



The Impact of Innovation Activities, Foreign Direct Investment on Improved Green Productivity: Evidence From Developing Countries

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This paper from the perspective of productivity changes examines the impact of innovation activities and foreign direct investment (FDI) on improved green productivity (IGP) in developing countries. We divide the sample into two sub-groups; the BRICS and the other developing countries so as to account for underlying country heterogeneity. The analysis follows a panel data approach over the period 1991 to 2014, and used the global Malmquist-Luenberger productivity index to measure IGP. The results indicate that IGP in developing countries has declined. Innovation activities have a positive impact on IGP. FDI has a significant negative impact on IGP. Further study finds that there are threshold effects between FDI and IGP based on innovation activities, when the developing countries with a low-level of innovation, FDI has a negative impact on IGP; when the developing countries innovation activities above the threshold, innovation activities and FDI both can promote IGP.

Keywords: moderating effect, foreign direct investment, improved green productivity, developing countries, innovation activities

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INTRODUCTION

As environmental pollution has become one of the most challenging issues facing the world, green productivity for sustainable development has received increasing attention (Li et al., 2020a; Zhang et al., 2020; Chevallier et al., 2021). The traditional output growth dependent on heavy resource use, resulting in a lot of pollution to the environment (Li and Lin, 2017). However, green productivity is based on quality rather than quantity; that is, it promotes growth through the creation of new green products, technologies, investments, and environment protection behavior (Chen and Golley, 2014; Li and Lin, 2016; Kroze, 2019). Therefore, enhancing green productivity is an important way of achieving environmental protection and economic development. Numerous studies use total factor productivity (TFP) considering both desirable and undesirable outputs to measure green productivity (Munisamy and Arabi, 2015; Emrouznejad and Yang, 2016; Du et al., 2018). However, the TFP measure considering undesirable outputs does not fully reflect the green part, so this paper introduces improved green productivity (IGP) to reflect the gap between TFP considering undesirable outputs and TFP without considering undesirable outputs.

FDI can promote technological innovation in developing countries through technology spillover effects, and technological innovation is critical for achieving green development (Li et al., 2020b). On the one hand, FDI corporates establish a value chain and industry chain forward and backward linkages to domestic corporates, especially in developed countries to developing countries, the

vertical technology spillover effect is particularly obvious. On the other hand, domestic corporates imitate and learn the advanced management concepts and management methods of FDI corporates. However, does FDI help improve green productivity? The relevant research is based on a certain country as a research sample, and there is a lack of research with an international perspective, and most of the research is focus on TFP, rather than improved green productivity.

Under the requirements of green development, it is necessary to have a new evaluation and understanding of the role of FDI from the perspective of innovation activities, and it is necessary to explore whether the impact of FDI on green productivity is heterogeneous under the influence of innovation activities. Only by correctly understanding the relationship between FDI, innovation activities and green productivity can we implement more effective strategies for different developing countries and ultimately achieve the goal of green development in an all-round way. Therefore, this paper from an international perspective examines the impact of innovation activities and FDI on IGP.

The rest of the paper is organized as follows. **Literature Review** reviews the literature on the relationship between innovation activities, FDI and TFP. **Methodology** based on global Malmquist-Luenberger productivity index introduces IPG to measure the green productivity change. **Research Design** presents the sample countries and data, explains the definition of variables, and constructs empirical models. **Empirical Results** examines the impact of innovation activities and FDI on IGP, and tests whether there is any nonlinear impact of FDI on IGP. Finally, **Conclusion** concludes the paper and suggests policy recommendations.

LITERATURE REVIEW

Innovation activities have always been an effective way to increase green productivity. Endogenous growth theories attribute the important driving force of productivity improvement to innovation activities in various fields (Chen et al., 2019). Innovation can lead to cleaner production activities that reduce environmental pollution and increase productivity. Alvarez-Herranz et al. (2017) confirm the positive effect that the innovation process exerts on environmental pollution. Baumann and Kritikos (2016) find that micro firms benefit in a comparable way from innovation processes like larger firms, as they are similarly able to increase productivity. Innovation brings about technological progress that enables us to use cleaner energy, improves energy efficiency, and reduces pollutant emissions. However, innovation activities are always accompanied by high input and high risk, and a large amount of resources investment may not be rewarded (Li et al., 2018b; Huang et al., 2019). Shen et al. (2019) showed that no evidence was found to show that innovation has spillover effects on TFP. Therefore, this paper wants to find out whether there is a positive impact of innovation activities on IGP and TFP.

