

# Fintech, Financing Pathway and Regional Innovation Performance: Based on China's Provincial Panel Data from 2011 to 2020

Zhaojiang Wang<sup>1,\*</sup>

<sup>1</sup>School of Governance, Nanjing University, Nanjing, China

\*Corresponding author

**Abstract:** Based on the panel data of 30 provincial administrative planning regions in China from 2011 to 2020, this paper examines the impact of fintech on the achievement of regional innovation, and further studies the regulatory effect and interaction of Foreign Direct Investment and Industry-University-Research Collaboration on the relationship between them. The results show that: fintech is positively correlated with the achievement of regional innovation; further research shows that Foreign Direct Investment makes an inhibitory role on fintech, Industry-University-Research makes a promotive role on fintech and there is a substitution effect between Industry-University-Research and Foreign Direct Investment in a long-term planning. The analysis of regional innovation efficiency of our country shows that regional independent innovation is still in the stage of Economies of scale, and the allocation of social resources has not reached the optimal level.

**Keywords:** Fintech; Regional Innovation performance; Foreign direct investment; collaborative innovation

## 1. Introduction

China is at the critical period of focusing on building a new development pattern of domestic and international double cycle. Technology innovation is crucial to the development of the regional economy. Fintech is a new technological revolution led by big data, cloud computing, artificial intelligence, blockchain and mobile Internet, whose application has reshaped traditional financial business scenarios, optimized financial ecology and greatly broadened the breadth and depth of financial services. The "Guidance on Financial Support for the Construction of a Strong Manufacturing Country" issued by the Chinese government emphasizes the need to play the role of financial innovation in boosting technological innovation. Local governments should attach great importance to financial services for the manufacturing industry and develop a financial product system that meets the characteristics of new industries. 2021 China's Government Work Report proposes to increase the proportion of R&D expenses of manufacturing enterprises with additional deduction from 75% to 100%. Therefore, it is important for policy guidance to study the influence mechanism of fintech on regional innovation performance.

A large number of studies have been conducted to demonstrate the relationship between fintech and regional innovation efficiency. Schumpeter pointed out that the improvement of financial operation efficiency would affect regional economic development by promoting technological innovation. Further studies have since found that the development of the regional financial system promotes innovation R&D intensity (Ang J B, 2010) [1]; from two different perspectives, developed countries and emerging economies, some scholars have found that the development of the financial system has a facilitating effect on R&D intensity (Reza H. Chowdhury and Min Maungm, 2012) [2]. Chinese scholars found that the development of China's financial system has different long-term incentives for regional autonomous innovation (Jiangbin Liu and Yanmei Li, 2008). The literature that has been studied is dominated by literature that emphasizes the effects of the role. Fewer studies have incorporated the role of fintech on regional innovation from the perspectives of external opening and internal role into one framework.

In this paper, regional innovation is evaluated through a factor analysis approach based on panel data of 30 provincial administrative planning regions in China from 2011 to 2020. The article analyzes the relationship between fintech and regional innovation performance in China, and the study finds that there is a significant facilitative moderating effect of fintech on regional innovation performance. In a further study, the article analyzes the interactive relationship among fintech, foreign direct investment, and

industry-university-research cooperation, and finds that foreign direct investment has a substitution effect with fintech, and industry-university-research cooperation has a complementary effect with fintech.

The possible contributions of this paper are: (1) this paper incorporates fintech, FDI, and industry-university-research cooperation into one framework for analysis, and uses factor analysis to respond to regional innovation performance; (2) this paper investigates the influence mechanism of fintech on regional innovation performance from both the external opening perspective and the internal role perspective.

## 2. Literature Review and Research Hypothesis

The existing literature has mainly studied the relationship between fintech and regional innovation performance in terms of regional innovation financial environment (Ari Hyytinen and Otto Toivanen, 2005) [3], corporate investment and financing methods (Lei Wang and Xinghua Dang, 2008), and risk management (Yong You and Xiaoyan Yang, 2009). The study shows that regional fintech has a catalytic effect on the expansion of market size as well as the improvement of market efficiency in the whole financial system. The spillover effect contributes to the increase of regional investment and foreign trade openness. In this environment, fintech provides financial support or technical support for the development of regional enterprises and research institutions, thus promoting the improvement of regional innovation efficiency (Dong Wang and Zhihong Zhao, 2019).

The development of fintech has brought the prominence of the status of Internet finance. The information asymmetry of the traditional financial model has been alleviated. This has eased the environmental pressure that makes financing difficult for Chinese SMEs (Huang Y et al,2018)[4]. Internet finance has also broadened the sources of corporate finance through cloud platforms, thus enhancing the efficiency of regional innovation (Song Tang et al,2020). On the other hand, fintech also enables innovative companies to be identified more precisely for targeted investment. (Taihui Zhu, 2018).

