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Nonlinear Effect of Scientific and Technological Innovation on Economic Development

Based on Spatial Panel and Threshold Model

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***Abstract*—Against the background of "strengthening a country through science and technology", the problem of how to promote scientific and technological innovation to effect economic development is of great importance. In order to explore the action mechanism of scientific and technological innovation on economic development, based on the relevant data of 29 provinces, municipalities and autonomous regions in China from 2007 to 2016, this paper adopts the spatial panel regression model and the threshold panel regression model to inspect the non-linear spatial relationship between science and technology and economy. The results show that there is a significant spatial dependence of scientific and technological innovation on economic development in China, and the spatial Durbin panel model is the best research model. Scientific and technological innovation, financial development, opening up and government investment have posed significant positive spatial spillover effects on the economy of neighboring provinces. Human capital and opening up have played a significant role in provincial economy, but it has posed a significant negative effect on the economy of neighboring provinces through the "resource closure effect". The impact of scientific and technological innovation on economic development has obvious threshold effect of opening up and financial development. Hereby, the paper puts forward some countermeasures that promote scientific and technological innovation to influence economic development.**

Keywords—scientific and technological innovation; economic development; spatial spillover effect; threshold model

I. INTRODUCTION

In the report of the Nineteenth National Congress of the CPC, General Secretary Xi Jinping emphasized that, sticking to the principle of "strengthening a country through science and technology", it is necessary to speed up the construction of an innovative country, focus on the world's scientific and technological frontiers, strengthen basic research, and achieve major breakthroughs in forward-looking basic research and leading original achievements. There is no doubt that science and technology play a central driving role in this process. General Secretary Xi Jinping has repeatedly emphasized that in order to promote the sustained and healthy development of China's economy and society, promote the structural reform on the supply side and carry out the task of "cutting overcapacity, inventory, leverage, reducing cost reduction, improving weak links", it is necessary to realize a fundamental change in the endogenous power and vitality that promote development, and shape more leading development that depends on innovation-driven and gives full play to its first-mover advantages. In order to further research and solve the scientific and technological problems urgently needed for economic and industrial development, it is needed to promote the transfer and transformation of scientific and technological achievements and promote the industry and products to jump to the middle and high end of the value chain through focusing on the needs of promoting economic transformation and structural adjustment, constructing modern industrial system, fostering strategic emerging industries and developing modern service industries.

The related research on scientific and technological innovation and economic growth can be roughly divided into the following several kinds: the first is research on scientific and technological innovation system, such as Rasmussen E [1], Harman G [2], Bozeman B [3], Nordfors J et al[4], Decter M et al[5], Buenstorf G [6], Cai Yuezhou [7]; the second is research on transformation of scientific and technological achievements, such as Edward et al[8], Henry [9], Yusuf [10], Anderson [11], Qi Yong [12] , Zhang Huiying[13]; the third is the relationship between technological innovation and economic growth, such as Solow [14], Romer [15], Griliches [16], Guellec [17], Pang Ruizhi [18], Zhang Youzhi [19]. This paper obtains the following evaluations based on the research status of scholars at home and abroad: first of all, previous researches mostly assume the linear relationship between scientific and technological innovation and economic development, while ignoring the possible existed non-linear relationship, namely ignoring the differential effects of scientific and technological innovation on economic development under different conditions. Secondly, due to the different level of economic development of 29 provinces, municipalities and autonomous regions in China, the traditional hypothesis of spatial homogeneity has some defects in explaining the relationship between scientific and technological innovation and economic development. Thirdly, most of the previous researches on the relationship between scientific and technological innovation and economic development adopt time series data for analysis, and lack of empirical research by introducing spatial panel regression model and panel threshold regression model. Based on this and in reference of existing research results, this paper attempts to build the spatial panel regression model and threshold panel regression model to analyze the spatial spillover effect and threshold effect of scientific and technological innovation on economic development in order to provide empirical evidence for further exploring the impact of technological innovation on economic development.

II. Data and Variable Description

According to the principle of data availability and validity, this paper finally selected 29 provinces, municipalities and autonomous regions in China for analysis (Tibet, Xinjiang is left out due to the serious lack of data). The data in this paper stem from China Statistical Yearbook (2007-2016) and China Financial Yearbook (2007-2016), as show in “Table I”. The main variables are as follows:

The explained variable is economic development level (ECO). In consideration of the availability and comparability of data, this paper mainly constructs the indicator system from such three aspects as economic aggregate, economic structure and economic benefits. The principal component analysis method is adopted to extract the principal components of all indicators, and the economic development level strength index of each region in each year is calculated.

