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Authors: Yongsheng, Cheng, Deyuan, Zhang, and Xia, Wang

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Promote or Inhibit? The Green Effect of Environmental Regulation in China—Based on the Perspective of FDI

CHENG Yongsheng[1,2,*], ZHANG Deyuan[2], WANG Xia[1]

1. School of Business, Fuyang Normal University, Fuyang, Anhui 236037, China;
2. Academy of Strategies for Innovation and Development, Anhui University, Hefei 230039, China

Abstract: Promoting the green development effect characterized by green total factor productivity (GTFP) is the key to achieving high-quality development in the new era. Using the 2001–2021 inter-provincial panel data, the energy and environmental factors were simultaneously included in the analysis framework for assessing the green effect of environmental regulations in China. The Malmquist-Luenberger index based on the SBM directional distance function was used to measure the GTFP and its decomposition terms, the dynamic panel model was further constructed, and the GMM method was used to empirically test the direct and indirect effects of three types of environmental regulation and foreign direct investment (FDI) on GTFP. The results show that China's GTFP is growing at an average annual rate of 2.13%, green technology progress is the source of GTFP growth, and the GTFP regional gap is expanding. There is not a non-linear effect in command-controlled environmental regulation, while the economic incentive type and the voluntary agreement type of environmental regulation respectively show a "U" shaped relationship and an inverted "U" shaped relationship. The control type regulation does not have an indirect effect on GTFP through FDI, but the incentive type and protocol type regulations can drive the promotion of GTFP indirectly through FDI. The GTFP lifting effects of the different types of environmental regulation and FDI show regional heterogeneity. Exploring the green development effect and characteristics of environmental regulation has important theoretical significance and practical value for selecting rational environmental regulation types, adopting differentiated environmental regulation intensities, implementing two-wheel drive to boost GTFP growth, realizing the benign interactions between environmental regulation and FDI, and ultimately promoting high-quality economic development.

Key words: environmental regulation; FDI; GTFP; high quality development

1 Introduction

With the rapid development of society and the economy, energy shortages and environmental pollution are becoming more and more prominent, and green development has become a global consensus. In 2016, the Chinese government made an "overall improvement in the quality of the ecological environment" one of the main goals of economic and social development for the first time, with an emphasis on environmental regulation to guide enterprises in focusing on energy conservation and emission reduction, and began to gradually introduce energy-saving and emission reduction technologies to ultimately achieve the goal of green development (Cheng and Zhang, 2022). China's reform and opening-up over more than 40 years has made great achievements that have attracted worldwide attention. Not only has the total economic volume jumped to the second place in the world, but the economic contribution rate has also steadily ranked the first in the world. Under the double pressures of the complex and severe international environment and the domestic epidemic impact, China's contribu

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***Corresponding author:** CHENG Yongsheng, E-mail: chengyongsheng@aliyun.com

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tion to world economic growth in 2022 reached one-fourth, with an annual GDP of 121.0207 trillion yuan, up 3% from the previous year. Not only that, according to the latest China Foreign Investment Development Report (2022), China's actual use of foreign direct investment (FDI) increased from USD 111.716 billion in 2012 to USD 173.48 billion in 2021, an increase of more than 55%; with the annual use of foreign investment steadily ranking second in the world and first in developing countries for 30 consecutive years, and the ten-year cumulative use of FDI at more than USD 1.2 trillion. The structure of foreign investment has been gradually upgraded, the quality and level of foreign investment have been significantly improved, and the proportion of foreign investment absorbed in high-tech industries has increased from 14.1% in 2012 to 30.2% in 2021, or more than 2-fold (MOC, 2022). To this end, we have also paid a painful price in the ecological environment. According to the latest data, there are still 146 prefecture-level cities in the country, accounting for 43.3%, where the air quality exceeds the standard, causing serious negative impacts on the quality of economic growth, the image of the government and the physical and mental health of the people. According to incomplete statistics, the current air pollution problem in China leads to the premature deaths of 178000 people per year due to dating, the number of deaths due to environmental pollution has reached 358000 per year, and more than half of the 338 cities in the country that have their air quality data recorded are considered as moderately or severely polluted (Cheng et al., 2022). For this reason, the 20th National Congress of CPC proposed to accelerate the construction of a new development pattern, to accelerate the green transformation of the development mode, and to make the realization of high-quality development as one of the essential requirements of Chinese-style modernization, which is clearly the strongest voice of development for the next five years and even longer.

The green effect is usually characterized by green total factor productivity (GTFP), also generally called the green development effect or green productivity effect (Wang et al., 2020). GTFP represents the addition of energy and environmental factors to the traditional TFP, which both conforms to the real economic production process and reflects the concept of green development that has become a power source to boost high-quality economic development in the new era (Shapiro and Walker, 2018; Zhan and Li, 2022). In this context, it is of great theoretical and practical significance to explore how the government can optimize the combination of environmental regulations, internalize environmental external costs, compensate for market failures, and play the dual role of "economic growth" and "environmental protection"; as well as what mechanism of "black box" environmental regulations can be used to attract FDI and enhance GTFP (Zhou et al., 2022), and clarify the internal influence mechanism among the three, in order to start a new journey and promote more obvious and substantial progress of common prosperity.

2 Study area

Green and high quality development is one of the eternal propositions of economics, and the attention to GTFP has become a hot spot in academia. Throughout the existing literature, previous studies on environmental regulation, FDI and GTFP have mainly focused on three main aspects.

Firstly, given the limitations of green cognition and technical methods, research on GTFP started relatively late. However, subject to the reality of increasingly tight resources and rigid ecological constraints, scholars have launched an extremely rich exploration around the issue of green development, and the existing research has gradually focused on the connotation and the level of measurement. 1) The connotation was defined. Based on the premise of resource and environmental carrying capacity, green development at least covers the connotation of sustainable practices and technologies, as well as green system and multi-dimensional development goals, which are not only related to the deepening of high-quality development, but also to the basic composition of the "double carbon" strategy, which requires the integrated layout and coordination of economy, society and environmental control. 2) The level of measurement. Given that GTFP increases the objective negative (non-desired) output, it is more consistent with economic development and real performance to focus on the efficiency relationship between factor inputs and actual output (including negative output), and it thus becomes a characterization variable of green development. Throughout the academic field, the mature measurement methods can be broadly divided into two categories: parametric estimation methods and non-parametric estimation methods. Most scholars tend to choose the non-parametric estimation methods, among which the DEA technique represented by the Malmquist-Luenberger productivity index is the most concentrated and frequently used. In terms of indicator selection, the GTFP takes into account the non-desired output, and it incorporates negative external factors such as resource and environmental depletion, which makes the existing productivity accounting system more scientifically valid and closer to the real situation of production development. As for the treatment of resource and environmental depletion indicators, more scholars prefer the negative output indicator method, which considers that resources and the environment are lost and polluted in the production process, and that these are unavoidable "undesirable by-products" of output. However, due to the constraints of research objects and data availability, the composition of the above-mentioned indicators varies greatly, leading to various controversies among different scholars. In terms of measurement and evaluation, most of the existing studies have focused on the national, provincial or industrial levels of specific regions,

such as the Yangtze River Economic Belt or the Yellow River Basin, and there is a lack of focus on microscopic fields such as farmers, etc. The most common influencing factors include the development of productive service industry, technological progress, urban-rural income gap, infrastructure construction, the level of large-scale operation, the degree of population aging and agricultural share, and others. In general, the green development measurement technology characterized by GTFP is becoming more and more optimized and mature (Cheng, 2022), which has laid a solid foundation for the advancement of this study. However, regarding the construction of evaluation indexes and exploration of the framework of influencing factors, the research is scattered, objective and in-depth, and the exploration of its influencing mechanisms is lacking (Gai et al., 2022). In other words, a scientifically valid research system has not yet formed, which is inconvenient for the focused follow-up exploration.