Fintech has an impact on regional innovation performance through the mediating effect of international finance. With closer international finance, countries with comparative advantage expand the production of some high foreign-dependent products, thus promoting international financial flows as well as the transformation of innovation outcomes (Quy-Toan Do and Andrei A,2006)[5]. However, in Chinese scholars' studies, there is an incongruity between international and regional finance in China, and thus there is uncertainty about the impact on regional innovation (Chengsi Zhang et al.,2013). The role of FinTech in international finance is mainly reflected in the transformation of results, while it is not significant in the R&D stage of science and technology (Zhenyao Zhao et al,2016).

Fintech makes regional governments more accurate in identifying the innovation capabilities of enterprises. Fintech uses big data technology to assess the operation and innovation capacity of enterprises, thus promoting policy efficiency (Christina Zhu,2019)[6]. Other scholars argue that competition is the first facilitator for innovative firms. Long-term policy support from regional governments also makes some enterprises stagnate in innovation and rely on policy operations. Facing this situation, fintech gives governments the ability to track firm innovation over time. The government can effectively avoid the problem of over-support through data mining technology.

In summary, it can be concluded that fintech enhances the expansiveness of financial system functions thus enhancing regional innovation capacity, acting on enterprises or research units. The path of action can be divided into financing path and non-financing path, as shown in Figure 1.

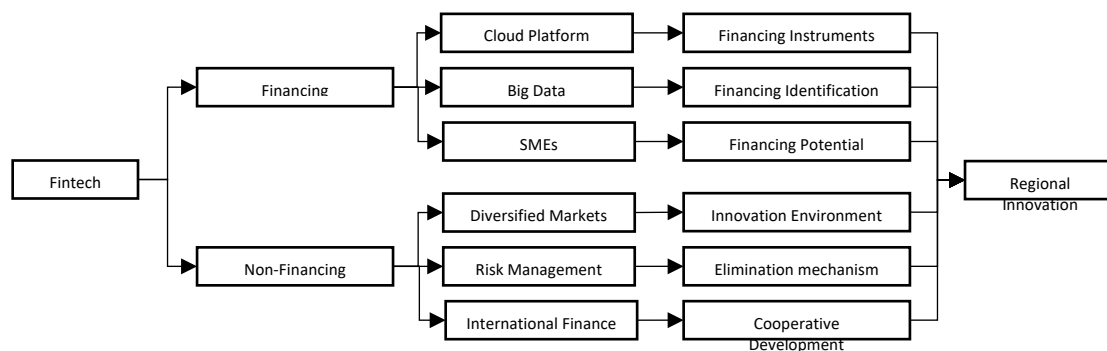


Figure 1: Mechanisms of Fintech's impact on regional innovation performance.

At the early stage of regional innovation development, regional enterprises and scientific research

units are in the initial stage. The development of fintech drives the development of regional trade openness. On the one hand, big data, cloud platform, artificial intelligence and other technologies brought by FinTech reduce the cost of knowledge dissemination, save the time of dissemination, bring into play the network effect of technical knowledge as well as Internet dissemination (Michael L. Katz and Carl Shapiro, 1985)[7], and promote horizontal imitation dissemination among technical industries. On the other hand, the risk control system alleviates the information asymmetry between banks and firms in the region and promotes the development of emerging industries. In addition, fintech facilitates the mobility of technicians, promotes technology diffusion, and drives regional innovation development.

After the gradual maturity of regional innovation, independent innovation has become the new development direction of regional innovation. The impact brought by the non-financial path of FinTech is gradually obvious. Fintech makes the financial efficiency in the region increasing and the induction for regional innovation demand deepening. A vibrant financial ecosystem provides a good market environment for the transformation of innovation results (Christoph Kumpan, 2017)[8]. The mature development of FinTech derives regulatory technology for business institutions, which enables the quality of regional innovation to be guaranteed. Fintech addresses the risk of uncertainty in innovation, builds a sound exit mechanism, and optimizes the regional innovation environment. The promotion of decentralization mechanism breaks the regionalization restriction of market factors, gives innovative enterprises more capital sources and product marketing channels, and enables the long-term development of inter-regional innovation cooperation. Based on this, the research hypothesis 1 of this paper is proposed.

H1: Fintech has a positive relationship with regional innovation performance.

