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Two-Way FDI Coordinated Development Promotes Efficient and Balanced Development of Regional Technological Innovation Activities

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Abstract As an important path to promote the transmission of international knowledge and technology, the impact of two-way FDI coordinated development on one country's technological innovation efficiency deserves in-depth exploration. This study uses the fixed effect panel stochastic frontier analysis model and the coupled coordination model to measure the technological innovation efficiency and the two-way FDI coordinated development level of China's 31 provincial administrative regions from 2011 to 2021, and uses the fixed effect panel least squares regression model, the fixed effect panel quantile regression model, the Moran's index model, the fixed effect spatial Durbin panel model and the fixed effect panel β convergence model to test the impact of two-way FDI coordinated development on technological innovation efficiency. The results show that two-way FDI coordinated development can directly and significantly promote the improvement of technological innovation efficiency in the province, and with the improvement of technological innovation efficiency, the promoting effect of two-way FDI coordinated development has also become stronger. In addition, two-way FDI coordinated

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development can also indirectly generate significant positive spatial spillover effects on the technological innovation efficiency of neighboring provinces, narrow the technological innovation efficiency gap between regions, and thereby promote the efficient and balanced development of regional technological innovation activities. The research conclusions reveal the positive impact of two-way FDI coordinated development on the efficient and balanced development of regional technological innovation activities, which has enlightening significance for building a strong country in science and technology.

Keywords two-way FDI; coordinated development; technological innovation; efficiency measurement; spatial effect; balanced development

1 Introduction

According to the endogenous economic growth theory, technological innovation is the core driving force and source that leads a country's economic development level to maintain sustainable growth. Especially in the current context of rapid technological development and continuous industrial transformation, the core competitiveness of technological innovation has gradually become a key element for a country to take the lead in development and enhance its international competitiveness and international status [1,2]. As an important manifestation of the core competitiveness of technological innovation, technological innovation efficiency not only directly reflects a country's ability to operate and allocate technological innovation resources, but also profoundly affects a country's technological innovation vitality and technology transformation success rate [3,4], determines the core competitiveness level of a country's technological innovation undertakings. Improving the technological innovation efficiency is not only an important means for countries with strong technological innovation to maintain their competitive advantages, but also an effective way for countries with weak technological innovation to catch up with countries with strong technological innovation [5,6]. Therefore, how to effectively improve the technological innovation efficiency has become a hot topic in academic circles. In this regard, a large number of literatures have deeply explored the impact of Internet development, digital finance, digital economy, urbanization efficiency, public library construction, public service efficiency, fiscal decentralization, higher education development, talent introduction policies and foreign technology control policies on technological innovation efficiency, and it is generally believed that the above factors can effectively promote the improvement of technological innovation efficiency [7–16].

But it should be noticed that as the main channels for acquiring international advanced technology and knowledge, the impact of technology spillovers from inward foreign direct investment (IFDI) and reverse technology spillovers from outward foreign direct investment (OFDI) on technological innovation efficiency cannot be ignored. In theory, both IFDI and OFDI can not only accelerate the efficient cross-border flow of general monetary capital [17,18], but also promote the effective cross-border transfer of high-quality technological innovation factors such as non-monetary capital, advanced technology, management experience and human capital [19,20]. By generating technology spillover effects and resource allocation effects, IFDI and OFDI can guide the above-mentioned high-quality technological innovation factors to flow into the key links of one country's technological innovation chain [21], solve the technological innovation obstacles and bottlenecks that it may encounter, and optimize the internal structure and traditional layout of its technological innovation business, thereby improving its technological innovation efficiency and enhancing the core competitiveness of its technological innovation business.

Therefore, as an important path for the transmission of advanced technology and knowledge among countries, studying the relationship among IFDI, OFDI and technological innovation efficiency has important theoretical and practical significance. However, the existing literature has paid insufficient attention to the impact of IFDI or OFDI on technological innovation efficiency, especially the lack of putting IFDI and OFDI into the same framework to study the potential impact of their coordinated development on technological innovation efficiency. In addition, the existing literature easily ignores the regional heterogeneity of technological innovation efficiency and lacks the exploration of possible spatial spillover effects. In this regard, based on the scientific measurement of China's technological innovation efficiency and two-way FDI coordinated development level, this study deeply explores whether two-way FDI coordinated development can effectively promote the efficient and balanced development of China's regional technological innovation activities.

2 Literature Review and Hypotheses Development

At present, there are a large amount of academic literature that have discussed in depth the impact of IFDI and OFDI on technological innovation efficiency. Unfortunately, the existing literature has not yet formed a relatively consistent research conclusion. Some studies believe that IFDI and OFDI can significantly increase technological innovation efficiency [22–25], but some studies believe that IFDI and OFDI have no significant impact on technological innovation efficiency [26–29], and some studies even believe that IFDI and OFDI will significantly decrease technological innovation efficiency [30–33]. In addition, most of the existing literature separates IFDI and OFDI, either based on the research perspective of IFDI or based on the research perspective of OFDI, and analyzes the relationship between IFDI and technological innovation efficiency or the relationship between OFDI and technological innovation efficiency in a local and single manner. IFDI and OFDI are rarely analyzed in the same framework, ignoring the importance of two-way FDI coordinated development, and lacking the exploration of the potential impact of two-way FDI coordinated development on technological innovation efficiency. It should be pointed out that if a country's IFDI introduction scale and OFDI investment scale are seriously unbalanced, it will not only lead to unreasonable competition in its technological innovation market, but also cause the ineffective occupation of its domestic technological innovation resources, which will have a negative effect on its technological innovation efficiency that cannot be ignored.

In fact, IFDI is an important foundation for promoting the development of OFDI. When the development level of OFDI is improved, it can in turn strongly support the development of

IFDI, and promote the technology spillover effect of IFDI and the reverse technology spillover effect of OFDI to form a benign interactive force. This can not only effectively promote the exchange of technology and knowledge, make full use of external technological innovation advantages, and accelerate the accumulation of a country's technology and knowledge stock [34,35], but also can integrate domestic and foreign technological innovation resources with comparative advantages, strengthen the interconnection of domestic and foreign technological innovation industries, and form a cultivation effect of technological advantages [36], and generate a learning effect and demonstration effect on a country's technological innovation activities, so that the country can directly or indirectly imitate and improve existing technologies in the process of introducing foreign capital and investing abroad [37], thereby building a domestic and international technological innovation dual circulation mutual promotion system [38], effectively increasing a country's technological innovation efficiency.

Specifically, with the increase in the scale of IFDI introduction, it can not only directly bring sufficient funds to the host country's technological innovation activities, but also introduce advanced knowledge and technology, high-quality talents and mature management concepts to it [39]. This will prompt the various technological innovation entities in the host country to optimize their innovation resource allocation while learning and absorbing the technological innovation advantages of foreign-funded enterprises at a lower cost, thereby effectively increasing the host country's technological innovation efficiency, narrowing the gap between it and technological innovation powers, and enhancing the international competitiveness of the host country's products [23], ultimately reducing the barriers for host country enterprises to enter overseas markets, promoting the increase in their OFDI investment scale, and strengthening the reverse technology spillover effect generated by OFDI.