Secondly, there are some controversies about the relationship between environmental regulation and GTFP. 1) Starting from the compliance cost hypothesis, one argument is that environmental regulation will have a crowding-out effect on productive investments, such as production technology innovation and production process improvements of enterprises under short-term static conditions, causing enterprises to follow the rising environmental cost (Gray, 1987), which goes against the corporate goal of profit maximization and is not conducive to reducing environmental pollution through green technology improvements and innovation (Funfgelt and Schulze, 2016). Studies have found that the firms' incentive to emit intensifies as the level of environmental regulation increases, leading to a relaxation of investment in technology development and innovation (Blackman and Kildegaard, 2010), which may even lead to an increase in regional environmental pollution over a certain period of time (Xu, 2016). For example, one study found that public resource-based and market-incentive-based environmental regulations are not conducive to GTFP growth in the short term (Wu et al., 2020), and may also hinder GTFP growth to some extent (Fang and Liu, 2020). In addition, long-term public pressure and media overexposure can put companies in difficult situations regarding their business (Ye, 2021). 2) Starting from Porter's hypothesis, it is believed that moderate environmental regulation is beneficial for inducing enterprises to increase environmental technology research and development, and enhancing comprehensive competitiveness under long-term dynamic conditions (Porter and Linde, 1995). Its specific effects include "innovation compensation", "knowledge learning" and "spatial spillover", etc. At the medium- to long-term level, the GTFP is increased to achieve a "win-win" pattern of external environmental protection and green development of enterprises (Feng et al., 2017; Dong and Wang, 2019). Also, for regulatory policies, a recent study found that the joint synergy of incentive-based and restrictive policies is conducive to the effectiveness of GTFP (Li and Bai, 2020). 3) The non-linear hypothesis suggests that the relationship between environmental regulation and GTFP will be asymmetric with changes in the economic development stage and the institutional environment, showing a non-linear relationship as the external expression (Xiao et al., 2021), and it argues that the relationship between environmental regulation and GTFP is uncertain (Wang and Shen, 2016).

Thirdly, there is no consensus on the impact of FDI on GTFP. As an empirical synthesis of technology, management, capital, and knowledge, on the one hand, FDI can significantly enhance GTFP through demonstration, learning and diffusion that brings about learning imitation of the advanced technologies and reinvention effects, etc. Studies have found that FDI has significant technology spillover effects on host countries, significantly enhancing the diffusion of advanced environmental technologies, and the enhancement of GTFP for industrial enterprises is also supported by micro evidence (Cui and Lin, 2019), which helps to promote green development. On the other hand, FDI may lead to product structure and "pollution sanctuary" effects (Zhou and Tao, 2021). These effects eventually exceed the diffusion spillover of technology, indirectly hindering the progress of green technology and the improvement of GTFP, especially China's foreign investment attraction approach based on market scale expansion, which makes the green technology spillover effect not obvious (Jing, 2021), thus negatively affecting GTFP (Shen and Jin, 2019).

The aforementioned frontier literature provides the basis for the development of this study, but two shortcomings remain. 1) Environmental regulation tools are regarded as homogeneous variables, mostly using a single indicator measure, ignoring the possible differentiated impact of different types of regulatory tools on GTFP. 2) As an important factor affecting GTFP, most scholars treat it as a fragmented element, and no scholars have yet combined environmental regulation, FDI and GTFP into a unified framework for analyzing the possible impact of their interaction on GTFP, which provides more room for the advancement of this study. In addition, the possible reasons for the divergent conclusions mentioned above twofold. Firstly, the variability of different scholars' research samples and methods makes their conclusions inconsistent. Secondly, there is an endogenous bias in environmental regulation or FDI, which makes it difficult to reveal the causal relationship between either environmental regulation or FDI and GTFP (Shen et al., 2017). The possible marginal contributions of this study are twofold. 1) This study explores the direct effects of different types of regulatory instruments on GTFP from three refined types of environmental regulations: command control, economic incentive, and voluntary agreement. 2) Environmental regulation and FDI are included in a unified analytical framework to ascertain whether environmental regulation

has the function of screening the quality of FDI, and the possible indirect effects of their interaction on GTFP are then investigated.

3 Theoretical analysis and research hypothesis

3.1 The mechanism of action by which environmental regulation affects GTFP

The scarcity of environmental resources, negative externalities and the ambiguity of property rights make the goal of cost minimization for firms based on environmental regulation constraints uncertain. When the degree of internalization of environmental external costs is higher, the private costs that firms need to share will be relatively higher, resulting in a greater crowding-out effect on other productive investments of the firms. When added to the different levels of environmental regulation, GTFP in areas subject to more stringent regulations will be hit harder in the short term compared to their competitors. As mentioned above, environmental regulations may positively affect GTFP through two channels. First, based on the perspective of enterprises, environmental regulations can prompt them to improve environmental processes, introduce environmentally friendly and clean equipment, force the product mix to shift in a green and clean direction, cater to the green preferences of society at large, and gain competitive advantages and profit advantages in the market for green products. Second, from the industry's perspective, increasingly restrictive environmental regulations may result in some of the "three high" enterprises, unable to bear the high cost of green transformation and forced to exit. These released idle elements in the market competition through dynamic reallocation, help to alleviate the mismatch between supply and demand of resources, and enhance the overall green competitiveness of the industry. Therefore, the magnitude and direction of the direct effect of environmental regulation on GTFP depends on the net synergy of the two-way influence, which shows asymmetry at different developmental stages, so there may be a non-linear relationship between the two, and there are heterogeneous effects of different types of environmental regulation tools and significant differences in the direct effects on GTFP. Accordingly, the following research hypothesis is proposed.

H_1: There is a non-linear relationship between environmental regulations and regional GTFP, and there are significant differences in the direct effects of different types of environmental regulations on GTFP.

3.2 The mechanism of action by which FDI affects GTFP

As mentioned above, the impact of FDI on GTFP has three main interactions: the "pollution refuge" effect dominated by the negative inhibitory effect, the "pollution halo" effect dominated by the positive promotional effect, and the institutional environment effect dominated by the uncertainty effect. Among them, the "pollution sanctuary" effect suggests that the stringent environmental regulations in western developed countries will increase the cost of non-productive investment and induce pollution-intensive enterprises in developed countries to shift their production to developing countries with relatively lax regulations. In this scenario, the comparative advantage of policy havens is beneficial to enterprise development, but may negatively affect the GTFP of the host country. In contrast, the "pollution halo" effect suggests that FDI has more advanced clean technology, more cutting-edge pollution control, and a more active technological innovation climate than domestic capital, which can lead to a wider imitation and absorption of green and clean technologies through the technology spillover effect, the human capital flow effect, and the demonstration and promotion effect. This wider adoption of green and clean technologies will directly improve the level of green technology in the host country, which will positively contribute to the improvement of GTFP. The institutional environment effect suggests that the host country plays the role of catching up with the technological frontier of developed countries. However, due to the different degrees of market reform and the inadequacy of the institutional environment, the introduction of the frontier technology and management system may not match the innovation environment and human capital level of the country, resulting in the uncertainty of the impact of FDI on GTFP in the short term. Accordingly, the following research hypothesis is proposed.