TABLE I. Evaluation Index System and Weighting of Regional Economic Development Level

First-level Index	Second-level Index	Three-level Index	Weighting
Economic development level	Economic aggregate	The proportion of regional industrial added value in the whole country	0.1934
		Per capita GDP	0.0653
		The proportion of gross investment in fixed assets in the whole country	0.0340
		The proportion of the number of regional employees in the employment of the whole country	0.1906
	Economic structure	The added value of primary industry accounts for its regional GDP	0.0436
		The added value of secondary industry accounts for its regional GDP	0.0755
		The added value of tertiary industry accounts for its regional GDP	0.1436
		Advanced index of industrial structure	0.1058
	Economic benefits	The proportion of industrial added value to its GDP	0.0959
		Elasticity coefficient of national GDP growth to regional growth	0.0517

As show in “Table II”, the core explanatory variable is scientific and technological innovation level (ST). In consideration of the availability and comparability of data, this paper mainly builds the index system from such four aspects as the level of science and technology base, the level of scientific and technological input, the level of scientific and technological output and the transformation of scientific and technological achievements. The principal component analysis method is adopted to extract the principal components of all indicators, and the strength index of scientific and technological innovation level of each region in each year is calculated.

TABLE II. Evaluation Index System and Weighting of Regional Scientific and Technological Innovation Level

First-level Index	Second-level Index	Three-level Index	Weighting
Scientific and technological innovation level	Level of science and technology base	Number of scientific research institutions	0.0570
	level of scientific and technological input	Total number of professional and technical personnel	0.0975
		Senior professional post	0.0995
		The proportion of professional and technical personnel in scientific research institutions with senior professional post	0.0397
		Gross investment of scientific research institutions (1,000 RMB)	0.1037
	Level of scientific and technological output	Number of scientific papers published	0.0843
		Number of science and technology patents accepted	0.0933
		Number of science and technology patents granted	0.0955
		Number of scientific and technological topics	0.0915
	Transformation of scientific and technological achievements	Number of topics of application of achievements	0.0797
		Percent conversion of scientific and technological achievement	0.0176
		Gross industrial output value of scientific and technological achievements	0.0831
		The proportion of gross industrial output value of scientific and technological achievements to gross industrial output value	0.0571

Control variables: (1) Opening up (OPEN). This paper adopts the method that is commonly used in most documents to measure region's opening up by using the proportion of total import and export volume to GDP.

(2) FD represents financial development. In consideration of the availability and comparability of data, this paper mainly builds the index system from such three aspects as the scale of financial development, the structure of financial development and the structure of financial development. The principal component analysis method is adopted to extract the principal components of all indicators, and the comprehensive financial strength index of each region in each year is calculated, as show in "Table III".

TABLE III. COMPREHENSIVE INDEX SYSTEM AND WEIGHT OF FINANCIAL DEVELOPMENT

First-level Index	Second-level Index
scale of financial development FD1	Gross output value of financial industry/GDP of provinces
Structure of financial development FD2	The proportion of on-the-job personnel in financial industry to total employment
Structure of financial development FD3	Loan-deposit ratio of financial institutions

(3) Human Capital (HC): This paper adopts the proportion of national illiterate and semi-illiterate occupied population * 1.5 + the proportion of occupied population that receives primary education * 7.5 + the proportion of population that receives junior middle school education * 10.5 + the proportion of population that receives senior high school education* 13.5 + the proportion of occupied population that receives junior college and above * 17.

(4) Government input (GI). This paper uses the proportion of scientific and technological fiscal expenditure to GDP to measure government input.

(5) Technical input (TI). This paper uses the proportion of technology trading volume to GDP.

III. ANALYSIS OF SPATIAL SPILLOVER EFFECT OF SCIENTIFIC AND TECHNOLOGICAL INNOVATION ON ECONOMIC DEVELOPMENT

A. Spatial Correlation Test

In this research, the bivariate global spatial auto-correlation Moran's I index is used to test the global spatial correlation between scientific and technological innovation and economic development. The calculation formula is as follows:

$$I_{sr} = \frac{N\sum_{i=1}^{N}\sum_{j\neq i}^{N} W_{ij} z_i^s z_j^r}{(N-1)\sum_{i=1}^{N}\sum_{j\neq i}^{N} W_{ij}} \tag{1}$$

