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Sustainable relationship between FDI, R&D, and CO_2 emissions in emerging markets: An empirical analysis of BRICS countries

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Abstract

This paper empirically analyzes sustainable relations between inward FDI (IFDI), outward FDI (OFDI), the R&D expenditure ratio and CO_2 emissions based on balanced panel data from the BRICS (namely, Brazil, Russia, India, China and South Africa) countries for the period 2003–2017. Generally, the results confirm a negative effect of IFDI and a positive effect of OFDI on the R&D expenditure ratio, both with statistical significance. Further exploration of the IFDI, OFDI and R&D impacts on CO_2 emissions was based on an assumption that innovation development mitigates environmental pollution. The research outcome revealed positive associations between IFDI and the R&D expenditure ratio with CO_2 emissions, showing the connection of environmental pollution to growth-focused national economic strategies. Based on these results, we recommend the following policies: (1) rethinking domestic industries protectionism trends and research support to enhance FDI spillover effects, (2) the drafting of New Development Bank specific environment-friendly investment programs aimed at innovation activities, and (3) looking into further easing the green technologies from developed countries.

Keywords: foreign direct investment, FDI, research and development, R&D, environment pollution, panel analysis.
JEL classification: C01, O19, P33, P45.

1. Introduction

The modern economy is fueled by the flows of cross-country capital movements to obtain global competitiveness amongst differently endowed countries (Moon et al., 1995; Moon et al., 1998). FDI is a form of these international capital movements, which has a direct effect on economic growth and indirect effect

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on innovation development via spillover effects (Johnson, 2006; Yao and Wei, 2007; Pegkas, 2015; Herzer and Donaubauer, 2018; Khachoo et al., 2018, etc.). As economies are improved to achieve sustainable development, much emphasis is put on innovation (Posch and Steiner, 2006; Kardos, 2012) and this has in turn led to a line of studies investigating FDI spillover effects on innovation activities. In addition, the growing significance of environmental pollution and its negative impact on economic sectors significantly spurred researchers to explore the association of innovation development with mitigating effects of air pollution (for instance, CO_2 emissions) (Fernández et al., 2018; Yu and Du, 2019; Chen and Lee, 2020; Cheng et al., 2021).

BRICS (namely, Brazil, Russia, India, China and South Africa), the leading developing countries, are also making efforts to increase the stability of their economies, but at the same time they are largely dependent on investment flows and innovative cooperation to achieve their goals. BRICS countries are striving for structural transformations that will ensure the modernization of their economies and the development of modern knowledge-intensive industries (Lankapotu, 2020).

BRICS nations' leaders have regularly confirmed that joint work in the field of science, technology and innovation has remained a priority area of cooperation between them. It would seem that BRICS states have great potential due to their complementary scientific basis, and their goal of technical development, as well as huge markets for high-tech products (Kovalev and Shcherbakova, 2019). However, it is visible from the GDP proportion allocated to research activities that although China has been showing significant progress in developing a national innovation structure, the corresponding progress of other BRICS nations has been stagnating to a large extent (Table 1). Each country has its own set of reasons, but the result seems to indicate that a significant portion of technologies has to be transferred from developed countries.

In terms of FDI flows, the overall heterogeneous nature of the BRICS shows a general momentum toward the inflow side (Sumathy and Dhanasekaran, 2021). The FDI in question is a composite term combining the sum of equity capital, reinvestment of earnings, and other capital, having a cross-border control or a significant degree of influence on the management of an enterprise in another economy. As can be seen from Table 2, FDI turnover reliance has been a significant trait of all BRICS economies within most of the period of time studied. Noticeable FDI flows, while having the potential to hold back local R&D development (Azman-Saini et al., 2018), certainly have contributed to the construction of the state innovation structure through accompanying tech transfer.

Table 1
Research and development expenditure (R&D) of BRICS, 2003–2017 (% of GDP).

Country	2003	2008	2013	2017
Brazil	0.999	1.129	1.196	1.263
Russia	1.286	1.044	1.025	1.107
India	0.719	0.859	0.706	0.666
China	1.120	1.446	1.998	2.145
South Africa	0.760	0.888	0.725	0.832

Source: World Bank (2021).

Table 2
Foreign direct investment (FDI) of BRICS, 2003–2017 (billion U.S. dollars at current prices).