H_2: FDI is an important factor affecting GTFP, but its mechanism of action is affected by a combination of the "pollution sanctuary" effect, the "pollution halo" effect and the institutional environment effect, while the net effect on GTFP depends on the relative magnitudes of these three forces.

3.3 Environmental regulation, indirect mechanisms by which FDI affects GTFP

Practice shows that the political objectives of government officials based on local tax maximization and promotion incentives may lead to the government maximizing competition for highly mobile FDI while selectively and incidentally enforcing environmental regulations, inducing the proliferation of disorderly "bottom-up competition". The information asymmetry between the central government and the local government makes the effective supervision of the central government inevitably blind, and this distorted behavior with inconsistent objectives will make the "principal-agent" problem more prominent. In recent years, with the accelerated construction of ecological civilization, green development has become a strategic arrangement for economic social development and the good life of the public in the 14th Five-Year Plan period. The previous "GDP-only" assessment and promotion mechanism for officials is being

significantly optimized by focusing on the quality of foreign investment introduction, and promoting the quality and efficiency of economic development has become the keynote of local economic assessment. As an important threshold for allowing FDI to enter the internal market of developing countries, environmental regulations impose additional environmental compliance costs on resource- and environment-intensive foreign enterprises, which helps to raise the threshold for polluting enterprises to enter the host country and weakens their comparative advantage. This constraint forces industrial restructuring and the entry of environmentally friendly and clean foreign investment, which increases and optimizes the proportion of "greening of industrial structure" and ultimately positively promotes the growth of GTFP. Therefore, the tight environmental regulation policy is a kind of compulsory "screening" for foreign enterprises, which plays the role of "storage and decontamination" and guides the FDI to indirectly promote the increase of GTFP. Accordingly, the following research hypothesis is proposed.

H_3: The interactive effect of environmental regulation and FDI may have a positive impact on GTFP, and environmental regulation can cause FDI to indirectly contribute to the improvement of GTFP.

Based on the above theoretical analysis, this study constructs a theoretical hypothesis model of the green effect of environmental regulation, which incorporates environmental regulation, FDI and GTFP into a unified analytical framework in order to explore and analyze the impact mechanism and effect.

4 Data and methods

4.1 Measurement method selection

In this study, resource consumption and environmental pollution are both included in the productivity measurement framework. In this regard, many scholars in the existing literature have adopted the SFA or traditional DEA method, despite their technical shortcomings which may lead to overestimations of GTFP. In response, foreign scholars have proposed that slack variables can be put directly into the objective function and constructed a non-radial, non-angle-based measure (SBM) based on slack variables, which optimized the traditional DEA and better resolved its technical defects (Tone, 2001), ultimately improving the accuracy of efficiency evaluation (Fukuyama and Weber, 2009). Therefore, this study draws on the frontier results, integrating the Malmquist-Luenberger productivity index (ML index) to measure the GTFP growth rate and decomposition term in order to analyze the dynamic evolution law of productivity change of decision units, in which the distance function adopts the SBM directional distance function constructed by Tone (2001, 2003). This approach overcomes the weighting hypothesis and the unavoidable measurement bias problem of the traditional method, and enables cross-period comparison. Specifically, the ML index is defined as follows.

$$ML_t^{t+1}=\left[\frac{1+\vec{D}_0^t(x^t,y^t,z^t;y^t,-z^t)}{1+\vec{D}_0^t(x^{t+1},y^{t+1},z^{t+1};y^{t+1},-z^{t+1})}\times\frac{1+\vec{D}_0^{t+1}(x^t,y^t,z^t;y^t,-z^t)}{1+\vec{D}_0^{t+1}(x^{t+1},y^{t+1},z^{t+1};y^{t+1},-z^{t+1})}\right]^{1/2} \quad (1)$$

where t denotes the period, x, y, z denote the input, desired and non-desired outputs, respectively, ML_t^{t+1} denotes the change in GTFP from period t to $t+1$, and $\vec{D}_0^t(x^t,y^t,z^t;y^t,-z^t)$ denotes the directional distance function. Meanwhile, the *ML* productivity index in equation (1) can be further decomposed into the product of green technical efficiency (*MLEFFCH*) and green technical progress (*MLTECH*), and expressed as follows:

$$MLEFFCH_t^{t+1}=\frac{1+\vec{D}_0^t(x^t,y^t,z^t;y^t,-z^t)}{1+\vec{D}_0^{t+1}(x^{t+1},y^{t+1},z^{t+1};y^{t+1},-z^{t+1})} \quad (2)$$

$$MLTECH_t^{t+1}=\left[\frac{1+\vec{D}_0^{t+1}(x^t,y^t,z^t;y^t,-z^t)}{1+\vec{D}_0^t(x^t,y^t,z^t;y^t,-z^t)}\times\frac{1+\vec{D}_0^{t+1}(x^{t+1},y^{t+1},z^{t+1};y^{t+1},-z^{t+1})}{1+\vec{D}_0^t(x^{t+1},y^{t+1},z^{t+1};y^{t+1},-z^{t+1})}\right]^{1/2} \quad (3)$$

4.2 Sample selection and description

Given the availability and comparability of data, this study focuses on the dynamic evolution of GTFP in 30 Chinese provinces (excluding Tibet, Hong Kong, Macao Special Administrative regions and Taiwan) from 2001 to 2021. The input and output data in the measurement model were obtained from the China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook and the statistical yearbooks of each province. The average values of non-missing years were used for individual missing values. Among the variables, the input indicators include labor force expressed by the number of employees in the whole society; physical capital stock was indirectly calculated by using the practice of Xu (2017); and the energy input was selected as the total energy consumption converted into standard coal. Output indicators include the desired output expressed in terms of real regional gross product; and non-desired output was combined into an environmental pollution index using the entropy method for industrial wastewater, waste gas and solid waste.

Based on the basic data above, the GTFP growth rates of 30 Chinese provinces were measured and decomposed into

green technical efficiency and green technical progress, and the results are shown in Table 1.

Based on the measurement results, the mean values of GTFP, green technical efficiency and green technical progress during the sample period are 1.04, 1.01 and 1.03, respectively, which are lower than those of the eastern region but higher than those of the midwestern region. Specifically for the eastern and midwestern regions, the corresponding mean values of the eastern region are 1.08, 1.04 and 1.04, which are 7%, 4% and 2% higher than those of the midwestern region. Regarding the trend of change, it seems that the GTFP generally shows an incremental trend with an average annual increase of 2.13% during the sample period. Among the components, the average annual growth rates of green technical efficiency and green technical progress are –0.62% and 2.75%, while the GTFP growth mainly comes from green technical progress. Furthermore, the GTFP growth in the eastern region shows a two-wheel-driven pattern of green technical efficiency and green technical progress, while the midwestern region shows a single-wheel-driven pattern of green technical progress. Meanwhile, an examination of the dynamic evolution of GTFP using the nonparametric kernel density estimation method shows that the center of the kernel density curve gradually shifted to the right over time, and the curve crest evolved from a single peak to a double peak, indicating that GTFP has been in the stage of continuous optimization and improvement. However, the regional gap kept expanding, and the synergistic improvement of linkage development still has a long way to go.

