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Effectiveness of environmental policies on carbon emissions: A panel threshold analysis[1]

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Abstract: The aim of this study is to test the possible non-linear effect of environmental policy stringency on carbon emissions and thus make policy recommendations for emission reduction. For this purpose data for the period 1995–2015 for selected emerging countries were used. According to the findings obtained from fixed-effects panel threshold regressions environmental policy stringency has no significant effect on the relationship between gross domestic product *per capita* and carbon dioxide emissions. However, it has statistically significant effect if the share of the service sector and the foreign direct investment are taken as regime-dependent variables. Accordingly, in the high policy stringency regime an increase in the share of the service sector and the foreign direct investment reduce emission levels. In the case of using market-based environmental regulations the threshold effect faced by foreign direct investment is much more pronounced. In order to reduce carbon emissions it is recommended to increase environmental policy stringency, especially in market-based tools.

Keywords: carbon emissions, environmental policy stringency, threshold models.

JEL codes: H23, Q53, Q58.

Introduction

Climate change is one of the most challenging global problems today. In recent years storms and forest fires in many parts of the world have adversely affected environmental quality in connection with global temperature increases due to climate change. Moreover environmental pollution is considered as one of the causes of death and many important diseases today. According to the First World Health Organization Global Conference on air pollution and Health (WHO, 2018) air pollution is estimated to cause seven million deaths per year and more than half of all pneumonia deaths in children under five years of

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age are caused by air pollution. Based on the negative effects of climate change one of the United Nation's (UN) sustainable development goals has been determined as climate action.

Unfortunately, the predictions for the future are not comforting either. The Intergovernmental Panel on Climate Change (IPCC, 2018) points out that we will face painful environmental problems sooner than we expected. In this process greenhouse gases and the resulting air pollution are seen as the most important causes of climate change. Therefore, it is crucial to investigate the determinants of greenhouse gases to find policy alternatives to reduce it.

According to Pigou (1920), environmental degradation creates externalities that market forces cannot solve on their own and government intervention is needed to reduce the threat to the ecosystem. Environmental policy is one of the main tools of environmental governance. At this point the most frequently used tools can be divided into two: market-based and non-market-based environmental policies. While both instruments create an explicit or implicit cost for polluting market-based instruments work through price signals.

Although there are many studies in the literature to find out the determinants of environmental pollution and carbon dioxide (CO_2) emissions yet in particular studies that test the effects of environmental policies and policy stringency have only developed in recent years. Yet in none of these studies was environmental stringency policy index modelled to act as a mediator in the relationship between carbon emission and its determinants. However, it is thought that environmental policy stringency may affect the behaviour of economic agents and thus have indirect effects on the pollution level. Therefore, this study aims to empirically test these indirect effects. For that purpose it focuses on six emerging countries including Brazil, the Russian Federation, India, Indonesia, China and South Africa (BRIICS). These countries are responsible for nearly 47% of the world's CO_2 emissions in 2020 (BP, 2021) and have relatively less stringent environmental policies (The environmental policy stringency index of Organization for Economic Co-operation and Development (OECD) is 1.03 in 2012) than the highly developed economies (the 2012 average of the index for OECD countries is 2.90) (OECD, 2021).

This paper contributes to the literature in several ways. First, instead of focusing solely on environmental taxes an overall policy index is used. In fact, there are some challenges in measuring environmental policy stringency (Brunel & Levinson, 2016). Firstly, it is difficult to balance the multidimensionality of environmental regulations, secondly, there are problems with identification and thirdly, the problem of missing data often arises. However, EPS (environmental policy stringency) of OECD uses a comprehensive index that includes both economic incentives and command and control regulations (Wang, Yan, Wang & Chang, 2020). This index is an internationally comparable measure of environmental policies and allows the investigation and comparison of the effects of market-based and non-market-based regulations.

Secondly, the panel threshold methodology of Hansen (1999) which allows the observation of non-linear relationships and determination of a specific threshold value that has a regime-switching effect is used. This technique uses asymptotic distribution theory to construct confidence intervals for the parameters and a bootstrap method to assess the statistical significance of the threshold effects. However, the main reason why the method was preferred in this study is that it allows the threshold value to be determined for the policy variable. Depending on whether the policy stringency is above or below the threshold it will be possible to formulate more concrete policy recommendations. Additionally, by using this method the multicollinearity problem that may arise if the products and squares of the variables are used, has been removed. Thirdly, this study focuses on the BRIICS countries which are generally emerging economies with less environmental policy stringency and which account for around half the world's CO_2 emissions. Lastly, when examining the effects of environmental policies on emissions, there is a differentiation between market-based regulations and non-market-based regulations. Thus this study had the opportunity to observe which types of policies are more effective and make policy recommendations accordingly.