Country	FDI direction	2003	2008	2013	2017
Brazil	Total	10.352	76.832	90.855	90.226
	Net Inflows	10.123	50.716	75.211	68.885
	Net Outflows	229.000	26.115	15.644	21.341
Russia	Total	17.653	130.446	155.725	65.314
	Net Inflows	7.929	74.783	69.219	28.557
	Net Outflows	9.724	55.663	86.507	36.757
India	Total	4.920	62.663	29.918	51.056
	Net Inflows	3.682	43.406	28.153	39.966
	Net Outflows	1.238	19.257	1.765	11.090
China	Total	66.357	228.277	363.899	304.377
	Net Inflows	57.901	171.535	290.928	166.084
	Net Outflows	8.456	56.742	72.971	138.293
South Africa	Total	1.336	7.765	14.752	9.508
	Net Inflows	783.000	9.885	8.233	2.059
	Net Outflows	553.000	–2.120	6.520	7.449

Source: World Bank (2021).

Table 3
CO_2 emissions of the BRICS, 2003–2017.

Country	2003		2008		2013		2017	
	Billion tons	Ratio (%)	Billion tons	Ratio (%)	Billion tons	Ratio (%)	Billion tons	Ratio (%)
World	27.176	100	31.946	100	34.987	100	35.696	100
BRICS	7.759	28.55	11.349	35.53	14.400	41.16	14.804	41.47
Brazil	0.318	1.17	0.380	1.19	0.495	1.41	0.4846	1.36
Russia	1.525	5.61	1.637	5.12	1.619	4.63	1.646	4.61
India	1.059	3.90	1.463	4.58	2.033	5.81	2.457	6.88
China	4.452	16.38	7.375	23.09	9.797	28.00	9.751	27.32
South Africa	0.404	1.49	0.495	1.55	0.456	1.30	0.466	1.31

Source: Ritchie and Roser (2020).

The studied period of time has also been marked by a growing pressure for updating the development of global capital markets to new economic realities — the threat of climate change, water scarcity, general natural resource depletion and other factors related to human activity (Ranjbari et al., 2021). Some, like the European Union, promote basic consensus around Sustainable Development as a way to sustain stable economic and industrial development. The adoption of the European Green Deal 2030 declared the intention of developed countries to pay serious heed to the dangers of climate change and invest heavily in R&D activities in an effort to reduce CO_2 emissions through innovative transformation of their economies. However, it is evident that the role of the BRICS nations (being the most populated states with goods per capita income growth prospects) in achieving the Sustainable Development agenda is crucial. As shown in Table 3, the proportion of CO_2 emissions of the BRICS nations in the world has consistently increased from 28.55% to 41.47% for the period 2003–2017.

The economies of BRICS countries have had diverse development paths over the last two decades, predominantly based on import substitution and active industrial policy ideology. It can currently be stated that BRICS productive competencies have a slightly greater technological content and complexity compared to other developing countries (Santiago, 2020). However, the BRICS industrial sector includes a significant portion of extraction, utilities, manufacturing and construction industries (Kutu and Ngalawa, 2016), consuming an increasing amount of energy and consequently inflating their CO_2 emission ratios (Stolyarova, 2013). However, the development of the BRICS has led to an increasingly high innovation and FDI turnover within the group. Also, despite the trend of increasing the share of the services sector and de-carbonization efforts, the decrease in emissions has not yet shown serious pace. With this regard, this study focused on investigating FDI spillover effects on innovation development in the BRICS nations (which were chosen as the most representative examples of developing countries). R&D expenditure ratio is selected as a proxy for innovation development. The authors of a large number of previous studies estimate FDI spillover effects by employing total factor productivity (TFP) (for instance, Herzer, 2011; Amann and Virmani, 2015; Herzer and Donaubauer, 2018; Vujanović et al., 2021). However, as stated by Stiebale and Reize (2011), productivity development may not be the optimal measurement of a domestic firm's performance. The current study adopts R&D expenditure ratio as another proxy to estimate the direct effects of FDI on innovation activities. Also, the current research attempts to deal with both inward and outward FDI to reflect a discussion on newly industrialized countries' (NIC) outward FDI. Contrary to conventional developed economies whose outward FDI is in line with asset exploitation, that of NICs aims at asset-seeking and is considered as a learning opportunity from abroad for bringing higher technologies back to their home countries (Eden and Dai, 2010, p. 20; Pradhan, 2010; Elia and Santangelo, 2017). Finally, considering the growing significance of sustainable development, the study further explored the impacts of (inward and outward) FDI on CO_2 emissions, assuming that investments are a contributing factor of innovation development that should mitigate the emissions in question. In terms of methodology, as a baseline study, we utilized fixed effects (FE) and fixed effects generalized least square (FE-GLS). For the robustness and control of endogenous variables, fixed effects 2 stage least square (FE–2SLS-GLS) was also applied. We assume that the achievements of this study can be applied to other developing economies to accelerate technological progress and strengthen sustainable development.