Table 1 Average annual growth rates of the GTFP and decomposition terms

Province	GTFP index	Green technology efficiency	Green technology progress	Province	GTFP index	Green technology efficiency	Green technology progress
Beijing	1.08	1.01	1.07	Hunan	1.06	1.00	1.06
Tianjin	1.08	1.02	1.06	Guangdong	0.96	0.96	1.00
Hebei	1.02	0.98	1.03	Guangxi	1.05	1.01	1.04
Shanxi	0.95	0.99	0.97	Hainan	0.99	0.98	1.02
Inner Mongolia	1.00	0.99	1.01	Sichuan	1.06	1.01	1.05
Liaoning	1.00	0.99	1.01	Chongqing	0.98	1.00	0.97
Jilin	1.01	0.99	1.01	Guizhou	1.00	0.98	1.02
Heilongjiang	1.00	0.99	1.01	Yunnan	0.99	0.99	1.00
Shanghai	1.11	1.03	1.07	Shaanxi	0.98	0.98	1.00
Jiangsu	1.07	1.02	1.05	Gansu	1.01	0.99	1.02
Zhejiang	1.08	1.02	1.06	Qinghai	0.97	0.97	1.00
Anhui	1.02	1.00	1.02	Ningxia	1.00	0.98	1.02
Fujian	1.50	1.41	1.06	Xinjiang	1.02	0.99	1.03
Jiangxi	1.15	1.13	1.02	Nationwide	1.04	1.01	1.03
Shandong	1.04	1.00	1.04	Eastern	1.08	1.04	1.04
Henan	1.01	0.99	1.02	Midwestern	1.01	1.00	1.02
Hubei	1.03	1.00	1.03	–	–	–	–

Note: The total of 12 provinces in the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shandong, Jiangsu, Zhejiang, Shanghai, Fujian, Guangdong, Hainan and Guangxi, and the remaining provinces are the midwestern region.

4.3 Model setting

Based on the theoretical analysis, the following econometric model was constructed to test research hypothesis 1.

$$GTFP_{i,t} = \alpha_0 + \phi GTFP_{i,t-1} + \alpha_1 ER_{i,t-1} + \alpha_2 ER_{i,t-1}^2 + \beta X_{i,t} + \mu_i + \eta_t + \varepsilon_{i,t} \quad (4)$$

In equation (4), i and t are province and time, respectively; μ_i denotes province fixed effects, η_t denotes time fixed effects, and $\varepsilon_{i,t}$ is a random error term. $GTFP_{i,t}$ denotes GTFP, bearing in mind that since the GTFP enhancement itself is a process of dynamic change, the current GTFP not only depends on the current period factors, but it is also affected by the previous period factors. Therefore, this study introduces a one-period lag of GTFP to reflect its dynamics and continuity, which makes equation (4) into a dynamic panel model. The advantage of this model is that it accounts for the dynamics and path dependence of GTFP, so it can avoid the endogeneity problem caused by omitted variables, thus making the estimation results of the model more reliable (Yu, 2015). $ER_{i,t-1}$ denotes environmental regulation, and the one-period lagged value is taken for the environmental regulation variable, considering that productive behaviors such as firms' investment decisions usually lag behind environmental regulations. In addition, this approach can effectively alleviate the problem of association bias between GTFP and environmental regulation that may result from bidirectional causality. $ER_{i,t-1}^2$ is introduced to examine whether there is a non-linear relationship between

environmental regulation and GTFP. $X_{i,t}$ are the control variables, which include the level of economic development $EDL_{i,t}$ and its squared term $EDL_{i,t}^2$, human capital $HC_{i,t}$, industrial structure $IS_{i,t}$, energy structure $ES_{i,t}$, factor endowment structure $FES_{i,t}$, and the level of science technology and innovation $R\&D_{i,t}$, as explained later.

To test research hypotheses 2 and 3, the following econometric model was constructed.

$$GTFP_{i,t} = \alpha_0 + \phi GTFP_{i,t-1} + \alpha_1 ER_{i,t-1} + \alpha_2 FDI_{i,t} + \alpha_3 ER_{i,t-1} \times FDI_{i,t} + \beta X_{i,t} + \mu_i + \eta_t + \varepsilon_{i,t} \quad (5)$$

In equation (5), $FDI_{i,t}$ is FDI, and $ER_{i,t-1} \times FDI_{i,t}$ is the interaction term. In order to alleviate the covariance problem between the main term (environmental regulation, FDI) and the interaction term and to make the main term have an economic meaning, the interaction term can be centralized (Dalal and Zickar, 2012), and the other variables have the same meanings as in equation (4). When the coefficients of the interaction term are $\alpha_3 > 0$ and pass the significance test, hypothesis 3 is valid and environmental regulation leads FDI to indirectly promote GTFP, indicating that environmental regulation plays a positive role in the process of "screening" foreign investment as an entry threshold.

4.4 Variables and data description

As stated above, the panel data of 30 Chinese provinces from 2001–2021 were selected as the study sample. The raw data were obtained from the China Statistical Yearbook, China Statistical Yearbook of Industrial Economy, China Statistical Yearbook of Energy, China Statistical Yearbook of Science and Technology, China Statistical Yearbook of Environment, and the statistical yearbooks of each province in previous years. The mean values of data in non-missing years were used for individual missing years. To ensure the smoothness of the data, the natural logarithm values were used for all variables. The specific variables were selected as follows.

(1) Green total factor productivity (GTFP). Given that the GTFP measured by the ML productivity index is the chain growth data, in order to obtain the corresponding absolute values, the absolute value data of GTFP for the 30 provinces in the sample period were calculated by drawing on the adjustment method of Qiu et al. (2008).

(2) Environmental regulation (ER). The existing studies have examined the measurement of environmental regulation from a single dimension, thereby ignoring the fact that environmental regulation is rich in connotation and involves three subjects: government, enterprises and residents, which is somewhat one-sided. Therefore, this study distinguishes environmental regulation into command control, economic incentive, and voluntary agreement types, and it examines the direct and indirect effects of different types of regulatory instruments on GTFP. Following the approach of Peng and Li (2016), command control type regulation was measured by the number of environmental laws and regulations (ERC), economic incentive type regulation was measured by the total emission fee revenue (ERP), and voluntary agreement type regulation was measured by the batch of mass environmental problem petitions (ERS).

(3) Foreign Direct Investment (FDI). The ratio of total actual foreign investment utilized to real GDP, after converting the annual average value of USD to the RMB exchange rate, was used as the measure of FDI.

(4) Control variables. Economic development level (EDL): The gross regional product per capita of each province was chosen as the measure and a squared term was introduced to test whether a U-shaped relationship between GTFP and economic development level exists and whether the environmental Kuznets hypothesis holds. Human capital (HC): The average years of education was used to express HC. Industrial structure (IS): The share of industrial value added in regional GDP was chosen to represent IS. Energy structure (ES): The share of coal consumption converted to standard coal in total energy consumption was chosen to express ES. Factor endowment structure (FES): The ratio of physical capital stock to the number of employed persons was used to express FES. Science and technology innovation level (R&D): This variable was expressed using the share of internal expenditure on R&D to regional GDP.

5 Results

Due to the endogeneity problem of dynamic panel models, this study applied the systematic GMM approach to estimate equations (4) and (5), and then empirically tested the research hypotheses proposed above. Because FEM is based on strict exogenous assumptions, all variables to be included in the study (except for random error) must have real effect sizes, which is an overly demanding research context that is clearly difficult to meet in real research and only applicable to "idealized" research scenarios.