Investment in industry-university-research cooperation and regional foreign direct investment reflect the role of investment development in science and innovation, which is closely related to financial development (Lingyun Huang et al, 2012). It has been shown that there is a significant positive relationship between foreign direct investment and regional innovation efficiency (Xiaolan Fu, 2010)[9], and foreign direct investment enhances regional innovation capacity in regional innovation through demonstration effect (Dianchun Jiang, Yu Zhang, 2008) and knowledge spillover effect (Xu and Lian et al, 2007). In addition, industry-academia-research cooperation has contributed to regional innovation (Li X B, 2009) and technology catch-up and R&D (Liu X and White S, 2001)[10].

Research on the impact of FDI on regional innovation can be briefly divided into three processes. The first studies concluded that FDI has a catalytic effect on regional innovation performance (Brian J Aitken and Ann E Harrison, 1999) [11]. Subsequent studies began to distinguish between horizontal and vertical spillover effects of FDI. Some of the studies suggest that horizontal spillovers arise from the demonstration and pro-competitive effects of foreign investment. The vertical spillover refers to foreign investment driving regional vertical integration and industrial chain development through more advanced management concepts. Both have positive effects on regional innovation performance (Ping Lin et al, 2009) [12]. Based on this, the research hypothesis 2a of this paper is proposed.

H2a: Foreign direct investment has a short-term facilitative effect on the development of fintech through horizontal and vertical spillover effects.

Some studies suggest that industry-academia-research cooperation and FDI have complementary effects (Chuntao Li et al, 2020), and subsequent studies have investigated the effects of all three on innovation outcomes and efficiency from the perspective of Chinese firms or industries (Dun Bao, 2020). They argue that the market expansion brought by foreign investment has led to the further development of regional autonomous innovation capabilities. On the other hand, they argue that local firms have less room to survive under foreign competition, thus inhibiting the development of industry-university cooperation (Guanghe Ran et al., 2013). Based on this, the research hypothesis 2b of this paper is proposed.

H2b: The development of fintech and industry-academia-research cooperation is not significantly affected by the crowding-out effect of foreign investment in the short term, but has a stable mutual promotion in the long term due to their independent innovation.

### **3. Regional Innovation Capacity Model and Variable Setting**

#### **3.1. Model Setting**

The model was constructed by combining the study of Guo B (2008)[13], using panel data and

analyzing foreign investment, industry-academia-research investment with a lagged one-period factor score to obtain the following model (1).

$$\lnscore_{i,t} = \alpha_0 + \alpha_1 \ln Fintch_{i,t} + \alpha_2 K\_foreign_{i,t-1} + \alpha_3 K\_corporation_{i,t-1} + \beta M_{i,t} + \varepsilon_{i,t} \quad (1)$$

### Explanatory variables

**Regional innovation performance** (lnscore). Because regional innovation capacity is shown by various aspects, this paper uses factor analysis to make a comprehensive measure of regional innovation capacity (Yongfei Jia et al., 2020). Combining the needs of this study and the indicators selected from the existing literature (Hongyuan Zhang et al., 2020), this paper selects the variables in Table 1 for factor analysis. In this paper, the data of 30 provincial administrative divisions of China from 2011 to 2020 were selected for evaluation and analyzed, and the data were obtained from the China Statistical Yearbook.

Table 1: Factor analysis variable selection

Factors	Variables
Innovation Strength	RD staff volume
	RD funding expenses
	RD project topics
	Invention patents
	Utility patents
	Technology Market Turnover
Innovation potential	Full Senior Faculty
	Associate Senior Faculty
	Colleges and Universities
	School Staff
	Average salary of education staff
	Average salary of private educators
Innovation Environment	Pollution treatment investment amount
	Pollution control completed investment
	Public library volume
	Internet penetration rate
	Share of tertiary sector in GDP
	Telephone penetration rate

### Control variables

**Fintech index** (lnFintch). In this paper, the Peking University Digital Inclusive Finance Index is selected as the core explanatory variable. **Foreign direct investment** (K\_foreign). In this paper, a relative indicator is selected to indicate the spillover effect of foreign direct investment on innovation, i.e., the ratio of FDI to total regional fixed assets in each province of China. **Industry-academia-research cooperation investment** (K\_corporation). In this paper, the ratio of corporate capital to total internal expenditure is selected.

**Marketization index** (lnMrtlevel). This paper selects the data of total marketization index of each Chinese province as the basis of analysis (Xiaolu Wang, Gang Fan, Lipeng Hu, 2021). **Exchange rate** (exchange), **per capita gross domestic product** (avergdp), and **population quality** (population\_quality). In this paper, the product of university graduates and urbanization rate of each region in China is selected as the basis for the analysis of population quality.

The above data are obtained from the National Bureau of Statistics of China.

