + \beta_1' TI_{it} + \beta_2' \chi_{it} \cdot I(TF_{it} \leq \gamma) + \beta_3' \chi_{it} \cdot I(TF_{it} > \gamma) + \varepsilon_{it}$---------------4

And if there are more thresholds existing in the variables of TF, the equation would be as equation 5:

$PGDP_{it} = \alpha_0 + \beta_1' TI_{it} + \beta_2' \chi_{it} \cdot I(TF_{it} \leq \gamma_1) + \beta_3' \chi_{it} \cdot I(\gamma_1 < TF_{it} \leq \gamma_2) + \beta_4' \chi_{it} \cdot I(\gamma_2 < TF_{it} \leq \gamma_3) + \cdots + \beta_n' \chi_{it} \cdot I(TF_{it} > \gamma_n) + \varepsilon_{it}$------------------------------------ 5

The main reasons to apply threshold regression are:

1. The existence of a nonlinear relationship between economic growth and technological innovation.
2. The relationship is moderated by technology finance, which in this case acts as the threshold variable (Lei & Weike, 2018).

4. Empirical results

4.1. PCA analysis of TF and TI

Technology finance was measured using three indicators: the number of technology professionals, the number of financial industry professionals, and loans for technology expenditures issued by financial institutions. The Kaiser-Meyer-Olkin (KMO) test for these indicators yielded a value above 0.4, as shown in Table 2, indicating that the data is suitable for factor analysis. Based on the factor analysis and the scree plot in Figure 2, it was determined that one principal component could be extracted.

Table 2: KMO Test Results

Variable	kmo
lnNoT	0.5816
lnNoF	0.7685
lnLfT	0.6117
Overall	0.6282

Source: calculated by the author

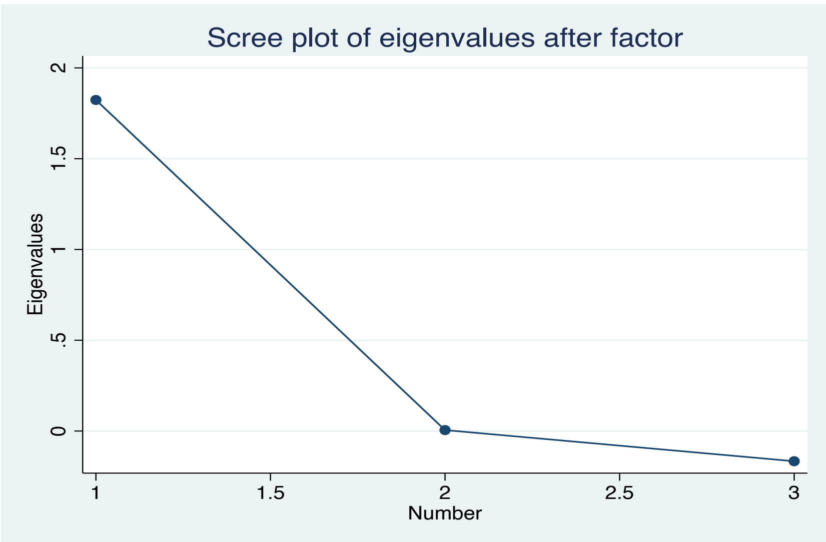

Figure 2: Scree Plot of Eigenvalues of technology finance.

Principal component factor analysis revealed that the extracted principal component effectively represents the indicators of technology finance, explaining 74.48% of the combined variance of the three indicators, as shown in Table 3. As a result, a single principal component, labeled as TF, has been extracted to represent technology finance.

Table 3: Eigenvectors Explaining indicators of technology finance

Variable	Comp1	Unexplained
lnNoT	0.6226	0.1339
lnNoF	0.5131	0.4117
lnLfT	0.5908	0.22

Source: calculated by the author

Similarly, after performing the SMC tests on the two indicators of technological innovation, both indicators scored above 0.7, as shown in Table 4, indicating they are suitable for principal component analysis. Factor analysis and the corresponding scree plot suggest that a single principal component can be extracted.

Table 4: SMC Test Results

Variable	SME
lnCfT	0.7506
lnPatent	0.7506

Source: calculated by the author

Principal component analysis for technological innovation shows that the extracted principal component accounts for 93.32% of the combined variance of the two technological innovation indicators, as indicated in Tables 5 and 6. As a result, one principal component, labelled TI, has been extracted to represent technological innovation.

