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IMPACT OF FDI ON INDUSTRIAL STRUCTURE UPGRADING UNDER GREEN TECHNOLOGY INNOVATION IN JIANGSU, CHINA

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Highlights

- Detailed analysis of FDI and industrial structure in Jiangsu.
- Application of dynamic panel model and threshold model.
- There is a U-shaped relationship between FDI and industrial structure advancement.
- Technological innovation in green technology has a positive threshold moderating effect.

Abstract. Industrial structure upgrading plays an important role in improving economic development efficiency. Taking Jiangsu as the study subject, the paper selects panel data from 2005 to 2018 and performs dynamic panel models and threshold models to analyze the influence mechanism of foreign direct investment (FDI) and green technology innovation on industrial structure upgrading (including rationalization and advancement). The results show that FDI acts negatively on industrial structure upgrading, exhibiting U-shaped relationship with advancement, in contrast, green technology innovation shows a positive contribution to upgrading. In addition, rationalization is limited by fixed assets growing but increases with rising education levels. An increase in fixed assets and education both have a positive effect on advancement. Further, FDI plays a facilitating role in advancement considering the positive moderating effect of green technology innovation. Therefore, the study provides a theoretical reference for the development path of foreign investment and industrial structure upgrade breakthrough in Jiangsu.

Keywords: FDI, green technology innovation, industrial structure upgrading, dynamic panel models, panel threshold model.

Introduction

Against the backdrop of deepening globalization, FDI is occupying an increasingly important position in the economic development of various countries since it works on the flow of intangible resources such as capital, technology, marketing, and management (Chanegriha et al., 2020). Especially, the process of industrial restructuring, optimization and upgrading urgently needs to be accelerated in the new stage of China for seeking high-quality development. FDI not only brings financial flows to regional development but also drives the industrial structure optimization and upgrading within the region through technology transfer effects (He, 2007). Generally, technology innovation, the main driver of economic development and breaking the resource constraint, has brought about innovation and diffusion of green technology, promoting green industries from the production side, thereby eliciting structural changes in the industry (Du et al., 2019). According to the Ministry of Commerce's China Foreign Investment Statistics Bulletin 2020, the actual use of foreign investment in Jiangsu was US$26.12 billion in 2020, accounting for 18.9% of the country's total, clearly positioning it at the forefront of attracting investment in China. Although Jiangsu, as a region with relatively advanced economic development, investing substantially in environmental pollution control, has achieved a lower increase in regional emissions of various pollutants than the national average, the trend of total emissions is on the rise and pollution problems remain owing to crude economic growth patterns that have not been fundamentally transformed, which have also posed an important obstacle in the process of upgrading Jiangsu's industrial structure (Hu & Zhang, 2021). Facing the current new development

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pattern, they are driving forces for the industrial structure upgrading in Jiangsu that adhering to a green and sustainable development path and continuously optimising foreign investment. It is clear that technology innovation has brought unavoidable externalities while promoting industrial structure upgrading is imperative. Meanwhile, the introduction of FDI has effects on industrial structure (Tang et al., 2020). Then it is indispensable to analyze and examine the relationship between FDI, green technology innovation, and industrial structure optimization and upgrading under the same framework, how to highlight the role of FDI and green technology innovation on industrial structure optimization and how to further vigorously develop high-end industries to promote the green upgrading of industrial structure and then form a mature high-end modern industrial system. These are theoretical and practical guidelines for realizing a multi-win situation of FDI introduction, environmental protection, technology innovation and industrial structure upgrading.

The role of FDI on the industrial structure has long been discussed and has drawn substantial attention from both academics and policymakers. The following two views are generally held. First, FDI inflows are beneficial to the upgrading of industrial structure in host countries. It is generally believed that the indirect promotion effects embody that FDI mainly promotes the industrial restructuring of the host country through the path of increasing capital supply and technology spillover (Chen et al., 2011; Driffield & Love, 2007). And most scholars believe that FDI has a significant positive contribution to industrial structure rationalization and upgrading (Amighini & Sanfilippo, 2014; Zhang, 2016), using models such as two-way stationary models, systematic generalized method of moments (GMM) models, and vector autoregressive models (Nie & Lu, 2012; Yang, 2018; Yang et al., 2019). On this basis, scholars propose that the path of FDI's role on industrial structure includes improving employment structure, in other words, FDI expands production capacity and optimizes industrial structure via expanding employment (Luan, 2018). In the same vein, scholars construct an FDI-induced endogenous technological progress model, arguing that FDI-induced technological progress fosters industrial structure upgrading (Xie et al., 2018). Dividing the industrial structure change into rationalization and advancement, where the former mainly emphasizes the degree of coordination of industries (including the coordination of production scale between industries, the coordination of output value structure, the coordination of capital structure, etc.), and the latter stresses the degree of upgrading of industries (the performance of high value-added, high-tech industries and the formation of industrial chains). Ye et al. (2020) empirically conclude that the FDI-promoting effect on rationalization, in contrast to the effect on advancement is statistically significant and negative, indicating the limited FDI-driving effect on the tertiary industry in China. Second, FDI hardly pushes the optimization of industrial structure in the host country or even brings negative effects. The negative impact mainly hurts companies in the same position of the industry chain, followed by hindering the entire industry. The FDI entry occupies the human resources and market share of domestic enterprises dominating similar manufacturing types, causing a decline in their market competitiveness, which impairs whole industrial structure upgrading (Zhou et al., 2002; Wu, 2016). Tian et al. (2016) argues that FDI, relying on the advantages of the industrial chain, obtains the core technological talents of host country enterprises, and local enterprises with domestic markets have little incentive to innovate proactively, triggering the hampering effect of FDI. And Zheng et al. (2018) asserts that FDI inflows have negative effects via widening the income gap. In addition, some scholars find that there is no long-term stable relationship between FDI and industrial structure upgrading, and that there may be non-linear (inverted U-shaped), with the influence of threshold variables such as environmental regulations and technological inputs (Yin & Zhang, 2016). Specifically, a non-parametric panel model is used to find an inverted U-shaped relationship between FDI and industrial restructuring in China and shows a significant marketization threshold effect (Jia & Han, 2018; Wang, 2014).