The remaining paper is structured as follows. Section 2 covers the literature review on inward and outward FDI's impacts on innovation development and environmental pollution. Section 3 presents the data and model specifications. Panel analyses are carried out in Section 4. Lastly, in conclusion, we provide policy directions related to FDI and innovation activities for the BRICS nations.

2. Literature review

Positive impact of FDI on national economies can be direct and indirect: the former is measured by FDI's contribution to market size expansion or economic growth, while the latter is achieved via spillover effects leading to production, technology and managerial innovations, which are used as a basis for economic development. The spillover effects of FDI are discussed in a variety of studies, but the results are mixed depending on the period, the proxy use for innovation, country of research, and the direction of the FDI (inward or outward).

It is evident that a multitude of studies have previously explored the relationship between inward FDI and productivity development. Herzer and Donaubauer (2018) in their study on 49 developing countries for the period 1981–2011 demonstrate that inward FDI is negatively associated with TFP in the long-term, while the magnitude of these negative impacts varies according to other control variables (i.e. human capital, financial condition, openness). Vujanović et al. (2021) investigate the impacts of three types of inward FDI spillovers (i.e., horizontal, backward and forward spillovers) on TFP in Croatia and Slovenia's manufacturing and services sectors during the pre- and post-financial crisis (2006–2014) period, but the results are inconsistent depending on the sector, country and type of spillover. This inconsistent relation of inward FDI to innovation is also shown in Khachoo et al.'s (2018) study of Indian manufacturing firms which approaches innovation in three aspects (R&D, patents and TFP). The study revealed that FDI spillover effects are more associated with companies in high-tech industries.

In addition, there are studies which investigate the association of outward FDI with productivity growth. Herzer's (2011) study demonstrates a positive long-run effect of 33 developing countries' outward FDI on their home countries' TFP development. The same results are presented in his follow-up study on Germany based on datasets during 1980–2008 (Herzer, 2012). Amann and Virmani (2015) further clarify that outward (inward) FDI to (from) developed economies contribute to the TFP growth of developing economies based on the datasets of 18 emerging and 34 OECD countries from 1990–2010. Li et al. (2016) also test reserve spillover effects derived from outward FDI based on datasets of 29 Chinese regions from 2003–2013 which support a positive relation of outward FDI to productivity growth when the technology gap with host countries is low or moderate.

Meanwhile, innovation development is estimated by various proxies other than productivity growth to verify its association with FDI. Cheung and Ping (2004) demonstrate innovation development (proxied by three different types of patent applications) derived from inward FDI in Chinese regions based on data for the period 1995–2000. In a similar manner, Khachoo and Sharma's (2016) research, which adopted patent grants as a dependent variable to test the spillover effects of inward FDI on the Indian manufacturing companies, reveals a positive association between inward FDI and innovation development, but much more evident than that in the supplying sectors. Hoang et al. (2021), in their firm-level analysis, verify a positive relation of inward FDI to technology innovation in Vietnamese companies (that are located in Hanoi). The positive effects of inward FDI in terms of knowledge spillovers are also addressed in Vahter's (2011) study of Estonian manufacturing firms. Huang and Zhang (2020) test both inward and outward FDI's effects on innovation development for Chinese firms located in Shandong province during 2002–2007 and find significant positive innovation spillovers for both of them, especially outward FDI.

In contrast, in a case study of Czech manufacturing firms, Kinoshita (2000) insists that inward FDI itself does not create spillover effects, but does so only when it is in conjunction with R&D. In addition, Iwasaki and Tokunaga's (2016) research further demonstrates insufficient productivity spillover effects from inward FDI in transition economies.

Meanwhile, a growing awareness of environmental issues has led scholars to demonstrate a linkage between innovation and CO_2 reductions in recent years. The impacts seem to be applied differently depending on the country of research, but are much positively sufficient in economically developed areas. For example, Fernández et al. (2018) reveal that R&D helps to decrease CO_2 emissions in the EU(15) and US, but it does not in China. Chen and Lee (2020) insist that there is no significant impact of R&D on CO_2 reductions on a global level, but its impacts are shown to be significant in high-income, high-technology and high-CO_2 emission countries. In a follow-up study, the positive impact of technological innovation on the reduction of CO_2 emissions is supported by Cheng et al.'s (2021) study by scoping down datasets to 35 OECD countries. Yu and Du (2019), in their study on Chinese provinces during 1997–2015, also induce similar results: the CO_2 mitigation effects of innovation are significantly stronger in high-speed growth provinces than low-speed growth provinces.

