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# Nonlinear Influence of Financial Technology on Regional Innovation Capability: Based on the Threshold Effect Analysis of Human Capital

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**Abstract:** According to the data of financial technology and high-tech innovation level of 17 cities in the pilot area of China Independent Innovation Demonstration Zone (Shandong Province) from 2007 to 2017, and taking human capital as the threshold variable, this paper empirically analyzes the nonlinear influence of financial technology development on regional innovation capability under different absorptive capacity by constructing a panel threshold regression model. The results show that: (1) Taking human capital endowment as the threshold variable, the influence mechanism of financial technology development on regional innovation capability has an inverted S-shaped double threshold effect, that is, the driving effect of financial technology development on regional innovation capability has the "optimal range" of human capital absorption capability; (2) When the endowment of human capital is less than the first threshold, there is a significant negative relationship between financial technology and regional innovation capability, and in this case, financial technology development cannot promote the improvement of regional innovation capability; (3) When the human capital endowment crosses the first threshold, there is a significant positive relationship between the development of financial science and technology and the regional innovation capability, which indicates that only when the human capital endowment can better realize R&D learning, digestion and absorption can the development of financial science and technology achieve collaborative innovation and enhance the regional innovation capability; (4) After the endowment of human capital crosses the second threshold, although there is still a positive relationship between the development of financial technology and regional innovation capability, the driving effect of financial technology has a diminishing marginal effect, which shows that the scale of technology and finance should match with human capital, and unlimited expansion of human capital investment will also lead to the imbalance of the allocation of innovation elements and reduce the efficiency of regional innovation. Based on the empirical analysis results, the paper finally puts forward policy suggestions from the aspects of differentiated development strategy, innovative talent incentive policy, and the construction of financial technology leading center.

**Keywords:** financial technology; regional innovation capability; human capital; threshold effect



**Citation:** Han, W.; Wang, P.; Jiang, Y.; Han, H. Nonlinear Influence of Financial Technology on Regional Innovation Capability: Based on the Threshold Effect Analysis of Human Capital. *Sustainability* **2022**, *14*, 1007. https://doi.org/10.3390/su14021007

Academic Editor: Doojin Ryu

Received: 1 December 2021
Accepted: 11 January 2022
Published: 17 January 2022



## 1. Introduction

Innovation capability is very important for the sustainable development of a country or region, especially for countries in the period of economic transition. Under the background of "innovation-driven" era, both product innovation and technological innovation cannot be separated from the support and promotion of financial technology. Therefore, the rapid

and effective development of financial technology will help promote the development of scientific and technological innovation activities at the micro level, optimize and adjust the regional industrial structure at the meso level, and promote the regional innovation capability at the macro level.

In recent years, "improving the ability of independent innovation and building an innovative country" has become the strategic focus of China's economic development. At prese nt, with the support of the national policy of "innovation-driven strategy", China's economy is in a leap-forward development stage, and the development of financial technology is an important guarantee for the high-quality development of China's regional economy under the new normal of innovation-driven economy. At present, China has initially completed the top-level design of the financial technology policy, and the financial technology investment has increased year by year. According to the 2020 China Science and Technology Statistics, from 2010 to 2020, the intensity of China's R&D investment (R&D expenditure as a proportion of GDP) has increased from 1.71% to 2.40%. However, with the strong support of financial science and technology policies, problems such as the shortage of compound talents, the inefficiency of innovation in high-tech industries and the unbalanced construction of innovation platforms still exist, which indirectly restricts the effective promotion of regional innovation capabilities.

Therefore, based on China's situation, exploring the driving mechanism of financial technology development on regional innovation capability and its actual influence path will help government departments and financial institutions to fully understand the key influencing factors of financial technology development, and then formulate financial technology implementation policies suitable for China's situation. It is also conducive to accumulating empirical evidence of the interaction between financial technology and regional innovation capability, which has a certain complementary role in theory.

## 2. Literature Review

### *2.1. The Influence Mechanism of Financial Technology*

Financial technology meets the financial service needs of technological innovation by devoting itself to the R&D of financial products, which is the advanced stage of financial services for the real economy. Therefore, the effective integration of financial technology is an important driving force to realize regional innovation and development and enhance regional core competitiveness. George and Prabhu [1] and Brown et al. [2], respectively, demonstrated the coupling relationship between financial development and technological innovation, and held that technological development is conducive to deepening financial innovation, while financial innovation is conducive to supporting technological innovation, which provides a research starting point for the combined development of finance and technology. Then, the relevant scholars separately from venture financing [3,4], business model [5], financial inclusive policy [6], etc., systematically studied the driving force function of financial technology, all of which believed that the innovation efficiency of enterprises or industries was highly dependent on the support of financial technology, and the effective integration of finance and technology was the key way of innovation development and technological progress. With the increasing relevance of financial technology to the real economy, Benczúr et al. [7], Fagiolo et al. [8], Senyo et al. [9], Berman et al. [10] and other scholars gradually turned to pay attention to the interactive mechanism of financial technology on regional economic development, especially the path and motivation of financial technology supporting innovation and development, which laid a theoretical foundation for the interactive relationship between financial technology and regional innovation.

### *2.2. Financial Technology and Regional Innovation Capability*

In practice, can the development of financial technology effectively promote the improvement of regional innovation capability? Many scholars began to conduct empirical research on this issue, but did not reach a consistent conclusion. Some empirical studies support the view that financial technology can effectively promote regional innovation

capability [11,12]. For example, from the perspective of causality between financial technology development and regional innovation capability, Wang and Yang [13], Chen et al. [14], Guo and Li [15], Hou and Song [16], and Hua and Huang [17], respectively, empirically studied the correlation effect between the financial technology and the level of regional innovation, and proved that financial technology development has a significant role in promoting regional innovation capability. However, some scholars have come to different conclusions through empirical analysis. For example, taking different regions as the research objects, Gu and Wang [18], Ma and Li [19], Ma et al. [20], Hornuf et al. [21], Alaassar et al. [22], and Gravina and Lanzafame [23] confirmed that the development of financial technology does not promote regional innovation capability significantly in the short term, and there are significant regional differences. This shows that there are some restraint mechanisms for the influence of financial technology development on regional innovation capability, and the conclusions drawn in different regional environments are inconsistent.