Increasing environmental concerns have prompted scholars to differentiate technological innovation from the perspective of environmental effects and to study the production competitiveness of green technologies (Jin, 2021). Braun and Wield (1994), who believe that green technologies can simultaneously reduce emissions and increase energy efficiency, resulting in environmental production, delivered the initial concept of green technology. Derived from the concept of green technology, green technology innovation refers to the introduction of new technologies, techniques and products to resolve environmental pressures caused by the enterprises' production activities, or to achieve specific ecologically sustainable development goals, aiming to diminish the negative impact on the environment (Qi et al., 2018). The typical green technology innovations are pollution control and prevention technologies, which are key elements in achieving a win-win situation for both economic growth and environmental protection (Hai & Li, 2021). However, few studies investigate the relationship between green technology innovation and industrial structure upgrading. Given that green technology innovation is a special form of technology innovation that considers environmental factors, the relevant literature featuring the relationship between technology innovation and industrial structure also provides a useful reference. Scholars generally believe that technology innovation, a driving force of industrial structure upgrading, improves the absorptive capacity and production efficiency of enterprises to promote industrial agglomeration, which in turn motivates industrial restructuring and upgrading (Greunz, 2004; Chen & Zhou, 2017), in other words, there is a causal relationship between them (Han et al., 2020). To identify this causality, for example, a study using grey correlation analysis is conducted to point out that technology innovation driven by research and development (R&D) investment has an optimization effect on industrial structure (Wu & Liu, 2021). Further, spatial econometric methods are combined to find the existence of long-term spatial spillover effects and emphasized that economic agglomeration has the function of amplifying the spatial effect of innovation on industrial structure (Lin & Kong, 2016; Li & Dong, 2018). Another model, the LSTAR model, is applied to find that the optimal adjustment of technology innovation on industrial structure in China is not a linear promotion relationship, but shapes in an inverted U-shaped with a certain lag (Zhang & Liao, 2019). The explanation is that technology penetration and knowledge-based factor penetration. However, as argued by some scholars, the relationship identification is not singularly promotional, even mutually reinforcing (Xu et al., 2020; Zameer et al., 2020). Green technology innovation is increasingly important owing to the country's urgent need for industrial transformation and the importance attached to green development (Wang et al., 2021). The study by Liu and Wang (2021) states a significant short-term positive effect of green science and technology innovation on industrial structure upgrading, indicating that only part of the innovation results is applied to green production practices. Thus, most literature regarding the relationship between FDI and industrial structure upgrading focuses on the linear relationship, with less discussion on the possible non-linear relationship. Also, less literature has studied green technology innovation as an intermediate variable affecting industrial structure upgrading, and the measurement of the degree of green technology innovation is not uniform.

In summary, the paper has three major margin contributions, first, we deepen and verify the research on the controversial topic that is whether FDI has a positive impact on industrial structure and whether it is worth taking additional measures to introduce FDI continually for Jiangsu under the vigorous implementation of green technology innovations. Second, this paper focuses on the relationship between green technology innovation and industrial structure upgrading, compared with previous literature related to technology innovation. We also consider whether the green features of technology innovation have a threshold moderating effect; that is, how the FDI-structure upgrading relationship changes in response to green technology innovation. Third, the paper provides a detailed analysis of the FDI situation, industrial structure trend and state of green technology innovation in Jiangsu to inspect the intrinsic development. Therefore, based on the panel data of 13 cities in Jiangsu from 2005 to 2018, we establishes a dynamic panel GMM model to examine the specific effects of FDI and green technology innovation on industrial structure and explore whether there are threshold characteristics, so as to make relevant suggestions on industrial structure upgrading, the introduction of foreign investment, and green technology innovation in Jiangsu.

1. Theoretical analysis and research hypothesis

1.1. FDI flows and industrial structure upgrading

Industrial structure optimization includes industrial structure rationalization and advancement, with the latter being the basis for rationalization. The inflowing FDI, as a crucial external source of knowledge and technology for technological upgrading in the host country, brings newly created knowledge and processing management models (Athreye & Cantwell, 2007). The paths of FDI influencing industrial structure are capital input and technology diffusion. Under the capital input path, foreign capital is brought into the host country through investment or mergers and acquisitions (M&A), either directly or indirectly into production. The growth volume of capital in the production chain alleviates the difficulties of insufficient capital in the stagnant development industry, accelerates capital formation, and improves the quality of capital. Correspondingly, the allocation of capital in the market is optimized, which allocates resources more reasonable among the three industries and improves the efficiency of resource usage to make resources fully utilized, namely, this accomplishes the industrial structure rationalization (Wang et al., 2016). Under the technology diffusion path, FDI brings in capital along with the entry of advanced technology and management experience. The correlation effect and demonstration effect accelerate the process of domestic technological progress, driving the industry to evolve from low technology and low value-added state to high technology and high value-added state, realizing the optimization and upgrading within and among the three industries, that is, realizing the industrial structure advancement. Specifically, the introduction of FDI relates to the industrial correlation effect. The referring theoretical terms are forward and backward correlation effect, meaning that when penetrating a certain industry of the host country, FDI causes production behaviour changes in both upstream and downstream industries. This brings spillover effects to the relatively technologically backward enterprises, bringing about the development of related enterprises in the host country and indirectly adjusting the industrial ratio (Song et al., 2020). Second, FDI inflowing has technology spillover effects. Instead of directly and automatically turning over advanced technologies to host enterprises, its action is creating knowledge spillovers (Meyer, 2004). The concrete channel that brings advanced technology and management experience related to industrial development to the host country promotes technological progress, improves production efficiency, and eliminates backward industries. From the perspective of market competition, attracting FDI could also activate the competitive consciousness of domestic enterprises, forcing them to increase R&D expenditures and improve technology levels. Meanwhile, the fierce competition effect accelerates the technological and management model renewal iterations within the host country. The demonstration effect of pioneering upgrading enterprises further radiates the development of enterprises within the same industry (or up-and-down industry chain), which in turn enhances integrated industry development (Lin et al., 2009).