### 3.2. Descriptive statistics

Table 2: Descriptive statistics

Variable	Explanation	Obs	Mean	Std. Dev.	Min	Max
lnscore	Regional innovation performance	300	.631	.193	.1	1
lnFintch	Fintech index	300	5.392	.734	2.026	6.117
lnMrtlevel	Marketization index	300	1.837	.312	.846	2.319
exchange	Exchange rate	300	6.449	.216	6.143	6.737
avergdp	per capita GDP	300	5.287	2.49	1.648	14.021
population quality	population quality	300	6.33	1.565	3.423	10.473
K forgien	Foreign direct investment	300	.705	.819	.01	4.239
K corporation	Industry-academia-research cooperation investment	300	.653	.247	.005	1.08

Descriptive statistics variable explanation, various indicators, etc. are shown in Table 2.

### 3.3. Hausman test

The model study in this paper uses fixed-effects and random-effects models to estimate the panel data, and the BP-LM test and the Hausman test show that it is reasonable to choose the fixed-effects model for the analysis. After that, heteroskedasticity and serial correlation were tested using Wald estimator and Wooldridge test, and the results showed that the model has heteroskedasticity and serial correlation, as shown in Table 3 and Table 4.

Table 3: Hausman test

TEST	Chi-Sq.Statistic	Prob.
BP-LM test	680.57	0.000
Hausman test	37.13	0.000

Table 4: Wooldridge test

TEST	Chi-Sq.Statistic	Prob.
Wooldridge test	178.20	0.000

## 4. Analysis of the mechanism of the role of financial technology on regional innovation

### 4.1. Model regression analysis

Based on the above tests, the model was analyzed by the Driscoll and Kraay robust standard error method, and the final results are shown in Table 5.

According to column (3) of Table 5, the p-values of the variables are less than 0.05, and the model is more significant by the significance test. The intra-group R-squared reaches 0.9, and the model fit is good. The coefficient of financial technology index is 0.032 and the p-value is 0.000, indicating that all of them have a significant positive effect on regional innovation index. The spillover effect coefficient of foreign direct investment is 0.009 with a p-value of 0.016; the spillover effect coefficient of industry-university-research investment is 0.026 with a p-value of 0.000, which is significantly and positively related to innovation performance at the 1% significance level. The relationship between fintech and regional innovation performance in China at this stage is a facilitating relationship, confirming hypothesis H1.

Column (1) shows that according to the results of robust standard error estimation, the contribution of fintech development to regional innovation performance amounts to a coefficient factor of 0.066. Column (3) decreases to 0.032 with the inclusion of control variables and industry-university-research and foreign variables, with a lagged contribution of 0.026 for industry-university-research cooperation and 0.009 for foreign direct investment, while column (2) shows that foreign direct investment inhibits regional innovation when only industry-university-research and foreign variables are added again, with a p-value less than 0.05.

In summary, financial technology, industry-university-research cooperation, and foreign direct investment can all promote regional innovation in the short term, but the promotion effect may change

over time.

Table 5: Driscoll and Kraay model analysis results

	(1)	(2)	(3)
Variables	Inscore	Inscore	Inscore
lnFintch	0.066*** (5.97)	0.067*** (4.50)	0.032*** (25.39)
K_forgien		-0.011** (-2.15)	0.009** (2.56)
K_corporation		-0.029 (-0.91)	0.026*** (11.61)
lnMrtlevel			0.105*** (8.30)
exchange			0.124*** (8.24)
avergdp			0.007*** (3.16)
population_quality			0.087*** (3.30)
Constant	0.276*** (5.55)	0.296*** (5.27)	-1.148*** (-4.88)
Observations	300	300	300
Number of groups	30	30	30
R-squared	0.6564	0.6707	0.8999

t-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

#### 4.2. Impact mechanism analysis

The above analysis explores around the relationship between fintech and regional innovation, but the interaction of fintech, foreign direct investment, and industry-academia-research cooperation on regional innovation is unclear. Therefore, the following model (2) is constructed.

$$lnscore_{it} = \alpha_0 + \alpha_1 lnFintch_{i,t} + \alpha_2 K_{for_{i,t-1}} + \alpha_3 K_{cor_{i,t-1}} + \alpha_4 int\_For_{i,t-1} + \alpha_5 int\_Cor_{i,t-1} + \beta M_{i,t} + \varepsilon_{i,t} \quad (2)$$

The new terms interact For and interact Cor denote the interaction terms of FinTech index with foreign direct investment and industry-academia-research cooperation, respectively, and the rest of the variables are the same as model (1), and similar results are obtained after the same test, so we continue to analyze model (2) using the robust standard error method and obtain the results as shown in Table 6.