By combing the relevant literature, it is found the existing studies are based on the assumption of linear relationship, which studies the influence of financial technology on innovation capability, while ignoring the nonlinear influence of financial technology on innovation capability caused by the heterogeneity of absorptive capacity in different regions. Specifically, the economic environment of different regions is quite different, and the human capital endowment reflecting the absorptive capacity of regions determines whether the financial technology promotion mechanism can play an effective role. Studying the impact of financial technology on regional innovation capability from the perspective of linear relationship cannot fully reflect the actual impact path.

### *2.3. Innovative Absorptive Capacity of Human Capital*

Financial technology is an important driving force to realize regional innovation and development by devoting itself to the research and development of innovative products and meeting the financial service demand of technological innovation. However, there are differences in human capital endowment, marketization degree and economic development level in different regions [24–26]. Among these differences, the level of human capital endowment is the key to the absorptive capacity of technological innovation. Therefore, the entrepreneurial experience, values and innovation vitality of human capital endowment will play a restrictive role in promoting regional innovation capability.

For example, from a macroeconomic perspective, Roy [27], Baldanzi et al. [28], Ghosh and Parab [29] and other scholars believe that human capital can significantly promote technological innovation, scientific and technological progress and economic development. However, Sun et al. [30], Wei et al. [31], Guo et al. [32], and Zhong et al. [33] verified through the empirical data of micro-enterprises that human capital has an important absorptive capacity for technological innovation activities, because the level of human capital significantly restricts the transformation of innovation achievements and innovation performance of innovative enterprises. Therefore, higher human capital can bring better R&D learning, digestion and absorption ability, so that the development of financial technology can effectively accelerate the efficiency of collaborative innovation and enhance the regional innovation capability.

Based on this, in the process of financial technology affecting regional innovation capability, there may be a threshold role of human capital absorption ability. Therefore, only by bringing human capital into the interactive relationship between financial technology and regional innovation capability can we more effectively analyze the actual influence mechanism of financial technology on regional innovation capability.

### *2.4. Possible Innovations of This Paper*

Therefore, according to the data of financial technology and high-tech innovation level of 17 cities in the pilot area of China Independent Innovation Demonstration Zone (Shandong Province) from 2007 to 2017, and taking human capital as the threshold variable, this paper empirically analyzes the nonlinear influence of financial technology development

on regional innovation capability under different absorptive capacity by constructing a panel threshold regression model.

The possible innovations of this paper are as follows: (1) From the existing research, it is found that although many scholars have studied the influence of financial technology on regional innovation capability from different angles, most scholars attribute the relationship between financial technology development and regional innovation capability to linear correlation, ignoring the nonlinear threshold characteristics caused by objective differences between regions, and only studying the influence of financial technology on regional innovation level from the perspective of linear relationship cannot fully reflect the actual influence path. (2) The difference of innovation capability in different regions largely depends on the influence of human capital absorptive capacity. This paper takes the absorptive capacity of human capital as the threshold variable, and brings it into the interactive relationship between financial technology and innovation capability, which provides a new perspective for the research on the driving mechanism of financial technology development. (3) Different countries or regions are quite different in terms of institutional environment and economic policies. Based on the Chinese situation, accumulating empirical evidence of the interaction between financial technology and innovation capability also has a certain complementary role in theory.

## 3. Data Sources and Variable Selection

### *3.1. Data Sources*

Considering the availability of data indicators and the consistency of statistical caliber, according to the Statistical Yearbook of Shandong Province of China from 2007 to 2018, this paper selects the relevant data of financial technology and high-tech innovation level from 17 cities in the pilot area of China's independent innovation demonstration zone (Shandong Province) from 2007 to 2017, and empirically tests the heterogeneous influence of financial technology on technological innovation level with regional human capital as the threshold variable.

### *3.2. Variable Selection*

#### 3.2.1. Explained Variable: Regional Innovation Capability (Innovation)

At present, the selection of variables related to regional innovation capability, Wang et al. [34], Hauge et al. [35], and Lu et al. [36] all think that patent system can stimulate the level of regional innovation capability of enterprises and reflect regional innovation capability to a certain extent. Therefore, according to their respective calculation methods, the number of regional effective invention patents is selected as the index of regional innovation capability, but the patent authorization will be affected by the political environment and economic environment of different regions. Because this paper focuses on the influence of regional financial technology development on regional innovation capability, the output value of regional high-tech industries is the most direct embodiment of regional economic development driven by regional innovation capability. Based on this, this topic selects the proportion of the total output value of regional high-tech industries to GDP of various regions to measure regional innovation capability.

#### 3.2.2. Explanatory Variables: Financial Technology Development (Techfinance)

The main sources of funds for financial technology are government financial support, technology loans, self-raised funds of enterprises, and other social funds. Zhang [37]; Guo and Li [15] selected the financial expenditure on science and technology, the investment in innovation funds of enterprises, and the total amount of financial credit as the level of financial technology support, and carried out the impact of financial technology on regional innovation capability in sample provinces of 30 provinces in China. However, considering the availability of regional data, it is difficult to divide the financial support for financial technology according to the main source, and the data of internal R&D funds of high-tech enterprises can reflect the investment level of financial technology to a certain

extent. Therefore, this paper measures the development of financial technology by the proportion of R&D funds to local GDP.