Specifically for Jiangsu, the utilization of FDI mostly focused on the secondary industry previously. The concentration of foreign capital in the secondary industry served as an important impetus to its development, nevertheless, it also exacerbated the imbalance between industries, namely curbing the rationalization of industries. Combined with the limited scale of foreign investment and the relatively high access threshold stemming from the light pollution and high value-added traits in the tertiary sector, it is hard for the inflow of capital alone to generate industrial structure pulling effects (Hu & Zhang, 2021). With the rapid economic development, infrastructure improvement and legal framework, the characteristics of inward FDI in Jiangsu have changed that as the increasing volume of foreign investment and the expanding inflowing fields of foreign investment. It is demonstrated that external sources of FDI in Jiangsu have broadened from Hong Kong and Macao to various countries in Europe and the United States, and the FDI structural characteristics have shifted from monocentric to diversified development, especially the rise in foreign inflows to the service sector. However, the transfer and spillover of core technology during the process are subject to the limitation of technology level, human resource level, and innovation capacity within the region, resulting in the technology transfer path of FDI being blocked and unable to play a facilitating role. In this case, the paper proposes,

Hypothesis 1. There is a non-linear relationship between FDI and industrial structure upgrading in Jiangsu.

1.2. FDI flows, green technology innovation, and industrial structure upgrading

Innovation is defined as the creation of a new production function, a new combination of production factors by entrepreneurs. Technology innovation is a subcategory meaning that market players (mainly enterprises), aiming to maximize long-term profits, apply new knowledge and technological inventions to develop new products or processes and achieve the first successful commercial application to adjust the supply and demand conditions in the product market. Green technology innovation adds environmental factors to further measure whether technological innovation is conducive to reducing the negative environmental and living impact (Hai & Li, 2021). As for the acting routing of green technology innovation on industrial structure, it divides into three respects. Firstly, green technology innovation brings new technologies, new materials and new equipment that can create higher production efficiency and bring more added value, thus reducing energy consumption and factor inputs, increasing alternative energy, improving enterprise productivity, and bringing cost advantages to enterprises. Thus, the synthesis results are the industrial structure changing. Moreover, the common point between traditional technology innovation and green technology innovation is transforming or creating new products, while the difference lies in the green quality of the new products (Du & Li, 2019). Green technology innovation, boosting continuous production technology and process upgrading, enables the division of labour between different sectors to become refined so that the originally related industries are constantly extended and the speed of product renewal is accelerated. Meanwhile, the increase in the income level of residents stimulates the demand for green products and forces enterprises to strengthen green technology innovation. The generation of green product demand can actively transform the original industrial sector and drive the new industrial sectors' development to progress the market demand structure to a higher level. Thirdly, as the spatial connection between regions becomes closer, the flow of green technology innovation between regions with different resource endowments accelerates the diffusion. And green production technology is enhanced in the form of co-built parks, project cooperation, and ecological compensation. The regions with relatively advanced production technology have knowledge spillover effects on the neighbouring regions with relatively backward green technology, and the latter gradually introduce the advanced green technology and management models of the neighbouring regions. Thereby, the differences in green technology between regions are gradually converged to enhance the synergy of industrial structure optimization (Huang & Wu, 2019).

The paper hypothesizes that green technological innovation has a positive moderating effect on the relationship between FDI and industrial structure upgrading, enabling to weaken the negative impact of polluting FDI on industrial structure upgrading to a certain extent. The first reason is that green technology innovation naturally sets the threshold of FDI entry. FDI with the purpose of pollution transfer obviously cannot enter the industry that strengthens green as the main feature. Then, the selected FDI featuring as green and useful enters the industry, adding impetus to green technological innovation, and encouraging the industry structure upgrading. In addition, green technology innovation stimulates FDI from labour-intensive industries to technology-intensive industries and inspires the increase of enterprise R&D investment to achieve innovation compensation; that is, reducing pollution consumption, improving resource utilization, and ensuring sustainable upgrading of industrial structure. In this case, the paper proposes,

Hypothesis 2. There is a positive relationship between green technological innovation and industrial structure upgrading in Jiangsu.

Hypothesis 3. Green technological innovation has a positive moderating effect between FDI and industrial structure upgrading in Jiangsu and weakens the negative impact of FDI on industrial structure upgrading.

The mechanism framework of this study is shown in Figure 1.