Table 5: The Results of Principal Component Analysis on Technological Innovation

Principal components/correlation	(unrotated = principal)		Number of obs	66
			Number of comp.	1
Rotation:			Trace	2
			Rho	0.9332
Component	**Eigenvalue**	**Difference**	**Proportion**	**Cumulative**
Comp1	1.86635	1.73271	0.9332	0.9332
Comp2	0.13346		0.0668	1.0000

Source: calculated by the author

Table 6: Eigenvectors Explaining Indicators of Technological Innovation

Variable	Comp1	Unexplained
lnCfT	0.7071	0.06682
lnPatent	0.7071	0.06682

Source: calculated by the author

4.2. Descriptive Statistics

Table 7 provides descriptive statistics for all the variables under study. The average GDP per capita across the dataset is $6,422.5 USD, with Beijing leading at $12,000 USD, followed by Tianjin at $8,675 USD, and Hebei at $4,164.5 USD. In terms of technological professionals, Beijing has, on average, 2.4 times more than Tianjin and 3.04 times more than Hebei annually. The number of financial professionals in Beijing and Hebei is similar, both approximately 3.27 times higher than in Tianjin. Regarding RMB loans for technology expenditure, Beijing's average is 4.6 times that of Tianjin and 10.57 times that of Hebei. For research funding, Beijing averages 3.27 times more than Tianjin and 5.24 times more than Hebei. In terms of patent applications, Beijing's average is 3.08 times that of Tianjin and 3.36 times that of Hebei. However, the scale of credit and foreign investment attraction in Beijing is not markedly different, being only about 1.1 times that of Tianjin and Hebei (for details, see Tables 15 to 18 in the appendix).

Table 7: Descriptive Statistics

Variables	Obs	Mean	Std. dev	Min	Max	p1	p99	Skew.	Kurt.
lnPGDP	66	8.709	0.875	6.735	10.29	6.735	10.2	-.382	2.416
TF	66	0	1.495	-3.32	3.05	-3.32	3.05	.174	2.615
TI	66	0	1.366	-2.609	2.709	-2.60	2.70	-.092	2.181
lnFD	66	7.785	1.095	5.619	9.532	5.619	9.53	-.367	1.956

lnFO	66	4.001	0.798	1.98	5.494	1.98	5.49	-.292	2.471
lnerhe	66	2.855	0.516	1.515	3.963	1.515	3.96	0.228	3.061

Source: calculated by the author

4.3. Efficient of Correlation

The two newly extracted indices are substituted into Equation 2, and the correlations among the variables are computed, resulting in the correlation matrix presented in **Table 8**. The matrix indicates that all variables exhibit positive correlations with each other.

Table 8: The correlation matrix among variables

	lnPGDP	lnFD	lnFO	TF	TI	lnERHE
lnPGDP	**1.0000**					
lnFD	0.8741	**1.0000**				
lnFO	0.8619	0.8061	**1.0000**			
TF	0.8207	0.8969	0.6555	**1.0000**		
TI	0.9168	0.9443	0.7708	0.9519	**1.0000**	
lnERHE	0.0654	0.4996	0.1920	0.2948	0.2799	**1.0000**

Source: calculated by the author

4.4. Test for non-linearity and Threshold application

To confirm whether the relationship between economic growth and technological innovation is non-linear and moderated/regulated by technology finance, Equation 3 is estimated by including the square term of technology finance interacted with technological innovation (TF^2TI), along with other control variables. The fixed effects method is applied to estimate Equation 3, based on the significance of the Hausman test. The results indicate that the square term of technology finance multiplied by technological innovation (TF^2TI) is significant in the fixed effect estimated model, as shown in **Table 9**. This indicates that the nexus between economic growth and technological innovation is non-linear and is moderated/regulated by technology finance.

Table 9: FE model for Check for non-linearity and moderation

Variable	Coefficient	t-value
TF^2TI	0.00862***	3.38
LnFD	0.608***	18.84
LnFO	0.0808**	2.62
Lnerhe	-0.00494	-0.07
Constant	3.661***	26.72
R^2	0.985	
N	66	
F	963	
Hauseman	305.65***	

*,**,** indicate significance at 10, 5 and 1 percent respectively. Source: calculated by the author

4.5. Results of Threshold Regression

Using Equations 3 and 4, we employ technology finance (TF) as the threshold variable to investigate the potential nonlinear relationship between technological innovation and economic development in the Jingjinji region. The estimation results, derived through Stata statistical software, confirm the existence of a threshold value, specifically **TF = 1.459**, as shown in **Figure 3** and **Tables 12 to 13**.