The spillover effect coefficient of FDI is 0.050 with a p-value of 0.000, which is significantly positively related to regional innovation. The coefficient of the spillover effect of industry-university-research investment is -0.126 with a p-value of 0.029, which is significantly negatively related to regional innovation and confirms hypothesis H2a. The results of industry-university-research investment are more complex and confidential, and only work within the enterprise. Meanwhile, industry-university-research cooperation enhances the efficiency and precision of the transmission of innovation results, which makes the release of innovation results take longer time and space. Foreign direct investment directly affects the regional market and innovation environment. Enterprises and institutions in the region can use external knowledge to improve their own innovation level, thus leading to the improvement of regional innovation capacity. That is, industry-university-research cooperation is biased to enhance the regional independent innovation capability, while FDI is biased to enhance the regional imitation and improvement innovation capability.

The coefficient of the interaction term between the financial technology index and foreign direct investment is -0.008, with a p-value of 0.000, which passes the significance test and has a significant negative effect. The coefficient of the interaction term between FinTech index and industry-academia-research cooperation is 0.033 with a p-value of 0.015, which passes the significance test and has a significant positive effect, confirming hypothesis H2b. This indicates that the development of FinTech

and the development of industry-academia-research cooperation are mutually reinforcing. The development of financial technology reduces the difficulty of enterprises to obtain innovation funds and improves their innovation environment. At the same time, the development of enterprise innovation drives the rising demand of regional financial industry, thus achieving a win-win situation. And foreign direct investment can bring about an increase in regional innovation capacity in the short term. However, improved innovation is characterized by short cycle and weak momentum. Improved innovation can only bring short-lived development to fintech. The improvement of independent innovation capability is the core element of regional innovation development. Improved innovation is the main innovation mode in the early stage of innovation. He promotes the improvement of regional innovation environment. However, along with the development of regional economic capacity, autonomous innovation will gradually replace imitative innovation as the source of regional innovation development.

Table 6: Interaction term model analysis results

Variables	Inscore
lnFintch	0.034*** (30.26)
lnMrtlevel	0.081*** (4.52)
exchange	0.109*** (8.41)
avergdp	0.007*** (3.42)
population quality	0.052*** (2.80)
K forgien	0.050*** (7.93)
K corporation	-0.126** (-2.29)
Interact For	-0.008*** (-9.97)
Interact Cor	0.033*** (2.81)
Constant	-0.814*** (-4.58)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

#### 4.3. Robustness analysis

To test whether the model is robust, this paper uses five replacement methods as follows.

##### 4.3.1. Robustness check by replacing Baidu Fintech Index instead of Fintech Index

In this paper, the Fintech index is replaced. Based on the analysis method adopted under the perspective of financial function and technology integration, this paper adopts the "text mining method" to data mine and analyze the Baidu Fintech index (Fintch\_factor) formed by each keyword of Baidu News. The specific factors selected are shown in Table 7.

The 28 provincial-level administrative regions in China were selected and searched in Baidu index search by year to obtain the annual average search index of each keyword in each province for each year from 2013 to 2022. Finally, the annual search index was used as the original data for constructing the FinTech index.

To ensure the consistency of inter-provincial and inter-year calculation methods, this paper adopts the full-year data analysis method. The data were subjected to dimensionality reduction factor analysis using SPSS software, and the conditions were met by KMO test. Therefore, the full-year data downscaling and rotation process was performed to finally synthesize the fintech indices of each provincial administrative region for each year, followed by the normalization process and logarithmic process.

The BP-LM test, Hausman test, Wald estimator, and Wooldridge test results were similar, and the robust standard error method above was adopted for the analysis. As shown in Table 8, FinTech still shows a significant positive impact on regional innovation, and foreign direct investment and industry-academia-research cooperation show a promotional effect, which is consistent with the previous findings.

Table 7: Baidu Fintech Index Keyword Factor Database

Core Dimension	Fintech Keyword Factor Database			
Payment settlement	Third party payment	Mobile payment	Online payment	Phone payment
Resource Allocation	Online Loans	Internet Finance	Crowd funding	Internet Investment
Risk Management	Internet Finance	Online Finance	Wealth Management Platform	Internet Insurance
Information Intermediation	E-Banking	Internet Banking	Internet Bank	Internet Financial Platform
Underlying Technology	Big Data	Cloud Computing	Blockchain	Artificial Intelligence

4.3.2. Robustness check by replacing regional innovation efficiency instead of regional innovation

The BCC-DEA model efficiency analysis can measure the effectiveness between multiple input indicators of the same type and output under the assumption of variable scale effects to obtain the system efficiency (Tech\_E). Considering that the innovation efficiency value is between 0 and 1, it is not appropriate to use the ordinary regression method, and this paper uses the random effects panel Tobit model for regression.