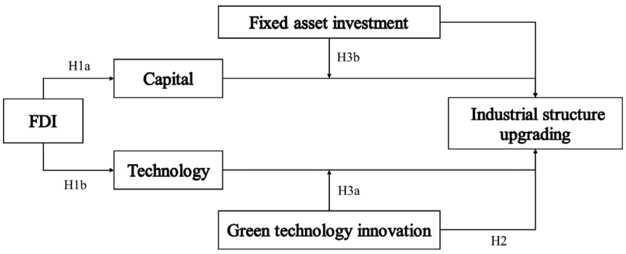

Figure 1. Research mechanism framework

2. Materials and methods

2.1. Modelling

Due to the lagging nature of FDI and green technology innovation, especially issues such as external effects, it is essential to carefully explore their impact on industrial structure. In this paper, factors such as foreign direct investment, green technology innovation, fixed asset investment, urbanization, and education level are subject to a certain lag. Therefore, the current period's value will be affected by the previous period's value in time. For more robust test results and to examine whether there are lags in industrial structure, we adopt Arellano's (1991) approach of adding one-period lags of the explanatory variables to the explanatory variables. The explanatory variables include the lagged term of the explained variables, whose individual effects may be autocorrelated with the disturbance term, and the endogeneity problem is inevitable. However, the dynamic panel model effectively controls the heteroskedasticity and endogeneity problems of the model, overcomes the shortcomings of the traditional static panel model that simply assumes the error term, and estimates both the horizontal variance and the difference equation. Thus, problems such as weak instrumental variables that cannot be solved by differential GMM are solved by the dynamic panel model. The paper uses the differential generalized moments (DIF-GMM) and systematic generalized moments (SYS-GMM) methods to test the robustness of the model and conclusions, respectively. As a consistency, the first-order autocorrelation of the first-order differences of the disturbance terms still exists, but there is no second-order or even higher-order autocorrelation. Also, models that pass the AR test and the Sargan test cannot reject the original hypothesis of all instrumental variables are valid, thus meaning that the instrumental variables used are reasonably valid. In addition, since SYS-GMM has significantly improved the validity and consistency compared with DIF-GMM, the estimation effect is better. Therefore, this paper focuses on the results of the estimation of the model by the SYS-GMM model. To verify Hypothesis 1 and Hypothesis 3, the squared term of FDI and the interaction term of *FDI* and *GTI* are added to the model. The specific model is shown as follows:

$$SR_{it} = \alpha + \beta_1 SR_{it-1} + \beta_2 FDI_{it} + \beta_3 FDI_{it}^2 + \beta_4 GTI_{it} + \beta_5 FDI_{it} \times \beta_4 GTI_{it} + \gamma X_{it} + \vartheta_{it} + \varepsilon_{it}; \quad (1)$$

$$SA_{it} = \alpha + \beta_1 SA_{it-1} + \beta_2 FDI_{it} + \beta_3 FDI_{it}^2 + \beta_4 GTI_{it} + \beta_5 FDI_{it} \times \beta_4 GTI_{it} + \gamma X_{it} + \vartheta_{it} + \varepsilon_{it}, \quad (2)$$

where i denotes the municipal cross-sectional unit, i = 1, 2..., 3; t denotes time; X_{it} denotes the control variable; α is the intercept term; θ_{it} is the time-varying individual fixed effects, and ε_{it} is the random error term.

To specifically analyze the threshold effect of the impact of *FDI* on green technology innovation, the threshold variables (including green technology innovation and fixed asset investment) are selected in the paper, and the following model is constructed by referring to Hansen (1999):

$$SR_{it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \gamma X_{it} + \omega_1 FDI_{it} \times I(W_{it} \le \lambda) + \omega_2 FDI_{it} \times I(W_{it} > \lambda) + \varepsilon_{it}; \quad (3)$$

$$SA_{it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \gamma X_{it} + \omega_1 FDI_{it} \times I(W_{it} \le \lambda) + \omega_2 FDI_{it} \times I(W_{it} > \lambda) + \varepsilon_{it}, \quad (4)$$

where λ is the corresponding threshold value and $I(\cdot)$ is the threshold indicative function. The observations are divided into different intervals by comparing the relative sizes of the threshold variables with the threshold values, and the different intervals correspond to different regression coefficients ω_1 and ω_2.

2.2. Variable selection

The variables of industrial structure upgrading, foreign direct investment, green technology innovation, fixed asset investment, urbanization, and education level are selected for the study. Considering data accessibility, we select panel data of 13 cities in Jiangsu from 2005 to 2018, obtained from Jiangsu Statistical Yearbook and National Intellectual Property Administration, PRC (CNIPA). And variables are partial logarithmically processed to avoid data heteroskedasticity and make the data more comparable. The specific meanings and treatments of each variable are as follows. The descriptive statistical analysis is shown in Table 1.

The explained variable is industrial structure upgrading. Generally, scholars have developed the measure of industrial structure upgrading in terms of both industrial structure rationalization and advancement (Jia & Chen, 2018). Specifically, industrial structure rationalization (*SR*) is measured by the Sill index method, which is calculated as follows:

$$SR = \sum_{i=1}^{3} (Y_i / Y) \ln\left[(Y_i / Y) \times (L_i / L)\right], \quad (5)$$

where Y denotes total regional output value, L denotes employment, i denotes the number of industrial sectors. Y_i denotes the output value of industry i, and L_i denotes the number of employees in industry i. *SR* is not 0 indicates that the industrial structure deviates from the equilibrium state, the larger value of *SR* is, the more irrational the industrial structure is. For the advanced industrial structure

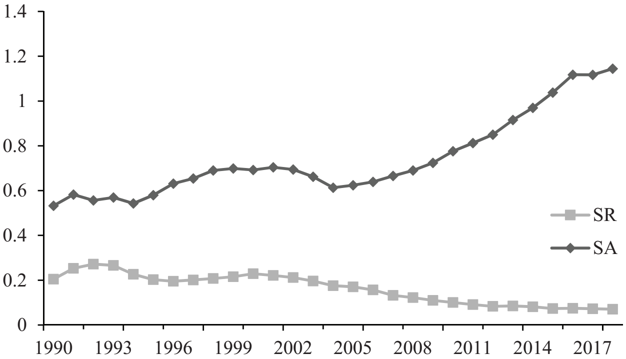

Figure 2. Trends in industrial structure rationalization and advancement of Jiangsu, China

(*SA*), the ratio of the output value of tertiary industry compared with the output value of the secondary industry is generally used to evaluate, reflecting the level of serviceability of industrial structure change, and when the value is increasing, the industrial structure is in the process of upgrading. And trends in industrial structure rationalization and advancement of Jiangsu from 1990 to 2018 are shown in Figure 2. As demonstrated in Figure 2, *SR* value remained fluctuating from 1990 to 2005 with the decreasing overall trend, and the value kept decreasing from 2005 to 0.07 in 2015 and stabilized afterwards. It is indicated that Jiangsu's industrial structure has been continuously rationalized, and the distribution of resources among the three industries has become more and more reasonable to break the condition that the previous excessive concentration of resources in the secondary industry. Moving to *SA* value, it is roughly in a growth trend, especially in 2005 showing a prominent growth trend, which is also the reason for choosing the sample period of 2005 to 2018. It is shown that the process of industrial rationalization in Jiangsu is accompanied by industrial advancement, and the speed of industrial advancement, accelerating since 2005, is faster than that of industrial rationalization.