#### 3.2.3. Threshold Variable: Endowment of Human Capital (Human)

The level of human capital is an important factor reflecting the absorptive capacity of financial technology development. Guan and Li [38] identified the technology spillover effect of China's industrial transfer by choosing human capital as the threshold variable of regional absorptive capacity. Sun et al. [30] and Guo et al. [32] took human capital as the threshold variable of regional absorptive capacity, and studied the collaborative innovation relationship between industry, university and research institute. Therefore, this paper chooses the ratio of the full-time equivalent of R&D personnel of enterprises in each region to the total population of each region to measure the level of regional human capital.

#### 3.2.4. Control Variables

According to the research literature [13,15,16,18,19] on the relationship between financial technology and regional innovation capability, this paper chooses the following control variables (as shown in Table 1): (1) market: In order to control the regional economic system environment, this paper chooses the proportion of non-state-owned industrial output value in the total industrial output value of each region to reflect the marketization degree of the economic environment of each region; (2) government: In order to control the support of regional government departments for the development of financial technology, this topic chooses the proportion of regional science and technology financial expenditure to regional GDP to measure the degree of regional government support; (3) open: Choose the ratio of foreign direct investment in each region to GDP to measure the degree of economic openness in each region; (4) urban: Choose the proportion of urban population in each region to the total population to reflect the urbanization level of each region; (5) gdp: The per capita GDP of each region is chosen to reflect the economic development level of each region.

**Table 1.** Variable Selection and Interpretation.

| Type | Variable | Symbol | Definition |
|---|---|---|---|
| Explained variable | Regional innovation capability | innovation | High-tech output value/Regional GDP |
| Explanatory variable | Financial technology development | techfinance | R&D expenditure/Total population of the region in that year |
| Threshold variable | Endowment of human capital | human | The full-time equivalent of R&D personnel in the region/The total population of the region in that year |
| Control variable | Degree of marketization | market | Output value of non-state-owned industry/Regional industrial output value |
| | Level of urbanization | urban | Number of urban population in the region/Total population in the current year |
| | Degree of openness | open | Actual utilization of foreign direct investment/Regional GDP |
| | Degree of government support | government | Regional fiscal expenditure/Regional GDP |
| | Level of economic development | gdp | Per capita GDP |

### *3.3. Descriptive Statistics of Variables*

Firstly, we make descriptive statistics for each variable (as shown in Table 2). Then, the scatter diagram between financial technology development (techfinance) and regional innovation capability (innovation), and the scatter diagram between human capital (human) and regional innovation capability (innovation) are made, respectively (as shown in Figures 1 and 2).

It can be seen from Figure 1 that there is a positive relationship between the development of financial technology and regional innovation capability, but the dispersion (variance) of the relationship between them is large, which shows that the driving mechanism of financial technology development to regional innovation capability has regional differences. It can be seen from Figure 2 that there is a significant nonlinear relationship between human capital and regional innovation capability, which shows that regional absorptive capacity (human capital) has significant heterogeneity, thus constraining the driving mechanism of financial technology to regional innovation capability. Therefore, through the scatter plot of core variables, it can be preliminarily judged that the impact of financial technology development on regional innovation capability has significant heterogeneity due to the difference of regional absorptive capacity, which provides a preliminary data basis for threshold regression analysis.

**Table 2.** Descriptive statistical results of variables.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| innovation | 187 | 0.643 | 0.255 | 0.209 | 1.370 |
| techfinance | 187 | 0.017 | 0.007 | 0.002 | 0.028 |
| human | 187 | 0.003 | 0.002 | 0.000 | 0.007 |
| market | 187 | 0.839 | 0.145 | 0.330 | 1.000 |
| gdp | 187 | 57,405.63 | 33,039.49 | 7504.05 | 17,7032.90 |
| government | 187 | 0.002 | 0.001 | 0.000 | 0.004 |
| open | 187 | 0.002 | 0.002 | 0.000 | 0.010 |
| urban | 187 | 0.481 | 0.139 | 0.194 | 0.726 |