FDI is viewed as an engine of productivity growth and development, which embodies technology (Alfaro, 2017). Developing countries spend considerable effort and policies to

attract FDI, by giving costly tax holidays, issuing regulatory exemptions and providing substantial incentives (Liang, 2017). The main reason why developing countries attract FDI is that FDI inflows directly or indirectly increase local firms' productivity and economic development (Demena and van Bergeijk, 2017). Previous studies have suggested that FDI has technology spillover effects and increases the productivity of domestic firms (Kim et al., 2015; Ramasamy et al., 2017; Amoroso and Müller, 2018). Most of the literature focuses on the impact of FDI on TFP, and less on the impacts of FDI on green productivity.

The impact of FDI on green productivity is ambiguous. The impact of FDI on green productivity is primarily through competitive effects, technology spillovers, and pollution shelter effects. On the one hand, the inflow of FDI can intensify competition and form a selection mechanism for survival of the fittest by crowding out the market share of domestic firms, thereby forcing domestic similar firms to carry out technological innovation, improve energy efficiency and reduce environmental pollution (Zhang and Zhou, 2016; Lu et al., 2017). At the same time, the flow of personnel between domestic and foreign-funded firms can significantly promote the overflow of advanced technology and management concepts brought by FDI from foreign-funded firms to domestic-funded firms (Zhang, 2017). In this case, FDI is conducive to the improvement of green productivity. On the other hand, the polluting industries in developed countries are shifting to developing countries to avoid harsh domestic environmental regulations and high environmental costs. To attract more foreign capital, developing countries often relax environmental standards to meet their needs. As a result, developing countries are more engaged in the production of pollution-intensive industries, thus becoming a pollution shelter in developed countries (Millimet and Roy, 2016; Solarin et al., 2017). In this case, FDI will have a negative effect on green productivity.

The study expands and supplements the existing literature in several respects. First of all, most of the researchers study green productivity through undesired output, rather than the gap between TFP considering undesirable outputs and TFP without considering undesirable outputs. Moreover, most of the relevant research based on a certain country as a research sample, and there is a lack of research from the perspective of developing countries level. Last but not least, this paper from an international perspective examines the impact of innovation activities and FDI on IGP, and finds the threshold effects between FDI and IGP based on innovation activities.

METHODOLOGY

Global Malmquist-Luenberger Productivity Index

In measuring TFP, commonly used methods include Solow residual analysis, stochastic frontier analysis and data envelopment analysis (DEA). Since DEA does not need assumptions in advance and requires a specific functional form of the production frontier, it is widely used to measure TFP (Liao and Drakeford, 2019; Shakouri et al., 2019). The traditional DEA

measurement method does not consider the undesirable outputs, and the TFP may be biased (Zhang et al., 2011; Yang et al., 2020). Chung et al. (1997) proposes the Malmquist-Luenberger (ML) index to measure the TFP considering undesired outputs. However, the ML index uses the geometric mean form of two current indices and it is not circular and it faces a potential linear programming infeasibility problem. Oh (2010) therefore proposes the Global Malmquist-Luenberger (GML) index measurement algorithm to overcome the above shortcomings. Fan et al., (2015) used the GML index method to estimate and decompose the total factor CO2 emission performance. Emrouznejad and Yang (2016) analyze and report the manufacturing industries' productivity evolution with respect to CO2 emissions using the GML. Based on the above, GML can be used to measure TFP.

Suppose each country as a decision-making unit uses N inputs, $x = (x_1, x_2, \dots, x_N) \in R_+^N$ to produce M desirable outputs, $y = (y_1, y_2, \dots, y_M) \in R_+^M$, and J undesirable outputs, $b = (b_1, b_2, \dots, b_J) \in R_+^J$. Thus, the production possibility set at time t is defined as:

$$P^t(x^t) = \{(y^t, b^t) | x \text{ can produce } (y^t, b^t)\}, t = 1, 2, \dots, T. \quad (1)$$

In order to measure the problem of undesired output efficiency, Chung et al. (1997) used the directional distance function combined with the traditional Malmquist index to obtain the optimal solution of the production possibility set, and the direction vector is given by $g = (g_x, g_y, g_b)$. Hence, the directional distance function is defined as:

$$\vec{D}_0^t(x^t, y^t, b^t; g) = \sup\{\beta : (y^t + \beta g_y, b^t + \beta g_b) \in P^t(x^t + \beta g_x)\} \quad (2)$$

On the contemporaneous technology set, $g = (-x, y, -b)$, desirable outputs y increases proportionally, while the undesirable outputs b and the input x decreases proportionally, while β seeks for the maximum possible function value which makes desirable outputs y to increase and undesirable outputs b and input x to decrease.

