2024 Volume 2, Issue 2
Computer Simulation in Application
ISSN: 2630-4597 (Online)

The Impact of FDI Technology Spillovers on Technological Progress in China's Computer, Communication, and Other Electronic Equipment Manufacturing Industry: A Study Based on a Panel Smooth Transition Regression Model

Liyang Qi, Weiran Wang*
Business School, Xinjiang Normal University, Urumqi 830017, Xinjiang, China

Corresponding author: Weiran Wang, wangweiran@163.com

Abstract:

With the development of economic globalization, foreign direct investment (FDI) has become a key area of focus for governments and academic research as an important means of strengthening international economic ties and promoting domestic economic development. The impact of technology spillover effects from direct investment on technological progress in host countries has also attracted widespread attention from scholars both domestically and internationally. Based on panel data from the computer, communication, and other electronic equipment manufacturing industry in 25 provinces in China from 2001 to 2021, this study employs a panel smooth transition regression model using MATLAB to investigate the impact of FDI horizontal spillover effects on technological progress in the industry, with R&D funding and R&D personnel input as transition variables. The findings of the study are as follows: (1) There is a nonlinear relationship between FDI horizontal technology spillovers and technological progress in the industry, and there are significant regional differences in the linear relationship. (2) From a national perspective, FDI horizontal technology spillovers promote technological progress in the industry, but when R&D personnel input exceeds a threshold value, FDI horizontal technology spillovers hinder technological progress in the industry. (3) At the regional level, FDI horizontal technology spillovers in the eastern region promote technological progress in the industry. However, when both R&D funding and R&D personnel input exceed their respective threshold values, FDI horizontal technology spillovers hinder technological progress in the industry. In the central and western regions, there is a linear relationship between FDI horizontal technology spillovers and technological progress in the industry. (4) The increase in FDI horizontal technology spillovers in the eastern region leads to a shift in the pathway of technological progress in the industry, from relying on technology spillovers to independent research and development.

Keywords:

FDI horizontal spillovers
Panel smooth transition regression model
Computer, communication, and other electronic equipment manufacturing industry
Technological progress
Absorptive capacity

Online publication: December 27, 2024

1. Introduction

After the reform and opening up, China has steadily increased its attraction of foreign direct investment (FDI), with actual utilization of FDI rising from US 113.3 billion in 2012 to US 173.5 billion in 2021, representing an average annual growth rate of 4.8%. Since 2020, China has ranked second in the world in terms of FDI attraction. The inflow of FDI can bring technology spillover effects to the host country, which are classified into two types: horizontal and vertical spillovers, based on the direction of the spillover. Regarding vertical spillover effects, Chinese scholars have generally reached a consensus that they are positive. However, there is significant disagreement on whether horizontal spillover effects are positive, negative, or insignificant.

China's computer, communication, and other electronic equipment manufacturing industry has made outstanding contributions to attracting FDI. From the perspective of actual FDI utilization, the cumulative amount of foreign capital utilized from 2001 to 2021 was 10,816.531 billion yuan, accounting for 20.67% of the total foreign capital utilized in the manufacturing industry. This industry ranks first in attracting FDI among the 21 sub-industries under the manufacturing sector. Simultaneously, the industry occupies a crucial position in China's high-tech industrial sector. Products in this industry undergo rapid upgrading, and technological progress and innovation are key concerns for all enterprises within the sector.

Technological progress in a country can be achieved primarily through two pathways: independent research and development (R&D) and the absorption of FDI technology spillovers. Since China's reform and opening up in the 1970s, it has continuously engaged in relevant practices, with the strategy of "exchanging the market for technology" being continuously tested in practice. Since then, China has introduced a large amount of foreign capital, alleviating capital shortages and relying on the resulting technology spillovers to promote domestic technological progress. However, the effectiveness of this approach has not met expectations. The technology dependence of China's computer, communication, and other electronic equipment manufacturing industry on foreign sources was above 40% before 2004, reaching 80%–90% in some years, indicating a high degree of external dependence on technological progress in the industry. It was only in 2008 that the industry's technology dependence on foreign sources gradually decreased to below 30%. The Ministry of Commerce pointed out in the "2005 Report on Multinational Companies in China" that "the result of a large amount of foreign direct investment is a lack of core technology." In 2006, China proposed strategies for rejuvenating the country through science and technology and promoting independent innovation. Yu believed that China's technological progress has since shifted from relying on foreign technology spillovers to focusing on independent innovation [1]. Therefore, it is of great practical significance to investigate whether FDI horizontal spillovers drive technological progress in this industry, how the industry can utilize FDI horizontal spillovers to promote technological advancement, and whether FDI horizontal technology spillovers can lead to a transformation in the pathways of technological progress within the industry.