Regarding the validity test of the systematic GMM estimation method, there are generally two ways of academic consensus (Arellano and Bover, 1995). One is the perturbation term differential autocorrelation, which generally allows the first-order differential AR(1) to survive autocorrelation. However, the correlation test of the second-order serial AR(2) must be uncorrelated, and its main function aims to test whether the residuals of the systematic GMM estimation are not serially correlated. When the two-stage autoregression is not serially correlated, that is, the value of AR(2) is greater than 0.1, then the estimation of this equation is valid. The second method is the over-identification constraint test, which is mainly used to verify whether the instrumental variables used in the estimation of the systematic GMM are generally valid. The Sargan test has the ad-

vantage of not being influenced by too many instrumental variables compared to Hansen's suggestion. Therefore, this study referred to Dong and Xia (2022), as well as the empirical approach of Tian et al. (2022), and the Sargan test was used for identification in the empirical evidence.

5.1 Analysis of regression results for the national sample

Table 2 shows that the set dynamic panel model is reasonable according to the Sargan test, as well as the AR(1) and AR(2) tests. The one-period lagged values of GTFP from model 1 to model 6 pass the 1% significance level test, and the estimated coefficients are positive, indicating that GTFP is dynamic and continuous. There is a certain degree of path dependence, as GTFP in the previous period positively contributes to the growth of GTFP in the current period.

In Model 1, the signs of the coefficients of the primary and secondary terms of command control regulation are negative and positive, respectively, but they do not pass the significance test. This indicates that there is no non-linear relationship between command control regulation and GTFP. The coefficients of command control regulation, FDI and their interaction terms in Model 2 do not pass the significance test, which indicates that command control regulation does not have an indirect effect on GTFP through FDI. One possible reason is that command control regulation is characterized by coercive governmental intervention, which directly influences the production behavior of the economy by setting market entry barriers. In this scenario, environmental and technical standards can promote GTFP in the short run, but it is likely to lead to rent setting and rent seeking, which distorts the optimal allocation of resources, and makes it difficult for the direct and indirect effects of environmental regulation to actually promote GTFP.

In Model 3, the primary and secondary coefficients of economic incentive regulation are –0.502 and 2.032, and they pass the 1% and 5% significance tests, respectively. This indicates that as the intensity of incentive regulation

Table 2 Econometric regression results for the national sample

Variables	Command control environmental regulation		Economic incentive-based environmental regulation		Voluntary agreement-based environmental regulation	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$GTFP_{t-1}$	0.291*** (7.99)	0.322*** (6.58)	0.613*** (19.25)	0.580*** (16.10)	0.593*** (20.26)	0.570*** (18.91)
ERC	–0.0211 (–1.26)	0.031 (1.32)				
ERC^2	0.214 (1.10)					
FDI		1.905 (1.36)		–1.238* (–1.94)		–0.749** (–2.24)
$ERC \times FDI$		1.052 (1.24)				
ERP			–0.502*** (–4.18)	0.201*** (5.09)		
ERP^2			2.032** (2.22)			
$ERP \times FDI$				1.093** (2.35)		
ERS					0.182*** (3.03)	0.095* (1.81)
ERS^2					–3.322*** (–2.99)	
$ERS \times FDI$						1.297*** (3.27)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Sargan test	20.037 [1.000]	19.887 [1.000]	25.441 [1.000]	21.932 [1.000]	19.312 [1.000]	21.967 [1.000]
AR(1) test	–3.891 [0.000]	–3.340 [0.000]	–4.023 [0.000]	–4.351 [0.000]	–3.600 [0.000]	–3.744 [0.000]
AR(2) test	1.732 [0.191]	1.652 [0.211]	1.383 [0.123]	1.491 [0.176]	1.842 [0.156]	1.731 [0.161]
Regional effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Time effect	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Number of samples	660	660	660	660	660	660

Note: ***, ** and * denote significance at the 1%, 5% and 10% significance levels, respectively. The data in ( ) are the Z statistic and the data in [ ] are the test probability of the corresponding test.

increases, GTFP shows a "U" shaped trend of decreasing and then increasing, and the direct effect of incentive regulation on GTFP shows a non-linear effect. The direct effect of incentive-based regulation on GTFP shows a non-linear effect. Therefore, research hypothesis 1 is verified. According to the regression results, the inflection point of the incentive-based regulation on GTFP is 0.1235. If the existing incentive-based regulation is stronger than 0.1235, it will be beneficial to GTFP, and vice versa. Setting 0.1235 as the benchmark point, the comparison of the study sample reveals that the regulation intensity in the majority of provinces successfully crosses this benchmark point (Fig. 1), indicating that the current incentive-based regulation tools in most provinces have become the main thrust of green development. In Model 4, the regression coefficients of FDI and its interaction term with incentive-based regulation are –1.238 and 1.093, and they pass the 10% and 5% significance tests, respectively. This indicates that the current foreign investment introduced in China is pollution-intensive and not conducive to GTFP improvement, while the interaction effect of FDI and incentive-based regulation promotes GTFP improvement. Therefore, research hypotheses 2 and 3 are confirmed. The reason for this is that developed countries usually have more stringent environmental regulation standards, so pollution-intensive enterprises move their production to developing countries with lower regulation standards to avoid the high cost of pollution control. This move allows them to maintain the price advantage and competitiveness of their products, which stimulates China's high energy consumption, high emissions and high pollution economic development model, thus making China a "pollution refuge" for developed countries. Although the current FDI inflow has a negative impact on GTFP, a strict incentive-based regulation can prompt the government to continuously adjust and optimize the structure of foreign investment, raise the green threshold for foreign investment entry, play a "screening" role on the quality of FDI, and prioritize the introduction of clean FDI that is conducive to technological upgrading and environmental protection; thus the current FDI inflow can indirectly have a positive impact on GTFP growth.

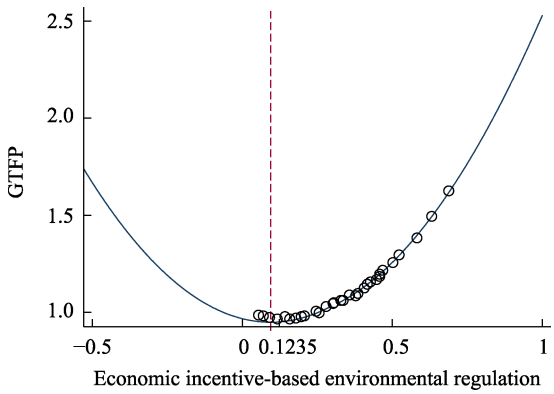

Fig. 1 "U" shaped curve of the relationship between incentive-based regulation and GTFP

In Model 5, the coefficients of the primary and secondary terms of voluntary agreement-based regulation are 0.182 and –3.322, respectively, and both pass the 1% significance test, implying that the direct effect of agreement-based regulation on GTFP has an inverted "U" shaped relationship. Therefore, hypothesis 1 is confirmed. According to the regression results, the inflection point of the inverted "U" curve is 0.0274. By comparing the study samples, only Shanghai, Zhejiang, Jiangsu, Fujian and Hainan are located to the left of the inflection point (Fig. 2), and protocol-based regulation has a positive impact on GTFP. The "voluntary" commitment of enterprises to achieve higher environmental performance motivates them to achieve green technological progress and green efficiency improvements through eco-product certification and environmental management. In the long run, their voluntary and proactive green economic behavior helps to cultivate a good green reputation in the market and increase their green market share, which in turn drives the rise of GTFP. In model 6, the coefficients of FDI and its interaction term with agreement-based regulation are –0.749 and 1.297, and they pass the 5% and 1% significance tests, respectively, indicating that although FDI hinders the GTFP growth channel, the enhancement of agreement-based regulation can positively guide the FDI to have a positive effect on GTFP, and the interaction effect between the two is obvious. Therefore, hypotheses 2 and 3 are confirmed.