Core explanatory variables are foreign direct investment (*FDI*) and green technology innovation (*GTI*). We use the actual utilization of FDI to measure the level of foreign direct investment in each city. Using this indicator to measure the amount of FDI attracted to Jiangsu could be a good way to examine the trend of FDI changes and the actual utilization. The comparison of FDI distribution in Jiangsu between 2005 and 2018 is exhibited in Figure 3. Apparently, the FDI values of southern Jiangsu (including Nanjing, Suzhou, Changzhou, Wuxi and so on) are marked in red in both 2005 and 2018, indicating a high amount of foreign investment attracted, while the FDI attractiveness of Zhenjiang decreases in 2018. It is easy to understand that the region with high FDI absorption in central Jiangsu is Nantong, because of its geographical advantage of being close to Shanghai and the sea, which is naturally attractive to foreign investors. And in northern Jiangsu, Xuzhou has been prominent in its ability to attract capital in recent years (marked in yellow in 2005, while marked in red in 2018), and the ability to attract capital in Huaian and Yancheng has improved. Thus, the distribution of FDI resources within Jiangsu remains in an uneven state. For the measurement of green technology innovation (*GTI*), different scholars have various criteria, which include the number of patent applications received, the elasticity of total R&D investment, the amount of emissions per unit of industrial gross domestic product (GDP) and the sales revenue of new products in high-tech industries per unit of GDP (Yuan & Xie, 2015; Li, 2020). Note that in most studies, the number of green patents is the index of the level of green technology innovation, as green patents are generally considered technical progress and new green technology is related to green technology innovation (Li et al., 2016; Shan et al., 2021). Thus, *GTI* in our study is also measured by the sum of applications for the current years of invention patents and utility model patents (excluding less innovative design patents) related to environmental problem-solving (Shang et al., 2022). Specifically, we retrieve patent data from the National Intellectual Property Administration, PRC, including application number, filing date, patent name, classification number, applicant name and other relevant information. In 2010, the World Intellectual Property Organization (WIPO) launched an online tool designed to facilitate the search for information on patents related to environmentally friendly technologies, known as the International Patent Classification (IPC) Green Inventory. The IPC Green Inventory classifies green patents into seven categories based on the United Nations Framework Convention on Climate Change (UNFCCC); that is, transportation, waste management, energy conservation, alternative energy production, administrative regulatory or design aspects, agriculture or forestry, nuclear power generation[1] (Qi et al., 2018). Based on the classification, patents are matched according to classification numbers to identify whether they are green or not, and are further aggregated to the city-level as a measure of the level of green technology innovation. For a given city, more green patents denote greater regional green technology innovation capacity. Figure 4 plots the Kernel density distribution of GTI (log-specific) in 2005 and 2018. It can be seen that the number of GTI in 2018 is more than that in 2005, showing that the overall level of green technology innovation in Jiangsu has greatly improved over time.

Referring to Shang et al. (2022) and Shan et al. (2021), we choose some control variables to avoid problems arising from omitted variables. Domestic fixed asset investment is one of the important prerequisites for industrial structure upgrading. It is essential for the optimization of industrial structure to consider the domestic investment quantity increasing, the investment direction adjustment and the investment quality improvement. Thus, the paper selects the indicator of total fixed capital formation of

[1] More detailed sub-categories are available under the seven main categories, enabling clearer definitions of the green patents, such as carbon/emissions trading under the administrative regulatory or design aspects, and alternatives to pesticides under the agriculture or forestry.

Table 1. Descriptive statistical analysis of variables

Variable	Measurement	Unit	Mean	Std.Dev	Min	Max
SR	Sill index	–	0.076	0.003	0.011	0.216
SA	Tertiary industry output/second industry output	–	0.832	0.015	0.469	1.571
FDI	Actual use of foreign direct investment	Hundred million US$	19.939	1.436	0.330	91.650
GTI	Number of green patent applications	Item	1459.687	2319.653	6	13627
FI	Total fixed assets investment	Billion yuan	2060.29	122.421	124.550	6362.210
U	Population urbanization rate	%	59.167	0.885	30.700	82.300
E	Number of students enrolled in ordinary high school	Ten thousand	13.161	1.422	0.200	84.080

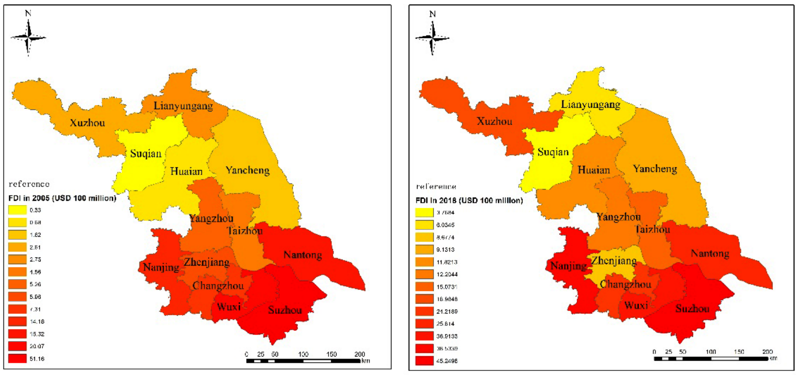

Figure 3. Distribution of FDI in Jiangsu, China in 2005 and 2018

each municipality, which reflects the influence of social fixed investment (*FI*) on the change of industrial structure. Urbanization (*U*) includes population urbanization, land urbanization, economic urbanization, and social urbanization. In general, population urbanization with a labour pool to cities, provides labour for the development of secondary and tertiary industries and promotes the increase of output value to optimize the industrial structure. Therefore, each urbanization rate of the population represents the level of urbanization. Since the reserve of high-quality talents promotes the technology-intensive industries development to increase the added value of industries and helps the industrial structure upgrade, the education level of the population is the basis of the talent reserve and provides human capital for the high-tech industry.