2. Literature review

According to the definition provided by Blomström and Kokko [2], two of the most renowned scholars in the field of FDI spillover research, "FDI spillovers refer to the economic external effects that occur when multinational companies implement FDI in host countries, leading to local technological or productivity advancements, of which the multinational companies cannot capture all the benefits." FDI spillovers are classified into horizontal and vertical spillovers. Since the existence of FDI spillover effects was verified, a significant amount of literature on FDI spillover effects has been published. The number of studies on vertical spillovers is noticeably more than those on horizontal spillovers. Currently, scholars unanimously agree that the direction of vertical spillovers is positive, but there is still no consensus on the direction of horizontal technology spillovers. Fan and Wu [3] empirically tested the horizontal and vertical technology spillovers of FDI using panel data from 35 industrial sectors in China and concluded that FDI horizontal spillovers are negative. Bi and Yang [4] conducted an empirical analysis using relevant data from 23 industrial sectors over seven years and found that FDI horizontal spillover effects positively impact the reduction of carbon emission intensity. Zhao [5] studied the relationship between FDI technology spillovers and enterprise entry and exit in the manufacturing industry using three years of data from China's manufacturing sector. The results showed that FDI horizontal spillovers are significantly negative, reducing the entry rate of domestic enterprises. Yue [6] used a sample of 900,000 enterprises from 15 sub-sectors of China's manufacturing industry and found that upstream suppliers have a positive horizontal spillover effect on local enterprises. Chen and Lu [7] measured the horizontal technology spillover effects in 23 industrial sectors in China using technological similarity. They believed that significant spillover effects from foreign advanced technology can only occur when the technologies used within or between industries are similar and closely connected at the technological level. When technological similarity is not considered, the horizontal technology spillover effect is significantly negative.

After integrating the 39th industry, "Computer, Communication, and Other Electronic Equipment Manufacturing," under Category C of the "Classification of National Economic Industries" released by the National Bureau of Statistics of China in 2017, with the "Electronic and Communication Equipment Manufacturing" classification in China's high-tech industry classification, this paper found that eight out of the nine sub-categories within China's computer, communication, and other electronic equipment manufacturing industry fall under the electronic and communication equipment manufacturing classification. These are: communication equipment manufacturing, radio and television equipment manufacturing, radar and supporting equipment manufacturing, non-professional audio-visual equipment manufacturing, smart consumer device manufacturing, electronic component manufacturing, electronic parts and specialized electronic materials manufacturing, and other electronic equipment manufacturing. The ninth sub-category, computer manufacturing, overlaps highly with the sub-categories under the computer and office equipment manufacturing industry in China's high-tech industry classification. Therefore, the data for the threshold variables in this paper are selected from the electronic and communication equipment manufacturing and computer and office equipment manufacturing industries in China's high-tech industry database. Wang *et al.* [8] analyzed the R&D performance of the communication equipment, computer, and other electronic equipment manufacturing industry and found that since 2004, China's scientific and technological investment in this industry has been increasing continuously. As of 2004, a total of 210,800 scientific and technological personnel were invested, accounting for 11.47% of the total number of scientific and technological personnel in all industrial enterprises. The high investment and high output of scientific and technological activities and R&D activities in the communication equipment, computer, and other electronic equipment manufacturing industry have attracted more investment, and various regions have increased their scientific and technological investment in this industry. Zhu [9] analyzed the industrial efficiency of Shaanxi Province, taking the communication equipment manufacturing industry in the province as an example. The scientific and technological innovation platform is an important foundation for the scientific and technological innovation system of Shaanxi's communication equipment, computer, and other electronic equipment manufacturing industries, and it is an important carrier for promoting enterprises to become innovation subjects. Detailed suggestions were also provided for improving the independent innovation capability of the industry. Liu *et al.* [10] summarized the characteristics of the industry as being highly influenced by the macro environment, having strong technology, high investment, high risks, and rapid technological upgrades and product replacements when evaluating the value of mergers and acquisitions of micro-companies in the industry. This shows that the computer, communication, and other electronic equipment manufacturing industry has high requirements for technological levels. Analyzing whether FDI horizontal spillovers in this industry promote technological progress has practical significance.

The potential marginal contributions of this paper are as follows: (1) Industry focus: Examining the impact of FDI horizontal spillovers on technological progress in the computer, communication, and other electronic equipment manufacturing industry. Existing literature often selects broad categories such as manufacturing, services, and agriculture when studying FDI technology spillovers, with less focus on specific sub-sectors within these broader classifications. (2) Model innovation:

Utilizing MATLAB to conduct a Panel Smooth Transition Regression (PSTR) model to investigate the influence of FDI horizontal technology spillovers on technological advancement. Current research frequently employs Hansen's [11] threshold regression model (PTR) for nonlinear testing in related areas. However, this model uses a discrete indicator function, resulting in abrupt transitions at thresholds. Gonzalez *et al.* [12] introduced an improved PSTR model that incorporates a transformation function involving threshold variables, enabling smoother transitions at these points. (3) Extended time span: The sample period selected in this paper spans from 2001 to 2021, totaling 21 years of panel data, which enhances the persuasiveness of the results obtained.

3. Theoretical analysis and mechanism of action

3.1. Theoretical foundations of FDI spillover effects

3.1.1. Technology diffusion theory

Multinational corporations introduce advanced production technologies and management experiences into their investment target countries. When local businesses and labor forces collaborate or compete with these multinationals, they enhance their productivity and efficiency through technology transfer, skills training, and the absorption of management practices. This technology diffusion can generate positive spillover effects in the target investment countries and potentially similar impacts in other operational locations of the multinationals. This paper empirically analyzes whether such technology spillovers exist in the computer industry.