At the same time, when the scale of OFDI investment increases, in the international technological innovation competition environment, in order to ensure the sustainability of survival and development, OFDI enterprises of the home country will not only spontaneously increase their R&D investment in technological innovation, but also actively guide the inflow of high-quality foreign technological innovation elements into the home country, break the technological barriers of foreign advanced enterprises, and effectively increase its technological innovation efficiency [40]. This can not only promote high-end cooperation between the home country and technological innovation powers, thereby strengthening the home country's attractiveness to IFDI, but also can force the home country's local enterprises to form a technological innovation competition effect, prompting their technological transformation and upgrading, and continuously improving their comprehensive technological level, thereby avoiding inferior IFDI while introducing more high-quality IFDI and enhancing the technological spillover effect generated by IFDI. And it is also important to note that as technological innovation efficiency increases, the local single spillover effect of IFDI or OFDI will become increasingly weak. On the contrary, the composite overall spillover effect formed by two-way FDI coordinated development is the pillar force to ensure the sustainable growth of technological innovation efficiency. Based on the above analysis, this study proposes the following hypotheses:

Hypothesis 1 Two-way FDI coordinated development can promote technological innovation efficiency.

Hypothesis 2 As technological innovation efficiency increases, the promoting effect of two-way FDI coordinated development will continue to increase.

In addition, two-way FDI coordinated development will also certainly promote the efficient and balanced development of regional technological innovation activities. The reason is that according to the resource capability allocation theory and strategic alliance theory, two-way FDI coordinated development can also effectively build a unified national technological innovation chain, promote the complementary and coordinated development of technological innovation activities among regions, and ensure the smooth flow of technological innovation elements across the country, so as to efficiently use and allocate various technological innovation elements among different regions, effectively enhance the technological innovation competitiveness of each region, form technological innovation synergy effect and scale effect, and finally effectively narrow the technological innovation efficiency gap among regions. Based on the above analysis, this study proposes the following hypotheses:

Hypothesis 3 Two-way FDI coordinated development has a positive spatial spillover effect on the technological innovation efficiency of adjacent regions.

Hypothesis 4 Two-way FDI coordinated development can narrow the technological innovation efficiency gap among regions.

In summary, placing IFDI and OFDI in the same framework and studying the impact of two-way FDI coordinated development on technological innovation efficiency can not only further enrich existing research results, but also help interpret the controversial conclusions in existing literature on the relationship between one-way FDI and technological innovation efficiency. In view of this, in order to make up for the lack of relevant research on the relationship between two-way FDI coordinated development and technological innovation efficiency, this study selects 31 provincial administrative regions in China as the research objects, sets the research period from 2011 to 2021, and uses the fixed effect panel SFA model and the coupled coordination model to measure China's technological innovation efficiency and two-way FDI coordinated development levels during this period. On this basis, this study uses the fixed effect panel least squares regression model and the fixed effect panel quantile regression model to analyze the impact of two-way FDI coordinated development on technological innovation efficiency. The reason for choosing China as the research object is that China has long been the world's second largest country in terms of two-way FDI flows. In particular, with the continuous and in-depth promotion of the "Belt and Road" and free trade zone strategies, China's dual identities as a host country and an investing country are playing an increasingly important role in the international cross-border capital arena[41]. If China is chosen as the research object, the research conclusions on the relationship between two-way FDI coordinated development and technological innovation efficiency will be more convincing and instructive.

In addition, given that both IFDI and OFDI can promote the inter-regional flow of technological innovation elements [22], this study also uses the fixed effect panel spatial Durbin model to test whether two-way FDI coordinated development can generate a significant spatial spillover effect on technological innovation efficiency, and uses the fixed effect panel β convergence test model to examine whether two-way FDI coordinated development will promote or inhibit the efficient and balanced development of regional technological innovation activities. Compared with the existing literature, the marginal contribution of this study is mainly reflected in the following two aspects: First, the existing literature mainly focuses on the impact of IFDI or OFDI on technological innovation efficiency, ignoring the potential impact of the coordinated development of IFDI and OFDI on technological innovation efficiency. Therefore, based on the scientific measurement of the technological innovation efficiency and two-way FDI coordinated development levels of each provincial administrative region in China, this study deeply analyzes the impact of two-way FDI coordinated development on technological innovation efficiency under the mean condition and different quantile conditions. Second, when existing literature explores the relationship between IFDI and technological innovation efficiency or the relationship between OFDI and technological innovation efficiency, it is easy to ignore the possible spatial impact. Therefore, this study also tests whether two-way FDI coordinated development can generate a significant spatial spillover effect on technological innovation efficiency, and determines the impact of this spillover effect on the efficient and balanced development of regional technological innovation activities.

3 Research and Data Methodology

3.1 Variable Selection

3.1.1 Dependent Variable

The dependent variable of this study is technological innovation efficiency (TIE). Existing research methods for measuring technological innovation efficiency can be generally summarized into two categories. One is based on the data envelopment analysis (DEA) model. Its advantage is that it does not require subjective setting of the production function and can avoid structural bias caused by incorrect setting of the production function. However, in the actual efficiency measurement process, the DEA model cannot take the impact of random errors on the efficiency value into account, and the DEA model can only evaluate relative efficiency and cannot measure absolute efficiency [42,43]. The other is based on the stochastic frontier analysis (SFA) model. Compared with the DEA model, although the SFA model needs to set the production function autonomously, the SFA model can fully consider the impact of random errors on the efficiency value and effectively distinguish the impact of environmental variables, random errors, and internal management factors, thereby measuring a relatively more realistic efficiency value.

Therefore, taking the impact of factors such as random errors on efficiency values into full account, this study uses the panel stochastic frontier analysis (SFA) model to measure the technological innovation efficiency of China's 31 provincial administrative regions from 2011 to

2021. However, the traditional panel SFA model can only be used to measure efficiency under the condition of a single output indicator. To overcome this defect and make the measurement results more accurate and comprehensive, this study draws on the approach of Xiao and Zhang[44] and uses the panel entropy value weighting method to relatively objectively and effectively calculate the comprehensive output of technological innovation activities of China's 31 provincial administrative regions from 2011 to 2021. The calculation results are used as the output indicator in the panel SFA model to measure the technological innovation efficiency values of China's 31 provincial administrative regions from 2011 to 2021. The specific measurement process is as follows.

1) Technological innovation comprehensive output. Referring to existing studies[45–47], this study constructs an evaluation indicator system for the technological innovation comprehensive output in 31 provincial administrative regions in China from the two dimensions of patent application output and technology transfer output (see Table 1). Specifically, this study selects the number of patent authorizations and the number of green patent authorizations as proxy indicators for patent application output, and selects new product sales revenue and technology market turnover as proxy indicators for technology transfer output.

Table 1 Evaluation indicator system of technological innovation comprehensive output

Indicator name (direction)	Mean	Indicator unit	Indicator weight
Number of patent authorizations (+)	6.46229	Ten thousand item	0.2369
Number of green patent authorizations (+)	3751.2434	One item	0.2221
New product sales revenue (+)	5695.7557	100 million CNY	0.2361
Technology market turnover (+)	471.7169	100 million CNY	0.3049

Based on the above evaluation indicator system, this study further uses the panel entropy weighting method to calculate the comprehensive output scores of technological innovation activities in China's 31 provincial administrative regions from 2011 to 2021. The specific models are set as follows.