The rest of the paper is organized as follows. The following section briefly reviews the relevant literature on carbon emissions, its determinants and environmental regulation. The next section presents data and methodology while last two sections show the empirical findings and conclusion.

1. Literature review

Environmental quality is of great significance for both developed and developing countries and there is vast literature investigating environmental quality (Yakubu, Salamzadeh, Bouzari, Ebrahimi, & Fekete-Farkas, 2022). In particular the relationship between environmental quality and economic development has attracted the attention of researchers especially after the study of Grossman and Krueger (1991) which asserts an inverted U-shaped relationship. Thereafter the relationship was named "Environmental Kuznets Curve (EKC)" by Panayotou (1993), Grossman and Krueger (1995) and Stern, Common and Barbier (1996). Accordingly, economic expansion increases the level of pollution in the early stages of development. Nevertheless, pollution starts to decrease with the shift of production to the services sector and the adoption of environmentally-friendly technologies.

There is a huge amount of literature that tries to find out the determinants of environmental degradation and test the validity of the environmental Kuznets curve (e.g., Cole, Rayner, & Bates, 1997; Perman & Stern, 2003; Aslanidis & Iranzo, 2009; Narayan & Narayan, 2010; Saboori & Sulaiman, 2013; Chen & Huang, 2014; Heidari, Turan Katircioglu, & Saeidpour, 2015; Esso & Keho, 2016;

Aye & Edoja, 2017; Hanif, 2017; Yasin, Ahmad, & Chaudhary, 2021). Some of them consider non-linear effects when testing determinants of CO_2 emissions and the environmental Kuznets curve. Accordingly, Aslanidis and Iranzo (2009), Chen and Huang (2014) and Heidari and others (2015) tested the non-linear relationships between economic growth and CO_2 emissions using the panel smooth transition methodology. Aslanidis and Iranzo (2009) confirmed the existence of non-linear effects for non-OECD countries, Chen and Huang (2014) for thirty six country groups, and Heidari and others (2015) for five ASEAN countries. Additionally, Saboori and Sulaiman (2013) and Yasin and others (2021) tested the non-linear effects on income on environmental degradation by using the square of income variable. While the findings of Yasin and others (2021) confirmed the environmental Kuznets curve in a group of 59 less developed countries Saboori and Sulaiman (2013) confirmed the environmental Kuznets curve for Thailand and Singapore.

Aye and Edoja (2017) tested the effect of economic growth on CO_2 emissions using a dynamic panel threshold model. Their sample consisted of a panel of 31 developing countries. They analysed the effects separately for middle and low-income groups. Because they used the panel threshold methodology they were also able to observe the regime-switching effects of the growth. The findings of the study surprisingly pointed to an U-shaped relationship between economic growth and CO_2 emissions instead of an inverted U-shaped relationship.

Another economic variable that is frequently addressed as a possible determinant of environmental pollution in the literature is foreign direct investment (FDI). While the pollution haven hypothesis suggests that regulatory stringency in developed countries shifts high polluting industries to the developing world with less environmental regulations (Levinson & Taylor, 2004) the pollution halo hypothesis suggests that foreign direct investments contribute to the host country's reduction of emissions due to green technology transfer (Mert & Caglar, 2020, p. 32934). It is worth noting that the pollution haven hypothesis is based on the scale effect mentioned by Grossman and Krueger (1995) while the pollution halo hypothesis is based on technology, composition and policy effects. In the relevant literature there are both findings supporting the pollution haven hypothesis (e.g., Blanco, Gonzalez, & Ruiz, 2013; Kivyiro & Arminen, 2014; Gokmenoglu & Taspinar, 2016; Bae, Li, & Rishi, 2017; Hanif, Raza, Gago-de-Santos, & Abbas, 2019; Temurlenk & Lögün, 2022) and ones supporting pollution halo hypothesis (e.g., Pao & Tsai, 2011; Kivyiro & Arminen, 2014; Hao & Liu, 2015; Mert & Boluk, 2016; Rafindadi, Muye, & Kaita, 2018; Balsalobre-Lorente, Gokmenoglu, Taspinar, & Cantos-Cantos, 2019; Mert & Caglar, 2020).