There into, I_{sr} represents the bivariate global spatial auto-correlation coefficient or bivariate global Moran's I index, which reflects the correlation between science and technology and the weighted average value of economic space in the surrounding areas as a whole. Z_i^s represents the standardized value of provincial and municipal i-technology and Z_j^r represents the standardized value of provincial and municipal j-economy. The value range of I_{sr} index is from -1 to 1. In case of its value is greater than 0, it shows that science and technology have spatial spillover effect on the economy in the surrounding areas, and the larger the value is, the stronger the spatial spillover effect is. On the contrary, it shows that scientific and technological innovation has spatial inhibiting effect on economic development, and the stronger the value is, the stronger the spatial inhibition effect is. This paper uses stata15 to test the significance of bivariate global Moran's I index, as shown in "Table IV" and "Table V".

TABLE IV. SCIENCE AND TECHNOLOGY MORAN I INDEX

Year	Moran I	Critical Value z(I)	Year	Moran I	Critical Value z(I)
2007	0.268	2.216	2011	0.309	2.526
2007	0.306	2.409	2012	0.282	2.345
2008	0.227	1.979	2013	0.311	2.595
2009	0.309	2.607	2014	0.277	2.404
2011	0.334	2.685	2016	0.317	2.634

TABLE V. ECONOMY MORAN I INDEX

Year	Moran I	Critical Value z(I)	Year	Moran I	Critical Value z(I)
2007	0.259	2.166	2011	0.356	2.742
2007	0.271	2.234	2012	0.348	2.679
2008	0.291	2.346	2013	0.347	2.693
2009	0.345	2.664	2014	0.235	2.122
2011	0.354	2.736	2016	0.285	2.425

B. Model Specification

Scientific and technological innovation and economic development have significant spatial auto-correlation. The estimated accuracy of traditional non-spatial panel data model will decrease, therefore, the establishment of spatial panel data of the relationship between scientific and technological innovation and economic development is considered.

The spatial lagged model mainly researches the spatial spillover phenomena of various variables to other regions. As shown in formula (2):

$$ECO = c + \rho \times WECO + \beta_1 \times ST + \beta_2 \times FD + \beta_3 \times HC + \beta_4 \times OPEN + \beta_5 \times GI + \beta_6 \times TI + \delta_i + \mu_t + \varepsilon_{it} \quad (2)$$

$$\varepsilon_{it} \sim N(0, \sigma_{it}^2 I_n)$$

Spatial error model: Because of the existence of spatial relations, ε is affected by many factors, which make up the following spatial error model:

$$ECO = c + \beta_1 \times ST + \beta_2 \times FD + \beta_3 \times HC + \beta_4 \times OPEN + \beta_5 \times GI + \beta_6 \times TI + \delta_i + \mu_t + \varepsilon_{it} \quad (3)$$

$$\varepsilon_{it} = \lambda W \varepsilon_{it} + \varphi_{it} \quad \varphi_{it} \sim N(0, \sigma_{it}^2 I_n)$$

This research refers to spatial Durbin model given by Anselin [20] and Le Sage and Pace [21], the Model specification is as follows:

$$ECO = c + \rho \times WECO + \beta_1 \times ST + \beta_2 \times FD + \beta_3 \times HC + \beta_4 \times OPEN + \beta_5 \times GI + \beta_6 \times TI + \theta_1 \times WST + \theta_2 \times WFD + \theta_3 \times WHC + \theta_4 \times WOPEN + \theta_5 \times WGI + \theta_6 \times WTI + \delta_i + \mu_t + \varepsilon_{it} \quad (4)$$