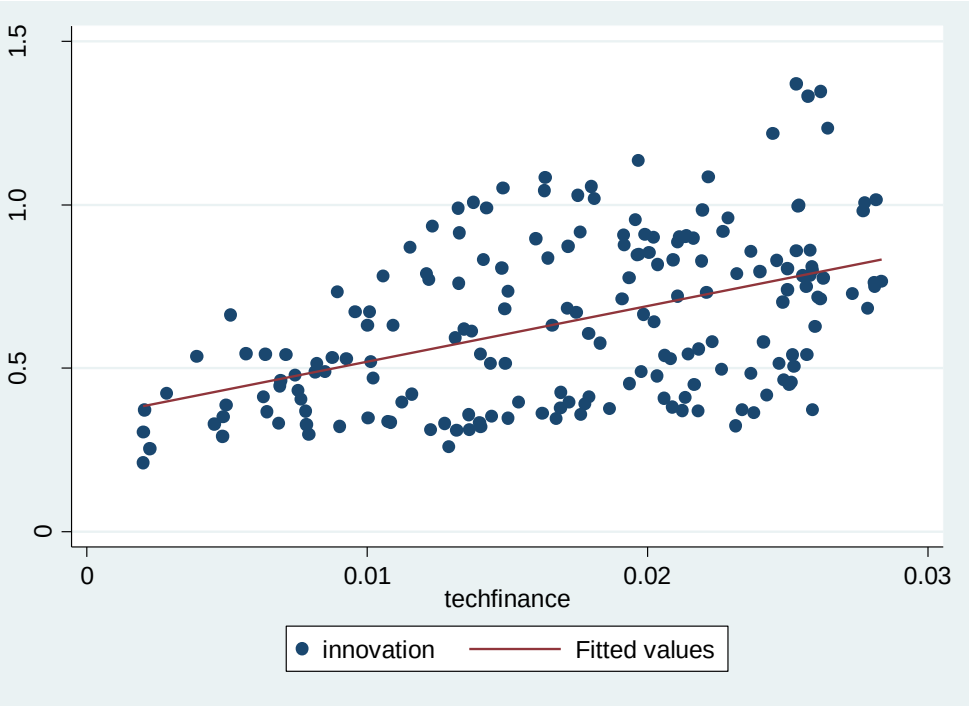


**Figure 1.** Scatter diagram of financial technology development and regional innovation capability.

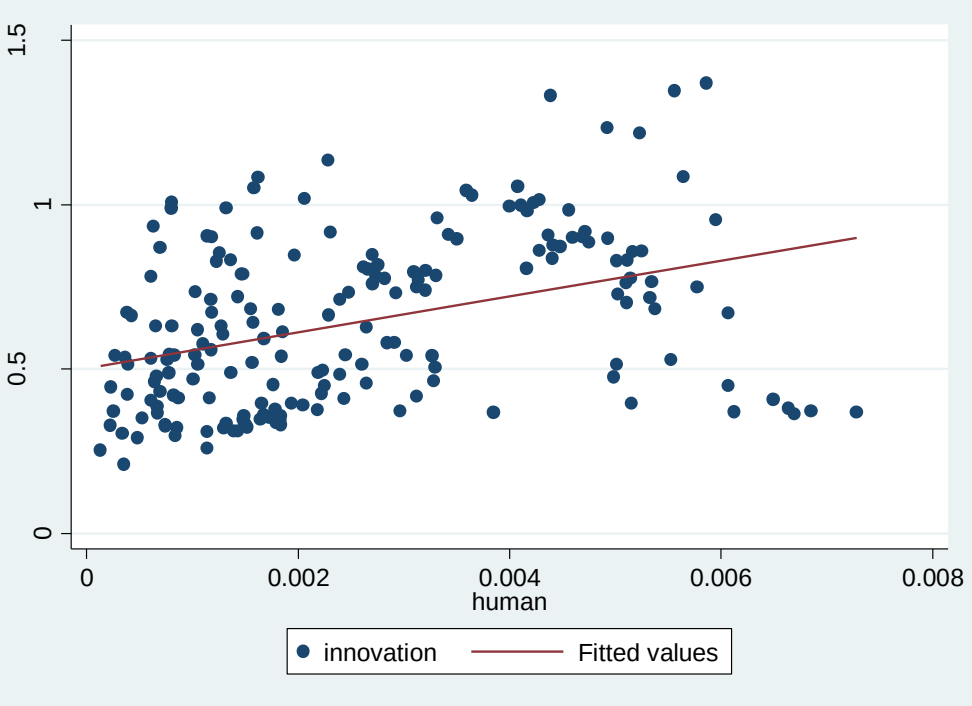


**Figure 2.** Scatter diagram of human capital and regional innovation capability.

## 4. Empirical Model

Firstly, the panel data need to be tested for stability and fixed effect respectively, which is the prerequisite for effective threshold regression test. Then choose the level of human capital as the threshold variable, and carry out threshold panel regression analysis to test whether there is threshold effect in the relationship between financial technology development and regional innovation capability.

### *4.1. Construction of Static Panel Regression Model*

Panel data regression analysis can be divided into fixed effect model and random effect model. Firstly, determine whether the impact of financial technology development on regional innovation capability conforms to the fixed effect model:

$$innovation_{it} = \alpha_0 + \alpha_1 techfinance_{it} + \sum_{j=1}^{n} \beta_j X_{it} + \delta_t + \varepsilon_{it} \quad (1)$$

where $i$ represents the sample city of section unit; $t$ represents the year; $\alpha_0$ represents coefficient vector; *innovation* represents the explained variable (used to measure the level of regional innovation capability of each city); *techfinance* represents the explanatory variable (used to measure the development degree of financial technology in various cities); $X_i$ represents other control variables that affect the level of regional innovation capability of cities and regions: including the degree of marketization(*market*), the level of urbanization(*urban*), the degree of openness(*open*), the degree of government support(*government*), and the level of economic development(*gdp*); $\delta_t$ represents the intercept term of individual heterogeneity; If $\delta_t$ is related to an explanatory variable, the model shows a fixed effect, and $\varepsilon_{it}$ represents an error term, which obeys an independent normal distribution.

### *4.2. Construction of Panel Threshold Regression Model*

Hansen's method is used to further test whether the influence of financial technology development on regional innovation capability has threshold effect, which can be divided

into single threshold, double threshold and multiple thresholds. Firstly, a single threshold regression model is constructed as follows:

$$\begin{aligned} innovation_{it} = \alpha_0 \quad & +\alpha_1 techfinance_{it} I(human_{it} \le \gamma) \\ & +\alpha_2 techfinance_{it} I(human_{it} > \gamma) + \sum_{j=1}^{n} \beta_j X_{it} + \delta_t + \varepsilon_{it} \end{aligned} \tag{2}$$

In Formula (2), $i$ represents the sample city of section unit; $t$ represents the year; $ff_0$ represents the corresponding coefficient vector; *innovation* represents the explained variable (used to measure the regional innovation capability of each city); *techfinance* represents explanatory variables (used to measure the development of financial technology in various cities); $X_i$ indicates other control variables that affect the regional innovation capability; $\delta_t$ represents the intercept term of individual heterogeneity; $\varepsilon_{it}$ represents the error term and obeys independent normal distribution. In Formula (2), $I(\cdot)$ is an illustrative function, in which $\gamma$ is the threshold value and *human* is the threshold variable.