Oh (2010) proposes the concept of a global set of production possibilities, setting a global set of production possibilities using all production set observations over the entire time period as $P^G(x) = P^1(x^1) \cup P^2(x^2) \cup \dots \cup P^T(x^T)$. This set is the union of all current production possibilities sets. Here we construct the global directional distance function as $\vec{D}_0^G(x^t, y^t, b^t; g)$. The GML index can be calculated as:

$$GML_{it}^{t+1} = \frac{1 + \vec{D}_0^G(x^t, y^t, b^t; -x^t, -y^t, -b^t)}{1 + \vec{D}_0^G(x^{t+1}, y^{t+1}, b^{t+1}; -x^{t+1}, -y^{t+1}, -b^{t+1})} \quad (3)$$

GML index indicates the change of TFP of each country from t to $t+1$. If $GML = 1$, this indicates that TFP has not changed. If $GML > 1$, this indicates that TFP has improved. If $GML < 1$, this indicates that TFP has declined.

Improved Green Productivity

Compared with TFP, IGP focuses on green productivity change. Although GML index takes into account undesirable outputs, it

does not reflect the green part in TFP. Based on GML index, we can measure TFP reflecting carbon dioxide emissions. TFP considers the economic benefits and the environmental pollution brought by production to maximize economic benefits and reduce pollution at the same time. Therefore, TFP contains both the green and non-green parts of productivity. Based on the global Malmquist (GM) index, we use the same data and method measuring TFP, which we denote as TFP2, in which carbon dioxide emissions are not considered. The TFP2 only considers the economic benefits brought by production; that is, the maximum economic benefits, ignoring environmental factors. Therefore, TFP2 does not consider the optimization of the green part. The gap between TFP and TFP2 shows improved green productivity.

As the productivity measured by the index based on GML and GM is only the improvement of productivity in each year, to more truly reflect the productivity situation of the year, this paper converts the GML and GM indexes into an improvement index. Then, we use Eqs 4, 5, 6 to get the TFP, TFP2 and IGP.

$$TFP_i^{t+1} = GML_i^{t+1} \times TFP_i^t \quad (4)$$

$$TFP2_i^{t+1} = GM_i^{t+1} \times TFP2_i^t \quad (5)$$

$$IGP_i^t = TFP_i^t - TFP2_i^t \quad (6)$$

Input and Output Variables

This paper analyzes developing countries' TFP from the perspective of factor input and output. According to existing literature, labor, capital and energy consumption are the most frequently used input indicators and gross domestic product (GDP) and carbon dioxide emission are the most frequently used desirable and undesirable outputs, respectively, in measuring environmental efficiency (Zhang, et al., 2016). In this paper, input indicators include energy input, labor input, and capital input. Output indicators include desirable economic output and undesirable environmental pollution indicators. Energy consumption as a ratio of GDP, per unit of energy consumption, is used to measure energy input, where the unit is 1,000 tons. The number of people engaged in the country in millions is taken as labor input. Capital input is measured by capital stock. We employ the perpetual inventory method to estimate the capital stock, which is measured in millions of constant 2010 dollars. Based on previous studies, the real GDP in millions of constant 2010 dollars is used to measure the desirable output. Due to lack of data of other environmental pollutant indicators, carbon dioxide emission discharged during the production is chosen as the only undesirable output and measured in millions of tons.

RESEARCH DESIGN

Sample and Data

This study focuses on the impact of innovation activities and FDI on IGP in developing countries. Developing countries concentrate on producing pollution-intensive products and

primary products, while developed countries specialize in producing clean products and service-intensive products. Developing countries often face serious environmental pollution problems while they develop their economics. Technological progress is the most effective way to reduce environmental pollution (Yin et al., 2015). Innovation activities can reflect the country's potential technological progress. FDI can reflect the potential technological progress brought by foreign countries (Song et al., 2015; Liao et al., 2019). It is therefore important to study how innovative activities and FDI can increase green productivity in developing countries.

In view of the completeness of the data, there is a serious lack of data in most developing countries, so the research sample only retains the 16 developing countries with complete data. According to the economic development features of developing countries, the BRICS countries have stronger comprehensive strength. At the same time, according to the calculation results of this paper, we find that the best performing IGP countries are the BRICS countries. Therefore, this paper considers it necessary to divide the BRICS countries and other developing countries into sub-samples for research. BRICS includes five countries (Brazil, Russia, India, China and South Africa) with the high levels of area, population and development potential development in the world. Our sample includes 11 other developing countries (Argentina, Chile, Egypt, Indonesia, Iran, Mexico, Malaysia, Philippines, Poland, Thailand and Turkey). The data are obtained from the Penn World Table, World Intellectual Property Organization (WIPO) statistics and World Bank database (The latest data available for all 16 countries ends in 2014). Hence, we use annual data for 16 developing countries during the period 1991–2014.