First, standardize each original indicator data to eliminate the dimensional differences among different indicators, thereby ensuring the comparability of various indicators and making the calculation results more accurate. In addition, in order to meet the subsequent demand for taking the logarithm of the standardized indicator data, this study sets the objective function as follows:

$$y_{ijt} = \frac{x_{ijt} - \min(x_{jt})}{\max(x_{jt}) - \min(x_{jt})} * 0.999 + 0.001. \tag{1}$$

In the above formula, y_{ijt} and x_{ijt} respectively represent the j-th original indicator of provincial administrative region i in year t after standardization and without standardization. $\max(x_{jt})$ and $\min(x_{jt})$ respectively represent the maximum values and minimum values of the j-th original indicator without standardization in year t.

Second, calculate the entropy value of each indicator:

$$e_{jt} = -\frac{1}{\ln(n)} * \sum_{i=1}^{n} p_{ijt} \ln p_{ijt}. \tag{2}$$

In the above formula, $p_{ijt} = y_{ijt} / \sum_{i=1}^{n} y_{ijt}$. When $p_{ijt} = 0$, set $p_{ijt} \ln p_{ijt} = 0$, so as to ensure $0 \le e_{jt} \le 1$.

Third, calculate the weight of each indicator:

$$w_{jt} = \frac{1 - e_{jt}}{\sum_{j=1}^{m}(1 - e_{jt})} = \frac{1 - e_{jt}}{m - \sum_{j=1}^{m} e_{jt}}. \tag{3}$$

In the above formula, $0 \le w_{jt} \le 1$, and $\sum_{j=1}^{m} w_{jt} = 1$.

Fourth, calculate the score of technological innovation comprehensive output:

$$\mathrm{STIS}_{it} = \sum_{j=1}^{m} w_{jt} y_{ijt}. \tag{4}$$

In the above formula, the larger the calculated value of STIS_{it} it is, the higher the technological innovation comprehensive output score of provincial administrative region i in year t is. The measurement results are shown in Figure 1.

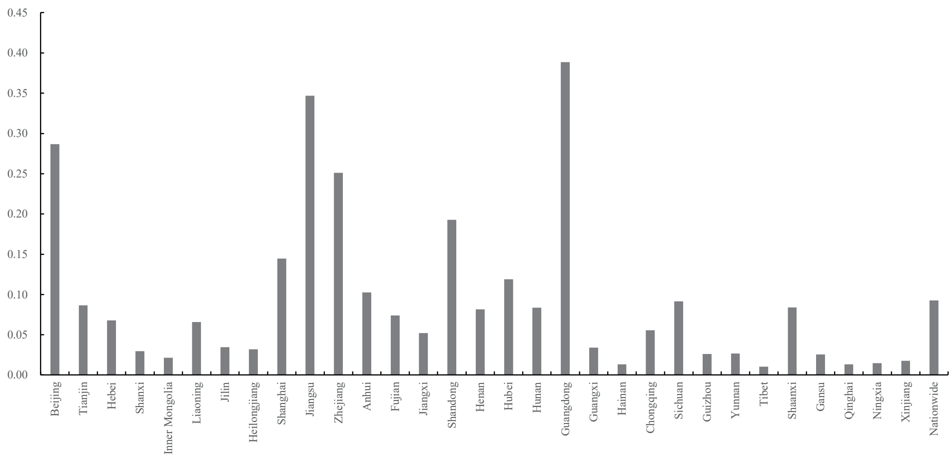

Figure 1 Average technological innovation comprehensive output of China's 31 provincial administrative regions

2) Technological innovation efficiency. Referring to existing studies [48–50], this study selects input indicators to measure technological innovation efficiency from the two aspects of labor and capital. Specifically, this study selects the number of employees in scientific research and technological services and the number of R&D personnel as labor input indicators, and selects the R&D funds and the new product funds as capital input indicators (see Table 2).

Based on the above measurement indicator system, and further based on the calculation results of the technological innovation comprehensive output scores of China's 31 provincial

Table 2 Measurement indicator system of technological innovation efficiency

Indicator name	Mean	Indicator unit
Number of employees in scientific research and technological services	12.9117	10,000 people
Number of R&D personnel	9.0375	10,000 people
R&D funds	362.0238	10,000 CNY
New product funds	419.3516	10,000 CNY
Technological innovation comprehensive output	0.0926	Score

administrative regions from 2011 to 2021, this study sets the panel SFA model for measuring technological innovation efficiency as follows:

$$\begin{aligned}\ln \mathrm{TIS}_{it} = {} & \alpha_0 + \alpha_1 \cdot \ln \mathrm{TISE}_{it} + \alpha_2 \cdot \ln \mathrm{RDE}_{it} + \alpha_3 \cdot \ln \mathrm{RDF}_{it} + \alpha_4 \cdot \ln \mathrm{NPF}_{it} + \\ & \mathrm{province}_i + \mathrm{year}_t + \nu_{it} + \mu_{it}.\end{aligned} \tag{5}$$

In the above formula, $\ln \mathrm{TIS}_{it}$, $\ln \mathrm{TISE}_{it}$, $\ln \mathrm{RDE}_{it}$, $\ln \mathrm{RDF}_{it}$, and $\ln \mathrm{NPF}_{it}$ respectively represent the logarithm of the technological innovation comprehensive output score, the logarithm of the number of employees in scientific research and technological services, the logarithm of the number of R&D personnel, the logarithm of the R&D funds, and the logarithm of the new product funds of provincial administrative region i in year t. $\mathrm{Province}_i$ and year_t respectively represent the province fixed effects and year fixed effects. α_0 represents the constant term. α_1, α_2, α_3, and α_4 respectively represent the coefficients to be estimated before different input indicators. The error term consists of ν_{it} and μ_{it}, where ν_{it} represents the independent and identically distributed normal random variable and μ_{it} represents the technological inefficiency term. Based on this, technological innovation efficiency can be defined as follows:

$$\mathrm{TIE}_{it} = \exp(-\mu_{it}). \tag{6}$$

In the above formula, TIE_{it} represents the technological innovation efficiency of provincial administrative region i in year t, and $\mathrm{TIE}_{it} \in [0, 1]$, which means the ratio of actual output of technological innovation to fully effective output under given input conditions. The larger the measurement value of TIE_{it}, the higher the technological innovation efficiency of provincial administrative region i in year t. The measurement results are shown in Figure 2.