$$\varepsilon_{it} \sim N(0, \sigma_{it}^2 I_n)$$

C. Spatial Weight Matrix

Spatial weight matrix represents the interdependency and the degree of correlation between spatial units. It is very important to choose the right and reasonable spatial weight matrix for spatial econometrics. The main construction method of spatial matrix can be divided into three kinds: the first is 1-0 matrix, which makes use of the proximity of spatial unit as the gist of weight matrix construction, the adjacent units are set to 1, and the non-adjacent units are set to 0. The advantage of this method is that weight definition is simple and intuitive. The disadvantage is that it is only suitable for the construction based on the premise of global units, and there is larger error in the weight definition of specific non-adjacent units. The second is the inverse distance matrix. Under the determination of latitude and longitude coordinates of each unit's geometric center, the spherical distance is calculated by using professional geographic software such as Arcgis, and the distance reciprocal is taken as the weight determination criterion. The spatial weights determined by the inverse distance matrix have obvious geographical characteristics that can accurately reflect the geographical differences among the units, which can better avoid the problem of unit proximity of 1-0 matrix. But the disadvantage is that the calculation process is much more difficult, which requires certain ability of using geographic software. The third is the economic distance matrix, which takes the reciprocal of the absolute value of the difference between the indicators of the overall economic situation of each unit (such as per capita GDP) as the criterion for spatial weight definition. For the vast majority of non-global economic research, this method can not only accurately reflect the osculation degree of economic correlation of each research unit, and but also reflects to some extent the correlation between different geographical distribution and economy. Therefore, this paper uses the economic distance weight matrix in the empirical research. According to the reciprocal of the per capita GDP gap between the two provinces, the bigger the GDP gap between the two provinces is, the smaller the weight given is. On the contrary, the greater the weight given is. The form is as follows:

$$W_{ij} = \begin{cases} \dfrac{1}{|Y_i - Y_j|}, i \neq j \\ 0, i = j \end{cases} \quad (5)$$

In formula (5), Yi is the actual per capita GDP level of i province.

D. Selection of Spatial Panel Model

The selection of fixed and random effects: the spatial Hausman test is used to test whether the selection has random effects. If the result is negative, it shows that the hypothesis is not valid. When the hypothesis is not valid due to the influence of non-stationary variables, this paper chooses to reject the original hypothesis and then choose the fixed effect. Therefore, it is available to consider establishing a dual-fixed spatial model.

As show in "Table VI", as for the selection of spatial econometric model, the fitting degree of spatial Durbin model is better from the perspective of R2 and Log-likelihood values. Based on LR test and Wald result, Wald and LR test reject the original hypothesis at 5% significance level, so the spatial Durbin model should not be simplified to the spatial lagged model. Therefore, a dual fixed spatial Durbin model should be established and the following conclusions can be drawn:

TABLE VI. REGRESSION RESULTS OF SPATIAL ECONOMETRIC MODEL

Variable	SEM Dual Fixed	SAR Dual Fixed	SDM Dual fixed
ST	0.1038 (0.000)	0.8176 (0.000)	0.3043 (0.000)
FD	-0.0326 (0.083)	-0.1699 (0.098)	0.1149 (0.03)
HC	-0.0978 (0.082)	0.0230 (0.000)	0.0150 (0.059)
OPEN	0.0070 (0.045)	0.0091 (0.042)	-0.0770 (0.002)
GI	-0.0056 (0.465)	-0.0542 (0.004)	0.0244 (0.046)
TI	-0.0132 (0.262)	-0.0218 (0.069)	0.0269 (0.053)
W×ST			-0.0959 (0.000)
W×FD			-0.1171 (0.000)
W×HC			-0.0035 (0.001)
W×OPEN			-0.0140 (0.000)
W×GI			0.0170 (0.009)
W×TI			-0.0574 (0.000)
ρ & γ	0.1727 (0.000)	0.6215 (0.000)	1.1899 (0.000)
sigma2	0.0002 (0.000)	0.0031 (0.001)	0.0037 (0.001)
R2	0.9834	0.9889	0.9989
Logl	184.2812	206.9553	243.2565
Wald			16.5249 (0.000)
LR			10.67 (0.001)

From the perspective of core explanatory variables, there is a positive correlation between scientific and technological innovation and economic development. Every 1 percentage point increase in scientific and technological innovation will give rise to a positive economic development of 0.3043, which shows that China's economic development is highly affected by the positive correlation of scientific and technological innovation. The coefficient of the product of scientific and technological innovation and weight matrix has also passed the 1% significance testing, which reflects that scientific and technological innovation has posed spillover effect on economic development. The identical level of scientific and technological innovation in self province have posed a positive impact on the economic development of neighboring provinces, which also shows that scientific and technological innovation has posed certain spatial spillover effect on economic development.

From the perspective of control variables, financial development, human capital, government investment and technology investment possess a significant positive impact on the economic development of local region, which is line with our theoretical anticipations. However, the impact of opening degree on the economic development of local region is not significant, which is mainly affected by two reasons: first of all, the open to the outside world is still dominated by import and export trade, and does not promote the exchange of science and technology and technological progress; secondly, the spatial distribution of open to the outside world of various provinces and municipalities is unbalanced as evidenced by Shanghai, Guangdong, Shandong and other economically developed areas have a high degree of openness, while the rest have the low degree of open to the outside world, which leads to the insignificant effect of scientific and technological innovation on economic development.