On the other hand, multiple studies demonstrate the nexus between FDI and environment pollution to test whether the former is a factor in the degradation of the environment of host countries as a trade-off for economic growth, but the results of different studies do not reach common ground (Aliyu, 2005; Hoffmann et al. 2005; Yang et al., 2008; Hitam and Borhan, 2012; Jun et al., 2018; Mukhtarov et al., 2020).

To conclude, the impact of (inward and outward) FDI would not appear to have any universal common ground and its results vary, depending on the country, period, industry and methodology. The same goes for the relationship of (inward and outward) FDI, innovation development and CO_2 emissions. In this respect, our study is focused on the BRICS countries with fresh datasets by employing three different types of econometric techniques (which are FE, FE-GLS and FE2SLS-GLS).

3. Data, methodology and model specification

The empirical analysis employed in this study utilizes country-level panel data of BRICS countries for the period of 2003–2017. Detailed data descriptions and data sources are shown in Appendix A. A descriptive data analysis for every variable—which are *RnD*, *IFDI*, *OFDI*, Ln(CO_2), *Capital*, *Human*, *Growth* and *TFP*—is provided in Table 4. It presents mean, standard deviation, minimum and maximum values of dependent and independent variables in our models. The results of skewness and kurtosis reveal that each variable is normally distributed.

To construct a theoretical model, Cheung and Ping's (2004, pp. 28–29) innovation to FDI equation is employed, but divides *FDI* into inward and outward FDI as follows:

$$I = f(L, K, IFDI, OFDI), \quad (1)$$

where *L* and *K* denote labor and capital inputs and *IFDI* and *OFDI* denote inward and outward FDI, respectively. Our study assumes that both *IFDI* and *OFDI* are positive and important factors of innovation development. For estimations, the effects of *FDI* are measured both in year *t* in Eq. (2) (Herzer and Donaubauer, 2018) and year *t* – 1 in Eq. (3) (Cheung and Ping, 2004) to test immediate and 1-year lagged (considering the time needed to absorb knowledge) effects of FDI.

Table 4
Descriptive data analysis ($N = 75$).

Variables	Mean	Std. dev.	Min.	Max.	Skewness	Kurtosis
RnD	1.097159	0.374005	0.665840	2.145120	1.301147	4.135171
IFDI	0.023867	0.011676	0.002295	0.045543	0.019128	2.081229
OFDI	0.012270	0.010231	–0.007391	0.037735	0.741123	2.846303
Ln(CO_2)	7.177878	1.092386	5.760503	9.192213	0.497954	2.088286
Capital	28.17224	10.18719	14.63039	46.66012	0.548989	1.701193
Human	2.555156	0.455518	1.826568	3.403041	0.419059	2.225992
Growth	4.117771	4.032594	–7.827749	13.63582	–0.314371	3.085264
TFP	1.594437	3.141662	–7.226635	10.52120	–0.287746	3.546523

Source: Authors' calculations.

Based on the above theoretical equation, the following two types of econometric equations are rendered:

$$RnD_{it} = \beta_0 + \beta_1 IFDI_{it} + \beta_2 OFDI_{it} + \beta_3 Human_{it} + \beta_4 Capital_{it} + \\ + \beta_5 Growth_{it} + \gamma_{it} + \varepsilon_{it}, \quad (2)$$

$$RnD_{it} = \beta_0 + \beta_1 IFDI_{it-1} + \beta_2 OFDI_{it-1} + \beta_3 Human_{it} + \beta_4 Capital_{it} + \\ + \beta_5 Growth_{it} + \gamma_{it} + \varepsilon_{it}, \quad (3)$$

where: *RnD* (a proxy for innovation development)—R&D expenditure ratio (% of GDP); *IFDI*—net inflows (U.S. dollars)/GDP (U.S. dollars); *OFDI*—net outflows (U.S. dollars)/GDP (U.S. dollars); *Human*—human capital index (based on years of schooling and returns of education); *Capital*—gross capital formation ratio (% of GDP); *Growth*—per capita GDP growth (annual %) (considering that the economic development is related to absorptive capability). In addition, *i* is an index for a country and *t* is an index for an year. γ_{it} represents country-fixed effects and ε_{it} is an error term. Our key variables are *IFDI* and *OFDI*, while the other remaining variables are utilized as control variables.