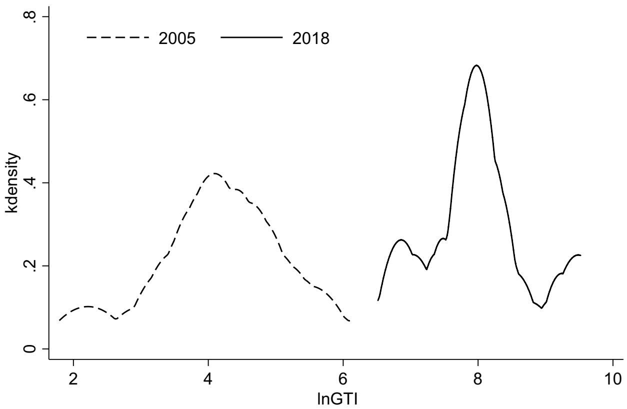

Figure 4. Distribution of GTI in Jiangsu, China in 2005 and 2018

Accordingly, we use total number of students enrolled in general colleges and universities to measure the education level (*E*).

3. Results and discussion

3.1. Analysis of GMM estimation results

The variance inflation factor (VIF) test is conducted before the empirical test to determine whether there was cointegration between the variables, where a larger VIF indicates more serious multicollinearity, and the maximum VIF cannot exceed 10. The VIF distribution between the variables was between 1.04 and 2.84, which was much less than 10, so the possibility of multicollinearity could be excluded[2].

To better compare the effects of each influencing factor on industrial structure rationalization and industrial structure advancement, the empirical results are shown in Table 2. Each model has the following specific implications, Models I, III and V are the estimation results (*SR* as the explanatory variable) of fixed effects of the static panel model, DIF-GMM and SYS-GMM of dynamic panel model, respectively, Models II, IV and VI are the estimation results of fixed effects (*SA* as the explanatory variable) of static panel model, DIF-GMM and SYS-GMM of dynamic panel model, respectively. As seen in Table 2, all estimation results pass the AR test and Sargan test, proving that

[2] The results of the variance inflation factor VIF for each explanatory variable cannot be shown here due to space limitations. We can provide if request.

the model setting is reasonable and the estimation results are credible. It is observed from Table 2 that the coefficients of models I and II are less significant than those of models III, IV, V and VI, indicating that the method that introduces the lagged terms of the explanatory variables of solving the endogeneity problem optimizes the estimation effect. Also, the effect of the SYS-GMM estimation is better than that of the DIF-GMM, thus we focus on model V and model VI.

First, we examine the regression results using the first-order lagged terms of explanatory variables (that is *L.SR* and *L.SA*). It is revealed that the estimated coefficients are both positive at the 1% significance level, suggesting that the first-order lagged terms of industrial structure upgrading have a significant positive impact on the current period, which means certain inertia of industrial structure upgrading in Jiangsu, which is in lines with Zhou and Zhang (2021). Next, the impact of the core variables is examined. The impact of FDI on industrial structure rationalization (*SR*) is positive. At a 1% significance level, for every 1% increase in FDI, the deviation value of industrial structure rationalization increases by 0.2%. This indicates that FDI induces an increase in the degree of industrial structure irrationality. Meanwhile, there is a non-significant positive correlation between the squared term of FDI (FDI^2) and industrial structure rationalization, which shows that a non-linear relationship between FDI and SR does not exist yet. Taking another view at the result of FDI on the industrial structure advancement (*SA*), it can be found that the primary term is significantly negative and the secondary term is significantly positive; that is, there is a non-linear relationship between FDI and SA, which partially verifies Hypothesis 1. The result is relatively consistent with the study of Hu and Zhang (2021) on the Yangtze River Delta, when FDI accumulation breaks through the inflexion point, it will gradually promote industrial structure upgrading. Since the measurement of variable SA is whether the output value of the tertiary industry has increased compared with that of the secondary industry, in general, the output value of the tertiary industry in Jiangsu is only slightly more than that of the tertiary industry with an overall ratio at 1.17, indicating that majority of cities in Jiangsu are still in the stage of gradual advanced industrial structure. Thus the FDI-promoting effect on the industrial structure is limited. And from Table 2, the green technology innovation (*GTI*) is negatively correlated with

Table 2. Regression results of differential GMM and system GMM

Variables	FE		DIF-GMM		SYS-GMM	
	I	II	III	IV	V	VI
L.SR			0.518*** (0.106)		0.585*** (0.144)	
L.SA				0.562*** (0.056)		0.703*** (0.056)
FDI	−0.003*** (0.001)	−0.004*** (0.001)	−0.001** (0.0005)	−0.007** (0.003)	0.002*** (0.0005)	−0.009** (0.004)
FDI^2	0.002** (0.001)	1.345*** (0.215)	0.012** (0.005)	0.014* (0.008)	0.0001 (0.0001)	0.008* (0.0047)
ln*GTI*	−0.139* (0.079)	0.067*** (0.014)	−0.009 (0.006)	−0.005 (0.008)	−0.004** (0.002)	0.016** (0.007)
FDI×*GTI*	0.015* (0.0088)	0.002*** (0.0002)	−0.630 (0.409)	0.004** (0.002)	−0.001 (0.001)	0.001*** (0.0002)
ln*FI*	0.008* (0.0044)	0.152*** (0.028)	0.005** (0.002)	0.004*** (0.001)	0.004** (0.002)	0.064*** (0.017)
U	1.011* (0.566)	0.012*** (0.003)	−0.001** (0.0005)	0.003* (0.0017)	−0.002** (0.001)	0.001 (0.003)
E	−0.093 (0.106)	0.012*** (0.002)	−0.055* (0.031)	0.002** (0.001)	−0.006 (0.005)	0.003** (0.0015)
Constant	−5.766*** (1.724)	−0.377*** (0.057)	0.095*** (0.031)	0.128** (0.059)	0.041** (0.020)	−0.144*** (0.054)
AR(1)			−2.375 [0.009]	−2.619 [0.009]	−2.149 [0.032]	−3.044 [0.002]
AR(2)			2.352 [0.519]	0.843 [0.599]	2.283 [0.211]	1.880 [0.186]
Sargan			9.804 [1.000]	11.299 [1.000]	8.204 [1.000]	11.844 [1.000]