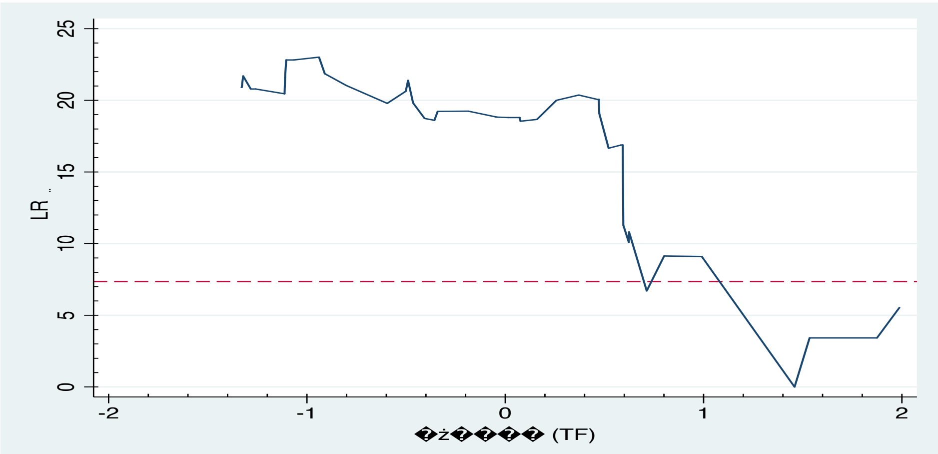

Figure 3: The First Threshold

Table 12: Threshold Estimates and Confidence Intervals

	Threshold Estimates	95%Conf. Interval
Single Threshold	1.459	[0.713, 1.987]
Double threshold		
Ito1	0.370	[-1.113,0.472]
Ito2	0.991	[0.991, 0.991]
Triple Threshold	-1.113	[-1.483, 2.998]

Source: calculated by the author

Table 13: Threshold Bootstrap Test

				Critical Value		
Model	**F-statistic**	**P-values**	**BS times**	**1%**	**5%**	**10%**
Single Threshold	20.102*	0.072	500	25.260	20.102	12.026
Double Threshold	22.696	0.106	500	31.483	31.483	30.724
Triple Threshold	2.775	0.790	500	32.684	26.377	17.922

Source: calculated by the author

4.6. Robust test

After determining a threshold value for technology finance through threshold regression, we performed tests for heteroscedasticity, serial correlation, and cross-sectional dependence on the panel data. The results revealed no heteroscedasticity issues but did indicate the presence of serial correlation and cross-sectional correlation. Consequently, we compared the regression outcomes from various models: ordinary least squares regression without a threshold (reg), ordinary least squares regression with a threshold (reg1), fixed effects regression with a threshold (fe1), fixed effects regression accounting for heteroscedasticity (fe_robust1), and a model that simultaneously considers heteroscedasticity, serial correlation, and cross-sectional correlation (p_all), as shown in **Table 14**.

Table 14: The Result of Robust Test

	(1)	(2)	(3)	(4)	(5)
	reg	**reg1**	**fe1**	**fe_robust1**	**p_all**
TF	-0.177***				
	(-3.45)				
TI	0.236***				
	(2.76)				
lnFD	0.728***	0.663***	0.642***	0.642*	0.608***
	(6.52)	(5.90)	(9.70)	(3.76)	(7.02)
lnFO	0.136**	0.207***	0.0408	0.0408	0.110***
	(2.38)	(3.89)	(1.32)	(1.14)	(2.95)
lnerhe	-0.725***	-0.759***	0.219**	0.219*	-0.593***
	(-9.69)	(-9.76)	(2.59)	(3.27)	(-7.14)
TI		0.120	-0.0580	-0.0580	0.160***
$(TF \leq 1.459)$		(1.66)	(-1.10)	(-0.39)	(3.04)
TI		-0.00866	0.0783	0.0783	0.116*
$(TF > 1.459)$		(-0.12)	(1.38)	(0.57)	(1.93)
_cons	4.570***	4.928***	2.879***	2.879	5.239***
	(7.64)	(7.99)	(6.32)	(2.50)	(9.84)
r2	0.965	0.963	0.987	0.987	
r2_w			0.987	0.987	
N	66	66	66	66	66
F	328.2	316.3	859.7		

t statistics in parentheses * p<0.1, ** p<0.05, *** p<0.01. Source: calculated by the author

The findings show that without accounting for the threshold effect, most variables positively influence economic growth in the Jingjinji region, except for technology finance (TF) and the gross enrollment rate of higher education, which negatively correlate with economic growth. Among these variables, financial development exerts the strongest positive impact on economic growth, aligning with the work of Goldsmith (1969), McKinnon (1973), Shaw (1973), Gurley & Benston (1976), and Ross & Sara (1998). Technological innovation also significantly contributes to economic growth. In terms of significance, all coefficients are significant at the 1% level, except for financial openness, which is significant at the 5% level.