3.1.2. Human capital theory

When multinational companies invest in a country, they often provide high-quality employment opportunities, training and development programs, and experience related to international business. These investments may attract and retain local talent or draw foreign talent to the investing country. The increase in such talent can facilitate the flow of technology and knowledge, leading to spillover effects. As FDI flows into China's computer industry, relevant talent may gradually influx, potentially generating technology spillover effects. This paper intends to examine whether this phenomenon exists.

3.2. Mechanisms of FDI horizontal spillover effects

FDI horizontal technology spillovers occur within the same industry in the host country, also known as intra-industry technology spillovers. They primarily influence technological progress in the host country through competition effects, demonstration effects, and human resource mobility effects.

3.2.1. Competition effects

With the inflow of foreign capital, multinational corporations compete with domestic enterprises. To enhance their competitiveness in the market, host country enterprises shift their focus to improving their independent innovation capabilities, thereby promoting technological advancement in the host country. The competition effect is particularly prominent in the computer industry, where product updates are rapid, and independent innovation ability is a core competitiveness of enterprises.

3.2.2. Demonstration effects

The inflow of foreign capital provides a reference for innovation in host country enterprises. By imitating foreign-invested enterprises, host country businesses can stimulate their own innovation capabilities. As foreign capital flows in, some more advanced technologies may also enter the industry. However, computer companies typically have strong protections for their core technologies, which are not easily disclosed. Therefore, the effectiveness of this effect remains to be tested.

3.2.3. Human resource mobility effects

To ensure their smooth operation, foreign-invested enterprises train local employees. When these trained employees enter the job market, some may join host country enterprises and apply their acquired knowledge and skills, thereby contributing to technological progress in the host country. The computer industry experiences high employee turnover, and the human resource mobility effect resulting from foreign capital inflow influences technological advancement in the computer industry through talent influx.

4. Variables and data

4.1. Dependent variable

Total Factor Productivity (TFP): Referring to the method used by Wang and Lai [13] to calculate TFP in Shandong Province, this paper adopts the Solow residual method to calculate the TFP of various provinces in China from 2001 to 2021 in the computer, communication, and other electronic equipment manufacturing industries. TFP is used as an indicator to measure technological progress in this industry.

4.2. Core explanatory variable

Due to the lack of FDI values for various sub-sectors of the manufacturing industry, this paper refers to the method proposed by the Peking University China Economic Center Research Group [14]. It calculates the sum of foreign capital and Hong Kong, Macao, and Taiwan capital in the computer, communication, and other electronic equipment manufacturing industries in various provinces. The producer price index with 2001 as the base period (2001=100) is used to deflate it, and this data is used to measure the level of FDI spillover.

4.3. Control variables

After reading a large number of relevant literature on TFP, this paper selects marketization level (market), industrial structure (industry), human capital status (people), financial development (finance), and foreign trade dependence (trade) as control variables.

4.3.1. Marketization level (market)

TFP is affected by the free flow of production factors and the effective allocation of resources. Referring to the approach of Liao and Wang [15], this paper uses the proportion of state-owned enterprise employees in total employment to measure the level of marketization.

4.3.2. Industrial structure (industry)

This indicator is an important measure of positive development, reflecting the relationship between various production factors within the industry and between industries. Referring to the practices of Fu *et al.* [16] and He [17], this paper uses the proportion of the added value of the secondary industry in GDP to measure the industrial structure and explore its impact on TFP.

4.3.3. Human capital status (people)

Currently, the most authoritative measure of human capital status is years of education. According to China's education system and referring to the approach of Li *et al.* [18], the formula for calculating human capital is as follows:

$$(A1 \times 6 + A2 \times 9 + A3 \times 12 + A4 \times 16) / A5$$

Where A1 = number of people with primary school education, A2 = number of people with junior high school education, A3 = number of people with high school and technical secondary school education, A4 = number of people with college and above education, and A5 = total population aged 6 and above.

4.3.4. Financial development (finance)

Technological progress in the computer, communication, and other electronic equipment manufacturing industries in various provinces is inseparable from funding support. Therefore, the level of financial development is closely related to TFP. Referring to the approach of Yang and Cheng [19], this paper uses the ratio of total deposits and loans of financial institutions to GDP to measure the level of financial development.

4.3.5. Foreign trade dependence (trade)

Foreign trade dependence is an important indicator of economic openness and has a significant impact on TFP. Referring to the approach of Zhang and Min [20], this paper calculates foreign trade dependence using the ratio of total import and export volume to GDP in each province.