Note: ***, **, * denote the test results are significant at 1%, 5%, and 10% levels, respectively; the standard errors are in parentheses below the coefficients; AR(1) and AR(2) denote the Arellano- Bond autocorrelation test for the first- and second-order difference residual series; and the Sargan test is an over-identification test with its p-value in parentheses.

industrial structure rationalization and positively correlated with industrial structure advancement, and the coefficients all pass the 1% significance level. It shows that for every 1% increase in the number of patents granted, the degree of rationalization and advanced industrial structure will rise by 0.4% and 1.6% respectively, namely, the higher the degree of green technology innovation, the more significant the upgrading of industrial structure. This is because Jiangsu, as a large economic province, has been actively advocating technology innovation, especially independent R&D innovation to drive development. As a concentration of universities and research institutes where science and technology-oriented talents are piled up, Jiangsu has been at the forefront of innovation ability and has a good foundation to build a green innovation region (Dechezleprêtre & Sato, 2017). Thus, the development of green technology innovation promotes the rapid increase of the output value of secondary and tertiary industries, bringing about the optimization of industrial structure. However, the test results of green technology innovation affecting industrial structure reflect that the current level of innovation is very uneven among the three industries. In addition, the regression coefficient of the interaction term between FDI and GTI ($FDI \times GTI$), a major object of study, is significantly positive at the 1% statistical level with an effect strength at 0.001 (take *SA* as explained variable), indicating that for every 1% increase of the interaction term ($FDI \times GTI$), the industrial structure advancement increases by 0.01% on average. This implies that green technological innovation has a positive moderating effect on the relationship between FDI and industrial structure upgrading, which is partially verified by Hypothesis 3.

Examining the regression results of the control variables, it is easy to view that fixed-asset investment (ln*FI*) is positively correlated with both industrial structure rationalization and advancement. And the coefficients are significant at the 1% level, indicating that the increase in fixed-asset investment inhibits industrial structure rationalization and promotes industrial structure advancement. The reason is that fixed-asset investment in Jiangsu is mainly concentrated in the secondary industry, with an unbalanced amount of investment in each industry and a pile-up of investment in the secondary industry, resulting in an unreasonable industrial structure. Meanwhile, the degree of contribution of capital to the output value of the tertiary industry is higher than its contribution to the secondary industry, which promotes the output increase in the tertiary industry and brings the capital-advancement effect on the industrial structure. Moreover, urbanization (*U*) is negatively correlated with industrial structure rationalization, education (*E*) is positively correlated with industrial structure advancement, and the other results are insignificant. It indicates that the development of urbanization, to a certain extent, enhances the degree of industrial rationalization. Because the increase in urbanization level brings the increasing working population in secondary and tertiary industries, and the increase in total resources promotes the allocation of resources more. The higher the level of education is, the degree of industrial structure advancement is higher. High education and a high number of school students provide high-quality talents for industrial development, thus promoting the industrial structure upgrading in Jiangsu.

Robust tests examine the rigidity of the evaluation methods and indicators in terms of their explanatory power, meaning whether they maintain a relatively consistent and stable explanation of the evaluation results when certain parameters change. The results' robustness can be examined by using a model regression such as ordinary least squares (OLS) from the measurement method, or replacing the variables with other variables from the variables. Therefore, the paper uses OLS models to analyze the effect of the explanatory variables on the dependent variable. The regression results show that each explanatory variable has the same coefficient sign and significance as determined by the results of the systematic GMM regression, thus can further verify that the previous regression results are robust[3].

3.2. Analysis of threshold test results

In the previous, it is analyzed that there is a positive moderating effect of green technology innovation in the relationship between FDI and industrial structure upgrading, and it is further considered that green technology innovation is used as a threshold variable to test whether it can mitigate the FDI-hindering effect on industrial structure. When FDI inflowing, countries or regions with good digestion and absorption capabilities, innovation capabilities, and strong economic and technological foundations make better use of other countries' technologies and processes, and then transform them into national productivity, overriding economic and social development. Therefore, it is significant that FDI flowing into these countries can lift green technology innovation to promote the industrial structure upgrading in the host country. Whereas, some countries or regions that lack sufficient foreign investment funds, poor economic strength cannot exert technology spillover effects. Therefore, these countries could not cross the threshold of economic development. Then FDI inflowing even hinders green technology innovation and restrains the industrial structure upgrading in the host country. In other words, FDI does bring about technology spillovers, but there is still a certain degree of threshold characteristics in the absorption capacity of such spillovers. Only when green technology innovation and fixed asset investment exceed a certain level, the spillover effect of FDI will change in a leap.

We conduct a threshold effect test on green technology innovation to further analyze the specific impact of FDI on industrial structure upgrading. First, determine the number of thresholds for green technology innovation. Since

[3] The results of robust tests cannot be shown here due to space limitations. We can provide if request.

Table 3. Self-sampling test of the threshold model for green technology innovation

Model (*SR*)	F-value	P-value	Threshold		
			10%	5%	1%
single	19.57**	0.032	10.432	18.481	22.356
double	5.35	0.582	18.660	25.447	44.502
triple	10.06	0.233	13.855	17.000	30.684
Model (*SA*)	F-value	P-value		Threshold	
			10%	5%	1%
single	20.32**	0.043	15.626	19.241	25.804
double	8.25	0.510	15.084	17.606	19.932
triple	6.70	0.497	14.403	17.402	21.561

Note: *, ** and *** represent 10%, 5% and 1% signficance levels, respectively.

the number of thresholds is not clear, this paper adopts the self-sampling test to verify the hypotheses based on the single threshold, double threshold and triple threshold in turn, and the results are shown in Table 3. Based on the results in the table, this paper finally determines that the analysis of green technology innovation will be based on the single threshold model.