Definition of Variables

The key independent variables of this paper are innovation activities and FDI. Since innovation activities are hard to measure, it has become common practice to use proxy variables in place of innovation activities. As Patent counts measure the outcome of the technological development process, researchers have over the years increasingly relied on patent application counts as one the most important and most reasonable indicators of innovation activities (Johnstone et al., 2010; Lindman and Söderholm, 2016). Therefore, this paper takes the number of patent applications per million (IP) as a measure of innovation activities. In the following, we use IP to refer to innovation activities. The large inflow of FDI not only brings sufficient capital for economic development, but also provides research and development funds for technology improvement. This variable is calculated by the proportion of the net inflow of FDI to the GDP.

We included several control variables in our model to control the factors that potentially affect IGP. The trade openness (OPE) an important factor that may affect the IGP and it is calculated by exports plus imports as a percentage of GDP. The human capital (HC) index quantifies the contribution of health and education to the productivity of the next generation of workers. The industrial level (IS) variable is calculated by the industrial added value as a

percentage of GDP. The energy consumption structure (ES) is calculated by the share of renewable energy in total final energy consumption. The GDP per capita (PGDP) is calculated using 2010 United States constant prices.

Table 1 provides descriptive statistics for all variables in the empirical study. The full sample shows that our primary variable of interest, IGP, is slightly negative with a mean value of -0.034 . This means that overall green productivity has not improved. But there is a big difference between BRICS and other developing countries. The BRICS' IGP is positive with a mean value of 3.1176 , but other developing countries' IGP is negative with a mean value of -1.4666 . The IGP in the BRICS is 4.5842 higher than in other developing countries. The IP in the BRICS is 40.3249 higher than in other developing countries. The ES in the BRICS is 10.195 higher than in other developing countries. These statistics show that the BRICS countries have better capabilities in green production and innovation activities than other developing countries.

Other developing countries perform better than BRICS in certain variables. Their TFP and TFP2 are 0.0076 and 0.1234 , respectively, which are higher than BRICS. We see that the productivity gap between BRICS and other developing countries is significantly reduced after considering the undesired output, indicating that the productivity of other developing countries is slightly higher than BRICS, but at the cost of the environment. FDI, OPEN, HC, IS, and PGDP values in other developing countries are 0.428 , 27.0122 , 0.1201 , 2.4827 , and 749.459 , respectively and higher than BRICS. This shows that other developing countries are more dependent on secondary industries, foreign capital and import and export trade than BRICS.

Model Construction

To investigate the impact of innovation activities and FDI on IGP. We specify the following model.

$$IGP_{it} = \mu_i + \alpha_1 LnIP_{it} + \alpha_2 FDI_{it} + \alpha_3 \sum X_{it} + \varepsilon_{it} \quad (7)$$

In the model described above, for $i = 1, 2, \dots, N$ and $t = 1, 2, \dots, T$ where N and T denote the cross-section and time dimensions of the panel, respectively; IGP is the improved green productivity; LnIP is the natural logarithm of patent applications per million people; FDI is the net inflow of foreign direct investment as a percentage of GDP; X_{it} is a vector of control variables; μ_i represents the individual difference of the sections of each country that do not change with time, that is, the model is an individual fixed effect model, ε_{it} is a random disturbance term.

To further study the threshold effects between FDI and IGP based on innovation activities. The empirical model can be written as follow:

$$IGP_{it} = \mu_i + \alpha_1 FDI_{it} I(LnIP_{it} \leq \phi) + \alpha_2 FDI_{it} I(LnIP_{it} > \phi) + \alpha_3 \sum X_{it} + \varepsilon_{it} \quad (8)$$

where Ln IP is the threshold variable, ϕ is the threshold value, $I(\cdot)$ is the indicator function.

TABLE 1 | Descriptive statistics.

