Research on Industrial Upgrading and Technology Spillovers by Mathematical Model and Calculation Analysis

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Abstract. In the context of global economic integration, the economic links between countries are getting closer and closer, and international direct investment is an important link to connect the economies of various countries. In recent years, with the rapid development of China's economy and the further improvement of the level of opening to the outside world, China's IFDI (foreign direct investment) and OFDI (outbound direct investment) have developed rapidly. At the same time, the contradiction of China's industrial structure has gradually emerged, and it is urgent to promote economic intensive development and industrial structure upgrade. Based on this research background, the thesis puts IFDI, OFDI and China's industrial structure upgrade into the same theoretical analysis framework, and explores the mechanism of two-way FDI to promote industrial structure upgrade from the perspective of technology spillover; Panel data of several provinces (municipalities), through the construction of simultaneous equation models, empirical analysis of the impact of two-way FDI technology spillovers on the optimization and upgrading of China's industrial structure.

1. Introduction

Since reform and opening, attracting foreign investment on a large scale with preferential policies has been one of China's important strategies for opening, and foreign direct investment in China has developed rapidly. At present, China has surpassed the United States and become the first country to attract IFDI (foreign direct investment). Since China joined the WTO (World Trade Organization) in 2001, China's opening-up strategy has gradually shifted from "introducing" to "introducing" and "going out" in the direction of coordinated development. With this opportunity, China's OFDI (foreign direct investment) has also developed rapidly. Based on this, it is urgent to promote economic intensive development and industrial structure upgrade. Under today's open economy, production factors and information resources have "leaked out" of a country. The global flow and allocation of factors that restrict the upgrading of a country's industrial structure is no longer limited to domestic related factors, but should also include Related factors such as international economic activities. Therefore, IFDI and OFDI, as important ways for developing countries to participate in the economic globalization competition, have an important impact on a country's industrial structure upgrade and sustained economic development.
This article intends to review and sort out the classic theories of international direct investment and industrial structure upgrading and related research, and incorporate IFDI, OFDI and industrial structure upgrading into the same analytical framework to solve the following problems: (1) Based on the perspective of technology spillover, How IFDI and OFDI work together to promote the upgrading of China's industrial structure; (2) The specific impact of China's two-way FDI technology spillover on China's industrial structure upgrade, and the specific impact of each region's two-way FDI technology spillover on the regional industry structure upgrade; Theoretical analysis and empirical analysis put forward suggestions to promote the optimization and upgrading of China's industrial structure. By systematically analyzing and answering the above questions, it will not only help enrich the theoretical system of FDI and industrial structure upgrade, but also provide a theoretical basis for the government to formulate policies to promote industrial structure upgrade [1].

2. Related theoretical basis

2.1. Industrial structure upgrade theory

The upgrading of industrial structure is based on the general law of industrial structure evolution. While satisfying rationalization, through continuous technological innovations, the goal of evolving from a lower level to a higher level is achieved. From the perspective of structural development direction, its characteristics are as follows: (1) With the development of the economy, the proportions of GDP in the primary, secondary, and tertiary industries are decreasing, increasing, and increasing; The characteristics of the factor-intensive industries' share of GDP are different. Among them, "the industries with relatively intensive labor factors show a downward trend; at the same time, the industries with relatively intensive capital technology factors show the opposite trend." (3) In the manufacturing industry, the proportion of industries that manufacture primary products gradually decreases, and the proportion of industries that manufacture intermediate products and final products gradually increases. As shown in Figure 1, it is the theory of industrial structure upgrade.

![Figure 1. Theory of industrial structure upgrade.](image-url)
While the industrial structure is transitioning to a high level, industries that dominate in the national economy will often use the existing industrial structure as a springboard to jump out of the original low level, and then use high-tech and high-tech industries as carriers to achieve the advanced development of the high-level structure, and then take the point to face, give full play to the radiating role and driving effect of high-tech content, high-tech efficiency industries, and finally realize the leap-forward development of the remaining related industries and the economy as a whole. Since the evolution of industrial structure is affected by many factors, exploring the basic principles of industrial structure optimization and upgrading is conducive to laying a theoretical foundation for the subsequent research of the article.