This study additionally derives Eq. (4) to verify the sustainable relationship between R&D, FDI and CO_2 emissions. To consider the period necessary for absorbing innovation development through *RnD* and *FDI*, one-year-lagged variables are also tested according to Eq. (5). The equations are as follows:

$$\mathrm{Ln}(CO_2)_{it} = \beta_0 + \beta_1 RnD_{it} + \beta_2 IFDI_{it} + \beta_3 OFDI_{it} + \beta_4 TFP_{it} + \gamma_{it} + \varepsilon_{it}, \quad (4)$$

$$\mathrm{Ln}(CO_2)_{it} = \beta_0 + \beta_1 RnD_{it-1} + \beta_2 IFDI_{it-1} + \beta_3 OFDI_{it-1} + \\ + \beta_4 TFP_{it-1} + \gamma_{it} + \varepsilon_{it} \quad (5)$$

where CO_2—a natural logarithm of CO_2 emissions (million tons); *TFP*—growth (%). *RnD*, *IFDI* and *OFDI* are used as key independent variables. *TFP* is included as a control variable by employing the notion of the environmental Kuznets curve (EKC) (Stern, 2004). We posit that productivity development may have CO_2 mitigation effects such as reducing factory processing hours per product unit.

In terms of methodology, at first this study attempted to apply country fixed effects models in the beginning. But country fixed effects models had cross-section correlations for all units as the p-value of the BP-LM test was below 0.05. Thus, to handle cross-section dependence, this study further employs fixed effects (FE) with GLS weights, cross-section Seemingly Unrelated Regression (SUR) (Sarafidis and Wansbeek, 2012). In addition to baseline regression models, FE–2SLS-GLS (with cross-section SUR weights) regression analyses are conducted for robustness. 2SLS is helpful to control when an independent variable is correlated with an error term (the issue of endogeneity) by applying the method of instrumental variables (IV) (Wooldridge, 2015). For the regression analysis, we considered key independent variables (due to the potential simultaneity with the dependent variable, *RnD*) as endogenous variables and the $t-1$ and $t-2$ lagged of them are used as instrument variables (in these times-series of *IFDI*, *OFDI* and *RnD* are autocorrelated and thus those activities are highly related to those in the previous year). For Eq. (4) and (5), the results of a Granger causality test proved a causality from Growth to TFP (a control variable) and from Growth to Ln(CO_2) (a dependent variable) at the 5% significance level, Growth (an omitted variable in the model, which affects both independent and dependent variables) is exploited to capture the endogeneity of TFP for the 2SLS regression analysis.

As shown in Table 5, Pearson correlation tests are carried out on dependent and key explanatory variables. *RnD*–*IFDI* and *RnD*–Ln(CO_2) present a positive co-movement at the 1% significance level. *IFDI*–Ln(CO_2) shows a positive coefficient at the 5% significance level. Except for *RnD*–Ln(CO_2), the correlation coefficients ranged between 0.076729 and 0.388752, which may not cause multicollinearity at a linear function. As the correlation coefficient of *RnD*–Ln(CO_2) is above 0.5, it

Table 5
The coefficients of Pearson correlation.

Variables	RnD	IFDI	OFDI	Ln(CO_2)
RnD	1.000000			
IFDI	0.388752***	1.000000		
OFDI	0.095951	0.092755	1.000000	
Ln(CO_2)	0.650668***	0.270314**	0.076729	1.000000

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations.

Table 6
Variance Inflation Factor (VIF) tests.

Dependent variable	RnD		Ln(CO_2)	
	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)
RnD	–	–	1.230577	–
RnD(–1)			–	1.280438
IFDI	1.238627	–	1.203332	–
IFDI(–1)	–	1.188551	–	1.260611
OFDI	1.983311	–	1.013518	–
OFDI(–1)	–	1.885459	–	1.018947
Human	2.493244	2.509757	–	–
Capital	2.069807	2.253906	–	–
Growth	2.041140	1.891945	–	–
TFP	–	–	1.095110	–
TFP(–1)			–	1.089001

Source: Authors' calculations.

has a potential multicollinearity issue in the estimation. In this respect, multicollinearity is further conducted before running FE, FE-GLS, and FE–2SLS-GLS regression analyses. Table 6 shows the Variance Inflation Factors (VIF) of explanatory variables in the four different models in our study for the pooled ordinary least square regression model. As no variable presents VIF above 5, there is no concern of multicollinearity at all in our regression models (Menard, 2001).