4.4. Transformation variables

Referring to relevant literature, this paper selects R&D personnel input (RDren) and R&D funding input (RDqian) to measure the host country's absorption capacity for FDI technology spillovers. Apart from the technological level itself, absorption capacity is also an important influencing factor for the impact of FDI horizontal spillovers on technological progress. R&D personnel and funding inputs are key indicators of technological absorption capacity. When these two indicators exceed a certain value, FDI horizontal technology spillovers may have a nonlinear impact on technological progress. Therefore, this paper directly selects R&D personnel and R&D funding from the

Table 1. Indicator measurement and data sources

Variable	Indicator	Calculation method	Data source
Dependent variable	TFP	Solow residual	Provincial statistical yearbooks, China Fixed Asset Investment Database, China Labor Statistical Yearbook
Independent variable	FDI horizontal spillover	(Foreign capital + Hong Kong, Macao, and Taiwan capital) / Producer Price Index	China Industrial Statistical Yearbook, China Industrial Economic Database
Transformation variable	R&D personnel input	-	China Statistical Yearbook on High-tech Industries, China High-tech Industry Database
	R&D funding input	-	China Statistical Yearbook on High-tech Industries, China High-tech Industry Database
Control variable	Marketization level	Number of state-owned enterprise employees / Total number of employed persons	China Industrial Statistical Yearbook, Provincial Statistical Yearbooks
	Industrial structure	Value-added of secondary industry / Regional GDP	Provincial statistical yearbooks, China Statistical Yearbook
	Human capital level	-	China Population Statistical Yearbook, China Education Database
	Financial development	Total deposits and loans of financial institutions / Regional GDP	Provincial statistical yearbooks, China Financial Database
	Foreign trade dependence	Total import and export volume / Regional GDP	Nanchang Statistical Yearbook, Jiangxi Statistical Yearbook, China Statistical Yearbook

"China Statistical Yearbook on High-tech Industries" as transformation variables. The specific calculation methods and data sources of each indicator are shown in **Table 1**.

5. Empirical analysis and conclusion

5.1. Calculation of TFP

In this section, the Solow residual method is used to calculate the value of TFP. The specific calculation steps and data are as follows:

5.1.1. Calculation of capital stock

Since China does not publicly release data on capital stock, which is a crucial variable for calculating total factor productivity and is highly significant in academic research, scholars often adopt the Perpetual Inventory Method (PIM) proposed by Goldsmith [21] to estimate China's capital stock. The formula under the geometric decline model of relative efficiency is:

$$K_t = K_{t-1}(1-\delta_t) + I_t \tag{1}$$

Where I_t represents the investment in year t, calculated as I_t = fixed asset investment / fixed asset investment price index; δ_t represents the depreciation rate in year t; K_{t-1} represents the capital stock in year t-1.

5.1.2. Calculation of TFP using Solow residuals

In 1957, Solow [22] introduced the concept of Solow residuals, which has become the most basic, longest-used, and widest-ranging method for calculating TFP. Therefore, this paper employs the capital stock data calculated in the previous section and uses the Solow residual method to calculate the total factor productivity of the computer, communication, and other electronic equipment manufacturing industries in various provinces of China. The calculation method is as follows:

Assuming that the aggregate production function is the Cobb-Douglas production function:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta} \tag{2}$$

Where Y_{it} represents the output of province i in year t; K_{it} represents the capital stock of province i in year t; L_{it} represents the labor input of province i in year t; A_{it}

represents the total factor productivity of province i in year t. The superscripts α and β represent the shares of capital and labor income in total output, respectively.

Taking the logarithm of both sides of the above equation:

Formula for calculating TFP:

$$A_{it} = Y_{it}/K_{it}^{\alpha}L_{it}^{\beta} \tag{3}$$

Formula for calculating TFP growth rate:

$$\frac{\Delta A}{A} = \frac{A_{t+1} - A_t}{A_t} \tag{4}$$

At the same time, considering the time error of TFP, the estimation model of TFP is obtained by rearranging formula (1):

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = lnA_0 + \alpha\ln\left(\frac{K_{it}}{L_{it}}\right) \tag{5}$$

Estimate the parameter α in the above formula, find α and β (β=1–α), and substitute them to calculate TFP and its growth rate, respectively.

Finally, the perpetual inventory method is used to calculate the annual capital stock of each province. Since the fixed asset investment price index for 2020 and 2021 has not been released, this paper refers to Liping Liao's approach and selects the commodity retail price index of each province for conversion.

After obtaining the capital stock data of each province, this paper estimates the parameters α and β in the Solow residual. Here, OLS is used for estimation. Regression of formula (5) using Stata yields α = 0.385 and β = 0.615, and the test results are significant at a 95% confidence interval. Substituting the parameters into the total factor productivity calculation formula gives the annual total factor productivity and total factor productivity growth rate for each province. **Table 2** provides descriptive statistics for the variables.

5.2. Construction of measurement model and threshold regression

5.2.1. Model construction

$$\text{TFP}_{it} = \alpha_0 + \alpha_1 FDI_{it} + \alpha_c contral + \varepsilon_{it} \tag{6}$$

$$\text{TFP}_{it} = \alpha_0 + \alpha_{11} FDI_{it} + \sum_{j=1}^{r} \alpha_{12} FDI_{it} \times g(RD_{ren_{it}}; \gamma_j; c_j) + \alpha_c contral + \varepsilon_{it} \tag{7}$$

$$\text{TFP}_{it} = \alpha_0 + \alpha_{11} FDI_{it} + \sum_{j=1}^{r} \alpha_{12} FDI_{it} \times g(RD_{qian_{it}}; \gamma_j; c_j) + \alpha_c contral + \varepsilon_{it} \tag{8}$$

$$g(q_{it}; \gamma_j; c_j) = \left\{1 + exp\left[-\gamma_j \times \prod_{j=1}^{m}(q_{it} - c_j)\right]\right\}^{-1} \tag{9}$$