3.1.2 Independent Variable

The independent variable of this study is two-way FDI coordinated development (TFDICD). This study uses the coupling coordination model to measure the coupling coordination degree of IFDI and OFDI of 31 provincial administrative regions in China from 2011 to 2021, that is, the level of two-way FDI coordinated development. Before measuring, this study first standardized IFDI and OFDI. The specific models are set as follows:

$$\mathrm{CCD}_{it} = \sqrt{\mathrm{CD}_{it} \cdot \mathrm{CDL}_{it}}, \tag{7}$$

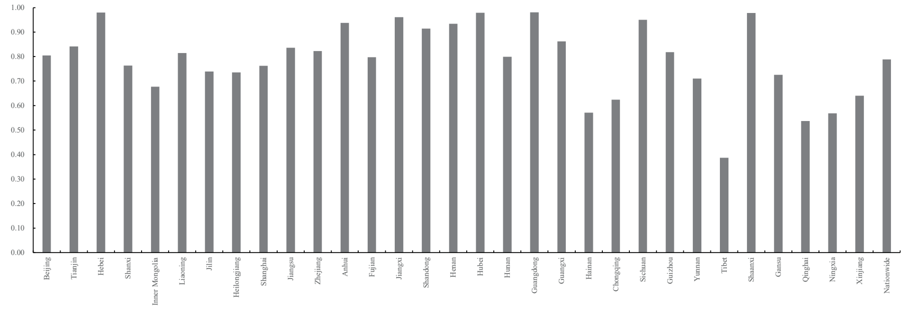

Figure 2 The average results of technological innovation efficiency measurement of China's 31 provincial administrative regions

$$\mathrm{CD}_{it} = \frac{2 \cdot \sqrt{\mathrm{SIFDI}_{it} \cdot \mathrm{SOFDI}_{it}}}{\mathrm{SIFDI}_{it} + \mathrm{SOFDI}_{it}}, \tag{8}$$

$$\mathrm{CDL}_{it} = w_1 \cdot \mathrm{SIFDI}_{it} + w_2 \cdot \mathrm{SOFDI}_{it}. \tag{9}$$

In the above formula, SIFDI_{it} and SOFDI_{it} respectively represent the standardized IFDI and OFDI of provincial administrative region i in year t. CD_{it} represents the coordination degree between the IFDI and OFDI systems of provincial administrative region i in year t. CDL_{it} represents the comprehensive development level between the IFDI and OFDI of provincial administrative region i in year t. w_1 and w_2 are the weights of the IFDI and OFDI, respectively, satisfying $w_1 + w_2 = 1$. Since this study considers IFDI and OFDI to be of equal importance, w_1 and w_2 are both assigned the value of 0.5. CCD_{it} represents the coupling coordination degree between the IFDI and OFDI of provincial administrative region i in year t, reflecting the coordinated development level of IFDI and OFDI, and its value range is $[0, 1]$. The higher the value of CCD_{it}, the higher the coupling coordination degree between the IFDI and OFDI, and the higher the level of two-way FDI coordinated development. The measurement results are shown in Figure 3.

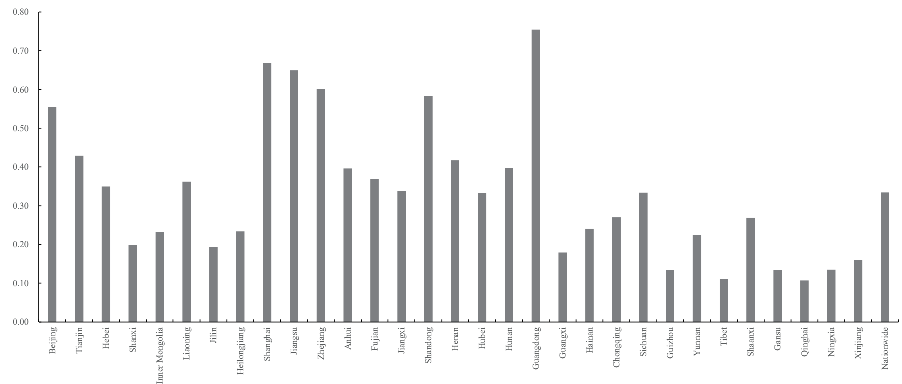

Figure 3 The average levels of two-way FDI coordinated development of China's 31 provincial administrative regions

3.1.3 Control Variables

Referring to existing studies[25,29,32], this study selects economic development (ED), industrial structure (IS), urbanization rate (UR), population size (PS), consumption willingness (CW), financial development (FD), public transportation construction (PTC) and employees' education level (EEL). Among them, ED is measured by the logarithm of regional GDP. IS is measured by the ratio of the added value of the tertiary industry to the added value of the secondary industry. UR is measured by the proportion of the regional urban permanent population to the total permanent population of the region. PS is measured by the logarithm of the total permanent population of the region. CW is measured by the ratio of regional per capita consumption expenditure to per capita disposable income. FD is measured by the ratio of the deposit and loan balance of regional financial institutions to regional GDP. PTC is measured by the proportion of the total length of regional public bus and tram operating lines to the regional land area. EEL is measured by the average years of education of regional employees.

3.2 Data Sources and Variable Statistics

This study conducts empirical analysis based on the panel data from 31 provincial administrative regions in China from 2011 to 2021. The data for measuring the dependent variable TIE mainly comes from the database of Chinese Research Data Services, the data for measuring the independent variable TFDICD mainly comes from the China Statistical Yearbook and the Statistical Bulletin of China's Outward Direct Investment, and the data for other control variables mainly comes from the China Statistical Yearbook, the China Population and Employment Statistical Yearbook, the China Fiscal Yearbook, and the China Financial Statistical Yearbook. The descriptive statistical results of each variable are shown in Table 3.

Table 3 Descriptive statistical results

Variable	Mean	Overall Sd	Within Sd	Between Sd	Minimum	Maximum	N
TIE	0.7888	0.1802	0.1034	0.1498	0.1076	0.9926	341
TFDICD	0.3343	0.1880	0.0654	0.1789	0.1000	0.8906	341
ED	9.7362	1.0049	0.2698	0.9825	6.4159	11.7338	341
IS	1.3513	0.7225	0.2444	0.6901	0.5271	5.2440	341
UR	0.5864	0.1307	0.0433	0.1252	0.2265	0.8958	341
PS	8.1302	0.8424	0.0302	0.8546	5.7333	9.4481	341
CW	0.7210	0.0547	0.0316	0.0453	0.5603	0.9055	341
FD	3.4412	1.1290	0.3994	1.0719	1.6776	7.5783	341
PTC	0.3717	0.7448	0.1332	0.7438	0.0006	3.9968	341
EEL	9.8722	1.2243	0.4416	1.1591	4.1440	13.9650	341

3.3 Empirical Model Building

3.3.1 Benchmark Regression Model

To examine the overall impact of two-way FDI coordinated development on technological innovation efficiency, this study sets the benchmark regression model as follows.

$$\mathrm{TIE}_{it} = \alpha_0 + \alpha_1 \cdot \mathrm{TFDICD}_{it} + \phi \cdot \mathrm{Controls}_{it} + \mathrm{province}_i + \mathrm{year}_t + \sigma_{it}. \tag{10}$$

In the above formula, TIE_{it}, TFDICD_{it}, and $\mathrm{Controls}_{it}$ respectively represent the technological innovation efficiency, two-way FDI coordinated development, and a series of control variables of provincial administrative region i in year t. α_0 represents the constant term. α_1 represents the regression coefficient of two-way FDI coordinated development. ϕ represents the regression coefficients of a series of control variables. $\mathrm{province}_i$ and year_t respectively represent the province fixed effects and year fixed effects. σ_{it} represents the random disturbance term.