4. Panel data analysis

The panel analysis is carried out by using Eviews (ver. 11). We applied GLS weights (cross-section SUR) to FE and FE–2SLS regression analyses to handle cross-section dependence. As shown in Tables 7 and 8, the *p*-value of the BP-LM test is above 0.05, indicating cross-section correlations of units are resolved in GLS weighted models. Table 7 presents the effects of IFDI and OFDI on RnD. IFDI negatively affects RnD with strong statistical significance in the (1) FE, (2) FE-GLS and (3) FE2SLS-GLS regression models. The same results are consistently present when conducting regressions by lagging one year in (4) FE, (5) FE-GLS and (6) FE2SLS-GLS regression models. This indicates that FDI inflows in the BRICS nations lead to negative innovation spillovers. This can be partially explained by the fact that FDI (in the case of mergers and acquisitions) could deteriorate the R&D activities of host countries' firms as foreign firms relocate important R&D activities to their headquarters (Stiebale and Reize, 2011). In addition, the nature of FDI inflows in developing countries can serve as a possible explanation, as the most successful industries of BRICS countries are mining, agriculture, basic materials, chemical, etc. rather than high-tech industries. As revealed in previous studies, the level of spill-over effects varies to a large extent (Vujanović et al., 2021), and it is evident in high-tech industries (Khachoo et al., 2018).

OFDI presents positive coefficients at 10% significance levels in (2) FE-GLS and (3) FE2SLS-GLS regression models. However, the coefficient signs of 1 year-lagged OFDI present mixed outcomes: in (5) FE-GLS regression model, it shows a positive coefficient at the 1% significance level; while, in (4) FE and (6) FE2SLS-GLS regression model, its statistical significance disappears. This means that outward FDI contributes to innovation development to some extent, although its positive effects could not offset the negative effects from inward FDI. The result is in line with those in previous studies (Herzer, 2011; Herzer, 2012; Amann and Virmani, 2015; Li et al., 2016). These results can be explained by the FDI outflows from developing to developed countries based on resource-based theory. Developing countries' multinational companies are motivated to invest in developed countries for strategic asset-seeking by considering FDI as a learning process (Eden and Dai, 2010, p. 20; Pradhan, 2010; Elia and Santangelo, 2017).

In terms of control variables, the human capital index and the gross capital formation ratio consistently show a statistically positive relationship to the R&D expenditure ratio as expected from Eq. (1). Meanwhile, it is worth noting that Growth shows a statistical negative association with RnD. This implies that income growth of the BRICS nations does not increase national R&D expenditure. There may be different explanations for this result, depending on the way it is approached. As noted above, BRICS is not a homogenous set of countries, and in the last decade Brazil, Russia, and South Africa have suffered a drop in GDP per capita, while India and

Table 7
The relationship between *IFDI*, *OFDI* and *RnD* in BRICS, 2003–2017.

	Dependent variable: RnD					
	(1) FE	(2) FE-GLS	(3) FE2SLS-GLS	(4) FE	(5) FE-GLS	(6) FE2SLS-GLS
IFDI	–4.894617**	–2.903959***	–9.752749***	–	–	–
	(1.949985)	(0.822258)	(2.006414)			
IFDI(–1)	–	–	–	–4.359677**	–3.490788***	–10.299990***
				(1.777275)	(0.713831)	(2.291407)
OFDI	2.014982	2.346997*	7.933830*	–	–	–
	(2.656647)	(1.181310)	(4.277609)			
OFDI(–1)	–	–	–	2.511971	2.512381***	3.117150
				(2.507802)	(0.831396)	(6.410033)
Human	0.332282**	0.321836***	0.391716***	0.313774**	0.359010***	0.396215***
	(0.128733)	(0.054693)	(0.079459)	(0.131008)	(0.043833)	(0.073605)
Capital	0.023553***	0.014661***	0.014489***	0.021704***	0.017632***	0.019966***
	(0.006879)	(0.002976)	(0.004954)	(0.006903)	(0.002344)	(0.004108)
Growth	–0.009277	–0.012334***	–0.006256	–0.016104**	–0.013543***	–0.013942***
	(0.007064)	(0.002854)	(0.004706)	(0.006529)	(0.002057)	(0.003752)
Constant	–0.285118	–0.046905	–0.149674	–0.176250	–0.208345	–0.205794
	(0.390809)	(0.164213)	(0.244079)	(0.422350)	(0.124845)	(0.228272)
BP-LM test stat (Prob)	52.36147	7.002344	5.647129	51.02263	4.362508	6.218088
	(0.0000)	(0.7252)	(0.8440)	(0.0000)	(0.9295)	(0.7966)
Prob (*F*-statistics)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Adjusted R^2	0.845797	0.941000	0.910864	0.876536	0.968328	0.940732
N	75	75	70	70	70	65

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Country fixed effects are applied.
Source: Authors' calculations.