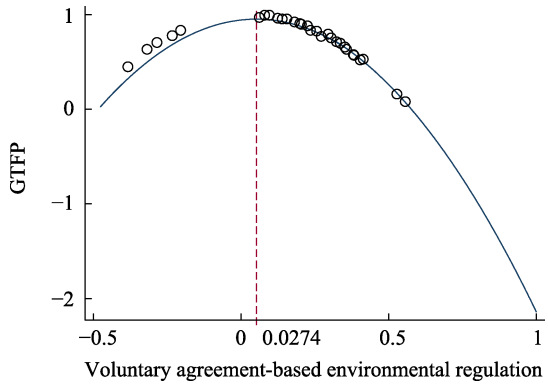

Fig. 2 Inverted "U" shaped curve of the relationship between protocol-based regulation and GTFP

5.2 Analysis of the regression results for regional samples

Considering the regional differences between the eastern region and the midwestern region, this study divided the national sample into these two regions for the regional heterogeneity analysis. Table 3 shows the econometric regression results of the regional samples.

Table 3 Econometric regression results for the regional samples

Variables	Command control environmental regulation		Economic incentive-based environmental regulation		Voluntary agreement-based environmental regulation	
	Eastern	Midwestern	Eastern	Midwestern	Eastern	Midwestern
$GTFP_{t-1}$	0.304*** (3.94)	0.276** (2.10)	0.763*** (7.14)	0.352*** (3.55)	0.502*** (4.03)	0.431*** (3.86)
ERC	–0.202 (–1.18)	–0.323** (–2.18)				
ERC^2	1.233 (0.85)	0.982 (0.70)				
FDI	–1.443** (–2.25)	–1.121 (–1.09)	–2.298*** (–3.18)	–1.903 (–1.34)	–2.092** (–2.33)	–1.364 (–0.47)
$ERC \times FDI$	2.368 (0.99)	–3.086* (–1.97)				
ERP			–0.465** (–2.40)	–0.288 (–1.06)		
ERP^2			4.233** (2.19)	2.496 (1.18)		
$ERP \times FDI$			3.591*** (4.43)	–1.791 (–1.44)		
ERS					–1.359* (–1.94)	–0.544 (–1.12)
ERS^2					6.608* (1.92)	2.956 (1.01)
$ERS \times FDI$					2.438*** (7.10)	–1.432 (–0.78)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Sargan test	12.312 [1.000]	10.073 [1.000]	11.094 [1.000]	9.851 [1.000]	8.733 [1.000]	8.644 [1.000]
AR(1) test	–2.132 [0.039]	–1.903 [0.020]	–2.166 [0.034]	–2.732 [0.010]	–2.086 [0.058]	–1.804 [0.002]
AR(2) test	1.186 [0.254]	–0.679 [0.487]	1.211 [0.172]	–0.764 [0.307]	1.300 [0.187]	0.471 [0.680]
Regional effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Time effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Number of samples	264	396	264	396	264	396

Note: ***, ** and * denote significance at the 1%, 5% and 10% significance levels, respectively. The data in ( ) are the Z statistic and the data in [ ] are the test probability of the corresponding test. The direct effect results are combined with the interaction term results in one table due to space limitations.

The data in Table 3 show that in the eastern region, the coefficients of the primary and secondary terms of command control regulation do not pass the statistical test, indicating that the direct effect of control-type regulation on GTFP does not show a non-linear relationship. The incentive effect of control-type regulation on GTFP has not yet been highlighted, probably because China's top-down control-type regulation, which regulates the production of enterprises by setting clear technical standards or emission standards, has severely constrained the innovative energy of enterprises and caused distortion in the allocation of production factors. Therefore, this type of regulation has not been able to bring into play the "green dividend" of environmental regulation. However, the direct impacts of incentive-based and voluntary agreement-based regulations on GTFP both show "U" shaped relationships, so they can indirectly promote the growth of GTFP by improving the quality of FDI, and the guiding effect of incentive-based regulations on FDI is better than that of agreement-based regulations. According to the calculations, the threshold values of incentive-based regulation and agreement-based regulation are 0.0549 and 0.1028, respectively, and most provinces have successfully crossed the threshold values to realize the "double dividend" of environmental regulation and green development. The root cause of this is the fact that the eastern region, with its location advantage and policy preference, can make full use of foreign advanced technology and management experience in foreign trade, resulting in the rapid accumulation of physical and human capital stocks and the public's gradual preference for the quality of economic development, which in turn leads to a significant increase in public concern and participation in environmental issues. In addition, the estimated coefficients of FDI are negative in all models and they all pass the statistical tests. This may be due to the fact that most of the FDI entering the eastern region is mainly aimed at seeking "quality and

cheap" labor, so it often flows to labor-intensive industries, which is a prominent phenomenon of industrial isomorphism and solidifies the "trade-induced" environment. The "trade-induced" environmental pollution seriously affects the rise of green productivity (Wang and Wang, 2017; Dong and Xia, 2022).

For the midwestern region, the direct effect of command control regulation on GTFP is negatively inhibited at the 5% significance level, the non-linear effect between control-based regulation and GTFP is no longer exhibited, and the interaction term between control-based regulation and FDI has a negative effect on GTFP at the 10% significance level. The incentive effects of incentive-based and agreement-based regulation are not significant and do not show a non-linear relationship, which may be related to the objective conditions in the midwestern region. Chinese decentralization has created a "development hunger" in the region, and local governments have enough incentives to compete for liquid resources to develop the local economy, which leads to the "bottom-up competition" behavior of regulatory policies. At the same time, the region's public is generally less educated, less aware of environmental quality requirements and environmental protection, and less able to cross the threshold of scientific innovation and human capital required for green technology uptake. Therefore, even if environmental regulations are tightened, it would be difficult to effectively guide FDI into green and clean industries or to create effective incentives for GTFP (Fu et al., 2018; Feng et al., 2021).

Comparing the estimation results of the eastern and midwestern regions, it is clear that the heterogeneity of geographical location has an important impact on the GTFP growth effects of environmental regulation, FDI and their interaction terms. Therefore, it is necessary to adopt environmental regulation tools and foreign investment access criteria that are regionally heterogeneous in order to promote the green transformation of economic development patterns and facilitate high-quality economic development.

6 Discussion

To examine the reliability of the empirical results in this study, robustness tests were conducted using the estimated results in Table 2 as the benchmark. In model 7, the GTFP growth rate was re-estimated using the Global Malmquist-Luenberger productivity index based on the traditional directional distance function. In model 8, the reliability of the results was verified by excluding two years of sample data from 2001 and 2021 to compress the sample time. In model 9, the 1% maximum and 1% minimum values of GTFP were excluded to eliminate the effect of the presence of outliers in the study sample on the econometric estimation results. The estimation results of the robustness test (Table 4) show consistency in the signs of the coefficients of the core explanatory variables, with only a few variables changing in significance, indicating good robustness of this study's findings.