3.3.2 Quantile Regression Model

On the basis of the benchmark regression model, in order to conduct heterogeneity analysis on technological innovation efficiency at different levels and avoid the endogenous influence of the regression results caused by the difference in the distribution of technological innovation efficiency, this study selects the 25th, 50th and 75th quantiles as the lower efficiency level, the medium efficiency level and the higher efficiency level, respectively, and further uses the panel quantile regression method to explore whether two-way FDI coordinated development will have a significant differential impact on technological innovation efficiency under different quantile conditions. The specific model is set as follows.

$$Q_\tau(\mathrm{TIE}_{it}) = \alpha_{0,\tau} + \alpha_{1,\tau} \cdot \mathrm{TFDICD}_{it} + \phi_\tau \cdot \mathrm{Controls}_{it} + \mathrm{province}_i + \mathrm{year}_t + \sigma_{it}. \tag{11}$$

In the above formula, $Q_\tau(\mathrm{TIE}_{it})$ represents the technological innovation efficiency of provincial administrative region i in year t under the τ quantile condition. $\alpha_{0,\tau}$ represents the constant term under the τ quantile condition. $\alpha_{1,\tau}$ represents the regression coefficient of two-way FDI coordinated development under the τ quantile condition. ϕ_τ represents the regression coefficients of a series of control variables under the τ quantile conditions. The meanings of the remaining symbols are consistent with the benchmark regression model.

3.3.3 Spatial Effect Model

In view of the first law of geography, this study chooses the geographic distance matrix as the weight matrix of the spatial effect model. Compared with the traditional geographic adjacency matrix, the geographic distance matrix can more accurately analyze the relationship between farther spatial units. The specific matrix is set as follows.

$$W_{ij} = \begin{cases} W_{ij} = \dfrac{1}{D_{ij}}, & \text{if } i \neq j, \\ W_{ij} = 0, & \text{if } i = j. \end{cases} \tag{12}$$

In the above formula, W_{ij} represents the geographic distance weight matrix. D_{ij} represents the geographical distance between spatial unit i and spatial unit j, that is, the straight-line Euclidean distance between the capital city of provincial administrative region i and the capital city of provincial administrative region j.

1) Spatial correlation model. After setting and calculating the spatial weight matrix, this study uses the Moran's index model to test the spatial autocorrelation of technological innovation efficiency to determine whether there is the property of technological innovation efficiency spatial correlation between spatial units. The Moran's index model includes the global Moran's index model and the local Moran's index model.

Global Moran's index model. The global Moran's index is used to test whether there is the property of technological innovation efficiency spatial correlation between spatial units as a whole, and its value range is between -1 and 1. If the global Moran's index of technological innovation efficiency is greater than 0, it means that the technological innovation efficiency of the spatial units is positively autocorrelated, that is, high efficiency spatial units are adjacent to high-efficiency spatial units, and low efficiency spatial units are adjacent to low-efficiency spatial units. If the global Moran's index of technological innovation efficiency is less than 0, it means that the technological innovation efficiency of the spatial units is negatively autocorrelated, that is, high efficiency spatial units are adjacent to low efficiency spatial units. The specific model is set as follows.

$$I_t = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(\mathrm{TIE}_{it} - \overline{\mathrm{TIE}_t})(\mathrm{TIE}_{jt} - \overline{\mathrm{TIE}_t})}{(\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij})\sum_{i=1}^{n}(\mathrm{TIE}_{it} - \overline{\mathrm{TIE}_t})^2}. \tag{13}$$

In the above formula, I_t represents the measurement result of the global Moran's index in year t. W_{ij} represents the geographic distance weight matrix. TIE_{it} represents the technological innovation efficiency of provincial administrative region i in year t. $\overline{\mathrm{TIE}_t}$ represents the average technological innovation efficiency of the 31 provincial administrative regions in year t. The specific measurement results of the global Moran's index are shown in Table 4. The results show that between 2011 and 2021, the global Moran's index has always been significantly positive, indicating that technological innovation efficiency has a significant positive spatial correlation and has spatial agglomeration characteristics. The increase of technological innovation efficiency of one province can generate a positive and significant forward radiation effect impact on the technological innovation efficiency of the neighboring provinces. This can promote the increase of technological innovation efficiency of the neighboring provinces.

Table 4 Global Moran's index measurement results (%)

Series	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Measurement	0.0386**	0.0386**	0.0385**	0.0384**	0.0382**	0.0379**	0.0374**	0.0366**	0.0356**	0.0342**	0.0323**
Z value	2.1468	2.1389	2.1292	2.1170	2.1017	2.0824	2.0580	2.0272	1.9883	1.9395	1.8789
P value	0.0318	0.0324	0.0332	0.0343	0.0356	0.0373	0.0396	0.0426	0.0468	0.0524	0.0603

Note: ** represents $P < 0.05$, * represents $P < 0.1$.

Local Moran's index model. The local Moran's index model can be used to further determine the specific agglomeration characteristics of spatial units and study the heterogeneity of local space. Specifically, the scatter plot of the local Moran's index is in a Cartesian coordinate system, and its four quadrants correspond to four different types of local spatial relationships. Among them, the first quadrant is HH-type aggregation, indicating that the efficiency values of the central unit and the adjacent units are both high, representing positive spatial autocorrelation. The second quadrant is HL-type aggregation, indicating that the central unit with low efficiency value is surrounded by adjacent units with high efficiency values, representing negative spatial autocorrelation. The third quadrant is LL-type aggregation, indicating that the efficiency values of the central unit and the adjacent units are both low, representing positive spatial autocorrelation. The fourth quadrant is LH-type aggregation, indicating that the central unit with high efficiency value is surrounded by adjacent units with low efficiency values, representing negative spatial autocorrelation. The specific model is set as follows:

$$I_{it} = \frac{(\mathrm{TIE}_{it} - \overline{\mathrm{TIE}})}{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{TIE}_{it} - \overline{\mathrm{TIE}})^2} \cdot \sum_{j \neq 1}^{n} W_{ij}(\mathrm{TIE}_{jt} - \overline{\mathrm{TIE}}). \tag{14}$$

In the above formula, I_{it} represents the local Moran's index measurement result of provincial administrative region i in year t. The meanings of other symbols are consistent with the global Moran's index model. In order to more clearly present the spatial agglomeration characteristics and changing trends of technological innovation efficiency, this study directly draws a local Moran's index scatter plot of technological innovation efficiency, but due to space limitations, only the results of 2011, 2014, 2017 and 2021 are shown (see Figure 4). The results show that from