Where i and t represent province and time respectively; TFP_{it} denotes the total factor productivity of province i in year t; FDI_{it} represents the level of FDI technology spillover in province i in year t; RD_{ren} and RD_{qian} refer to R&D personnel and expenditure inputs respectively, and control is a set of control variables including marketization level (market), industrial structure (industry), human capital level (people), financial development (finance), and foreign trade dependency (trade); g is a transfer function with a value between 0 and 1; r represents the number of transfer functions; q_{it} is the threshold variable of the transfer function. In this paper, R&D personnel input (RD_{ren}) and R&D expenditure input (RD_{qian}), which measure the absorption capacity of FDI technology spillover, are selected as the threshold variables. γ is the smoothing coefficient of the transfer function, indicating the speed of transition between different regimes in the model. c represents the location parameter, indicating where the transition occurs, and m

Table 2. Descriptive statistics of variables

Variable name	Variable symbol	Sample size	Mean	Standard deviation	Minimum value	Maximum value
Output	Y	525	20007.770	19627.450	1133.270	124719.500
Capital	K	525	414.353	724.820	27.227	7364.660
Labor	L	525	18.573	39.188	0.132	272.344

is the number of location parameters. m generally takes two values, 1 or 2, representing one or two transitions respectively: when m is 1, $q_{it} > c$ represents the high regime, and $q_{it} < c$ represents the low regime; when m is 2, $q_{it} < c_1$ and $q_{it} > c_2$ represent the outer regimes, while $c_1 < q_{it} < c_2$ represents the middle regime.

5.2.2. Descriptive statistics and basic processing of variables

Descriptive statistics of variables: There are significant differences in inter-provincial total factor productivity, and uneven development of regional technological levels. The minimum values of research personnel and expenditure inputs exist as zero, indicating varying degrees of emphasis on high-tech industries among provinces. China should encourage the development of high-tech industries and attach importance to the role of technology in economic development. **Table 3** presents the descriptive statistics of the variables.

Stationarity test: Before conducting regression analysis on panel data, it is necessary to test the stationarity of the data to prevent spurious regressions. Since the selected data is long panel data, the LLC method is used here to test the stationarity of the panel data. As shown in **Table 4**, the LLC stationarity test for the level of financial development passes the 5% significance level test, while the other variables pass the 1% significance level test. All variables in the above table are stationary.

Table 3. Descriptive statistics of variables

Variable name	Variable symbol	Sample size	Mean	Standard deviation	Minimum value	Maximum value
Total factor productivity	TFP	525	3.351936	4.032272	0.1538242	27.93366
FDI horizontal spillover	FDI	525	3.243632	6.489318	0.0001244	40.52153
Research personnel input	RDren	525	1.663373	4.273021	0	39.6547
Research funding input	RDqian	525	54.56245	163.4398	0	1821.861
Marketization level	market	525	0.3450013	0.3797811	0.0280348	1.646197
Industrial structure	industry	525	0.45378	0.0792148	0.158337	0.6147768
Human capital level	people	525	1526.873	785.6644	52.21295	5302.861
Financial development	finance	525	2.864525	1.164575	1.288197	8.131033
Foreign trade dependency	trade	525	0.332906	0.3850565	0.0270732	1.721482

Table 4. Results of stationarity test

Variable	LLC test value	*P*-value	Stationarity
TFP	-2.9104	0.0018 ***	stationary
FDI	-2.3588	0.0092 ***	stationary
market	-8.7878	0.0000 ***	stationary
industry	-2.3767	0.0087 ***	stationary
people	-3.1310	0.0009 ***	stationary
finance	-1.9551	0.0253 **	stationary
trade	-7.9688	0.0000 ***	stationary
RDren	-5.5854	0.0000 ***	stationary
RDqian	-11.1958	0.0000 ***	stationary

Note: *** indicates significance at the 1% level, ** indicates significance at the 5% level.

5.2.3. PSTR regression results and analysis

Nonlinearity test: This test aims to determine whether there is a nonlinear effect between FDI horizontal technology spillover and technological progress in the industry. The null hypothesis of this test is $\gamma = 0$, which indicates a linear relationship between the two and is not suitable for PSTR regression. The alternative hypothesis is $\gamma \geq 1$, suggesting a nonlinear relationship and further investigation using PSTR. In this paper, three methods, namely Wald, Fischer, and LRT, are employed for testing, with test values denoted as LM, LMF, and LRT respectively. The results presented in **Table 5** indicate that all three test statistics for Model (7) reject the alternative hypothesis at the 1% significance level, confirming the presence of a nonlinear relationship in the model. In other words, R&D personnel input serves as a threshold variable for the nonlinear relationship between FDI horizontal technology spillover and technological progress. However, for Model (8), under both $m = 1$ and $m = 2$ scenarios, the statistical values of the three test results are not significant, failing to reject the null hypothesis. This suggests that R&D expenditure input does not cause a nonlinear relationship between FDI horizontal technology spillover and technological progress. The reason may be that the industry in China has fully utilized funding, and issues such as corruption due to excessive funding input do not arise, thereby not leading to a nonlinear relationship between FDI horizontal technology spillover and technological progress. This result aligns with the actual situation, but further research is needed to determine whether regions with different levels of economic development yield similar findings. Since the continuous input of R&D expenditure does not affect the promotional effect of FDI horizontal technology spillover on technological progress, there exists a linear relationship between FDI horizontal technology spillover and technological progress under the condition of continuous R&D expenditure input. The following section further explores the nonlinear correlation between FDI horizontal technology spillover and technological progress in the industry, considering R&D personnel input.