The above is a single threshold regression test, and the double threshold model is further constructed below:

$$\begin{aligned} innovation_{it} = \alpha_0 \quad & +\alpha_1 techfinance_{it} I(human_{it} \le \gamma_1) \\ & +\alpha_2 techfinance_{it} I(\gamma_1 < human_{it} \le \gamma_2) \\ & +\alpha_3 techfinance_{it} I(human_{it} \ge \gamma_2) + \sum_{j=1}^{n} \beta_j X_{it} + \delta_t + \varepsilon_{it} \end{aligned} \tag{3}$$

In empirical test, the principle of searching threshold value is usually divided into two steps. Firstly, given the value of $\gamma_1$, search for $\gamma_2$, and calculate the sum of squares of residuals $SSR(\gamma)$ respectively. Secondly, $\gamma_2$ is selected to minimize $SSR(\gamma)$, and $\gamma_1$ is searched after $\gamma_2$ is fixed, so as to obtain the optimized consistent estimate. In this paper, the Bootstrap method proposed by Hansen (1999) is used to simulate the asymptotic distribution of likelihood ratio test. The principle of multiple threshold regression model is the same, so it will not be described again.

## 5. Empirical Results

### *5.1. Panel Data Stationarity Test*

Panel In this paper, the stationarity test of data is carried out at first. According to the LLC and Fisher-ADF unit root test methods, it can be seen that the panel data of this subject is nonstationary data, but after first-order difference, all variable data become stationary data. Therefore, it can be inferred that all variables of this subject are first-order unitary $I(1)$ data, and there is a long-term cointegration relationship among variables, so it is still possible to carry out panel threshold regression analysis (as shown in Table 3).

**Table 3.** Unit root test of variables.

| Variable | LLC Test | | Fisher-ADF Test | | Test Results of Stationarity |
|---|---|---|---|---|---|
| | Statistic | *p*-Value | Statistic | *p*-Value | |
| innovation | −1.9801 | 1.0000 | −4.1231 | 1.0000 | No |
| Δinnovation | −13.1190 | 0.0000 | 18.8612 | 0.0000 | Yes |
| techfinance | −0.6454 | 1.0000 | −4.1231 | 1.0000 | No |
| Δtechfinance | −9.0766 | 0.0000 | 1.6781 | 0.0467 | Yes |
| human | −0.1680 | 1.0000 | −4.1231 | 1.0000 | No |
| Δhuman | −10.8652 | 0.0000 | 13.6803 | 0.0000 | Yes |
| urban | −1.1339 | 1.0000 | −4.1231 | 1.0000 | No |
| Δurban | −11.2977 | 0.0000 | 2.8456 | 0.0022 | Yes |
| market | −1.2220 | 1.0000 | −4.1231 | 1.0000 | No |
| Δmarket | −10.7552 | 0.0000 | 45.2653 | 0.0000 | Yes |
| gdp | −1.0211 | 1.0000 | −4.1231 | 1.0000 | No |
| Δgdp | −8.6033 | 0.0000 | 23.4743 | 0.0000 | Yes |

**Table 3.** *Cont.*

| Variable | LLC Test | | Fisher-ADF Test | | Test Results of Stationarity |
|---|---|---|---|---|---|
| | Statistic | *p*-Value | Statistic | *p*-Value | |
| government | −0.5759 | 1.0000 | −4.1231 | 1.0000 | No |
| Δgovernment | −9.2540 | 0.0000 | 11.4098 | 0.0000 | Yes |
| open | −2.0164 | 1.0000 | −4.1231 | 1.0000 | No |
| Δopen | −32.8921 | 0.0000 | 2.8560 | 0.0021 | Yes |

Note: LLC test is the same unit root test; Fisher-ADF test is different unit root test.

In addition, for the sake of robustness, we use Kao method to test the cointegration relationship of the panel data of each variable in this subject. As can be seen from Table 4, the variable data has passed Kao tests (Dickey-Fuller, Augmented Dickey-Fuller and Unadjusted Dickey-Fuller), which further proves that the data has long-term cointegration relationship.

**Table 4.** Kao cointegration test results.

| Statistics Name | Statistic | *p*-Value |
|---|---|---|
| Modified Dickey-Fuller t | −0.8100 | 0.2090 |
| Dickey-Fuller t | −2.0497 | 0.0202 |
| Augmented Dickey-Fuller t | −2.0137 | 0.0220 |
| Unadjusted modified Dickey | −1.1050 | 0.1346 |
| Unadjusted Dickey-Fuller t | −2.2195 | 0.0132 |

Note: Kao test for cointegration: Ho. No cointegration; Ha. All panels are cointegrated.

### *5.2. Fixed Effect Test*

The threshold regression model is based on the fixed effect panel model. Therefore, before testing whether there is heterogeneity in the impact of financial technology development on regional innovation capability, it is necessary to conduct panel regression analysis of fixed effect and random effect, respectively. If the test results show that it is a fixed effect, it shows that there is significant heterogeneity in the impact of financial technology development on regional innovation capability. In this paper, Hausman test is used to determine whether panel data has fixed effect. From the test results, it can be seen (as shown in Table 5) that the rejection regression model belongs to the original hypothesis with random effect at 5% significance level, so it can be considered that panel data needs to adopt fixed effect regression model, which meets the precondition of threshold regression.