| | Variable | Obs | Mean | Std. Dev | Min | Max |
|----------------------------|----------|-----|------------|------------|-------------|-----------|
| All countries | IGP | 384 | -0.0340 | 5.2772 | -19.0128 | 13.6819 |
| | TFP | 384 | 0.9843 | 0.0923 | 0.6388 | 1.2012 |
| | TFP2 | 384 | 0.9846 | 0.1134 | 0.5466 | 1.2557 |
| | IP | 384 | 102.9750 | 89.4073 | 3.7792 | 680.3470 |
| | FDI | 384 | 2.4230 | 2.0685 | -2.7570 | 11.6540 |
| | OPEN | 384 | 54.7386 | 33.7276 | 10.0252 | 174.7225 |
| | HC | 384 | 2.3914 | 0.4326 | 1.4398 | 3.3572 |
| | IS | 384 | 35.5106 | 5.8943 | 23.8000 | 48.5000 |
| | ES | 384 | 20.9489 | 15.8346 | 0.4384 | 57.8287 |
| | PGDP | 384 | 6,123.8060 | 3,504.3290 | 530.8948 | 14,681.33 |
| BRICS | IGP | 120 | 3.117,633 | 5.062838 | -9.965,652 | 13.68189 |
| | TFP | 120 | 0.9309 | 0.1288 | 0.6388 | 1.0916 |
| | TFP2 | 120 | 0.8998 | 0.1415 | 0.5466 | 1.1617 |
| | IP | 120 | 130.6984 | 117.2784 | 3.7792 | 680.3470 |
| | FDI | 120 | 2.1288 | 1.5602 | 0.0020 | 6.1870 |
| | OPEN | 120 | 36.1677 | 15.4498 | 10.0252 | 63.5528 |
| | HC | 120 | 2.3088 | 0.4916 | 1.5091 | 3.3572 |
| | IS | 120 | 33.8007 | 6.6729 | 23.8000 | 47.6000 |
| | ES | 120 | 27.9549 | 17.5954 | 3.2278 | 57.6048 |
| | PGDP | 120 | 5,608.5530 | 3,591.224 | 530.8948 | 11,915.42 |
| Other developing countries | IGP | 264 | -1.466,598 | 4.729,145 | -19.01282 | 5.565,429 |
| | TFP | 264 | 1.008493 | 0.0549,268 | 0.8,468,096 | 1.201,249 |
| | TFP2 | 264 | 1.0232 | 0.0699 | 0.8580 | 1.2557 |
| | IP | 264 | 90.3735 | 70.0535 | 6.3626 | 299.1377 |
| | FDI | 264 | 2.5568 | 2.2521 | -2.7570 | 11.6540 |
| | OPEN | 264 | 63.1799 | 36.3277 | 17.6881 | 174.7225 |
| | HC | 264 | 2.4289 | 0.3982 | 1.4398 | 3.3272 |
| | IS | 264 | 36.2879 | 5.3393 | 25.3000 | 48.5000 |
| | ES | 264 | 17.7644 | 13.8736 | 0.4384 | 57.8287 |
| | PGDP | 264 | 6,358.0120 | 3,445.554 | 1,444.648 | 14,681.33 |

TABLE 2 | Panel unit root test.

| Variables | LLC | Fisher-ADF |
|-----------|------------------|------------------|
| IGP | -2.2309 (0.0128) | 78.5509 (0.000) |
| IP | -5.3649 (0.000) | 128.8417 (0.000) |
| FDI | -6.0992 (0.000) | 146.5854 (0.000) |
| OPEN | -2.5648 (0.0052) | 106.3543 (0.000) |
| HC | -5.0518 (0.000) | 81.7215 (0.000) |
| IS | -5.8919 (0.000) | 139.9110 (0.000) |
| ES | -4.2178 (0.000) | 114.4868 (0.000) |
| PGDP | -2.9789 (0.0014) | 117.7610 (0.000) |

Note: *p*-statistics are shown in parentheses.

EMPIRICAL RESULTS

The Effect of Innovation Activities and FDI on Improved Green Productivity

Before examining the impact of innovation activities and FDI to IGP, we test for stationarity of all variables applying the Levin-Lin-Chu (LLC) and the Fisher-Augmented Dickey-Fuller (Fisher-ADF) Results displayed in **Table 2** indicate that the LLC and Fisher-ADF tests reject the null hypothesis (non-stationarity) at both the 1 and 5% significance level for all variables used in this study. Hence, we conclude that our data are stationary and hence suitable for the next step of analysis.

Table 3 shows the regression result of the fixed-effect model. For the full sample, the LnIP of the estimated coefficient for IGP is 3.1136, statistically significant at 1%, which indicates that innovation activities have a significant positive effect on green productivity in developing countries. For the BRICS and other developing countries, innovation activities also have a significant positive effect on green productivity. This shows that developing countries can improve green productivity by increasing innovation activities. The innovation activities promote technological advancement, and successful innovation activities lead to more environmentally friendly production activities.