E. Spatial Spillover Effect

The form of spatial Durbin model is $y = \rho Wy + \alpha t_n + X\beta + WX\gamma + \varepsilon$, it can be transformed into:

$$(I_n - \rho W)y = X\beta + WX\theta + \alpha t_n + \varepsilon$$

$$y = \sum_{r=1}^{k} S_r(W)x_r + V(W)\alpha t_n + V(W)\varepsilon \qquad (5)$$

Among them,

$$S_r(W) = V(W)(I_n\beta_r + W\theta_r)$$

$$V(W) = (I_n - \rho W)^{-1} = I_n + \rho W + \rho^2 W^2 + \rho^3 W^3 + \cdots$$

Unfold the formula (5):

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_n \end{bmatrix} = \sum_{r=1}^{k} \begin{bmatrix} S_r(W)_{11} S_r(W)_{12} \cdots S_r(W)_{1n} \\ S_r(W)_{21} S_r(W)_{22} \cdots S_r(W)_{2n} \\ \cdots \\ S_r(W)_{n1} S_r(W)_{n2} \cdots S_r(W)_{nn} \end{bmatrix} \begin{bmatrix} x_{1r} \\ x_{2r} \\ \cdots \\ x_{nr} \end{bmatrix} + V(W)\alpha t_n + V(W)\varepsilon$$

This research analyzes the spatial spillover effect of scientific and technological innovation on economic development by establishing a spatial econometric model.

TABLE VII. TOTAL, DIRECT AND INDIRECT EFFECTS OF SPATIAL DURBIN MODEL

	Total Effect	Direct Effect	Indirect Effect
	Coefficient	***Coefficient***	***Coefficient***
ST	0.2464	0.0934	0.1530
	(0.000)	(0.000)	(0.000)
FD	0.0583	0.0215	0.0368
	(0.043)	(0.008)	(0.047)
HC	-0.3014	0.0960	-0.3974
	(0.05)	(0.009)	(0.01)
OPEN	0.0381	0.0109	0.0272
	(0.047)	(0.025)	(0.05)
GI	0.0275	0.0030	0.0245
	(0.02)	(0.001)	(0.043)
TI	-0.1388	0.0223	-0.1611
	(0.003)	(0.005)	(0.008)

As show in “Table VII”, from the direct effect, it can be seen that the factors of technological innovation, human capital, opening degree, government investment, financial development and technological investment will promote the economic development of self province.

According to indirect effects, it can be seen that science and technology pass the 1% significance test, financial development, opening up and government investment all pass the 5% significance test, which shows that there is a spatial spillover effect of science and technology innovation on economic development, and displays a non-linear feature. Through the spatial transmission mechanism, it can promote the economic development of neighboring provinces, that is, the preliminary integration of science and technology between provinces and regions have shaped, therefore, the trend of coordinated development have emerged. Human capital and technology input pass the 1% significance test, but it has negative externality to the economic development of neighboring provinces, that is, it has posed a negative impact on the economic development of neighboring provinces. The reason is that the development of human capital and technology investment will have the "closure effect" on various resources of adjacent provinces' economy and restrain the development of adjacent provinces' economy.

From the total effect, it can be seen that the level of scientific and technological innovation passes the 1% significance test, and the financial development, opening up and government investment pass the 5% significance test, which shows that financial development, opening up and government investment promote the economic development of all regions. Among them, the coefficient of scientific and technological innovation level in the core explanatory variable remains the largest, which shows that the input and development of science and technology have the greatest impetus for China's economic growth. Human capital and technology investment pass the 5% significance test, but they restrain the economy, which shows that the negative diffusion effect of human capital and technology investment on economic development is far greater than its direct effect. Specifically, human capital's academic background and skills need to be improved, the government's efforts to introduce and retain high-tech talents need to be improved, and the phenomenon of "cultivating talents but not retaining them" often occurs; the level of technology investment is low, which inhibits economic development.

IV. Empirical Analysis of Threshold Model

A. Model Specification

The traditional Cobb-Douglas production function is adopted to build the production function that reflects the impact of scientific and technological innovation on economic development:

$$ECO_{it} = A_{it} ST_{it}^{\alpha} \qquad (6)$$

Among them, ECO is economy, ST is science and technology, A is technical efficiency; α represents output elasticity of science and technology; i represents province, t represents year.

This paper further explores the possible existed non-linear relationship between science, technology and economy by constructing a threshold panel regression model. Therefore, by referring to Hansen's threshold regression model and based on formula (6), this paper establishes the double threshold regression model of scientific and technological innovation and economic development by firstly taking the degree of opening up as threshold variable.