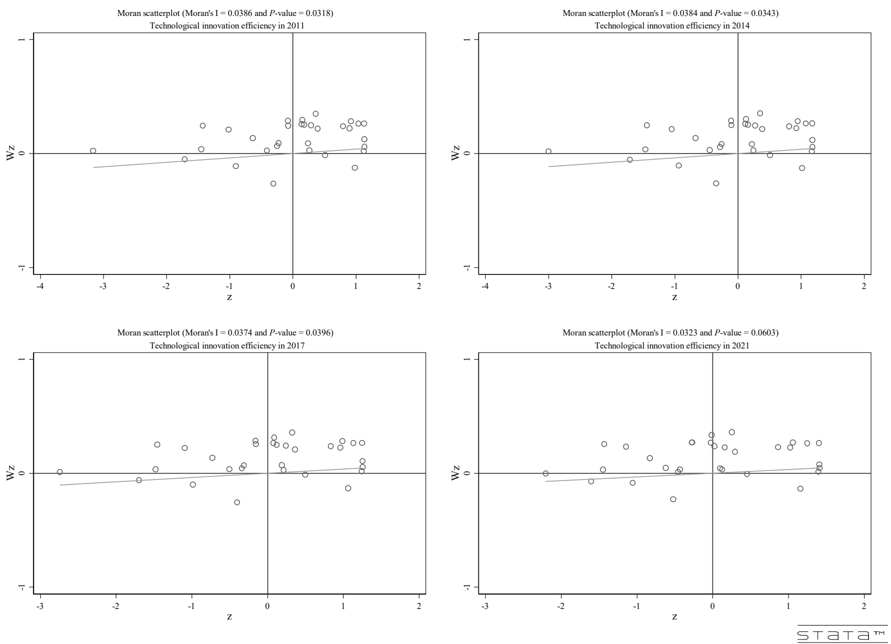

Figure 4 Local Moran's Index Scatter Plot

2011 to 2021, the quadrants in which the vast majority of provincial administrative regions are located did not change over time. Specifically, the HH type first quadrant accounts for the largest proportion, followed by the HL type second quadrant, and only 5 provincial administrative regions are located in the LL type third quadrant and the LH type fourth quadrant, showing the characteristics of high-high agglomeration (HH agglomeration) and high-low agglomeration (HL agglomeration). So, can two-way FDI coordinated development generate a significant spatial spillover effect on the increase of technological innovation efficiency? If there is a significant spatial spillover effect, will it promote or inhibit the efficient and balanced development of regional technological innovation activities? This needs to be further tested through the spatial Durbin model.

2) Spatial Durbin Model. After verifying the spatial correlation of technological innovation efficiency, this study uses the spatial Durbin model to further test whether two-way FDI coordinated development can generate a significant spatial spillover effect on technological innovation efficiency. The specific model is set as follows.

$$\begin{aligned}\mathrm{TIE}_{it} = \alpha_0 + \alpha_1 \cdot \mathrm{TFDICD}_{it} + \alpha W_1 \cdot \sum_{j=1}^{n} W_{ij} \cdot \mathrm{TFDICD}_{jt} + \phi \cdot \mathrm{Controls}_{it} + \\ \phi W \cdot \sum_{j=1}^{n} W_{ij} \cdot \mathrm{Controls}_{jt} + \mathrm{province}_i + \mathrm{year}_t + \sigma_{it}.\end{aligned} \tag{15}$$

In the above formula, W_{ij} represents the spatial weight, i and j respectively represent provincial administrative region i and provincial administrative region j. αW_1 represents the spatial spillover effect directly generated by two-way FDI coordinated development. ϕW represents the spatial spillover effects generated by a series of control variables. The meanings of the remaining symbols are consistent with the benchmark regression model.

3.3.4 β Convergence Test Model

If two-way FDI coordinated development indeed can generate a significant spatial spillover effect on technological innovation efficiency, whether the technological innovation efficiency gap among regions will be narrowed or expanded remains to be further verified. To this end, this study also uses the absolute β convergence test model to judge the convergence of regional technological innovation efficiency, that is, to test the absolute β convergence property of regional technological innovation efficiency, and uses the conditional β convergence test model to judge the impact of two-way FDI coordinated development on the convergence of regional technological innovation efficiency, that is, to test the conditional β convergence property of regional technological innovation efficiency. The main difference between the two β convergence properties is that the absolute β convergence property means that even without considering any other factors, as time goes by, the low-efficiency area of technological innovation can spontaneously converge to the high-efficiency area of technological innovation. The conditional β convergence property means that after introducing two-way FDI coordinated development on the basis of the absolute β convergence test model, the low-efficiency area of technological innovation can converge to the high-efficiency area of technological innovation at a faster growth rate, that is, two-way FDI coordinated development can effectively promote regional technological innovation activities to achieve efficient and balanced development. The specific models are set as follows.

$$\ln\frac{\mathrm{TIE}_{i,t+1}}{\mathrm{TIE}_{it}} = C_1 + \beta_1 \cdot \ln \mathrm{TIE}_{it} + \mathrm{province}_i + \mathrm{year}_t + \sigma 1_{it}, \tag{16}$$

$$\ln\frac{\mathrm{TIE}_{i,t+1}}{\mathrm{TIE}_{it}} = C_2 + \beta_2 \cdot \ln \mathrm{TIE}_{it} + \theta_1 \cdot \ln \mathrm{TFDICD}_{it} + \mathrm{province}_i + \mathrm{year}_t + \sigma 2_{it}. \tag{17}$$

In the above formula, $\ln\frac{\mathrm{TIE}_{i,t+1}}{\mathrm{TIE}_{it}}$ represents the natural logarithm of the ratio of the provincial administrative region i's technological innovation efficiency in year $t+1$ to the provincial administrative region i's technological innovation efficiency in year t. $\ln \mathrm{TIE}_{it}$ represents the natural logarithm of the technological innovation efficiency of provincial administrative region i in year t. β_1 and β_2 respectively represent the absolute β coefficient value and conditional β coefficient value of technological innovation efficiency. If $\beta_1 < 0$ is significant, it indicates that the technological innovation efficiency in this region has the absolute β convergence property. Even if there is no other external force, the technological innovation efficiency gap between the low-efficiency area and the high-efficiency area will gradually decrease over time. The convergence speed is $v_1 = -\frac{\ln(1+\beta_1)}{T}$, and T represents the time span. If $\beta_2 < 0$ is significant and numerically $< \beta_1$, it indicates that the technological innovation efficiency in this region has the conditional β convergence property, that is, with the increase of the two-way FDI coordinated development level, the technological innovation gap between the low-efficiency area and the high-efficiency area shows an accelerating narrowing trend and can converge at a faster speed. The convergence speed is $v_2 = -\frac{\ln(1+\beta_2)}{T}$. C_1 and C_2 represent the constant terms. $\sigma 1_{it}$ and $\sigma 2_{it}$ represent the random disturbance terms. The meanings of the remaining symbols are consistent with the benchmark regression model.

4 Empirical Analysis

4.1 Benchmark Regression Analysis

Table 5 reports the benchmark regression results. Among them, column (1) only adds the dependent variable (technological innovation efficiency, TIE) and the independent variable (two-way FDI coordinated development, TFDICD) to the model. It can be seen that the estimated coefficient of TFDICD is positive and significant at the level of 1% ($\beta_{\mathrm{TFDICD}} = 0.3702$, $P < 0.01$). Then a series of control variables are gradually added to the model in columns (2), (3) and (4), and province fixed effect and year fixed effect are also controlled. The results show that the estimated coefficient of TFDICD is still positive, and remains significant at the 1% level, indicating that two-way FDI coordinated development can indeed effectively increase technological innovation efficiency ($\beta_{\mathrm{TFDICD}} = 0.3591$, $P < 0.01$), which verifies hypothesis 1. Specifically, every 1% increase in the level of two-way FDI coordinated development can lead to an average increase of 0.3591% in technological innovation efficiency.