After incorporating the threshold effect and addressing issues of heteroskedasticity, serial correlation, and cross-sectional correlation, the results indicate that all variables, except for the number of regular college enrollments (which has a negative coefficient), positively influence economic growth. Financial openness has a modest positive effect with a coefficient of 0.11, while financial development remains the most significant factor, with a coefficient of 0.608. Technological innovation (TI) also positively impacts economic growth, but its effect is moderated by the threshold value of technology finance (TF). When TF is less than or equal to 1.459, TI significantly boosts economic growth with a coefficient of 0.16. However, when TF exceeds 1.459, the impact of TI diminishes, with a coefficient of 0.116. This latter result is significant at the 10% level, while all other coefficients remain significant at the 1% level.

The varying impacts of technology finance and technological innovation among Beijing, Tianjin, and Hebei provinces in the Jingjinji region can be attributed to several key factors:

1. **Technology Finance Threshold**: The study identifies a threshold of 1.459 for the technology finance index, above which the positive impact of technological innovation on economic growth begins to diminish. Beijing has surpassed this threshold, leading to a reduced positive effect of innovation on its growth. On the other hand, Tianjin and Hebei have not yet reached the threshold, allowing technological innovation to still have a stronger impact on economic growth in these provinces.
2. **Levels of Financial Development**: Beijing, being more financially developed, may experience diminishing returns from additional investments in technology finance as it has already reached a high level of financial maturity. In contrast, Tianjin and Hebei, with less advanced financial systems, may still benefit more from increases in technology finance.
3. **Degree of Technological Innovation**: Beijing likely has more advanced technological infrastructure and innovation capacity than Tianjin and Hebei. This could mean that the region has reached a saturation point where additional innovation does not contribute as significantly to growth as it does in regions with less technological advancement.
4. **Financial Openness**: Differences in financial openness across the three provinces might also explain the varying impacts. A more open financial system in Beijing could lead to a different interaction between finance, innovation, and growth compared to Tianjin and Hebei, which might have less openness and, thus, greater potential for improvement.
5. **Government Policies and Investment**: The allocation of government resources and incentives toward technological development and finance likely varies across the provinces. Beijing, as the capital, may have already benefited from significant investments in technology, whereas Tianjin and Hebei may still require more targeted policy support to enhance their growth.

In summary, the differences in the levels of technology finance, financial development, innovation capacity, financial openness, human capital, and government policies contribute to the varying impacts of technological innovation and technology finance on economic growth in Beijing, Tianjin, and Hebei.

5. Conclusions

This study offers new insights into the nonlinear relationship between technological innovation, technology finance, and economic growth, using data from the Jingjinji region between 2000 and 2021. The findings reveal a threshold value of technology finance (1.459) that influences the impact of technological innovation on economic growth. When the technology finance index is below this threshold, technological innovation has a greater positive effect on economic growth.

In Beijing, the technology finance index was below 1.459 before 2010, meaning that during this period, the government's innovative financial strategies significantly boosted technological innovation, which in turn drove economic growth. However, after 2010, the index exceeded 1.459, leading to a diminishing marginal effect of technological innovation on economic growth despite the increased scale of technology finance. This trend is evident from the smaller growth in patent applications relative to the increase in technology loan expenditures, indicating that the effectiveness of technological innovation in driving economic growth weakened as technology finance became more abundant.

The study's findings align with the research of Z. Lei & Weike (2018) and suggest that while Beijing's role as a national hub for technological innovation has fueled economic development, the law of diminishing marginal returns has also emerged. As technology finance in Beijing expanded beyond a certain point, it alleviated funding constraints for technology enterprises but also led to less efficient allocation of resources, reducing the marginal effectiveness of technology finance.

Additionally, the negative correlation between university enrollment numbers and economic growth in the Jingjinji region is explained by the concentration of talent in Beijing. Despite increasing university enrollments, Beijing's dominance in attracting talent has led to a talent drain from surrounding areas like Tianjin and Hebei, limiting their economic integration and coordinated development. The study suggests that college enrollment ratios, which represent the quality of human capital, have a negative effect on economic growth. If Beijing has a higher enrollment ratio, it might face challenges related to over-education or a mismatch of skills, limiting the potential gains from technological innovation. Tianjin and Hebei might not face the same level of saturation in their labour markets. For Tianjin and Hebei, the technology finance index remains well below the threshold value, with Hebei slightly outperforming Tianjin.