Table 5. Results of nonlinearity test

***m* = 1**	**Model 8**		**Model 9**	
	Statistic	***P*-value**	**Statistic**	***P*-value**
LM	7.556	0.006	2.893	0.089
LMF	7.286	0.007	2.765	0.097
LRT	7.611	0.006	2.901	0.089
***m* = 2**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	7.725	0.021	2.901	0.234
LMF	3.719	0.025	1.384	0.252
LRT	7.782	0.020	2.909	0.233

Remaining nonlinearity test: The purpose of the remaining nonlinearity test is to determine the optimal number of transfer functions, i.e., the value of r, under different m values. The null hypothesis of this test is $r = 1$, indicating that the model only contains one transfer function; the alternative hypothesis is $r = 2$, suggesting the presence of two transfer functions in the model. For the test of Model (7), as shown in **Table 6**, the statistical values of the three test results are not significant when $m = 1$ and $m = 2$, failing to reject the null hypothesis of $r = 1$. Therefore, Model (8) only includes one transfer function.

Table 6. Results of remaining nonlinearity test

***m* = 1**	**Model 8**	
	Statistic	***P*-value**
LM	0.027	0.870
LMF	0.025	0.873
LRT	0.027	0.870
***m* = 2**	**Statistic**	***P*-value**
LM	0.263	0.877
LMF	0.124	0.883
LRT	0.263	0.877

Determination of location parameters: This section focuses on determining the number of location parameters in the model, i.e., determining the value of m. The value of m is generally 1 or 2. Here, the AIC (Akaike Information Criterion) and BIC (Bayesian Information

Criterion) minimization criteria are used to determine the value of m. As shown in **Table 7**, both AIC and BIC have smaller values when $m = 1$ compared to when $m = 2$. Therefore, the optimal number of location parameters m for this model is 1.

Table 7. Results of determining the number of location parameters

Location parameters	Model 8	
	***m* = 1**	***m* = 2**
AIC	2.136	2.142
BIC	2.169	2.182

PSTR regression analysis: Based on the previous tests, it is known that Model (7) exhibits a nonlinear relationship with one transfer function ($r = 1$) and an optimal number of location parameters ($m = 1$), while Model (8) does not show a nonlinear relationship. In this section, MATLAB is used to perform PSTR regression analysis on Model (7).

As shown in **Table 8**, with R&D personnel input as the threshold, there is a nonlinear correlation between FDI horizontal technology spillover and technological progress in the computer, communications, and other electronic equipment manufacturing industry. As the investment in R&D personnel increases, the industry's technological absorption capacity gradually improves. Consequently, FDI horizontal technology spillover promotes industry technological progress through competition effects and other pathways. However, after the continuous investment in R&D personnel exceeds a certain level, FDI horizontal technology spillover can hinder industry technological progress.

The goal of continuous investment in R&D personnel, beyond a certain level, is to cultivate high-tech talents capable of independent innovation. The cultivation of relevant talents is a long-term process with relatively slow impacts [23], making it difficult to enhance the current stage of technological absorption capacity. A significant amount of FDI spillover is not immediately absorbed, leading to a situation where, beyond the threshold, FDI horizontal spillover hinders the technological progress of the industry.

5.2.4. Threshold crossing situation in different regions

Eastern region: For both Model (7) and Model (8), $r = 1$ and $m = 1$, indicating that both models have one transfer function and the optimal number of location parameters is 1 (**Tables 9** and **10**). In the case of the eastern region, the impact of FDI horizontal technology spillover on the technological progress of the industry is nonlinear. This nonlinearity is further explored using two indicators that measure technological absorption capacity: R&D personnel input and R&D expenditure input as thresholds. The specific nonlinear relationship can be studied through the PSTR model.

Central region: As shown in **Table 11**, none of the three tests for both models are significant when $m = 1$ and $m = 2$, indicating that the PSTR model is not suitable in

Table 8. PSTR regression results

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.3795 * (0.0591)	6.4197
Nonlinear part	FDI	α_{12}	-0.2699 * (0.0524)	-5.1505
Location parameter	c		4.5458	
Smoothing parameter	γ		5.4072	
Akaike information criterion (AIC)	AIC		2.136	--
Bayesian information criterion (BIC)	BIC		2.169	
Sum of squared residuals	RSS		4335.714	

Table 9. PSTR regression results for model (7)

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.3167 * (0.0573)	5.5286
Nonlinear part	FDI	α_{12}	-0.2125 ** (0.0493)	-4.3089
Location parameter	c		4.5883	--
Smoothing parameter	γ		6.2317	
Akaike information criterion (AIC)	AIC		0.468	
Bayesian information criterion (BIC)	BIC		0.532	
Sum of squared residuals	RSS		315.060	

Table 10. PSTR regression results for model (8)