Table 4 Robustness test results

Variables	Command control environmental regulation			Economic incentive-based environmental regulation			Voluntary agreement-based environmental regulation		
	Model 7	Model 8	Model 9	Model 7	Model 8	Model 9	Model 7	Model 8	Model 9
ERC	–0.110 (–1.02)	–0.072 (–0.78)	0.019* (1.98)						
ERC^2	0.409 (1.37)	0.511 (0.86)	0.281 (1.71)						
FDI	1.048 (0.98)	1.883 (1.55)	0.900 (0.83)	–1.114** (–2.40)	–0.932*** (–2.99)	–1.307* (–1.96)	–0.873** (–2.31)	–1.463 (–1.51)	–0.894** (–2.24)
ERC×*FDI*	2.210 (1.44)	1.400* (1.96)	1.519** (2.21)						
ERP				–0.202*** (–3.84)	–0.330** (–2.40)	–0.232*** (–5.23)			
ERP^2				1.305** (2.26)	0.856*** (5.82)	1.644* (1.99)			
ERP×*FDI*				1.843* (1.98)	1.277** (2.35)	0.853 (1.49)			
ERS							0.302*** (3.03)	0.244 (0.88)	0.094 (1.12)
ERS^2							–2.029*** (–2.98)	–1.631*** (–4.76)	–0.846** (–2.39)
ERS×*FDI*							0.658** (2.30)	1.974* (1.95)	1.290*** (3.70)

Note: ***, ** and * denote significance at the 1%, 5% and 10% significance levels, respectively, the *Z* statistic is given in parentheses, and the direct effect is combined with the interaction term results in a single table due to space limitations.

7 Conclusions

The main findings of this study are fourfold. First, the average annual growth of GTFP in China is 2.13%, within which the average annual growth rates of green technological efficiency and green technological progress are –0.62% and 2.75%, so the growth of GTFP mainly comes from green technological progress, and the regional disparity is increasing. Second, there is no non-linear relationship between command control environmental regulations and GTFP, while economic incentive and voluntary agreement environmental regulations show "U"-shaped and inverted "U"-shaped relationships with GTFP, respectively. Third, control-type regulations do not have an indirect effect on GTFP through FDI, while incentive-type and agreement-type regulations can indirectly promote GTFP through FDI. Fourth, the control-type regulation and FDI in the eastern region have no incentive effect on GTFP, but the promotion effects of incentive-type and agreement-type regulations are significant, while the control-type regulation in the midwestern region has a negative inhibitory effect on GTFP, and the promotion effects of incentive-type and agreement-type regulations and FDI on GTFP are not obvious.

Based on the findings of the this empirical study, the following policy recommendations are offered.

First, implement a two-wheel drive to boost GTFP growth. On the one hand, the government should continuously increase its investments in green technology research and development, actively cultivate the professional and technical talents required by the green market, and guide enterprises to cross the threshold of green technology. On the other hand, they should resolutely eliminate zombie enterprises with a low green technology level and pollution type, realize the reallocation of production factors in the whole industry, eliminate factor reallocation barriers, and allocate high-quality resources to high green technology and clean levels.

Second, implement differentiated environmental regulation intensities. In view of the large differences in the economic base, environmental technology and endowment structure of different regions, the government should not blindly increase the overall environmental regulation intensity and implement homogeneous environmental regulation policies, but it should implement diverse environmental regulation intensities according to local conditions. For regions that have already crossed the threshold of environmental regulation intensity, the existing regulation intensity should be maintained; but for regions that have not yet crossed the threshold, the regulation intensity should be gradually increased to force enterprises to increase their investment in green technology research and development and improve the level of green technology, which will lead to an increase in GTFP.

Third, rationalize the choice of environmental regulation types. Control-type regulation restricts the discretionary space of enterprises and lacks effective incentives for their R&D of green technologies; while incentive-type regulation is oriented toward the market allocation of resources and can provide internal motivation for enterprises to conduct R&D of cleaner production technologies; and agreement-type regulation can give full play to the subjective initiative of economic agents. Therefore, the government should realize the matching and combined use of various regulatory tools according to the characteristics of these three types of environmental regulations. For the developed eastern regions with a high degree of marketization, incentive-based and agreement-based regulations should be used, while control-based and incentive-based regulations should be applied to the less developed midwestern regions.

Fourth, realize the positive interaction between environmental regulation and FDI. The central government should moderately control the freedom of choice of local governments in implementing environmental regulation policies. This is necessary to avoid the "pollution sanctuary" effect that may arise due to the moral hazard of local governments and the "bottom-up competition" phenomenon of environmental regulation, and to build a rationalized competition platform for environmental regulation. Each region should set their environmental regulations as an important threshold for allowing foreign investment to enter the local market, screen the quality of foreign investment, give priority to foreign investment with high technology and clean and green features, and improve the coupling between environmental regulations and FDI.

Of course, due to the constraints of realistic subjective and objective conditions, this study still has some shortcomings and deficiencies, which need to be explored in greater depth and detail from two main aspects. Firstly, the methodology of the study has yet to be expanded. In the future, we can further draw on the latest research methods and combine the important statements to the 20th National Congress of the CPC on "high-quality development is the primary task of comprehensively building a modern socialist country" and "we should adhere to the theme of promoting high-quality development" to conduct a richer and more complete discussion and expand the research findings. Secondly, the relevance of this study has yet to be improved. In the future, it can be further deepened in various ways, such as specific to the city dimension for portrayal, while combining the key objectives of the respective regions and adjusting the weights of each corresponding indicator, so that the research findings can be more instructive for practice.

References

Arellano M, Bover O. 1995. Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, 68(1):

29–51.

Blackman A, Kildegaard A. 2010. Clean technological change in developing-country industrial clusters: Mexican leather tanning. *Environmental Economics and Policy Studies*, (3): 115–132.

Cheng S S, Zhang F. 2022. Optimal emission-reducing technology selection for green supply chain under penalty-sharing contract. *Soft Science*, 36(10): 131–137. (in Chinese)

Cheng Y S. 2022. Research on the influence of agricultural socialization service on green total factor productivity: Based on the perspective of farmer household's factor endowments. Diss., Hefei, China: Anhui University.

Cheng Y S, Zhang D Y, Zhao M C, et al. 2022. Research on the impact of haze pollution on the high-quality development of the Yangtze River Economic Belt from the perspective of human capital. *Journal of Chongqing University* (*Social Science Edition*), 28(5): 46–60. (in Chinese)

Cui X H, Lin M Y. 2019. How does FDI affect the green total factor productivity of firms?—An empirical analysis based on Malmquist-Luenberger index and PSM-DID. *Economic Management*, (3): 38–55. (in Chinese)

Dalal D K, Zickar M J. 2012. Some common myths about centering predictor variables in moderated multiple regression and polynomial regression. *Organizational Research Methods*, (15): 339–362.

Dong Y D, Xia W H. 2022. Foreign direct invest and green total factor productivity in China: An empirical study based on system GMM and threshold model. *Shanghai Journal of Economics*, 407(8): 94–106. (in Chinese)

Dong Z Q, Wang H. 2019. The "local-neighborhood" green technology progress effect of environmental regulation. *China Industrial Economics*, (1): 100–118. (in Chinese)

Fang Q Y, Liu D. 2020. Environmental regulation, foreign direct investment and urban skill premium—An empirical study based on data from 282 prefectural cities in China. *Urban Problems*, (12): 78–87.

Feng C, Shi B B, Kang R. 2017. Does environmental policy reduce enterprise innovation—Evidence from China. *Sustainability*, 9(6): 872–895.