6. Policy Implication

Based on the study's findings, the recommendations are as follows:

1. **Enhance Policy Precision and Effectiveness**: Improve the accuracy and effectiveness of technology finance policies in the Jingjinji region by refining top-level planning, enhancing inter-departmental coordination, and boosting policy implementation.
2. **Expand Beijing's Financial Services Spillover**: While Beijing focuses on refining its technology finance policies, it should also extend successful practices to Tianjin and Hebei. This includes increasing investments in these areas, optimizing resource allocation, and facilitating the transfer of technology finance funds and talent from Beijing to Tianjin and Hebei. By doing so, the benefits of technology finance policies can be better realized, promoting technological innovation and economic growth throughout the Jingjinji region.
3. **Shift Development Focus to Tianjin and Hebei**: It is highly recommended that the government of China divert development focus from Beijing to Tianjin and Hebei, particularly in terms of the allocation and rationalization of scarce financial, human, and capital resources. This would ensure balanced growth and minimize disparities among the provinces, leading to optimal productivity and efficient utilization of resources. Additionally, the government should design policies that support financial development and financial openness in underdeveloped provinces and regions, enhancing connectivity and integration through digitization.

7. Limitation and generalization

This study is conducted in the context of the Jingjinji region of China, which comprises Beijing, Tianjin, and Hebei provinces. Hence, the findings are confined to these provinces. However, the findings may be applied to architect and implement economic policies in other regions of China with similar characteristics. The data is sourced from secondary publications such as provincial, regional, and national statistical yearbooks.

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Appendix

Table 15: Descriptive statistics in the JINGJINJI region

Variable	min	p25	p50	p75	max
EGPGDP	841.000	3196.000	6422.500	1.2e+04	2.9e+04
NoT	2.320	4.620	11.165	17.720	33.830
NoF	2.500	8.200	18.030	27.000	40.900
LfT	2.070	6.246	10.865	19.772	181.874
CfT	53.490	181.240	436.690	734.970	2629.320
PATENT	1611.000	5584.000	1.7e+04	5.2e+04	2.0e+05
FDLFIN	275.600	929.800	2927.800	5682.600	1.4e+04
FDFDI	7.245.	32.2.	59.416.	101.004.	243.291
ERHE	4.550	14.190	15.617	25.030	52.620

Source: calculated by the author

Table 16: Descriptive statistics in Beijing

Variable	min	p25	p50	p75	max
EGPGDP	2713.000	5548.000	1.2e+04	1.8e+04	2.9e+04
NoT	9.530	16.840	20.550	25.330	33.830
NoF	7.100	10.800	24.000	34.900	40.900
LfT	7.200	11.000	57.738	88.548	181.874
CfT	372.590	700.200	1027.820	1484.580	2629.320
PATENT	5905.000	1.0e+04	3.7e+04	1.0e+05	2.0e+05
FDLFIN	730.200	1711.500	4921.150	8780.000	1.4e+04
ERHE	9.940	15.274	15.595	15.899	16.308

Source: calculated by the author

Table 17: Descriptive statistics in Tianjin

Variable	min	p25	p50	p75	max
EGPGDP	1961.000	3731.000	8750.000	1.2e+04	1.8e+04
NoT	2.320	3.340	8.515	16.070	17.770
NoF	2.500	5.150	7.335	15.800	19.800
LfT	2.070	7.380	12.665	16.047	24.066
CfT	54.350	178.470	313.720	464.690	574.320
Patent	1611.000	3045.000	1.2e+04	4.0e+04	9.8e+04
FDLFIN	275.600	576.500	2250.150	4328.900	6363.500
FOFDI	16.332	38.059	53.334	108.487	211.344
ERHE	4.550	10.360	13.310	14.610	17.500

Source: calculated by the author

Table 18: Descriptive statistics in Hebei

Variable	min	p25	p50	p75	max
EGPGDP	841.000	1568.000	4164.500	5824.000	8397.000
NoT	2.820	4.170	6.765	10.700	12.560
NoF	16.130	18.120	24.035	32.170	37.050
LfT	2.230	4.510	5.457	9.200	18.937
CfT	53.490	119.480	195.885	383.430	745.490
Patent	2790.000	3585.000	1.1e+04	3.2e+04	1.2e+05
FDLFIN	354.300	783.100	2568.350	5682.600	1.1e+04
ERHE	8.860	25.030	34.050	38.070	52.620

Source: calculated by the author