2.2. Foreign Direct Investment Theory
In the 1950s, with the end of the Second World War and the rise of the third industrial revolution, developed countries led by the United States began transnational operations on a global scale. In order to comply with the development trend of the times, Western scholars then put forward a series of theories on international direct investment for developed countries. After more than 20 years of development, the FDI theory with developed countries as the research object has been continuously adjusted, corresponding, and integrated with the real economy, and gradually formed a more systematic, mature, and complete theoretical collection. However, the development of the real economy will continue to challenge existing investment theories. With sustained and strong growth, some developing countries’ economic efforts are developing well, and their performance in international direct investment is more active. The economy is also becoming more frequent. However, most of the existing relevant international investment theories can only better explain and guide the investment behavior of developed countries. For the developing countries that OFDI started relatively late but the growth rate is relatively fast, the existing theories are not yet with a reasonable explanation, its practical guidance is not good. Therefore, the development of international direct investment-related theories has once again conformed to the background of the times, and the relevant investment theories, led by small-scale technology theories and aimed at developing countries' transnational business activities, have emerged.

3. Bidirectional FDI technology spillover calculation and status analysis

3.1. Bidirectional FDI technology spillover calculation
In this paper, the international R & D capital stocks obtained by China through IFDI and OFDI are calculated by referring to the measurement method of international knowledge spillover by Litchtenberg and Potterie, respectively, as indicators for measuring China's IFDI technology spillover and OFDI reverse technology spillover. The calculation formula is as follows.

$$K_{FI} = \sum_{i=1}^{n} \frac{FDI_{i}}{GDP_{i}} \times R_{i}$$ (1)

$$R_{i} = (1-\delta)R_{i-1} + RD_{i}$$ (2)

Where $K_{FI}$ is the foreign R & D capital stock obtained by China through FDI in $t$ year, $FDI_{i}$ is the direct investment of $i$ country in China in $t$ year or the foreign direct investment flow of China in $t$ country in $t$ year, $GDP_{i}$ is in $t$ year The GDP of country $i$; $R_{i}$ is the R & D capital stock of country $i$ as of year $t$. The calculation method is based on Goldsmith's perpetual inventory method, where $RD_{i}$ represents the total input of $i$ country R & D in $t$ year, and $\delta$ is the depreciation rate and is 5% [2].

3.2. Analysis of current situation of two-way FDI technology spillover
According to the formula of IFDI and OFDI technology overflow in 3.1, the calculated data is shown in Table 1. It can be found from the table that, during 2003-2014, although except for individual years,
China's foreign R & D capital stocks obtained through IFDI decreased, but overall, it showed an increasing trend from 2003 to US $ 48,856,460,830 It increased to 982,991736 million US dollars in 2014, with an average annual growth rate of 6.54%. At the same time, China’s acquisition of foreign R & D capital stock through OFDI maintained a rapid growth trend, especially during the period 2003-2008, which increased from US $ 85,678,385 to US $ 26,930,83,499, with an average annual growth rate of 99.29%, but it was affected by the 2008 international the spread of the financial crisis slowed this growth rate significantly, with an average annual growth rate of only 19.2%, which is far less than the growth rate before 2008. (See Table 1 for details)

Table 1. IFDI and OFDI technology spillovers from 2003 to 2014.

| Years | IFDI technology spillover | Growth rate | OFDI technology spillover | Growth rate |
|-------|--------------------------|-------------|--------------------------|-------------|
| 2003  | 488564.6                 | -           | 8567.139                 | -           |
| 2004  | 522986.7                 | 7.05%       | 20089.37                 | 134.49%     |
| 2005  | 546551.6                 | 4.51%       | 30207.29                 | 50.36%      |
| 2006  | 494365.9                 | -9.55%      | 51830.72                 | 71.58%      |
| 2007  | 476426.6                 | -3.63%      | 118945.8                 | 129.49%     |
| 2008  | 590780.8                 | 24.00%      | 269308.3                 | 126.41%     |
| 2009  | 665674.3                 | 12.68%      | 329240.6                 | 22.25%      |
| 2010  | 769600.6                 | 15.61%      | 382468.6                 | 16.17%      |
| 2011  | 890889.3                 | 15.76%      | 453836.2                 | 18.66%      |
| 2012  | 947080.6                 | 6.31%       | 569927.1                 | 25.58%      |
| 2013  | 1096534                  | 15.78%      | 636741.7                 | 11.72%      |
| 2014  | 980299.2                 | -10.60%     | 792620                   | 24.48%      |