Based on the panel threshold model, this paper analyzes the impact of foreign direct investment on green technology innovation under different threshold conditions. The results are shown in Table 4. It can be found that for the explained variable as the advanced industrial structure, there is a single threshold for the level of green technology innovation and fixed asset investment, while the explained variable is the rationalization of the industrial structure, it is shown that there is a single threshold for the level of green technology innovation and double thresholds for investment. Considering the threshold effect of the level of greentechnology innovation, the new technologies, new materials, and new equipment brought about by green technology innovation can create higher production efficiency and bring more added value, thereby reducing energy consumption and factor input, and improving enterprises' productivity, which in turn changes the industrial structure. Therefore, the higher the level of green technology innovation, the stronger the technological spillover effect of FDI, and the stronger the correlation effect on the upstream and downstream of the industry, which will bring spillover effects to relatively backward technological enterprises, promote the development of relevant enterprises in the host country, and promote the advanced and rationalized industrial structure. Moreover, when the investment in fixed assets is small, the inflow of FDI has not promoted the advancement of the industrial structure, but as the investment in fixed assets continues to increase, the effect of FDI's improvement in the industrial structure has increased, and the rationalization and advancement of the industrial structure have emerged.

Table 4. Threshold model estimation results

Threshold variables	SR		SA	
	GTI	FI	GTI	FI
$\ln FDI \times (w \le \gamma_1)$	0.046** (2.47)	0.026* (1.79)	–0.025** (–2.34)	–0.029* (–1.79)
$\ln FDI \times (\gamma_1 < w \le \gamma_2)$	–0.012* (–1.93)	–0.010*** (–3.95)	0.014* (1.74)	0.012* (1.86)
$\ln FDI \times (w > \gamma_2)$	–	–	–	0.404* (1.83)
Control variables	YES	YES	YES	YES
Constant	–0.157*** (–3.65)	–0.201* (–1.84)	–0.064** (2.43)	–0.067* (–1.89)
R^2	0.698	0.672	0.532	0.582

Note: ***, **, * denote the test results are significant at 1%, 5%, and 10% levels, respectively; the t-statistic value is in parentheses below the coefficients.

Conclusions

Using dynamic panel models (including DIF-GMM and SYS-GMM) and threshold effect models, the paper empirically tests the relationship between FDI, green technology innovation and industrial structure upgrading (divided into industrial structure rationalization and advancement) based on panel data of Jiangsu from 2005 to 2018. The following conclusions are obtained. First, FDI negatively affects the industrial structure rationalization in Jiangsu without any obvious non-linear relationship, while the relationship between FDI and industrial structure advancement presents an obvious U-shaped, that is when the FDI accumulation exceeds a certain amount, the FDI-promoting effect on industrial structure upgrading appears. And green technology innovation can promote industrial structure upgrading, of which the effect on the advancement is greater than that on rationalization. Second, regarding the regulating role of green technology innovation, it exhibits a positive regulating function between FDI and industrial structure advancement, showing that strengthening the coordination and cooperation between green innovation and FDI is conducive to structural upgrading. Furthermore, the fixed asset investment collection contributes to the industrial structure advancement, while inhibiting the rationalization of the industrial structure. Also, the urbanization development rationalizes the industrial structure, while the increase in the level of education is associated with the industrial structure advancement. Finally, the results of the threshold test indicate that there is a significant threshold effect of FDI on industrial structure upgrading in terms of green technology innovation and fixed asset investment.

Based on the above findings, the paper gives the following recommendations. Firstly, the U-shaped feature between FDI and industrial structure advancement prompts the government to further strengthen the FDI accumulation and strengthen the guidance of FDI to promote industrial structure advancement. In the stage of high-quality development, the reasonable layout of FDI inflow needs to be emphasized, and foreign capital ought to be encouraged and guided into high-end manufacturing industries. It is necessary to encourage and guide FDI into the core industries that Jiangsu focuses on, such as new-generation information technology and new materials, to form advantageous industrial clusters. And the FDI involved needs to be stimulated and directed to enter the financial, medical and pension, education and other high-end service industries to give full play to the active role of the tertiary sector in promoting the industrial structure upgrading. During the process, it is also imperative to consider enhancing the FDI introducing environment, as the blind foreign capital accumulation alone cannot lead to structure upgrading. Thus, on the one hand, there is the need to create a fair and transparent legal environment and a fair and competitive market environment to raise market expectations and attract quality foreign investment flowing; on the other hand, it is necessary to continue to strengthen the construction of service-oriented government and introducing relevant effective policies to retain high-quality FDI. Secondly, since green technology innovation promotes both the advancement and rationalization of industrial structure in Jiangsu, the channels ought to be widened to improve green technology innovation and optimize the spatial allocation of innovation resources. For example, constructing a stable funding channel for green technology innovation, increasing the investment of supporting funds, using government subsidies and accelerated depreciation policies to encourage enterprises to carry out green technology innovation activities, strengthening inter-regional exchanges and cooperation, and cultivating a competitive high-end green industrial sector (Xie et al., 2017). There are also improvements through environmental policies, such as consideration from the enterprise side. Through higher environmental pressure and pollution control costs to force the enterprise to green innovation, it further reduces the consumption brought by low-end industries, eliminates energy consumption and environmental pollution problems brought by industrial production, eliminates industrial surplus from the source, and optimizes industrial structure. Thirdly, considering the prominent role of education in industrial structure advancement, the development of education has to continue to be emphasized. Studies show that China's industrial structure is optimized and upgraded faster, but the employment structure of the three industries seriously lags behind the industrial structure, leaving human capital as the main driving factor at present (Rauscher, 2015). Therefore, Jiangsu needs to continue to pay attention to the development of education and play an active role in education, for example, intensifying the funding subsidies to universities and mobilizing the innovation ability of universities and research institutions. In addition, it is urgent to further accelerate the exchange and cooperation of regional scientific research and talent cultivation, and actively explore new modes and paths of cooperation among regional universities to provide high-quality innovative talents for the optimization and upgrading of Jiangsu industries.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

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Competing interests

The authors declare no conflict of interest.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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