Comprehensive patent licenses (direct knowledge output) and technology market turnover (indirect economic output) are selected as outputs, and RD personnel equivalent full-time equivalents of industrial enterprises above the scale and RD expenditure of industrial enterprises above the scale are taken as input terms. The analysis was conducted by DEAP 2.1 software, and the results were substituted into model 1 as the explanatory variables, and the results are shown in Table 9.

The LR test value is 75.440 and the p-value is 0.000, the result is significant and the model is chosen appropriately. The coefficient of financial technology index is 0.010 and the p-value is 0.010, which still has a significant positive impact on regional innovation, which is consistent with the previous conclusion.

Table 8: Baidu factor analysis results

Variables	lnscore
Fintch_factor	0.053*** (3.07)
lnMrtlevel	0.089*** (3.21)
exchange	0.015*** (5.66)
avergdp	0.124*** (7.93)
population_quality	0.110*** (4.24)
K_forgien	0.006 (1.51)
K_corporation	0.037*** (2.95)
Constant	-1.345*** (-5.87)
Observations	280
Number of groups	28

t-statistics in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1



Table 9: Panel Tobit model analysis results

Variables	Tech E
lnFintch	0.010*** (1.60)
lnMrtlevel	0.088*** (3.31)
exchange	-0.005 (-0.37)
avergdp	0.001 (0.19)
population_quality	-0.001 (-0.29)
K_forgien	0.007 (1.27)
K_corporation	-0.052*** (-2.81)
Constant	0.737*** (7.63)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

**4.3.3. Robustness check by replacing Fintech sub-index instead of Fintech index**

This robustness analysis takes its sub-variables as a proxy to test the impact of each pathway of action on regional innovation performance. The core explanatory variables are replaced by digital financial coverage breadth and digital financial usage depth in the Digital Inclusive Finance Index of Peking University, and the results are shown in Table 10 and Table 11.

This test shows that the impact of regional fintech on innovation performance is facilitated in both coverage breadth and usage depth, which is consistent with the previous findings.

Table 10: Coverage breadth analysis results

Variables	lnscore
cover breadth	0.040*** (6.22)
lnMrtlevel	0.036** (2.10)
exchange	0.093*** (11.66)
avergdp	0.011*** (5.00)
population_quality	0.073*** (4.16)
K_forgien	0.003 (1.25)
K_corporation	0.000 (0.04)
Constant	-0.754*** (-5.50)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

Table 11: Using depth analysis results

Variables	Inscore
usage depth	0.047*** (10.49)
lnMrtlevel	0.041 (1.14)
exchange	0.089*** (6.55)
avergdp	0.009*** (5.68)
population quality	0.102*** (5.29)
K forgien	0.003 (1.03)
K corporation	-0.006 (-1.20)
Constant	-0.953*** (-5.44)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

Table 12: Coverage breadth analysis results

Variables	Patent
lnFintch	0.185*** (5.54)
lnMrtlevel	1.363*** (13.11)
exchange	0.744*** (6.70)
avergdp	0.052*** (2.95)
population quality	0.535*** (4.82)
K forgien	0.086*** (6.74)
K corporation	0.136 (1.46)
Constant	-3.350** (-2.75)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

Table 13: Coverage breadth analysis results

Variables	Tech
lnFintch	0.017*** (3.51)
lnMrtlevel	0.210*** (3.83)
exchange	0.126*** (8.11)
avergdp	0.072*** (3.26)
population quality	0.055*** (2.84)
K forgien	0.023*** (6.30)
K corporation	0.02 (1.16)
Constant	-1.145** (-6.52)
Observations	300
Number of groups	30

*t*-statistics in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

#### 4.3.4. Robustness check by replacing comprehensive patent grant instead of regional innovation

The three types of patents (Patent) of regional invention, utility model, and design are weighted at the ratio of 0.5, 0.3, and 0.2 to obtain the regional comprehensive patent grant as a proxy variable for regional innovation performance, and the results are shown in Table 12 for robustness testing. Financial technology still shows a significant positive impact on regional innovation, and foreign direct investment and industry-university-research cooperation show a promotional effect, which is consistent with the previous findings.

#### 4.3.5. Robustness check by replacing technology industry output value instead of regional innovation

Using the share of high technology industry output value (Tech) in regional GDP as a proxy variable for regional innovation performance, the data were logarithmically and positively ranked, followed by the original model analysis, and the results were obtained as shown in Table 13. The coefficient of financial technology index is 0.017 with a p-value of 0.001, which still shows a significant positive impact on regional innovation, and foreign direct investment and cooperation between industry, academia and research institutes show a promotional effect, which is consistent with the previous findings.