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.2199 ** (0.0440)	4.9987
Nonlinear part	FDI	α_{12}	-0.1043 ** (0.0321)	-3.2501
Location parameter	c		2.1988	--
Smoothing parameter	γ		25.4037	
Akaike information criterion (AIC)	AIC		0.553	
Bayesian information criterion (BIC)	BIC		0.616	
Sum of squared residuals	RSS		332.893	

Table 11. Results of nonlinearity test for the central region

***m* = 1**	**Model (7)**		**Model (8)**	
	Statistic	***P*-value**	**Statistic**	***P*-value**
LM	0.255	0.614	0.715	0.398
LMF	0.242	0.624	0.679	0.411
LRT	0.255	0.613	0.716	0.397
***m* = 2**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	0.417	0.812	1.286	0.526
LMF	0.196	0.822	0.610	0.545
LRT	0.417	0.812	1.291	0.524

this case. In other words, for the central region, there is no nonlinear correlation between FDI horizontal technology spillover and technological progress in the industry.

The reason may be that the central region has relatively less investment in R&D personnel and expenditure, and competition effects, human capital flow effects, etc., have not yet reached the threshold level that would make the relationship nonlinear.

Western region: Similar to the central region, in the western region, the relatively insufficient investment in research and development is not enough to reach the threshold value that causes nonlinearity between the two (**Table 12**).

Table 12. Results of nonlinearity test for the western region

m = 1	Model (7)		Model (8)	
	Statistic	***P*-value**	**Statistic**	***P*-value**
LM	0.670	0.413	0.166	0.684
LMF	0.637	0.426	0.157	0.693
LRT	0.672	0.412	0.166	0.684
***m* = 2**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	9.132	0.100	2.559	0.278
LMF	4.571	0.120	1.222	0.298
LRT	9.429	0.900	2.581	0.275

5.2.5. Analysis of technological progress pathways: Independent innovation and FDI technology spillover

Technological progress primarily relies on independent innovation and FDI technology spillover. As demonstrated by the empirical results in the eastern region, when investment in research and development personnel and expenditure is excessive, FDI horizontal technology spillover does not significantly promote technological progress. Due to the dual nature of independent innovation [24], scientific research investment in the industry is directed towards enhancing independent innovation capabilities. This process has a long cycle and does not significantly promote technological progress. In this stage, an increase in FDI horizontal technology spillover does not facilitate technological progress. In the long run, improving independent innovation capabilities can enable China to break free from foreign technology monopolies. For a country to truly achieve technological progress, independent innovation is the best pathway. To absorb a significant amount of FDI horizontal technology spillover, the host country is bound to enhance its technological absorption capabilities. This enhancement not only improves the ability to absorb but also boosts independent innovation capabilities. An increase in FDI horizontal technology spillover drives the technological progress pathway of the host country from relying on technology spillover to independent innovation.

6. Conclusion and policy suggestions

6.1. Research conclusion

Based on panel data from the computer, communications, and other electronic equipment manufacturing industries in 25 provinces in China from 2001 to 2021, this paper employs the Panel Smooth Transition Regression (PSTR) model using MATLAB to investigate the impact of FDI horizontal spillover effects on technological progress in the industry, with R&D expenditure and R&D personnel input as transition variables. The following conclusions are drawn from both national and regional perspectives:

Firstly, FDI horizontal technology spillover promotes technological progress in the industry, but when R&D personnel input exceeds a threshold, FDI horizontal technology spillover hinders technological progress in the industry.

Secondly, in the eastern region, FDI horizontal technology spillover promotes technological progress in the industry. However, when both R&D expenditure and R&D personnel input exceed their respective thresholds, FDI horizontal technology spillover hinders technological progress. In the central and western regions, there is a linear relationship between FDI horizontal technology spillover and technological progress in the industry.

6.2. Policy suggestions

Based on the above research findings, this paper proposes the following suggestions:

For the government: Firstly, from a national perspective, provincial governments, especially in the eastern region, should pay attention to investing appropriate amounts and improving the utilization efficiency of R&D investment to prevent low utilization efficiency.

Secondly, the process of cultivating independent innovative talents should be accelerated. Technological progress cannot rely solely on FDI spillovers. Besides utilizing the human capital flow effect generated by foreign capital inflows, domestic independent research and development should become the main pathway, deepening the strategy of strengthening the country through science and technology.

Thirdly, when making R&D investments in the eastern region, attention should be paid to the amount of investment to prevent situations where excessive R&D investment hinders technological progress in the industry due to FDI horizontal technology spillovers.

Fourthly, the central and western regions should strengthen their economic development and increase R&D investment. According to technology diffusion and human capital theories, sustained R&D investment in these two regions will positively impact the phenomenon of FDI horizontal technology spillovers promoting technological progress in the industry.

For enterprises: Firstly, from the perspective of enterprises, they should invest in R&D according to their capabilities. More R&D investment is not always better. When FDI generates horizontal spillovers, excessive R&D investment can hinder technological progress, especially for enterprises in the eastern region. Enterprises should evaluate their technological absorption capabilities before deciding whether to continue increasing R&D investment.