Although there is much literature on the economic determinants of pollution the effects of some policy tools such as regulation on environmental degradation have only recently been considered by several studies (Hashmi & Alam, 2019; Ahmed, 2020; Neves, Marques, & Patricio, 2020; Wang, Yan et al., 2020; Demiral & Demiral, 2021; Demiral, Akca, & Tekin, 2021; Albulescu, Boatca-

Barabas, & Diaconescu, 2022). From these studies Hashmi and Alam (2019) tested the effects of environmental regulation on CO_2 emissions in 29 OECD countries by using fixed effects, random effects and GMM methodologies. They used environmental tax revenue as the policy indicator. They observed a negative relationship between environmental tax revenues and CO_2 emissions.

Ahmed (2020) investigated the effects of environmental regulations on CO_2 emissions in twenty OECD countries by using panel ARDL methodology. He used the environmental policy stringency index of OECD as an indicator of environmental regulation. His findings revealed that higher policy stringency reduces carbon emissions in the long run. Neves and others (2020) tested the effects of regulation on CO_2 emissions in seventeen EU countries by using the same method as Ahmed (2020). However, they employed different indicators of environmental regulation. They used environmental tax revenue and accumulated number of renewable energy sources policies of the International Energy Agency (IEA). Their findings confirmed the finding of Ahmed (2020) for EU countries and showed that regulation is effective in reducing CO_2 emissions in the long run.

Wang and others (2020) expanded the previous analyses by focusing on different air quality indicators such as fine particulate matter (PM2.5), NO*x* and SO*x* emissions in addition to CO_2 emissions. The authors benefited from panel data of twenty three OECD countries and used a system generalized method of movements. According to their findings more stringent environmental policies diminish the emission of all the indicators of air quality.

Demiral and Demiral (2021) tested the mediating effects of environmental policy stringency on the relationship between FDI and on green/gray growth for some selected developed and emerging countries. Their results indicated a positive relationship between inward FDI stocks and growth with a mediating effect of environmental policy stringency. In another study Demiral and others (2021) examined the determinants of CO_2 emissions for fifteen large greenhouse gas emitter countries. These countries consist of eight high-income and seven middle-income economies. The authors used the environmental policy stringency index of OECD as the regulation indicator. However, they observed that higher policy stringency increases the level of CO_2 emissions in the cases of all sample and middle-income economies. The effects were found to be statistically insignificant in the high-income economies. The authors argued that the direction of the effects of policy stringency depends on the effectiveness of the outcomes from those policies. According to this, especially in developing countries, industries will continue to pollute as long as the marginal revenue to be obtained from polluting activities is more than the cost of reducing emissions. In another recent study Albulescu et al. (2022), in line with expectations, argued that increases in environmental policy stringency reduce carbon emissions. However, although Demiral and Demiral (2021) and Albulescu and others (2022) considered the indirect impacts of environmental policy stringency they did not specify a mediation model.

Some of the current studies examining the relationship between regulation and environmental quality focused on the existence of regime-switching effects and tried to identify regime-switching variables with the help of different methodologies (e.g., Yin, Zheng, & Chen, 2015; De Angelis, Giacomo, & Vannoni, 2019; Ouyang et al., 2019; Wang et al., 2019; Wolde-Rufael & Weldemeskel, 2020, 2021; Sohag, Mariev, & Davidson, 2021; Wang & Zhang, 2022). From these studies Ouyang and others (2019) examine the effects of environmental policy on PM2.5 emissions in thirty OECD countries. They used panel threshold regression developed by Hansen (1999) and took both GDP and policy stringency as threshold variables. They concluded that an increase in environmental policy stringency first rises PM2.5 emissions but then showed no significant effect.

A few subsequent studies also took non-policy variables as threshold variables although they also focused on regime-switching effects (e.g., De Angelis et al., 2019; Wang et al., 2019; Sohag et al., 2021). From these studies De Angelis and others (2019); unlike Ouyang and others (2019) focused on the effects on CO_2 emissions. They tested the non-linear effects for a sample of thirty two countries. However, they took GDP as a regime-switching variable and tried to reveal non-linear relationships by using the square and cube of the variable. Environmental policy stringency remained a separate explanatory variable. Similarly Wang and others (2019) tested the relationship between environmental regulation and CO_2 emissions for thirty provinces of China. They took the energy intensity and FDI as threshold variables and suggested that there are differences of findings among eastern, central and western regions about the effects of environmental regulation. Their findings indicated an inverted U-shaped relationship between *per capita* GDP and *per capita* CO_2 emissions for the quadratic specification and an N-shaped pattern for the cubic specification. Later Sohag and others (2021) tested the role of environmental policy stringency on CO_2 emissions for seventy seven regions of the Russian Federation. They benefited from dynamic threshold regression and took gross product value as the threshold variable. Their results confirmed the threshold effect of gross product value and the EKC. In summary, while Ouyang and others (2019) focused on particulate matter emissions rather than CO_2 emissions, De Angelis and others (2019), Wang and others (2019), and Sohag and others (2021) took the energy intensity and foreign direct investments, GDP and gross product value, respectively as the threshold variables.