4. Analysis of the evolution of China's industrial structure

According to the laws of economic development and operation, the evolution of the industrial structure shows a trend that the ratio of the primary industry to the gross national product continues to decrease, while the proportion of the secondary and tertiary industries continues to increase. Since the reform and opening, with the economic development and the continuous improvement of the level of science and technology, China's three industries have been rapidly developed, and the industrial structure has been continuously adjusted. Its evolutionary path is basically consistent with the general law of industrial structure changes. In order to grasp the laws of the evolution of China's industrial structure in a more in-depth manner, this section divides the period from reform and opening (1978-2015) into four stages, and explains the development characteristics of China's industrial structure at each stage [3].

4.1. The stage of rapid development of the primary industry (1978-1984)

During this period, the specific characteristics of China's industrial structure are as follows: the value added of the primary industry's industrial added value to GDP continues to increase, from 27.7% in 1978 to 31.5% in 1984, an increase of nearly 4 percentage points; the secondary industry The value added of the industry ’s industrial added value to GDP showed a downward trend, from 47.7% in 1978 to 42.9% in 1984, a decrease of 4.8 percentage points; the value added of the tertiary industry ’s industrial added value to GDP remained basically unchanged, and Fluctuate around 23% (see Figure 2 for details).
4.2. The rapid development of the tertiary industry (1985-2001)
During the period from 1985 to 2001, China's industrial structure was characterized by the fact that the proportion of added value of the secondary industry remained basically unchanged. The tertiary industry absorbed the share of the primary industry and showed a rapid development trend. The specific performance is that the value added of the tertiary industry to the GDP continues to increase, from 29.4% in 1985 to 41.2% in 2001, an increase of nearly 12 percentage points; the value added of the primary industry accounts for GDP The proportion has continued to decline, from 27.9% in 1985 to 14% in 2001, a decrease of 11.9 percentage points; the added value of the secondary industry in GDP has remained basically unchanged, fluctuating around 45% (see Figure 3 for details). From the perspective of growth rate, the statistical data analysis results of the "China Statistical Yearbook" over the years show that from 1985 to 2001, the average annual growth rate of the added value of the tertiary industry was 18.18%, which was higher than 11.22% in the primary industry, and 16.17%.

4.3. Continuous development of the secondary industry (2002-2008)
In 2001, China's accession to the World Trade Organization not only deepened China's level of opening to the outside world, but also meant that China's opening to the outside world entered a new course. Based on this, China has attracted large-scale foreign investors to invest in China, and the distribution of FDI industries is mainly in the secondary industry. From 2002 to 2008, China's actual use of foreign direct investment increased from 527.43 million US dollars in 2002 to 923.95 million US dollars in 2008, with an average annual growth rate of 9.7%; The proportion of the total amount ranges from 57.33% to 74.82%, which is much higher than the actual utilization of foreign direct investment in the primary and tertiary industries. The distribution characteristics of this industry investment promote the rapid growth of China's secondary industry [4]. Specifically, on the one hand, from the perspective of growth
rate, during this period (2002-2008), the average annual growth rate of the value added of the secondary industry was 18.52% Is higher than 10.09% in the first phase (1978-1984) and 16.17% in the second phase (1985-2001); and higher than 12.46% in the primary industry and 17.71% in the tertiary industry during the same period. On the other hand, from the perspective of the proportion of industrial added value, the secondary industry has absorbed the share of the primary industry, and the proportion of the tertiary industry has remained basically unchanged. Specifically, the value added of the secondary industry to GDP increased from 44.5% in 2002 to 46.9% in 2008, an increase of 2.4 percentage points; the value added of the industry in the primary industry accounted for GDP from 2002 13.3% fell to 10.3% in 2008, a decrease of nearly 3 percentage points; the value added of the tertiary industry accounted for about 42% of GDP, with little fluctuation (see Figure 4 for details).