Feng Y H, Wang X H, Hu S L. 2021. Effects of FDI and OFDI on green total factor productivity in China: An analysis based on spatial econometric models. *Chinese Journal of Management Science*, 29(12): 81–91. (in Chinese)

Fu J Y, Hu J, Cao X. 2018. Different sources of FDI, environmental regulation and green total factor productivity. *Journal of International Trade*, 427(7): 134–148. (in Chinese)

Fukuyama H, Weber W L. 2009. A directional slacks-based measure of technical inefficiency. *Socio-Economic Planning Sciences*, 43(4): 274–287.

Funfgelt J, Schulze G G. 2016. Endogenous environmental policy for small open economies with transboundary pollution. *Economic Modelling*, 57(9): 294–310.

Gai M, Yang Q F, He Y N. 2022. Spatiotemporal changes and influencing factors of agricultural green development level in main grain-producing areas in Northeast China. *Resources Science*, 44(5): 927–942. (in Chinese)

Gray W B. 1987. The cost of regulation: OSHA, EPA and the productivity slowdown. *American Economic Review*, (5): 998–1006.

Jing G W. 2021. Low carbon city pilot policy and location choice of FDI. *East China Economic Management*, 35(12): 43–51. (in Chinese)

Li Z Y, Bai X J. 2020. How does industrial policy promote green total factor productivity in manufacturing industry? Based on the synergistic perspective of encouraging policy and restrictive policy. *Industrial Economics Research*, (6): 28–42. (in Chinese)

Ministry of Commerce. PRC. 2022. China Foreign Investment Development Report (2022): China's actual use of foreign direct investment grows steadily amid structural adjustment. http://chinawto.mofcom.gov.cn/article/ap/p/202212/20221203374648.shtml. Viewed on 2022-12-20. (in Chinese)

Peng X, Li B. 2016. A study on the green transformation of Chinese industry under different types of environmental regulations. *Finance and Economics Research*, (7): 134–144. (in Chinese)

Porter M E, Linde C V D. 1995. Towards a new conception of the environmental-competitiveness relationship. *Journal of Economic Perspectives*, (4): 97–118.

Qiu B, Yang S, Xin P J. 2008. A study of FDI technology spillover channel and productivity growth in China's manufacturing industry—An analysis based on panel data. *World Economy*, (8): 20–31. (in Chinese)

Shapiro J S, Walker R. 2018. Why is pollution from US manufacturing declining? The roles of environmental regulation, productivity and trade. *American Economic Review*, (12): 3814–3854.

Shen H L, Jin D. 2019. Heterogeneous environmental regulation, industrial enterprises R&D and employment skill structure—Empirical study based on the Panel Durbin Model. *Soft Science*, 33(8): 39–43, 53. (in Chinese)

Shen K R, Jin G, Fang X. 2017. Does environmental regulation cause pollution transfer in close proximity? *Economic Research*, (5): 44–59. (in Chinese)

Tian L, Zhang Y Y, Zhang S J. 2022. Research on the dynamic impact of digital inclusive finance on rural revitalization: Test based on system GMM and threshold effect. *Journal of Chongqing University* (*Social Science Edition*), 28(3): 25–38. (in Chinese)

Tone K. 2001. A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, 130(3): 498–509.

Tone K. 2003. Dealing with undesirable outputs in DEA: A Slacks-Based Measure (SBM) approach. *GRIPS Research Report Series* I: 44–45.

Wang S L, Wang X L. 2017. Does service inward foreign direct investment improve green total factor productivity: An empirical study based on China's provincial panel data. *Journal of International Trade*, 420(12): 83–93. (in Chinese)

Wang Y, Shen N. 2016. Environmental regulation and environmental productivity: The case of China. *Renewable & Sustainable Energy Reviews*, 62(9): 758–766. (in Chinese)

Wang Z, Wang L H, Ma Y T. 2020. Economic growth effect of coordinated industrial development—Empirical study based on the coupling of strategic emerging industries and traditional industries. *Journal of Southwest University* (*Social Science Edition*), 46(3): 69–78, 202. (in Chinese)

Wu L, Jia X Y, Wu C, et al. 2020. Impact of heterogeneous environment regulation on green total factors productivity. *China Population, Resources and Environment*, 30(10): 82–92. (in Chinese)

Xiao Y F, Yin H, Liao S H. 2021. Local and neighboring effects of environmental regulation on interregional division of labor in industrial chains: An empirical analysis based on the chemical industry in the Yangtze River Economic Zone. *Economic Geography*, 41(6): 116–125. (in Chinese)

Xu S D. 2017. Capital stock estimation and rate of technological progress in Chinese cities: 1992–2014. *Management World*, (1): 17–29. (in Chinese)

Xu Z W. 2016. Industrial economic development, environmental regulation intensity and pollution reduction effect: A theoretical analysis and empirical test based on the development model of "pollute first, treat later". *Finance and Economics Research*, (3): 134–144. (in Chinese)

Ye J H. 2021. A test on the non-linear relationship between environmental regulation and China's high-quality economic development. *Statistics & Decision*, 37(7): 102–108. (in Chinese)

Yu B B. 2015. Economic growth effects of industrial restructuring and productivity improvement—Based on dynamic spatial panel analysis of Chinese cities. *China Industrial Economy*, (12): 83–98. (in Chinese)

Zhan Y, Li S. 2022. Smart city construction, entrepreneurial vitality and high quality economic development—An analysis based on green total factor productivity perspective. *Financial and Economic Research*, 48(1): 4–18. (in Chinese)

Zhou W Q, Tao L. 2021. Effect of environment regulation on employment from the perspective of spatial spillover effect. *Population & Economics*, (2): 103–116. (in Chinese)

Zhou Z B, Deng L, Xiao H L, et al. 2022. The impact of foreign direct investment on China's high-quality economic development—An analysis based on index DEA and panel quantile regression. *China Management Science*, 30(5): 118–130. (in Chinese)

促进还是抑制？中国环境规制的绿色发展效应：基于 FDI 视角

程永生[1,2]，张德元[2]，汪　侠[1]

1. 阜阳师范大学商学院，安徽阜阳 236032；
2. 安徽大学创新发展战略研究院，合肥 230601

摘　要：提升以绿色全要素生产率（GTFP）为表征的绿色发展效应，是新时代实现高质量发展的关键。利用 2001–2021 年省际面板数据，将能源与环境因素同时纳入分析框架，运用基于 SBM 方向性距离函数的 Malmquist-Luenberger 指数测算 GTFP 及其分解项构建动态面板模型，采用 GMM 方法实证检验三种类型环境规制、FDI 对 GTFP 的直接和间接影响效应。结果显示，中国 GTFP 年均增长 2.13%，绿色技术进步是 GTFP 增长的源泉，GTFP 区域差距呈扩大趋势；命令控制型环境规制不存在非线性效应，经济激励型和自愿协议型环境规制与 GTFP 之间分别表现出 "U" 形和倒 "U" 形关系；控制型规制没有通过 FDI 对 GTFP 产生间接效应，而激励型和协议型规制则可以通过 FDI 间接促进 GTFP 的提升；不同类型环境规制、FDI 的 GTFP 提升效应呈现出区域异质性特征。探究环境规制的绿色发展效应及其特征，对于选取合理化环境规制类型，采用差异化环境规制强度，实施双轮驱动助推 GTFP 增长，实现环境规制与 FDI 良性互动，对促进经济高质量发展，具有重要的理论意义和现实价值。

关键词：环境规制；外商直接投资；绿色全要素生产率；高质量发展