However, the FDI of the estimated coefficient for IGP is -0.2027, marginally significant at 10%, which indicates that foreign capital has a significant negative effect on green productivity in developing countries. For the BRICS and other developing countries, FDI also has a significant negative effect on green productivity in BRICS countries, but the FDI has an insignificant influence on IGP in non-BRICS developing countries. This shows that the impact of FDI on the green productivity of BRICS and non-BRICS countries is heterogeneous. Because the BRIC countries have the characteristics of a large land area, a large population, and rich natural resources. Russia and Brazil have resource advantages. Russia is called the “world gas station”, Brazil is called the “world raw material base”; China and India have relative labor factor cost advantages, China is called the “world factory”, and India is called the “World Office”. These advantages have brought a lot of foreign investment to the BRIC countries and accelerated their

TABLE 3 | Basic regression.

| Dependent variable | Whole | BRICS | Other developing countries |
|--------------------|--------------------|--------------------|----------------------------|
| LnIP | 3.1136*** (7.07) | 6.2474*** (7.09) | 0.9566** (2.15) |
| FDI | -0.2027* (-1.67) | -1.1876*** (-5.7) | 0.1826 (1.54) |
| OPEN | 0.0492** (2.12) | 0.0491 (0.9) | 0.0593*** (2.74) |
| HC | -6.1878*** (-4.01) | 6.4641*** (3.39) | 5.2386* (2.02) |
| IS | 0.1397** (2.27) | 0.3176*** (3.76) | 0.0038 (0.05) |
| ES | 0.0162 (0.25) | -0.5761*** (-5) | 0.2527*** (4.12) |
| LnPGDP | -1.7292 (-1.15) | -15.432*** (-7.26) | -13.049*** (-5.41) |
| Intercept | 8.907 (0.79) | 95.0303*** (6.71) | 84.8734*** (5.01) |
| N | 384 | 120 | 264 |
| R ² | 0.1967 | 0.7474 | 0.2840 |

Note: *t*-statistics are shown in parentheses below the estimated coefficients. ***, **** and ***** Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

economic development, but they have brought a lot of pollution to the environment. Developed countries transfer resource and labor-intensive industries to the BRIC countries through FDI, resulting in FDI reducing the green productivity of the BRIC countries.

With the continuous development of the global economy, resource and environmental issues are becoming increasingly prominent. Developed countries have gradually attached importance to their own resources and environmental issues, and adopted strict environmental regulations to restrict the development of high energy consumption and high pollution industries and industrial chains in the country. The polluting industries in developed countries are shifting to developing countries to avoid harsh domestic environmental regulations and high environmental costs. In order to attract more foreign capital, developing countries often relax environmental standards to meet their needs. As a result, developing countries are more engaged in the production of pollution-intensive industries, thus becoming a pollution shelter in developed countries.

FDI as a collection of resources such as technology, management, human capital, and financial capital, has an important impact on the technological innovation of the host country, which in turn affects the host country's IGP. As an important factor of economic growth, technological innovation is the driving force and source for maintaining long-term sustainable economic development. Therefore, developing countries hope to stimulate local technological innovation and increase IGP through technological spillovers of FDI. Cheung and Ping (2004) believe that FDI can benefit innovation activity in the host country via spillover channels and find positive effects of FDI on the number of domestic patent applications. FDI boosts innovation activity, which in turn enhances firm productivity (Howell, 2019). Therefore, we need to further consider the interaction between FDI and innovation.

To further investigate the impact of FDI on IGP, we interact LnIP with FDI. From Table 4 results, we can find the coefficients of LnIP are positive for IGP and statistically significant at the 1% level in the whole and BRICS sample, which indicates that innovation activities have a significant positive effect on green productivity. And the coefficients on the interaction terms are 0.2972, 0.7495 and 0.1898, statistically significant at the 10% level or better, which indicates that FDI has a positive moderating effect on the impact of innovation activities on green

productivity. Because the introduction of FDI will promote domestic innovation activities with higher standards, it is more conducive to cleaner production.

FDI still has a significant negative impact on green productivity, but innovation activities have a positive moderating effect on the impact of FDI on green productivity. The coefficients of FDI are negative for IGP and statistically significant at the 1% level in the whole and BRICS sample, which indicates that increasing FDI is not conducive to green production. But the coefficients on the interaction terms are positive for IGP and statistically significant at the 10% level or better in all samples, which indicates that innovation activities have a positive moderating effect on the impact of FDI on green productivity. The improvement of domestic innovation level will correspondingly improve the quality of FDI, thereby reducing the impact of FDI on the environment.