Technical efficiency A of economy consists of financial development FD, human capital HC, government investment GI and technology investment TI. Therefore, technical efficiency A can be written as follows:

$$A_{it} = e^{\phi T_i} \bullet FD_{it}^{\lambda_1} \bullet HC_{it}^{\lambda_2} \bullet GI_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \qquad (7)$$

$$\begin{aligned} \ln ECO_{it} &= \lambda_1 \ln FD_{it} + \lambda_2 \ln HC_{it} + \lambda_3 \ln GI_{it} + \lambda_4 \ln TI_{it} + \\ &\alpha_1 \ln(ST) \bullet I(\ln OPEN \le \theta_1) + \alpha_2 \ln(ST) \bullet I(\theta_1 < \ln OPEN \le \theta_2) + \\ &\alpha_3 \ln(ST) \bullet I(\ln OPEN > \theta_3) + \phi T + \varepsilon_{it} \end{aligned} \qquad (8)$$

Secondly, by taking the degree of financial development as the threshold variable and formula (6) as the basis, the double threshold regression model of scientific and technological innovation and economic development can be established.

Technical efficiency A of economy consists of opening up OPEN, human capital HC, government investment GI and technology investment TI. Therefore, technical efficiency A can be written as follows:

$$A_{it} = e^{\phi T_i} \bullet OPEN_{it}^{\lambda_1} \bullet HC_{it}^{\lambda_2} \bullet GI_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \qquad (9)$$

$$\begin{aligned} \ln ECO_{it} &= \lambda_1 \ln OPEN_{it} + \lambda_2 \ln HC_{it} + \lambda_3 \ln GI_{it} + \lambda_4 \ln TI_{it} + \\ &\alpha_1 \ln(ST) \bullet I(\ln FD \le \sigma_1) + \alpha_2 \ln(ST) \bullet I(\sigma_1 < \ln FD \le \sigma_2) + \\ &\alpha_3 \ln(ST) \bullet I(\ln FD > \sigma_3) + \phi T + \varepsilon_{it} \end{aligned} \qquad (10)$$

B. Basic Regression Analysis Results

On the premise of not considering threshold variables and threshold effects, this paper first adopts static panel model estimation method to inspect the marginal effects of scientific and technological innovation on economic development. Combining with the results of F test, Hausman test and LR test, the model has significant individual effect and time effect, so the double fixed model of individual and time is chosen to estimate. According to "Table VIII", fixed effect estimation results show that the coefficient of science and technology is 0.229 that is significant at the level of 1%, which indicates that scientific and technological innovation has a significant positive effect on economic development as a whole.

TABLE VIII. Test Results of Basic Model of the Impact of Scientific and Technological Innovation with Crass Multiplication on Economic Development

Variable	Mixed Regression	Random Effect	Fixed-effect
ST	0.229	0.228	0.228
	(0.000)	(0.000)	(0.000)
OPEN	0.018	0.018	0.021
	(0.045)	(0.027)	(0.003)
FD	0.030	0.030	0.043
	(0.246)	(0.332)	(0.192)
HC	-0.277	-0.275	-0.256
	(0.009)	(0.000)	(0.000)
GI	-0.008	0.008	0.019
	(0.438)	(0.356)	(0.023)
TI	0.005	-0.006	-0.009
	(0.630)	(0.734)	(0.557)
Constant term	0.819	0.817	0.861
	(0.000)	(0.000)	(0.000)

C. Threshold Effect Test

By taking opening up as the threshold variable, this paper examines the threshold effect of scientific and technological innovation on economic development. Threshold self-sampling test is carried out under the assumption of single threshold, double threshold and triple threshold respectively. In order to judge the threshold model to be selected, P value is obtained by F statistical value and Bootstrap method.

The test results of the existence of single threshold, double threshold and triple threshold effects with opening up as threshold variables ("Table IX") show that the single threshold effect is significant (1%), the double threshold effect is significant (5%) and the triple threshold effect has not passed the test. Therefore, when taking opening up as the threshold variable, the double threshold model should be adopted. According to "Table II", it can be seen that the first threshold value is 0.882 and the second threshold value is 1.778. According to "Table II", it can be seen that the first threshold value is 0.882 and the second threshold value is 1.778.