4.4. Continuous optimization of industrial structure (2009-2015)

Affected by the international macroeconomic environment such as the 2008 global financial crisis and the 2012 European debt crisis, China's economic development is in a period of transition from high-speed growth to medium-to-high-speed growth, and a more stable transition period. The economic structure is constantly being adjusted and upgraded. Therefore, compared with the third stage (2002-2008), during the period of 2009-2014, the growth rate of China's three industries has decreased, that is, the average annual growth rate of the added value of the three industries is 11.30% and 11.62%, respectively, 14.76%, lower than the third stage of 12.46%, 18.52%, 17.71%. At the same time, the industrial structure is moving towards the high value-added tertiary industry, and the industrial structure is constantly optimizing. The main performance is as follows: the value added of the tertiary industry to GDP increased from 44.3% in 2009 to 2015 50.2%, an increase of nearly 6 percentage points; the value added of the secondary industry’s industrial added value in GDP decreased from 45.9% in 2009 to 40.9% in 2014, a decrease of 5 percentage points; as the basis of the national economy, the primary industry the proportion of industrial added value in GDP has not changed much, fluctuating around 9.4%.

Figure 4. The proportion of the value added of the three industries to GDP in 2002-2008.

Figure 5. The proportion of added value of the three industries to GDP in 2009-2015.
5. Analysis of the mechanism of two-way FDI technology spillovers affecting industrial structure upgrade

5.1. Mechanism analysis of two-way FDI technology spillover effect

IFDI promotes the formation of a domestic company's competitive advantage by encouraging local companies to acquire advanced technology and management experience; and the formation of a competitive advantage will help the OFDI of local multinational companies, and the overseas expansion of local companies provides strategies for the economic development of the home country Sexual resources and technical support, which can more attract the inflow of IFDI. The two complement each other is an important way to obtain international R & D capital spillover, and its specific mechanism of action is mainly as follows.

5.1.1. Human capital flow effect. The multinational operations of foreign-funded enterprises generally prioritize local employees in terms of talent selection and training, and focus on strengthening the training of employees at all levels, from top managers to grassroots operations and technical staff, to provide diversified training to enhance the company the quality of human resources. On the one hand, local employees can acquire rich management and technical knowledge through vocational skills training and long-term work experience accumulation in multinational companies. Once they flow to local companies or operate independently, they will produce a diffusion of technology and knowledge. On the other hand, due to the existence of a broad communication network platform among local talents, this informal platform can be used to acquire tacit knowledge that is difficult to overflow through formal channels, thereby enhancing the competitiveness of local enterprises.

5.1.2. Demonstration-imitation effect. The home country's enterprises can make close contact with advanced technologies or products of developed countries through the development of foreign direct investment for developed countries, and can use the host country's R & D resources to follow their "footsteps" to imitate and innovate at the product development stage without the need for Introduce, absorb and imitate the products of developed countries when they are in the mature stage. This is conducive to keeping up with the frontiers of science and technology in home country enterprises, keeping abreast of industry development trends, promoting home country enterprises to conduct synchronous research and development with host countries, shortening the technology acquisition cycle, and seizing market opportunities [5].

5.1.3. Competition effect. Kokko pointed out that competition is an effective way to cause technology spillover, and the competitive effect of two-way FDI is mainly reflected in the following two aspects: (1) The entry of foreign companies will inevitably break the original local market structure, relying on its advanced science and technology, management Operating experience seriously threatens the market competitiveness of the host country's enterprises and intensifies the fierce competition in the host country's market. Therefore, in order to consolidate the market position, local enterprises will inevitably increase investment in research and development and cultivate high-tech talents, to continuously improve their technological level and innovation ability. At the same time, in order to enhance the competitive advantage and occupy the market of the host country, the foreign businessmen will also strengthen the improvement of product process and technology innovation to improve the competitive advantage of the product. The game between the local company and the multinational company has been cyclically repeated, not only has the technical level of both sides been effectively improved, but also made the technical level of the entire industry have improved significantly. (2) Compared with operating in the domestic market, transnational operations are more uncertain and riskier, and competition is fiercer. Therefore, in order to quickly integrate into the host country with fierce market competition, the parent company needs to continuously improve product production technology and strengthen Independent innovation capacity building to improve the competitive advantage of enterprises, and thus
continuously promote the progress of their own technological development level. As shown in Figure 6, it is an analysis diagram of the overflow mechanism of two-way FDI technology.