Table 8
The relationships between *IFDI*, *OFDI*, *RnD* and Ln(CO_2) in BRICS, 2003–2017.

	Dependent variable: Ln(CO_2)					
	(7) FE	(8) FE-GLS	(9) FE2SLS-GLS	(10) FE	(11) FE-GLS	(12) FE2SLS-GLS
RnD	0.668296***	0.659407***	0.754554***	–	–	–
	(0.117383)	(0.030634)	(0.073808)			
RnD(–1)	–	–	–	0.590310***	0.550580***	0.606109***
				(0.112700)	(0.046211)	(0.069616)
IFDI	3.534820*	2.329441***	15.50278***	–	–	–
	(2.056413)	(0.602115)	(3.984779)			
IFDI(–1)	–	–	–	3.948807**	2.740672***	12.875840***
				(1.932821)	(0.677559)	(2.892095)
OFDI	–3.064185	–2.503244***	1.980097	–	–	–
	(2.845193)	(0.846378)	(11.18935)			
OFDI(–1)	–	–	–	–3.340740	–3.150517***	8.190162
				(2.671809)	(0.994707)	(7.482044)
TFP	–0.002046	0.004283*	–0.010560	–	–	–
	(0.007835)	(0.002499)	(0.008307)			
TFP(–1)	–	–	–	–0.001513	0.004987*	–0.010919
				(0.007180)	(0.002679)	(0.008294)
Constant	6.401147***	6.422693***	5.976517***	6.502002***	6.561761***	6.143336***
	(0.148659)	(0.035712)	(0.201843)	(0.139770)	(0.055685)	(0.135671)
BP-LM test stat (prob)	54.32741	8.050668	8.317877	40.35681	4.476235	13.33697
	(0.0000)	(0.6239)	(0.5978)	(0.0000)	(0.9233)	(0.2054)
Prob (*F*-statistics)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Adjusted R^2	0.978863	0.997018	0.978477	0.982666	0.996397	0.977323
N	75	75	70	70	70	65

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Country fixed (random) effects are applied.
Source: Authors' calculations.

China enjoyed a rather stable growth of this indicator. This might imply that in some countries the spending on R&D could not keep up with the rate of growth, while in others it suffered from anti-crisis cost cutting policies. However, another possible justification for this outcome is that innovation spending does not necessarily grow in parallel with national per capita wealth because the latter is situational and cannot be precisely predicted annually, while R&D spending in the BRICS nations is largely government-based, and is subject to long-term budget-planning.

Table 8 describes the effects of IFDI, OFDI and RnD (a proxy for innovation development) on CO_2 emissions. RnD and IFDI are positively and significantly associated with Ln(CO_2), regardless of year-lagging in (7) FE, (8) FE-GLS, (9) FE2SLS-GLS, (10) FE, (11) FE-GLS and (12) FE2SLS-GLS regression models. Also, (inward and outward) FDI is not related to CO_2 mitigation effects in the BRICS nations. The negative impact of FDI inflows on CO_2 emissions in the BRICS countries could potentially contribute to further research of the pollution havens theory, stating that economic factors aside, lower environment regulations could have been the driver for relocating polluting industries to developing countries (Javorcik and Wei, 2001; Guzel and Okumus, 2020). It may be that this trend has possibly not yet expired even in the more sophisticated economies of the BRICS nations.

However, the negative relation between R&D expenditures and CO_2 emissions in BRICS leaves a lot of room for discussion and further research. The highest potential is within the possible connection between the industrial output of BRICS nations and planned R&D budgets. As R&D expenses tend to be funded by BRICS governments, their increase would be politically more justified in times of industrial growth, leading to more export and taxation income. However, due to the largely non-emission-friendly character of the BRICS industries, the growth of industrial output leads to a rise in CO_2 emissions, leading to a consecutive relation between R&D expenses and the latter. However, due to the diverse character of the BRICS nations, this hypothesis needs to be researched on a more detailed basis per country.

The coefficient sign of OFDI and TFP does not match between FE, FE-GLS and FE2SLS-GLS typed regression models. Their statistical significance only appears in FE-GLS typed models regardless of year-lagging. It indicates the absence of statistical robustness in outcomes.