**Table 5.** Hausman test results of fixed effect.

| Variable | | (b) Fixed | (B) Random | (b-B) Difference | Sqrt(Diag(V_b-V_B)) S.E. |
|---|---|---|---|---|---|
| Explained variable | innovation | | | | |
| Explanatory variable | techfinance | 14.686850 | 12.261210 | 2.425640 | 2.186656 |
| | human | −84.542300 | −78.488610 | −6.053686 | 8.213049 |
| Control variable | market | 0.114062 | 0.098338 | 0.015724 | 0.022391 |
| | gdp | 0.000002 | 0.000004 | −0.000001 | 0.000001 |
| | government | −16.806570 | −14.640190 | −2.166381 | 8.722331 |
| | open | −25.670020 | −18.304700 | −7.365319 | 4.999766 |
| | urban | 0.326402 | 0.292206 | 0.034196 | 0.048939 |
| LR $\chi^2$ | | | 12.01 | | |
| Prob >$\chi^2$ | | | 0.0618 | | |

### *5.3. Threshold Effect Test*

In order to expand the size of test samples for parameter estimation, the Bootstrap method is used to repeat sampling for 300 times to effectively identify the threshold value. In this paper, human capital is selected as the reflection variable of regional absorptive capacity, and we use Bootstrap method to search the threshold value of the relationship between financial technology development and regional innovation capacity.

According to Table 6, if there is a single threshold, the test *F*-value is 38.394, with a significant level of 5%. If there is a double threshold, the test *F*-value is 12.838, which has a significance level of 10%. If there are triple thresholds, the test f value is 1.253, which is not significant. From the above, it can be judged that there is a double threshold effect between the development of financial technology and the regional innovation capability, which takes human capital as the threshold variable. After confirming that the development of financial technology and regional innovation capability meet the double threshold characteristics, the estimated value and confidence interval of the two thresholds are further searched. As shown in Table 7, the first estimated value of double threshold is 0.001, and its 95% confidence interval is [0.001, 0.001]; the second estimated value of double threshold is 0.002, and its 95% confidence interval is [0.002, 0.005]. In addition, the search process of the two thresholds can be identified more clearly through the likelihood ratio function diagram of threshold regression (as shown in Figures 3 and 4). This shows that the driving effect of financial technology development on regional innovation capability has obvious heterogeneity difference in regional absorptive capacity (human capital).

**Table 6.** Threshold effect test of human capital.

| Model | *F*-Value | *p*-Value | Bootstrap Times | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| Single threshold | 38.394 ** | 0.020 | 300 | 47.347 | 26.570 | 17.187 |
| Double threshold | 12.838 * | 0.083 | 300 | 28.999 | 16.841 | 11.157 |
| Triple threshold | 1.253 | 0.340 | 300 | 9.354 | 5.135 | 3.449 |

Note: ** Significant at $p < 0.05$, * Significant at $p < 0.10$.

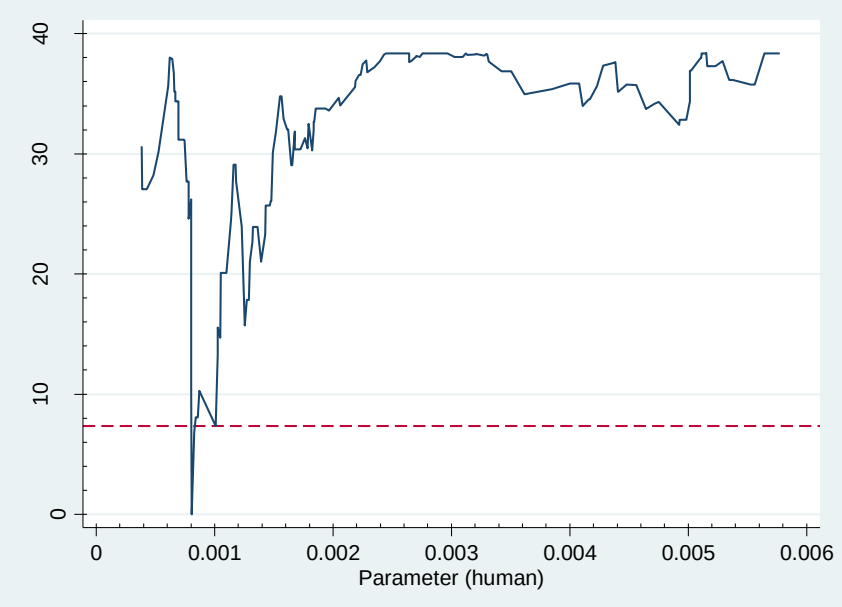


**Figure 3.** Estimated value and confidence interval of the first threshold.

**Table 7.** Estimation and confidence interval of threshold value of human capital.

| Model | Threshold Estimated Value | 95% Conf. Interval |
|---|---|---|
| Th-1 $(g1)$ | 0.001 | [0.001, 0.001] |
| Th-21 $Ito1(g1)$ | 0.001 | [0.001, 0.001] |
| Th-22 $Ito1(g2)$ | 0.002 | [0.002, 0.005] |