**Figure 6.** Analysis of the mechanism of two-way FDI technology overflow.

5.2. Effect mechanism of two-way FDI technology spillovers on industrial structure upgrade

5.2.1. Changes in demand structure. The source of the formation and development of industry comes from social demand, so among the many influencing factors of industrial structure, demand structure is the most fundamental influencing factor of industrial structure, but changes in demand structure are affected by technology.

Restrictions on development level. Mainly manifested in the following three aspects: (1) On the one hand, technological progress has greatly reduced the production cost of products, and the price of products has been reduced; on the other hand, the improvement of scientific and technological level has promoted the products in terms of quality and performance. Effective improvement and improvement; therefore, this will promote a significant increase in product demand and promote the rapid development of the corresponding industry. (2) Technological advancement provides scientific and technological support for the development of new products, which is conducive to promoting the transformation and upgrading of consumer products, and deriving new products, thereby driving changes in the demand structure. (3) Technological advances have reduced the consumption intensity of production resources and increased their utilization rate, resulting in changes in the allocation ratio of production factors of products themselves, thereby driving changes in the production demand structure [6].

5.2.2. Changes in supply structure. Natural resources, labor, and technological level are the basic elements of the supply structure. The supply structure ratio and allocation efficiency of the three are directly related to the improvement of labor productivity and the reduction of production costs, and are the direct factors that affect the change of industrial structure. As an important component of the supply structure, the level of technology development is the fundamental reason for restricting the supply structure, which is mainly manifested in the following two aspects: (1) Science and technology is an effective way to improve the efficiency of the allocation of production factors, but the level of
technology among industries. There are significant differences, so the benefits of factor allocation among industries are also significantly different. According to the principle of maximizing the benefits of factor allocation, resources will flow from sectors with low factor allocation efficiency to high-efficiency sectors, making the industrial structure focus on high-tech and high-productivity industries, and ultimately promoting the optimization and upgrading of the industrial structure. (2) The continuous advancement of technology has made the acquisition of production factors more dependent on scientific and technological principles, which has led to the transformation of the factor supply structure from the original resource and labor-based to technology-based, and also led to the corresponding industry from resource and labor-intensive Industry is upgraded to a technology-intensive industry, (see Figure 7 for details)

![Figure 7. The mechanism of the effect of two-way FDI technology spillovers on the upgrading of industrial structure.](image)

6. An empirical analysis of the impact of two-way FDI technology spillovers on the upgrading of China's industrial structure

6.1. Construction of the model

Theoretical analysis of two-way FDI technology spillover and industrial structure upgrade finds that two-way FDI is an important factor that affects the upgrading of China's industrial structure [7]. On the one hand, two-way FDI can optimize the industrial structure of the home country by directly adjusting its investment structure; on the other hand, two-way FDI can also use technology as a transmission factor to promote the optimization and upgrading of the industrial structure. However, the theoretical assumption of the joint role of IFDI and OFDI, using technology as a transmission factor to promote the optimization and upgrading of China's industrial structure, whether it is applicable to the current situation of China's two-way FDI and industrial structure upgrade at this stage, remains to be empirically explored. Therefore, in order to explore the impact of the technology spillover effect of two-way FDI on the upgrading of China's industrial structure, the article uses the relevant data of 30 provinces or municipalities in China (except Tibet) from 2004 to 2014 as samples to establish a recursive model, which is a simultaneous equation.