The test results of the existence of single threshold, double threshold and triple threshold effects with financial development as threshold variables ("Table X") show that the single threshold effect is significant (1%), the double threshold effect is significant (1%) and the triple threshold effect has not passed the test. Therefore, when taking opening up as the threshold variable, the double threshold model should be adopted. According to "Table XII", it can be seen that the first threshold value is 0.400 and the second threshold value is 0.536.

After determining the threshold value of scientific and technological innovation on economic development, the parameters of the double threshold model with opening up and financial development as the threshold variables are estimated and analyzed.

TABLE IX. SELF-SAMPLING TEST OF THRESHOLD EFFECT WITH OPENING UP AS THRESHOLD VARIABLE

Threshold	F	P	BS Time	Critical Value 1%	5%	10%
Single threshold	13.419***	0.063	300	17.291	14.257	12.471
Double threshold	2.433**	0.025	300	2.727	2.180	1.805
Triple threshold	0.000	0.110	300	0.000	0.000	0.000

a. Note: ***, ** and * represent significant at 1%, 5% and 10% significance levels respectively.

TABLE X. SELF-SAMPLING TEST OF THRESHOLD EFFECT WITH FINANCIAL DEVELOPMENT AS THRESHOLD VARIABLE

Threshold	F	P	BS Time	Critical Value 1%	5%	10%
Single threshold	2.270***	0.083	300	3.904	2.828	2.139
Double threshold	6.437**	0.000	300	3.076	1.882	1.204
Triple threshold	0.000	0.090	300	0.000	0.000	0.000

a. Note: ***, ** and * represent significant at 1%, 5% and 10% significance levels respectively.

TABLE XI. THRESHOLD ESTIMATED VALUE AND ITS CONFIDENCE INTERVAL WITH OPENING UP AS THRESHOLD VARIABLES

Threshold Value	Threshold Value	95% Confidence Interval
Double threshold model	0.882	[0.848,1.003]
	1.778	[0.701,1.860]

TABLE XII. THRESHOLD ESTIMATED VALUE AND ITS CONFIDENCE INTERVAL WITH FINANCIAL DEVELOPMENT AS THRESHOLD VARIABLES

Threshold Value	Threshold Value	95% Confidence Interval
Double threshold model	0.400	[0.421,0.563]
	0.536	[0.371,0.563]

D. Threshold Model Estimation and Analysis

During the sample period, there is not a simple linear relationship between scientific and technological innovation and economic development, and there are distinct threshold features. The estimated results of the double threshold model with opening up as the threshold variable are shown in "Table XI". Estimated results show that the threshold values of 0.882 and 1.778 divide the degree of opening up of various provinces in China into three levels, however, different degrees of opening up have significant differences in the impact of scientific and technological innovation on economic development: when the degree of opening up is lower than the minimum threshold value of 0.882, scientific and technological innovation will inhibit economic development; when the degree of opening up is between 0.882 and 1.778, the estimated coefficient value is 0.1878, which indicates that scientific and technological innovation will inhibit economic development, but the degree is much lower; after the degree of opening up spans a much higher threshold of 1.778, the estimated coefficient value will increase to 0.2140, which indicates that the greater the degree of scientific and technological innovation, the greater the degree of economic development. As for different degrees of opening up, the impact of scientific and technological innovation on economic development is extremely significant, and has obvious threshold characteristics. The fundamental reason is that the provinces in the much lower stage of opening up, due to their weak scientific and technological ability, weak human capital, inadequate government investment and backward infrastructure of scientific and technological environment, will make their scientific and technological innovation inhibit economic development in these areas.

The estimated results of the double threshold model with financial development as the threshold variable are shown in "Table XIV". According to estimated results, it can be seen that the threshold value of 0.400 and 0.536 divide the degree of opening up of various provinces in China into three levels, however, different degrees of financial development have significant differences in the impact of scientific and technological innovation on economic development: when the financial development is lower than the minimum threshold value of 0.400, scientific and technological innovation will inhibit economic development; when the financial development is between 0.400 and 0.536, the estimated coefficient value is 0.2128, which indicates that scientific and technological innovation will promote economic development, but the degree is much lower; after the degree of financial development spans a much higher threshold of 0.536, the estimated coefficient value will increase to 0.2339, which indicates that the greater the degree of scientific and technological innovation, the greater the degree of economic development. As for different degrees of financial development, the impact of scientific and technological innovation on economic development is extremely significant, and has obvious threshold characteristics. The fundamental reason is that the provinces in the much lower stage of financial development, due to their low financial support, lack of economic development support and financial environment for scientific and technological innovation, will make their scientific and technological innovation inhibit economic development in these areas.