## 5. Regional heterogeneity analysis: DEA-Malmquist model index dynamic analysis

The Malmquist index analyzes the changes in the innovation performance of each region from a dynamic perspective. In this paper, the regional innovation level (Inscore) from 2012 to 2018 in the above analysis is selected as output, and the financial technology index (lnFintch), foreign direct investment (K\_foreign), industry-academia-research cooperation (K\_corporation), population\_quality, and marketization level (lnMrtlevel) as input terms, Malmquist analysis was conducted for each region in China by DEAP2.1 software, and the results are shown in Table 14.

Table 14: MALMQUIST Index of Regional Innovation in China and its Decomposition

year	effch	techch	pech	sech	tfpch
2012-2013	1.003	1.049	1.003	1.000	1.052
2013-2014	1.038	1.069	0.998	1.040	1.109
2014-2015	1.016	1.000	1.005	1.011	1.016
2015-2016	0.992	1.180	0.995	0.997	1.171
2016-2017	1.012	1.027	1.004	1.007	1.039
2017-2018	0.997	0.996	1.000	0.997	0.993
mean	1.009	1.052	1.001	1.009	1.062

The average total factor productivity of regional science and technology innovation in China from 2012 to 2018 is 1.062, which is greater than 1 except for 2017-2018. This indicates that although the efficiency of regional innovation in China has increased, it has developed more slowly in recent years. The lack of technology in key industries and the talent gap are among the main reasons for this phenomenon. The average change index of technical efficiency is 1.009, the efficiency of innovation output has increased to 2015 to 2016 and 2017 to 2018 presenting a value less than 1. The average value of technical progress efficiency is 1.052 and 0.996 in 2017 to 2018, indicating that both promote our regional science and technology innovation, but together in 2017 to 2018 there is an inhibiting effect.

The mean values of pure technical efficiency as well as scale efficiency are 1.001 and 1.009, respectively, and both show an up-and-down trend between 2012 and 2018, which generally promote scientific and technological innovation and need to be further strengthened.

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Table 15: MALMQUIST index and its decomposition by provinces in China

firm	effch	techch	pech	sech	tfpch
Beijing	1.000	1.056	1.000	1.000	1.056
Shanghai	1.000	1.024	1.000	1.000	1.024
Guangdong	1.000	1.021	1.000	1.000	1.021
Shandong	1.000	1.034	1.000	1.000	1.034
Jiangsu	1.000	1.000	1.000	1.000	1.000
Zhejiang	1.000	1.063	1.000	1.000	1.063
Gansu	1.000	1.030	1.000	1.000	1.030
Neimenggu	1.000	1.072	1.000	1.000	1.072
Chongqing	1.012	1.021	1.002	1.011	1.034
Sichuan	1.002	1.071	1.000	1.002	1.073
Henan	1.016	1.042	1.001	1.016	1.060
Hebei	1.003	1.045	1.000	1.003	1.048
Fujian	1.001	1.028	1.005	0.996	1.029
Anhui	1.004	1.055	1.008	0.996	1.060
Hubei	1.004	1.034	0.999	1.005	1.038
Hunan	1.006	1.047	1.003	1.003	1.053
Liaoning	1.003	1.013	1.003	1.000	1.016
Jilin	1.016	1.046	0.999	1.018	1.064
Jiangxi	1.020	1.020	0.999	1.021	1.040
Guizhou	1.037	1.107	1.002	1.035	1.148
Guangxi	1.042	1.063	1.004	1.038	1.107
Ningxia	1.044	1.141	1.000	1.044	1.191
Hainan	1.082	1.056	1.000	1.082	1.143
Qinghai	1.078	1.041	1.000	1.078	1.122
Xinjiang	0.984	1.173	1.000	0.984	1.153
Yunnan	0.996	1.052	1.000	0.996	1.047
Tianjin	0.993	1.036	0.999	0.993	1.028
Shaanxi	0.993	1.023	1.000	0.993	1.016
Shanxi	0.978	1.059	1.000	0.978	1.036
Heilongjiang	0.978	1.095	1.000	0.979	1.071
mean	1.009	1.052	1.001	1.009	1.062

The results of MALMQUIST index by region are presented in Table 15.

The average value of total factor productivity of all regions in China between 2012 and 2018 is greater

than or equal to 1, indicating that the efficiency of science and technology innovation in China's regions is steadily increasing and developing well. Five provinces, namely Xinjiang, Qinghai, Ningxia, Guizhou, and Hainan, grew at a rate of more than 10%, and Jiangsu Province was the lowest.