5. Conclusion

This paper conducted two strands of studies based on panel datasets from BRICS nations for the 2003–2017 time period by employing FE, FE-GLS and FE2SLS-GLS regression analyses. Firstly, the spillover effects of inward and outward FDI on innovation development (measured by R&D expenditure ratio) were examined. The results of this panel data analysis disprove spillover effects from FDI inflows, while simultaneously supporting them with regard to FDI outflows. It is likely that FDI inflows (in the case of mergers and acquisitions) worsen the R&D activities of host countries' firms as foreign firms relocate important R&D activities to their headquarters (Stiebale and Reize, 2011). The results also can be explained by the nature of FDI inflows in developing countries, concentrated on low-tech industries (which have relatively unclear spill-over effects compared to those in high-tech industries) (Khachoo et al., 2018). This is partially supported by the fact that the BRICS countries utilize outward FDI predominantly for asset-seeking, which is in line with the resource-based view of internalization (Eden and Dai, 2010, p. 20; Pradhan, 2010; Elia and Santangelo, 2017; Liang et al., 2021). However, the positive effects of FDI outflows on innovation development do not offset the accompanying negative effects of FDI outflows on it.

Secondly, taking into account growing environmental challenges and sustainable development goals, the authors further investigated a nexus of (inward and outward) FDI and R&D expenditure ratio to CO_2 emissions, including TFP growth as a control variable. Contrary to the authors' assumption regarding the mitigation effects of innovation development on CO_2 emissions based on the existing literature (Fernández et al., 2018; Yu and Du, 2019; Cheng et al., 2021), FDI inflows and R&D expenditures significantly increase CO_2 emissions among the BRICS nations. This implies that the BRICS nations' innovation activities are still mainly aimed at further economic growth itself without much consideration for environmental sustainability. In addition, the negative impact of FDI inflows on CO_2 emissions is likely derived from the fact that eased environment regulations (compared to those in developed countries) have been the driver for transferring the polluting industries to developing countries (Javorcik and Wei, 2001; Guzel and Okumus, 2020).

The above results from empirical analysis allow us to draw a few policy implications. First, the empirical results above—the negative association of FDI inflows with the R&D expenditure ratio—point to the need for rethinking traditional protectionism patterns in domestic industries and research areas. The statistical relationship between a level of protectionism or privatization and FDI spillover effects has been proven in Moralles and Moreno (2020)'s study in Brazil and Wang and Wu's (2016) study in China. Despite the modern protectionism trends and sanction wars in the world economy, effective R&D still cannot be achieved by each of the BRICS nations alone, and would require shifting to developed country's investment patterns—with a significantly larger merger and acquisitions share. To achieve this, the BRICS countries would need to reconsider the patterns of state ownership in consistency with both global changes and their national innovation strategies.

Second, it is empirically demonstrated that FDI inflows increase CO_2 emissions and this can be explained by a lack of BRICS's colossal program to modernize domestic basic industries up to EU sustainability and emission standards. Thus, it is important for the policymakers to consider the possibility of launching a specific environment-friendly international investment program. The latter could be formed through the structure of BRICS-associated New Development Bank and would fund innovation projects specifically dealing with the environmental restructuring of BRICS industry.

The last point concerns the recently drafted European Green Deal, which aims to turn the EU into the first emission-free region and at the same time prepares a set of economic fines on products coming from emission-based economies (BRICS nations included). However, draining financial resources from developing countries in such a way would obviously fail to create the sufficient incentive or capacity in the BRICS industries to invest in actual modernization. The results of empirical analysis confirmed the resource-based view of internationalization in terms of FDI outflows. In this respect, reaching an agreement with the BRICS nations on relieving the intellectual property regulations in green technologies transfer seems to be a much more efficient activity on the part of the EU in moving toward an emission-free planet.

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Appendix A. Variable descriptions and sources

Variables	Descriptions	Sources
RnD	R&D ratio (% of GDP)	World Bank (2021)
IFDI	FDI net inflow (U.S. dollars) / GDP (U.S. dollars)	World Bank (2021)
OFDI	FDI net outflow (U.S. dollars) / GDP (U.S. dollars)	World Bank (2021)
Ln(CO_2)	CO_2 emission (million tons)	Ritchie and Roser (2020)
Capital	Gross capital formation (% of GDP)	World Bank (2021)
Human	Human Capital Index (based on years of schooling and returns to education)	PWT (2021)
Growth	GDP per capita growth (annual %)	World Bank (2021)
TFP	TFP growth (%)	TED (2020)

Source: Compiled by the authors.