TABLE XIII. THRESHOLD MODEL REGRESSION RESULTS WITH OPENING UP AS THRESHOLD VARIABLES

Explanatory Variables	Coefficient	Standard Deviation	t	P>|t|	95% Confidence Interval	
lgHC	-0.2560	0.0725	-3.53	0.001	-0.3999	-0.1121
lgGI	0.0153	0.0088	1.74	0.084	-0.0021	0.0327
lgTI	0.0063	0.0173	0.36	0.718	-0.0280	0.0405
lgFD	0.0278	0.0322	0.86	0.391	-0.0362	0.0917
lgST1	0.1643	0.0186	8.83	0.000	0.1273	0.2012
lgST2	0.1878	0.0171	10.99	0.000	0.1538	0.2217
lgST3	0.2140	0.0235	9.10	0.000	0.1673	0.2607
Constant number	0.8652	0.0776	11.17	0.000	0.7114	1.0190

TABLE XIV. THRESHOLD MODEL REGRESSION RESULTS WITH FINANCIAL DEVELOPMENT AS THRESHOLD VARIABLES

Explanatory Variables	Coefficient	Standard Deviation	t	P>|t|	95% Confidence Interval	
lgHC	-0.2569	0.0773	-3.32	0.001	-0.4106	-0.1033
lgGI	-.0116	0.0107	-1.08	0.285	-0.0328	0.0097
lgTI	0.0131	0.0182	0.72	0.472	-0.0230	0.0494
lgOPEN	0.0179	0.0080	2.24	0.027	0.0020	0.0339
lgST1	0.2030	0.0159	12.71	0.000	0.1713	0.2347
lgST2	0.2128	0.0156	13.61	0.000	0.1817	0.2438
lgST3	0.2339	0.0167	13.98	0.000	0.2007	0.2671
Constant number	0.7965	0.0872	9.13	0.000	0.6232	0.9697

V. CONCLUSION AND SUGGESTION

A. Conclusion

Based on the existing research and the spatial panel regression model and threshold panel regression model, according to the possible existed spatial spillover and threshold effect of scientific and technological innovation on economic development, this paper examines the spatial and non-linear relationship between scientific and technological innovation and economic development by using the relevant data of 29 provinces, municipalities and autonomous regions in China from 2007 to 2016. The results show that: (1) scientific and technological innovation has obvious spatial dependence on economic development, scientific and technological innovation of neighboring provinces will promote the economic development of self province, and its spatial linkage effect has developed steadily since 2007. (2) The spatial Durbin panel model incorporating the spatial lagged term of dependent variables and the spatial interaction term of independent variables is the best model to research the impact of scientific and technological innovation on economic development. The self province's scientific and technological innovation, financial development, human capital, opening up, government investment and technological investment have significantly promoted the self province's economic growth. Scientific and technological innovation, financial development, opening up and government investment have posed the significant positive spatial spillover effects on the economic development of neighboring provinces. Scientific and technological innovation, financial development, opening up and government investment promote the economy of all provinces. (3) Human capital and opening up have played a significant role in the economic development of self province, but the "resource closure effect" has posed a significant negative effect on the economic development of the neighboring provinces. (4) The impact of scientific and technological innovation on economic development has obvious threshold effect of opening up and financial development. When the degree of opening-up and financial development does not reach the single threshold, scientific and technological innovation will restrain economic development; when the degree of opening up and financial development is between single threshold and double threshold, scientific and technological innovation will promote economic development, but the degree is much lower; when the degree of opening up and financial development reaches the double threshold, scientific and technological innovation has significant promoting effect on economic development.

B. Suggestion

It is suggested to accelerate the construction of regional scientific and technological centers, integrate regional scientific and technological organizational system, establish complementary scientific and technological organizational network to boost economy; and to accelerate the construction of regional scientific and technological information platform, boost the radiation capacity, diffusing effect and functional effect of science and technology to boost economic development.

It is suggested to strengthen information communication and cooperation and exchange among local governments, give enough thought to the spatial spillover effect of the "growth pole" of scientific and technological innovation, promote the flow and agglomeration of scientific and technological resources, so as to promote regional economy.

It is suggested to improve the policy of training and introducing scientific and technological talents who is the critical factor to promote economy by science and technology. The government shall make great efforts to vigorously introduce foreign scientific and technological talents, to properly retain local scientific and technological talents, so as to provide solid talent support for science and technology to promote the economy.

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