Threshold Effects for the Innovation Activities

Non-linear effects are widespread in the study of economic issues (Papaioannou, 2017; Serdar and Ismet, 2019). According to the results from Table 3 and Table 4, we can find that the impact of FDI on IGP in different samples is heterogeneous. In the theoretical analysis, we also argued that the impact of FDI on green productivity is ambiguous. On the one hand, FDI will increase IGP through technology spillover effects. On the other hand, FDI will decrease IGP through developed countries transfer high energy consuming and high polluting industries to developing countries. Therefore, under different innovation activities level, the impact of FDI on IGP may be different (Li et al., 2018a). Therefore, it is necessary to further consider the non-linear relationship between FDI and IGP.

The threshold model can divide the sample into multiple intervals based on the characteristics of the data itself and the estimated threshold value endogenously, and estimate the relationship between variables in each interval. In order to study the nonlinear relationship between the variables mentioned in the theoretical analysis, this paper uses a fixed-effect panel threshold model to study the threshold effect of variables, trying to find the nonlinear relationship between FDI and IGP.

TABLE 4 | Moderating effect on IGP.

| Dependent variable | Whole | BRICS | Other developing countries |
|--------------------|--------------------|--------------------|----------------------------|
| LnIP | 2.6161*** (5.57) | 4.7251*** (5.71) | 0.6383 (1.34) |
| FDI | -1.4733*** (-3.2) | -4.3698*** (-7.24) | -0.6289 (-1.32) |
| LnIP*FDI | 0.2972*** (2.86) | 0.7495*** (5.54) | 0.1898* (1.76) |
| OPEN | 0.0483** (2.1) | 0.0599 (1.24) | 0.056** (2.59) |
| HC | -5.0127*** (-3.17) | 8.8718*** (5.09) | 6.2163** (2.35) |
| IS | 0.1698*** (2.75) | 0.4442*** (5.68) | 0.0143 (0.2) |
| ES | 0.0108 (0.17) | -0.781*** (-7.2) | 0.2616*** (4.27) |
| LnPGDP | -2.6965* (-1.77) | -20.269*** (-9.77) | -13.379*** (-5.56) |
| Intercept | 15.2957 (1.34) | 136.79*** (9.34) | 86.1853*** (5.1) |
| N | 384 | 120 | 264 |
| R ² | 0.2145 | 0.8039 | 0.2929 |

Note: *t*-statistics are shown in parentheses below the estimated coefficients. ***, **** and ***** Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

TABLE 5 | Test for the existence of threshold.

| Independent variable | Sample | Hypothesis test | F | p-value | Critical values | | |
|----------------------|----------------------------|------------------|-------|---------|-----------------|---------|---------|
| | | | | | 90% | 95% | 99% |
| IGP | Whole | Single threshold | 43.21 | 0.026 | 27.4516 | 34.746 | 50.0056 |
| | | Double threshold | 9.35 | 0.629 | 23.8082 | 29.5005 | 46.4618 |
| | BRICS | Single threshold | 42.79 | 0 | 20.3163 | 24.6146 | 32.8766 |
| | | Double threshold | 8.68 | 0.474 | 18.9374 | 23.4459 | 29.9216 |
| | Other developing countries | Single threshold | 24.43 | 0.052 | 19.3378 | 24.8804 | 38.1114 |
| | | Double threshold | 11.61 | 0.309 | 16.8431 | 19.4869 | 28.5719 |

Note: *p*-value and threshold values are from repeating bootstrap 1,000 times.

TABLE 6 | Panel threshold regression.

| Independent variable | Sample | Threshold values | Variables | Coefficients | Std. error |
|----------------------|----------------------------|------------------|-----------|--------------|------------|
| IGP | Whole | LnIP < 3.7453 | FDI | -0.9625*** | 0.1762 |
| | | LnIP > 3.7453 | FDI | 0.3547** | 0.1427 |
| | BRICS | LnIP < 3.8219 | FDI | -2.336*** | 0.2701 |
| | | LnIP > 3.8219 | FDI | -0.4941** | 0.2307 |
| | Other developing countries | LnIP < 3.6608 | FDI | -0.3865** | 0.1717 |
| | | LnIP > 3.6608 | FDI | 0.5618*** | 0.1329 |

Note: ***, **** and ***** Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

To examine the threshold effects between FDI and IGP based on innovation activities, we carry out the first part of the threshold effects by determining the number of thresholds. **Table 5** provides the single-threshold and double-threshold effects result between FDI and IGP based on innovation activities. The single-threshold effect is first tested to see if it exists. By using bootstrap estimation 1,000 iterations, we find that the test for a single-threshold is highly significant in all sample countries. However, the test for a double-threshold effect is insignificant, with *p*-value of 0.629, 0.474 and 0.309, respectively. Thus, we conclude that there is a single-threshold effect of FDI on IGP in all of the regression relationships.