In terms of control variables, UR ($\beta_{\mathrm{UR}} = 0.7309$, $P < 0.01$), CW ($\beta_{\mathrm{CW}} = 0.4052$, $P < 0.01$) and PTC ($\beta_{\mathrm{PTC}} = 0.1173$, $P < 0.01$) can all generate a significant promoting effect on techno-

Table 5 Benchmark regression results

Variable	(1)	(2)	(3)	(4)
TFDICD	0.3702***	0.4037***	0.3922***	0.3591***
	(0.0480)	(0.0587)	(0.0522)	(0.0528)
ED	-	−0.3109***	−0.2967***	−0.0590
		(0.0299)	(0.0417)	(0.0638)
IS	-	−0.0065	−0.0206	0.0312
		(0.0139)	(0.0188)	(0.0232)
UR	-	0.2451*	0.1154	0.7309***
		(0.1371)	(0.2151)	(0.2470)
PS	-	0.4172***	0.0234	−0.3603**
		(0.0304)	(0.1351)	(0.1470)
CW	-	0.3756***	0.6148***	0.4052***
		(0.1259)	(0.1214)	(0.1404)
FD	-	−0.0106	−0.0166	−0.0025
		(0.0099)	(0.0106)	(0.0121)
PTC	-	0.0291**	0.0269	0.1173***
		(0.0125)	(0.0266)	(0.0286)
EEL	-	0.0302***	−0.0099	−0.0168
		(0.0113)	(0.0103)	(0.0115)
Constant	0.6650***	−0.3904**	3.0183***	3.6830***
	(0.0184)	(0.1554)	(0.9936)	(0.9493)
Province-fixed	No	No	Yes	Yes
Year-fixed	No	No	No	Yes
R^2	0.1491	0.6711	0.7736	0.8072
N	341	341	341	341

Note: *** represents $P < 0.01$, ** represents $P < 0.05$, and * represents $P < 0.1$. The numbers in brackets are standard errors.

logical innovation efficiency, and the promoting effects show that continuing to promote urbanization, stimulating society's consumption willingness, and strengthening public transportation investment and construction can effectively increase technological innovation efficiency [51–53], while PS ($\beta_{\mathrm{PS}} = -0.3603$, $P = 0.015$) will generate a significantly inhibitory effect, indicating that the "crowding effect" produced by the excessively large population size on technological innovation efficiency cannot be ignored [54]. As for ED ($\beta_{\mathrm{ED}} = -0.0590$, $P = 0.356$), IS ($\beta_{\mathrm{IS}} = 0.0312$, $P = 0.180$), FD ($\beta_{\mathrm{FD}} = -0.0025$, $P = 0.838$) and EEL ($\beta_{\mathrm{EEL}} = -0.0168$, $P = 0.145$), these control variables will not have a statistically significant impact on technological innovation efficiency.

4.2 Quantile Regression Analysis

Columns (1), (2), and (3) of Table 6 respectively report the regression results under the 25th, 50th, and 75th percentile conditions. The results show that no matter what quantile conditions, the estimated coefficient of TFDICD is always significantly positive ($\beta_{25\text{thpercentile}} = 0.3107$, $P = 0.015$; $\beta_{50\text{thpercentile}} = 0.3638$, $P < 0.01$; $\beta_{75\text{thpercentile}} = 0.4085$, $P < 0.01$), and with the increase of technical innovation efficiency, the promoting effect generated by two-way FDI coordinated development has also continued to increase (see Figure 5), which verifies Hypothesis 2.

Table 6 Quantile regression results

Variable	(1)	(2)	(3)
TFDICD	0.3107**	0.3638***	0.4085***
	(0.1277)	(0.1001)	(0.1435)
Control variables	Controlled	Controlled	Controlled
Constant	2.6838***	1.1550	2.5897
	(0.6040)	(1.6894)	(0.7810)
Province-fixed	Yes	Yes	Yes
Year-fixed	Yes	Yes	Yes
R^2	0.8369	0.7692	0.7488
N	341	341	341

Note: *** represents $P < 0.01$, ** represents $P < 0.05$. The numbers in brackets are standard errors.

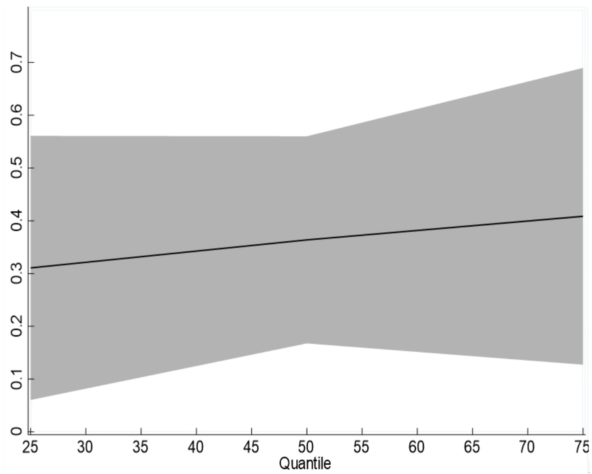

Figure 5 The quantile impact of two-way FDI coordinated development on technological innovation efficiency

Specifically, when technological innovation efficiency is at the relatively low level (25th percentile), every 1% increase in the value of two-way FDI coordinated development can increase the technological innovation efficiency by an average of 0.3107%. When technological innovation efficiency is at the medium level (50th percentile), every 1% increase in the value of two-way FDI coordinated development can increase the technological innovation efficiency by an average of 0.3638%. When technological innovation efficiency is at the relatively high level (75th percentile), every 1% increase in the value of two-way FDI coordinated development can increase the technological innovation efficiency by an average of 0.4085%.

4.3 Spatial Spillover Effect Analysis

Table 7 reports the spatial spillover effect test results. The results show that the estimated coefficients of the direct effect and spatial effect of TFDICD on TIE are not only positive, but also significant at the 1% level, indicating that two-way FDI coordinated development can generate a significant promoting effect on the technological innovation efficiency of one province itself and the neighboring provinces ($\beta_{\text{directeffect}} = 0.2176$, $P < 0.01$; $\beta_{\text{spatialeffect}} = 0.8248$, $P < 0.01$), which verifies Hypothesis 3.

Table 7 Results of spatial spillover effect test

Variable	Direct effect	Spatial effect
TFDICD	0.2176***	0.8248***
	(0.0463)	(0.2754)
Control variables	Controlled	
ρ	0.3035**	
	(0.1498)	
δ^2	0.0015***	
	(0.0001)	
Province-fixed	Yes	
Year-fixed	Yes	
R^2	0.7974	
N	341	

Note: *** represents $P < 0.01$, ** represents $P < 0.05$, and * represents $P < 0.1$. The numbers in brackets are standard errors.

In addition, it is worth noting that the spatial effect of two-way FDI coordinated development on the technological innovation efficiency of neighboring provinces is much greater than its direct effect on the technological innovation efficiency of one province itself, which is numerically about 3.79 times than the direct effect ($\beta_{\text{spatialeffect}}/\beta_{\text{directeffect}} = 0.8248/0.2176$). This shows that the increase of two-way FDI coordinated development can not only directly and effectively promote the increase of technological innovation efficiency of one province itself, but also can generate a stronger promoting effect on the technological innovation efficiency of the neighboring provinces.