Model 1 was established to discuss the relationship between two-way FDI technology spillover and technological progress. Through the research of the previous literature, we can find that in addition to the two-way FDI technology spillover, R & D funding and R & D personnel investment are important factors that affect industrial technological progress. Based on this, model 1 uses R & D funding and R & D personnel investment as control variables. The two-way FDI technology spillover and its interaction
are used as explanatory variables, and the technical level is selected as the explained variable. The specific form is shown in Equation 3.

\[ TFP_i = \beta_0 + \beta_1 T_K + \beta_2 \ln T_L + \beta_3 \ln T_O F D I_i + \beta_4 \ln T I F D I_i + \beta_5 \ln T O F D I_i \ast \ln T I F D I_i + \varepsilon_i \]  

(3)

6.2. Model calculation

6.2.1. Calculation of industrial structure upgrade. The paper estimates the level of industrial structure upgrading (SH) of 30 provinces or municipalities in China from 2004 to 2014 as an indicator to measure the upgrading of China's industrial structure in this paper. Where \( SH_i \) is the level of the industrial structure of province \( i \) in year \( t \); \( P_{ijt} \) is the output value of industry \( j \) in province \( i \); \( GDP_{it} \) is the gross output value of province \( i \) in year \( t \); \( L_{ijt} \) is the total number of employees in industry \( j \) in province \( i \), and \( LP_j \) is \( j \) The labor productivity of the industry after industrialization.

\[ SH_i = \sum_{j=1}^{n} \frac{P_{ijt}}{GDP_{it}} \ast \left( \frac{P_{ijt}}{L_{ijt}} / LP_j \right) \]  

(4)

6.2.2. IFDI and OFDI technology spillover calculation. About IFDI technology spillover (TIFDI) and OFDI reverse technology spillover (TOFDI) calculations. This paper calculates the international R & D capital stocks obtained by IFDI and OFDI technology spillovers of various provinces or municipalities by referring to the measurement method of international knowledge spillover by Litchtenberg and Potterie (2001), as indicators for measuring IFDI technology spillovers and OFDI reverse technology spillovers of various provinces or municipalities. To calculate the international R & D capital stock obtained by China's OFDI reverse technology spillover, the calculation formula is shown in Equation 5.

\[ KF_i = \sum_{i=t}^{22} \frac{OFD_{it}}{GDP_i} \ast R_i \]  

(5)

To calculate the foreign R & D capital stocks obtained by IFDI / OFDI reverse technology spillovers in municipalities directly under the Central Government, the calculation formulas are shown in Equation 6 and Equation 7.

\[ TOFD_{it} = \frac{OFD_{it}}{OFD_{it}} \ast KF_i \]  

(6)

\[ TIFD_{it} = \frac{IFD_{it}}{IFD_{it}} \ast KIF_i \]  

(7)

6.3. Results inspection

In order to avoid the deviation caused by the single test and improve the credibility of the test results, this paper uses LLC, IPS test and Fisher test to conduct a stationarity test on the control variables, explanatory variables and explained variables, where the LLC test assumes that each cross-section sequence exists the same unit root; both the IPS test and the Fisher test assume that each section sequence has a different unit root. The test results show that the original sequence of TFP, LNTK, LNTL, LNTIFDI, LNTOFDI, LNTIFDI * LNTOFDI is single integer, so the variables are all stable in the original sequence. The specific analysis results are shown in Table 2 [8].
It can be seen that the R & D capital investment in the three regions of East, Central and West is significantly positive at the level of 1%, and the regression coefficients are 7.338502, 3.02168 and 5.678150, respectively, indicating that the continuous increase of R & D capital investment in the three regions is conducive to promoting regional technology. The level of progress, but the degree of its impact shows regional differences. The eastern region's R & D capital investment has a better role in promoting technological progress than the central and western regions. The main reason is that technological progress requires more than large-scale R & D funds, it also needs to invest a corresponding number of R & D personnel to cooperate with it, but compared with the eastern region, the high-quality talents in the central and western regions are particularly scarce, resulting in the same capital investment cannot produce the same economic benefits.

7. Conclusion
When discussing the mechanism of the impact of two-way FDI technology spillovers on the upgrading of industrial structure, the article fails to analyze how the two-way FDI under different investment motivations can upgrade the industrial structure through technology spillovers from the perspective of investment motivation, so follow-up research needs to be strengthened. Since the World Bank database has not published the R & D capital stocks of the countries in the past two years, the sample time period for the empirical analysis of the article can only be selected from 2004 to 2014. The lack of data for the last two years makes the empirical analysis of the article insufficient. The impact of FDI technology spillovers on the upgrading of industrial structure, follow-up research can be urgently discussed from this aspect.

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