Table 6 reports the panel threshold regression result for the single-threshold effect of FDI on IGP. In the whole sample, where the LnIP is less than 3.7453, the coefficient is negative and statistically significant at the 1% level, indicating that an increase in FDI will reduce IGP. When the LnIP is greater than 3.7453, the coefficient is positive and statistically significant at the

5% level, indicating that an increase in FDI will enhance IGP. Therefore, when the developing countries with low-level of innovation activities (the number of patent applications per million less than 42.32), FDI has a negative impact on green productivity; that is, other countries will hurt the domestic environment by transferring polluting industries. When developing countries with high-level of innovation activities (the number of patent applications per million greater than 42.32), FDI has a positive impact on green productivity. Because the domestic innovation level reaches a certain level, some low-end polluting industries cannot enter through FDI, so that FDI can bring high-end technologies and have a positive impact on green production.

In the BRICS, FDI has always had a negative impact on IGP. When the LnIP is less than 3.8219, the coefficient is negative and statistically significant at the 1% level. When the LnIP is greater than 3.8219, the coefficient is also negative and statistically significant at the 5% level. But, when the BRICS innovation activities level from low to high, the negative impact of FDI

on green productivity is greatly reduced (from -2.336 to -0.4941). Because, compared with other non-BRICS developing countries, the BRICS have the characteristics of large land area, large population and good infrastructure, developed countries are more inclined to invest some labor-intensive industries in the BRICS, so FDI brings more pollution to BRICS than other developing countries. Even now, China and India are still the world's factory. Therefore, even when BRICS has a high level of innovation activity, FDI still has a negative impact on green productivity.

In the other non-BRICS developing countries, with the level of innovation activities from low to high, the impact of FDI on IGP will change from negative to positive. When the LnIP is less than 3.6608, the coefficient is negative and statistically significant at the 5% level. When the LnIP is greater than 3.6608, the coefficient is positive and statistically significant at the 1% level. The threshold value of LnIP is lower than BRICS, which indicates that BRICS need more innovation activities than other developing countries to change the impact of FDI on IGP.

CONCLUSION

In this paper, based on the global Malmquist-Luenberger productivity index, we have introduced an IGP index to measure the green productivity change for 16 developing countries over the period 1991 to 2014. The data are subdivided into the BRICS and non-BRICS developing countries to study the impact of innovation activities and FDI on IGP. The main conclusions drawn from this analysis are as follows.

First, innovation activities have a positive impact on IGP, but have a negative impact on TFP. Because innovation activities require a large amount of investment in the initial stage and cannot form effective output, and the success probability of innovation itself is low, resulting in a large amount of waste of resources and reduced production efficiency. But innovation activities continue to promote technological advancement, and successful innovation activities lead to more environmentally friendly production activities.

Second, FDI has a significant negative impact on IGP, but has a positive impact on TFP. The free flow of global trade and capital will lead to the pollution-intensive industries transfer to the developing countries. In order to reduce environmental governance costs and enhance competitive advantage, corporate will transfer from developed countries with strict environmental regulations to developing countries with relatively loose environmental regulations. This making developing country has gradually become a "refuge" for pollution-intensive industries. At the same time, FDI will improve TFP by bringing advanced production technology, management systems and business ideas to developing countries.

Third, the impact of FDI on IGP has a single threshold effect based on innovation activities. When the developing countries with a low-level of innovation, FDI has a positive impact on TFP, but has a negative impact on IGP; when the developing countries innovation activities above the threshold, innovation activities and FDI both can promote IGP.

Based on the conclusions of the empirical study, some policy implications are discussed as follows. When developing countries have low levels of innovation, they can increase productivity by actively introducing FDI, but at the expense of the environment. The impact of FDI on the environment can be reduced by improving innovation activities. When innovation reaches a certain level, innovation and FDI can jointly promote green productivity. Developing countries can find trade-offs between innovation activity and FDI can be sought to find situations that increase productivity without compromising the environment.

Our approach has relied on the number of patent applications per million as a measure of innovation activities. In addition to the number of patent applications, however, R&D is another important indicator to measure innovation activities. But this paper has not yet obtained relevant data. And our sample is limited to 16 developing countries.

Future research could add value two folds: First, compare the heterogeneity of the impact of different innovation activities on green productivity. Second, compare the impact of FDI and innovation on green productivity between developing and developed countries.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, SX and ZL; methodology, ZL; software, ZL; validation, SX and ZL; formal analysis, SX and ZL; investigation, SX and ZL; resources, SX; data curation, SX; writing—original draft preparation, SX and ZL; writing—review and editing, SX and ZL; visualization, SX and ZL; supervision, SX and ZL; project administration, SX and ZL; funding acquisition, SX and ZL. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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