Then, can two-way FDI coordinated development effectively narrow the technological innovation efficiency gap among regions, thereby accelerating the convergence of low-efficiency regions to high-efficiency regions, and ultimately promoting the efficient and balanced development of regional technological innovation activities? This question needs to be further verified through the β convergence test model.

4.4 β Convergence Test Analysis

Columns (1) and (2) of Table 8 respectively report the absolute β convergence test results and the conditional β convergence test results. The results show that the absolute β coefficient value and the conditional β coefficient value of TIE are not only significantly less than 0 at the 1% level, but also the conditional β coefficient value is less than the absolute β coefficient value ($\beta_{\text{absolute}} = -0.3179$, $P < 0.01$; $\beta_{\text{conditional}} = -0.3849$, $P < 0.01$), indicating that the technological innovation efficiency has both the absolute β convergence property and the conditional β convergence property.

Table 8 β convergence test results

Variable	(1)	(2)
β	−0.3179***	−0.3849***
	(0.0962)	(0.0893)
TFDICD	Uncontrolled	Controlled
Constant term	−0.0509	−0.1789***
	(0.0577)	(0.0697)
Convergence state	Convergent	Convergent
Convergence speed	3.83%	4.86%
Province-fixed	Yes	Yes
Year-fixed	Yes	Yes
R^2	0.2735	0.4310
N	341	341

Note: *** represents $P < 0.01$. The numbers in brackets are standard errors.

Specifically, without considering any other factors, the technological innovation efficiency gap among regions will spontaneously tend to be eliminated at a convergence rate of 3.83%. Furthermore, after introducing TFDICD into the model, the convergence speed of the technological innovation efficiency gap among regions increases from 3.83% to 4.86%, an increase of 26.89%. Regions with low efficiency in technological innovation activities are converging towards high efficiency regions at a faster rate. This shows that as an important convergence mechanism for the efficient and balanced development of regional technological innovation activities, two-way FDI coordinated development can not only directly and effectively increase the technological innovation efficiency of one province itself and its neighboring provinces, but also can significantly narrow the technological innovation efficiency gap among regions, accelerate the convergence of technological innovation efficiency among regions and ultimately promotes the efficient and balanced development of regional technological innovation activities, which verifies Hypothesis 4.

5 Discussion

In summary, this study not only qualitatively analyzes the possible positive interactive relationship between the technology spillover effect of IFDI and the reverse technology spillover effect of OFDI from a theoretical perspective, that is, the positive impact that two-way FDI coordinated development may have on regional technological innovation efficiency, but also quantitatively verifies from an empirical perspective that two-way FDI coordinated development can indeed effectively promote the efficient and balanced development of regional technological innovation activities. That is, in the process of mutual spillover between IFDI and OFDI, the coordinated development of IFDI and OFDI can effectively strengthen each other's technology spillover effect on regional technological innovation activities, thereby promoting the efficient and balanced development of regional technological innovation activities. This means that under the condition of limited technological innovation resources, it is important to reasonably allocate the scale of IFDI introduction and the scale of OFDI investment to ensure that two-way FDI coordinated development is an important policy measure to build a dual-cycle mutual promotion system of domestic and international technological innovation and strengthen the national unified technology innovation chain. In general, this study, by combining qualitative and quantitative methods, deeply analyzes and tests the impact of two-way FDI coordinated development on technological innovation efficiency from both theoretical and empirical perspectives. It has indeed enriched the existing theory and effectively made up for the lack of relevant research between two-way FDI coordinated development and technological innovation efficiency. However, it should be noted that this study also has some shortcomings. For example, in the context of the global digital age, digital technologies such as the Internet, big data and artificial intelligence have had a profound impact on a series of economic and social development activities, giving rise to and recreating many new models [55–57].

Among them, digital technology is in a state of deep integration with international investment activities and technological innovation activities. From the perspective of international investment, with the increase of the digital technology development, the impact of traditional factors such as labor and land on international investment entry and location selection can be significantly weakened [58], and the speed of integration and sharing of quasi-international investment online resources can be greatly increased, various transaction and research costs can be effectively reduced, and the investment environment can also be more open and transparent [59], digital technology has gradually become an important factor affecting international investment decisions. From the perspective of technological innovation, digital technology can break the limitations of time and space and establish an information sharing platform, so that technological innovation elements can flow freely and quickly in the digital space. While effectively reducing the knowledge and information asymmetry among technological innovation subjects, digital technology can greatly enhance the ability of each technological innovation subject to acquire and process knowledge and information, realize the efficient connection and reorganization of technological innovation elements, thereby generating a technological spillover effect and effectively increasing technological innovation efficiency [60–62]. So, will digital technology have a significant moderating effect on the relationship between two-way FDI coordinated development and technological innovation efficiency? If it occurs, will it be a positive moderating effect or a negative moderating effect? Answering these questions will help further explain the mechanism of the impact of two-way FDI coordinated development on technological innovation efficiency. Therefore, in future research, we will focus on how digital technology affects the relationship between two-way FDI coordinated development and technological innovation efficiency.

6 Conclusion and Policy Implications

Based on the panel data of 31 provincial administrative regions in China from 2011 to 2021, this study builds the fixed-effect panel SFA model and the coupled coordination model to measure the technological innovation efficiency and two-way FDI coordinated development level of each provincial administrative region in China during this period. On this basis, this study builds the fixed-effect panel least squares regression model, the fixed-effect panel quantile regression model, the Moran's index model, the fixed-effect spatial Durbin panel model and the fixed-effect panel β convergence test model to test whether two-way FDI coordinated development can promote the efficient and balanced development of regional technological innovation activities. The research conclusions are as follows.

First, two-way FDI coordinated development can significantly promote the increase of technical innovation efficiency, and as the level of technical innovation efficiency increases, the promoting effect of two-way FDI coordinated development on it is also increasing.

Second, two-way FDI coordinated development can not only significantly promote the increase of technological innovation efficiency of one province itself, but also have a significantly stronger positive spatial spillover effect on the technological innovation efficiency of neighboring provinces, promoting the technological innovation efficiency of neighboring provinces to achieve a higher level, thereby promoting the efficient and balanced development of regional technological innovation activities.

The above research conclusions have obvious policy implications. On the one hand, government departments should dynamically plan the scale of IFDI and OFDI to ensure two-way FDI coordinated development, so as to give full play to its compound technology spillover effect, produce the effect of "$1 + 1 > 2$", and effectively increase technological innovation efficiency. On the other hand, government departments should also actively use policy guidance to strengthen regional technological innovation cooperation and promote the establishment of regional technological innovation alliances, so as to make full use of the spatial spillover effect of two-way FDI coordinated development and effectively narrow the technological innovation efficiency gap among regions. In addition, government departments should also create an international, market-oriented, legal and convenient business environment by continuously and deeply expanding institutional opening, strengthening the construction of technology trading markets, flexibly adjusting the intensity of intellectual property protection and continuously improving digital infrastructure construction, so as to effectively reduce the barriers to the cross-border flow of technological innovation elements and provide institutional guarantees for two-way FDI coordinated development.

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