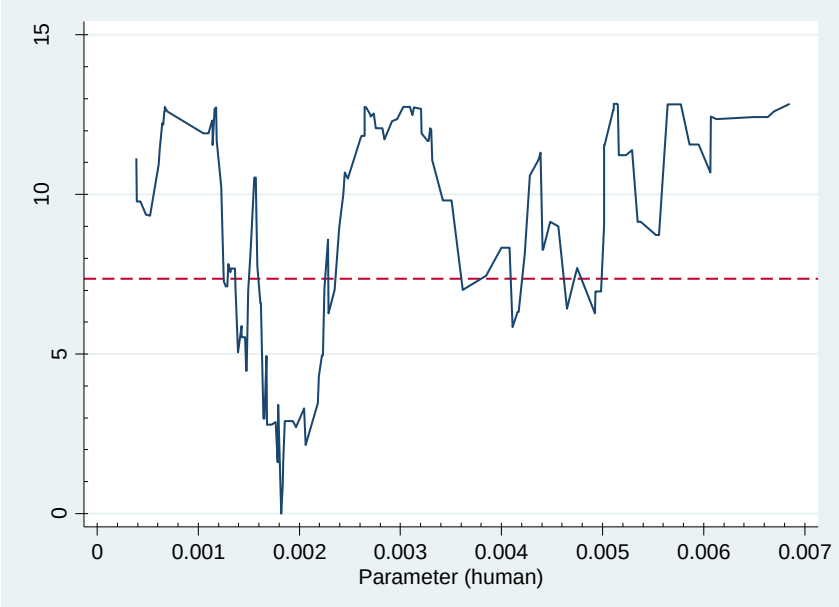


**Figure 4.** Estimated value and confidence interval of the second threshold.

### *5.4. Analysis of Threshold Regression Results*

According to the result of threshold effect, it can be concluded that the influence mechanism of the development of financial technology on regional innovation capability is affected by the double threshold value of human capital, showing a nonlinear relationship. According to the definition of human capital in this topic, the level of regional human capital is measured by the ratio of the full-time equivalent of R&D personnel in each region to the total population of each region. The two thresholds of human capital indicate that the proportion of R&D personnel in each region is 0.1% and 0.2%, respectively.

Table 8 further reports the panel threshold regression results of the impact of financial technology development on regional innovation capability. Firstly, from the perspective of control variables, the urbanization level (urban) of each region has a significant positive effect on regional innovation capability (the influence coefficient is 0.5065), which shows that the higher the urbanization level of a region, the more beneficial it is to realize the agglomeration of innovative activities such as scientific and technological talents, scientific and technological capital and innovative enterprises, and to promote regional innovation capability, which is also consistent with most empirical research conclusions. However, the openness degree (open) of each region has a significant negative impact on regional innovation capability (the influence coefficient is −19.4086), which shows that the improvement of innovation capability in this region mainly depends on local investment, while foreign direct investment cannot effectively improve innovation capability. In addition, in the threshold regression of this paper, the influence of regional economic level (gdp), marketization degree (market) and government support degree (government) on regional innovation capability failed the significance test, which may be caused by multiple collinearity among variables.

**Table 8.** Threshold Regression Estimation Results.

| Variable | Threshold Effect Test | | | |
|---|---|---|---|---|
| | **Coef.** | **Std. Err** | **t** | ***p*-Value** |
| techfinance (human $\leq$ 0.001) | −6.2897 *** | 1.8860 | −3.33 | 0.001 |
| techfinance (0.001 < human $\leq$ 0.002) | 28.5252 *** | 4.5583 | 6.26 | 0.000 |
| techfinance (0.002 < human) | 24.4709 *** | 4.9822 | 4.91 | 0.000 |
| market | 0.0363 | 0.0756 | 0.48 | 0.632 |
| gdp | 0.0000 | 0.0000 | −1.54 | 0.125 |
| government | −10.7915 | 22.9776 | −0.47 | 0.639 |
| open | −19.4086 * | 11.0573 | −1.76 | 0.081 |
| urban | 0.5065 *** | 0.1674 | 3.03 | 0.003 |
| _cons | 0.1501 * | 0.0853 | 1.76 | 0.080 |
| N | 187 | | | |
| F-stata | 20.50 *** | | | |
| $R^2$ | 0.503 | | | |
| sigma_u | 0.2371 | | | |
| sigma_e | 0.1178 | | | |
| rho | 0.8020 | | | |

Note: *** Significant at $p < 0.01$, * Significant at $p < 0.10$.

Then, it further investigates whether there is a threshold effect between the development of financial technology and the level of regional innovation capability. According to the estimated results of threshold regression, it can be seen (as shown in Table 8) that there is obvious heterogeneity in the influence of financial technology development on regional innovation capability in different threshold intervals of human capital variables reflecting regional absorptive capacity. The specific performance is as follows: (1) when the human capital is less than the first threshold value of 0.1%, the impact of financial technology development on regional innovation capability is negative (the impact coefficient is −6.2897), and it has passed the 1% significance level test, that is, when the proportion of regional R&D personnel is less than 0.1%, the development of financial technology cannot effectively promote the improvement of regional innovation capability, but will have a reverse impact. The main reason is that when the proportion of regional R&D personnel is low, the efficiency of financial technology integration is low, which limits the driving role of financial technology in regional innovation capability. (2) When the regional human capital is higher than the first threshold value by 0.1% and lower than the second threshold value by 0.2%, the impact of financial technology development on regional innovation capability is positive (the impact coefficient is 28.5252), and it has passed the 1% significance level test, that is, when the proportion of regional R&D personnel is between 0.1% and 0.2%, it reaches the "effective absorption capacity". At this time, it can effectively play the driving role of financial technology in regional innovation capability. (3) When the regional human capital is greater than the second threshold value by 0.2%, the impact of financial technology development on regional innovation capability is still positive (the impact coefficient is 24.4709), and it has passed the 1% significance level test, but the impact is marginal decreasing. It shows that when the proportion of R&D personnel in the region exceeds 0.2%, human capital is in a certain state of saturation, and the absorptive capacity is in a state of diminishing marginal scale, which leads to the weakening of the efficiency of the combination of finance and science and technology. Therefore, the driving effect of the development of financial technology on regional innovation capability is weakened.