Among provinces and cities: (1) some regions have a technical efficiency value of 1.000, and only the efficiency of technical progress has contributed to the improvement of regional total factor productivity. Such as Beijing, Shanghai, Shandong, Guangdong, Jiangsu, Zhejiang, etc. Such regions are more developed among Chinese provinces. A technical efficiency value of 1.000 indicates that the gains from imitative innovation are small. It should accelerate for the improvement of independent innovation capacity to promote the high-quality development of regional economy in the new stage.

(2) Most of the remaining regions show the synergistic promotion of technical efficiency and efficiency of technological progress. Such as Fujian, Sichuan, Hebei, Liaoning, Anhui, Hubei, Hunan, Chongqing, etc. Such regions generally show a greater role of promoting the efficiency of technical progress than the role of

The average total factor productivity of regional science and technology innovation in China from 2012 to 2018 is 1.062, which is greater than 1 except for 2017-2018. This indicates that although the efficiency of regional innovation in China has increased, it has developed more slowly in recent years. The lack of technology in key industries and the talent gap are among the main reasons for this phenomenon. The average change index of technical efficiency is 1.009, the efficiency of innovation output has increased from 2015 to 2016 and 2017 to 2018 presenting a value less than 1. The average value of technical progress efficiency is 1.052 and 0.996 in 2017 to 2018, indicating that both promote our regional science and technology innovation, but together in 2017 to 2018 there is an inhibiting effect.

The mean values of pure technical efficiency as well as scale efficiency are 1.001 and 1.009, respectively, and both show an up-and-down trend between 2012 and 2018, which generally promote scientific and technological innovation and need to be further technical efficiency. This indicates the crucial role of technological progress in the development of China's science and technology innovation efficiency, and reflects the strategic position and advantages of industry-university-research cooperation in long-term planning.

(3) Provinces such as Shanxi, Heilongjiang, Xinjiang, Tianjin, Shaanxi, and Yunnan exhibit the phenomenon that technical efficiency presents a suppressive effect on total factor productivity. Such regions also have the phenomenon of insufficient scale efficiency. This indicates that the lack of scale of research and the inefficiency of resource allocation often coexist and are mutually causal. Optimizing the synergy between foreign investment and university-industry cooperation is the key to solve the innovation efficiency problem.

## 6. Conclusion

In this paper, a time series analysis was conducted by building a panel model of innovation level with financial technology and two types of knowledge spillover. The relationship between regional innovation and financial technology and two types of knowledge spillover in China, as well as the interaction effects between financial technology and knowledge spillover, are examined. The dynamic analysis of Malmquist index was also applied to examine the efficiency of innovation in each region of China. Through the study, we found that:

(1) There is a significant positive effect of regional fintech level on regional innovation performance. The cooperation between financial technology and industry-academia-research has mutual promotion. Foreign direct investment has a suppressive effect on the development of regional financial industry and financial technology in the long run.

(2) The effects of FDI and university-industry cooperation on regional innovation performance are on regional innovation environment, demonstration effect and regional innovation capacity, respectively. The two have substitution effects and crowd out each other. The strong support for FDI for a long time will weaken the regional cooperation between industry, academia and research, and reduce the independent innovation capacity.

(3) China's regional innovation efficiency shows a trend of gradually increasing and fluctuating forward. The efficiency of technological progress is the new growth breakthrough point in China's regional innovation development. And the efficiency of economy of scale becomes the main obstacle affecting regional innovation efficiency in most provinces. The position of each region's independent

innovation capacity in the optimization of innovation efficiency and transformation of development model is becoming more and more obvious.

The policy implications brought by this paper are: (1) When there is a scale effect problem in regional innovation efficiency and the level of regional innovation is relatively low, the measures of introducing foreign investment should be taken. Improve the regional innovation environment and form a demonstration effect. Promote regional competitive enterprises to acquire existing advanced technology. And when the regional economy of scale reaches the optimum, consideration should be given to cultivating local independent innovation enterprises. Promote the cooperation between enterprises, universities and research institutes to optimize the regional financial technology level. Promote the digital innovation and upgrading of regional financial industry and real industry, so as to obtain benign development capability.

(2) For enterprises, imitating and learning the technology of other advanced enterprises is not a long-term solution. After having certain strength and a smooth operating environment, they should move towards self-innovation as soon as possible. Cooperate with local universities and research institutions, and use the regional financial technology, talent attraction ability and other quality environment to improve their own development and open up new growth paths.

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