Secondly, when deciding whether to make direct investments, foreign investors should not only consider the economic strength of the host country but also focus on the technological spillover absorption capabilities of host country enterprises. Absorption capability should become a key factor in foreign investors' decision-making. Countries lacking absorption capabilities may not be able to utilize the potential benefits brought by foreign capital, while countries with higher absorption capabilities are more likely to fully absorb and benefit from foreign direct investment, generating positive feedback. Therefore, foreign investors should prioritize absorption capabilities during their investigations.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Yu G, 2010, FDI Technology Spillover, Independent Research and Development, and China's Technological Progress, dissertation, Shandong University of Technology.

[2] Blomström AK, Zhao X, Huang K, 2005, The Economics of Foreign Direct Investment Incentives. Translated Economic Materials, 2005(2): 9–20.

[3] Fan L, Wu Y, 2011, Horizontal and Vertical Effects of FDI Technology Spillovers—An Empirical Analysis Based on Chinese Industrial Panel Data. International Economics and Trade Research, 27(3): 40–47.

[4] Bi K, Yang C, 2012, The Impact of FDI Spillover Effects on China's Industrial Carbon Emission Intensity. Economic Management, 34(8): 31–39.

[5] Zhao K, 2016, Foreign Direct Investment and the Entry and Exit of Host Country Enterprises, dissertation, Northeastern University.

[6] Yue X, 2019, Research on FDI, Indirect Horizontal Spillovers, and Enterprise Productivity in China's Manufacturing Industry, dissertation, Zhongnan University of Economics and Law.

[7] Chen S, Lu C, 2019, Research on FDI Technology Spillover Effects Based on Industry Technology Similarity. Journal of International Trade, 2019(1): 106–118.

[8] Wang H, Luo Y, Sun S, et al., 2007, R&D Performance Analysis of Communications Equipment, Computers and Other Electronic Equipment Manufacturing. Science Research Management, (Supplement 1): 158–162.

[9] Zhu C, 2012, Industry Efficiency Analysis Based on DEA—Taking Communications Equipment, Computers, and Other Electronic Equipment Manufacturing in Shaanxi Province as an Example. Journal of Xi'an University of Posts and Telecommunications, 17(4): 92–95.

[10] Liu C, Xu M, Chen J, 2022, Research on M&A and Restructuring Value Evaluation of Listed Companies in China—Taking the Manufacturing of Computers, Communications, and Other Electronic Equipment as an Example. China Appraisal, 2022(11): 27–33.

[11] Hansen BE, 1999, Threshold Effects in Non-Dynamic Panel Estimation, Testing, and Inference. Journal of Econometrics, 1999(93): 345–368.

[12] Gonzalez A, Terävirta T, Van Dijk D, et al., 2005, Panel Smooth Transition Regression Models, SSE/EFI Working Paper Series in Economics and Finance, No. 604, Stockholm School of Economics, The Economic Research Institute (EFI), Stockholm.

[13] Wang H, Lai F, 2022, Scientific and Technological Achievements Industrialization, Total Factor Productivity, and Economic Growth—Based on Panel Data from 16 Cities in Shandong Province from 2009 to 2019. Western Finance, 2022(8): 16–25.

[14] Peking University China Center for Economic Research, 2006, Peking University China Center for Economic Research Task Force: Vertical Specialization in China's Export Trade and Sino-US Trade. World Economics, 2006(5): 341.

[15] Liao L, Wang F, 2019, The Trajectory and Evolutionary Characteristics of Total Factor Productivity in Guangdong Under the Background of Opening Up. Journal of Guangdong University of Finance and Economics, 34(2): 102–112.

[16] Fu J, Hu J, Cao X, 2018, Different Sources of FDI, Environmental Regulations, and Green Total Factor Productivity. Journal of International Trade, 2018(7): 134–148.

[17] He X, 2022, Environmental Regulations, FDI, and Urban Total Factor Productivity, dissertation, Zhongnan University of Economics and Law.

[18] Li Y, Han B, Zhang Q, 2011, FDI Spillovers, Threshold Effects, and Regional Technological Progress in China—An Empirical Study Based on Panel Data from 29 Provinces and Cities. Forum on Science and Technology in China, 2011(3): 79–83.

[19] Yang L, Cheng X, 2023, Research on the Potential of China's Export Trade with Northeast Asia Under the Background of RCEP—An Empirical Analysis Based on the Gravity Model. Northern Economy and Trade, 2023(9): 15–19.

[20] Zhang X, Min W, 2021, Research on the Role of Education in Improving Total Factor Productivity—From Linear and Nonlinear Perspectives. Peking University Education Review, 19(3): 101–124.

[21] Goldsmith R, 1951, A Perpetual Inventory of National Wealth. NBER Studies in Income and Wealth, 1951(14): 5–61.

[22] Solow R, 1991, Analysis of Factors of Economic Growth [Shi Q, et al., Trans.], The Commercial Press, Beijing, 65–94.

[23] Chen X, 2021, Analysis of the Impact of Regional Absorptive Capacity on FDI Technology Spillovers and the Threshold Effect of Alternative Indicators, dissertation, Shanghai University of Finance and Economics.

[24] Cohen W, Levinthal D, 1989, Innovation and Learning: The Two Faces of R&D. Economic Journal, 1989(99): 569–596.