### *5.5. Further Discussion of Research Results*

According to the above empirical results, we can think that: due to the difference of human capital endowments, the efficiency of regional financial and technological integration presents obvious heterogeneity. Therefore, the driving mechanism of financial technological development on regional innovation capability has an inverted S-shaped double threshold effect, that is, the influence mechanism of financial technology development on regional

innovation capability, there is the "optimal range" of human capital endowment (absorptive capacity). When the regional human capital endowment is lower than the optimal range of "effective absorptive capacity", the development of financial technology cannot promote the improvement of regional innovation capacity; However, higher than the optimal range of "effective absorptive capacity", the role of financial technology development in promoting regional innovation capacity has a marginal decreasing phenomenon; Only in the optimal range of "effective absorptive capacity" can the driving mechanism of financial technology to regional innovation capacity be effectively exerted.

The research results of this paper are different from the existing research in that: (1) At present, most scholars study the influence of financial technology on innovation capability based on the assumption of linear relationship, while ignoring the nonlinear influence of financial technology on innovation capability caused by the heterogeneity of absorptive capacity in different regions [13,15–19]; However, this paper proves that there is a significant nonlinear relationship between financial technology and regional innovation capability, and further proves that the impact of financial technology development on regional innovation capability will be influenced by the threshold of human capital endowment. Therefore, the research conclusion of this paper enriches the empirical evidence of the interactive relationship between financial technology and innovation capability. (2) According to the theory of human capital [27], the endowment of human capital is the key to the absorptive capacity of technological innovation in each region. At present, many scholars have also conducted empirical research on the influence mechanism of human capital, and unanimously concluded that human capital endowment has a significant restraining effect on technological innovation [28–33]. However, at present, there is no literature to bring human capital into the interactive relationship between financial technology and regional innovation capability. Therefore, the research conclusion of this paper supports the application of human capital theory in the field of financial technology and deepens the understanding of the relationship between financial technology and technological innovation.

## 6. Conclusions

According to the panel data of financial technology development of 17 cities in Shandong Province of China from 2007 to 2017, this paper analyzes the influence of financial technology development on regional innovation capability with human capital endowment as the threshold variable, and the research conclusions are as follows: (1) Human capital endowment is the key factor of regional absorptive capacity, and it has played a restrictive role in the driving mechanism of financial technology. As a result, the influence of financial technology on regional technological innovation capability has a nonlinear relationship. (2) With human capital endowment as the threshold variable, the influence mechanism of financial technology development on regional innovation capability has an inverted S-shaped double threshold effect; (3) When the endowment of human capital is lower than the first threshold, the absorptive capacity of human capital is insufficient, which becomes the bottleneck to improve the regional innovation capability, so the development of financial technology cannot promote the improvement of regional innovation capability. However, when the first threshold is crossed, higher human capital can bring better R&D learning, digestion and absorption, and the development of financial technology can effectively accelerate the efficiency of collaborative innovation and enhance the regional innovation capability. However, after crossing the second threshold, with the continuous increase of human capital investment, the marginal effect of financial technology on regional innovation capability cannot keep increasing. Blindly expanding human capital investment is not conducive to the matching of financial technology scale and human capital, crowding out other innovation resources, thus reducing the efficiency of regional innovation.

Based on the above analysis results, the following policy recommendations are put forward: (1) Financial technology support policies should adopt differentiated development strategies. Regional government departments should coordinate the matching degree between financial technology development and human capital endowment. Combining

with the local actual situation, optimize the cultivation or introduction mode of innovative talents in financial technology, and rationally allocate human capital resources: not only to avoid the shortage of human capital investment, but also to avoid the saturation and waste of human capital. At the same time, government departments in various regions should also pay attention to the structural optimization and upgrading of human capital, and improve the absorption, transformation and secondary creation ability of human capital, so as to enhance the utility sustainability of human capital and give full play to the driving mechanism of financial technology for regional innovation capability. (2) A large number of emerging financial technology products and services, as well as complicated and profound technical means, have brought challenges to the sustainability of human capital. At first, all regions should establish financial technology talent training centers, integrate high-quality talent systems in various fields, and set up talent sharing platforms, so as to continuously cultivate compound talents who are proficient in financial technology, which is conducive to supporting the driving mechanism of financial technology for regional innovation capability; In addition, government departments should actively optimize the incentive policies for financial technology innovation talents, attract high-end talents to gather, enhance the regional absorptive capacity of financial technology development in various cities, optimize the matching degree between financial technology development and human capital endowment, and indirectly promote the integration efficiency of regional financial technology and technological innovation. (3) Actively build regional leading centers for financial technology development, promote information sharing, technology exchange and complementary resources among different regions, and enhance the coordination of financial technology development among regions. For areas where the development of financial technology is relatively mature, it has strong ability of financial technology gathering and diffusion, which can give full play to the advantages of financial technology resources in this area and play a radiating role. So as to realize the sharing of information resources and mutual assistance of innovative talents among different regions, thus strengthening the efficiency of absorption, sharing and transformation of innovative activities among different regions, and further improving the driving mechanism of financial technology to regional innovation capability.

**Author Contributions:** Conceptualization, W.H., P.W. and Y.J.; methodology, W.H.; software, H.H. and P.W.; validation, Y.J.; formal analysis, W.H., P.W. and H.H.; data curation, W.H.; writing—original draft preparation, W.H. and P.W.; writing—review and editing, H.H. and Y.J.; project administration, P.W.; funding acquisition, W.H. and Y.J. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Henan Soft Science Research Plan Project in China (grant number: 212400410084), the Key Scientific Research Projects of Colleges and Universities in Henan Province of China (grant number: 22A790025) and the National Natural Science Foundation of China (grant number: 72172129).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The original data of this study comes from the Statistical Yearbook published by Shandong Provincial Bureau of Statistics of China, which is located in http://tjj.shandong.gov.cn/col/col6279/index.html, accessed on 10 October 2021. In addition, the calculation and processing process of research data will be available upon request.

**Conflicts of Interest:** The authors declare no conflict of interest.

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