Some other works tested the nonlinear effects of environmental policy but they considered the square of the variable or its multiplication by other variables. For example Yin and others (2015) used the proportion of the amount of regional industrial pollution-elimination investment in the gross regional domestic product as the regulation indicator and observed a moderating effect of environmental regulation on the environmental Kuznets curve in twenty nine provinces of China. Therefore, they suggested more stringent policies to reduce carbon emissions earlier. Wolde-Rufael and Weldemeskel (2020) tested the effects of environmental regulations on CO_2 emissions in BRIICTS countries. That study is the first to use the environmental policy stringency index to test the effects of environmental regulation in reducing carbon emissions in these countries. They used panel mean group ARDL estimator as the methodology and observed an inverted U-shaped relationship between environmental regulation and carbon emissions. In a later study Wolde-Rufael and Weldemeskel (2021) focused on seven emerging economies that include the Czech Republic, Greece, Hungary, Korea, Poland, South Africa and Turkey. Their empirical results confirm their previous findings which point to an inverted U-shaped relationship between environmental policy stringency and CO_2 emissions. Thus they suggested that it takes time for environmental policy stringency to be effective. Wang and Zhang (2022), similarly sought the source of non-linear effects in environmental regulations. They analysed the effects of environmental policy stringency on CO_2 emissions for two hundred and eighty two cities in China. They used the generalized method of movements and the square of the variable to put forth the nonlinear effects. Their results indicated an inverted U-shaped relationship between environmental regulation and CO_2 emissions.

In summary as a result of the literature review it has been observed that there are very few studies dealing with the effectiveness and stringency of environmental policies. Although some recent studies focus on the regime-switching effects of the regulations the role of policy stringency in the relationship between determinants of environmental degradation and pollution has been ignored. However, environmental regulations will affect the behaviour of economic agents such as consumption, production, etc. (Borusiak, Szymkowiak, Lopez-Lluch, & Sanchez-Bravo, 2021). Neves and others (2020) draw attention to the fact that in deregulated markets economic agents do not have enough incentives to act in a more environmentally friendly fashion. Accordingly, and since acting in a more environmentally friendly fashion will bring additional costs, economic agents will stay away from such behaviour in the absence of environmental regulation. On the other hand, the existence of environmental regulations will encourage environmentally-friendly behaviour. Chen, Fan and Zhou (2020) also drew attention to the non-linear effects of environmental regulations on economic behaviour. According to this the implementation of environmental policy primarily increases the energy demands of enterprises and as a result leads to environmental degradation. But when emissions peak they will decrease as companies incur high environmental costs. In addition, Yin and others (2015) suggest that countries may be able to reach the turning point of the environmental Kuznets curve earlier with the help of regulatory policies and Pei, Zhu, Liu, Wang and Cao (2019) suggest that under stricter environmental regulation industries are forced to invest to reduce pollution. Therefore, the effects of regulations on economic behaviour may occur as more environmentally friendly technologies are preferred in production or already more environmentally friendly foreign direct investments are attracted to the country. I In this context it is thought that environmental regulations may have significant and non-linear effects on the relationship between emissions and their economic determinants such as production, foreign direct investments, etc.

Based on these discussions the main hypotheses of the study were determined as follows:

H_0: In high-regime countries where environmental policy stringency is above a certain threshold level the regime dependent economic variable has a negative impact on carbon emissions.

H_1: The level of environmental policy stringency has no effect on the relationship between the regime dependent economic variable and carbon emissions.

To the best of the author's knowledge this is the first study to test possible non-linear relationships in the determination of environmental pollution taking into account the mediating threshold effect of environmental policy stringency.

2. Data and methodology

This study aims to test the role of the stringency of environmental policy on the relationship between carbon emissions and their determinants based on the theoretical discussions presented in the previous section. For that purpose CO_2 emissions (metric tons *per capita*) has been used as an indicator. The countries in the sample cause a significant overall carbon emission and emissions in China have tended to increase in recent years. Figure 1 shows the course of CO_2 emissions over the years in the countries included in the sample.

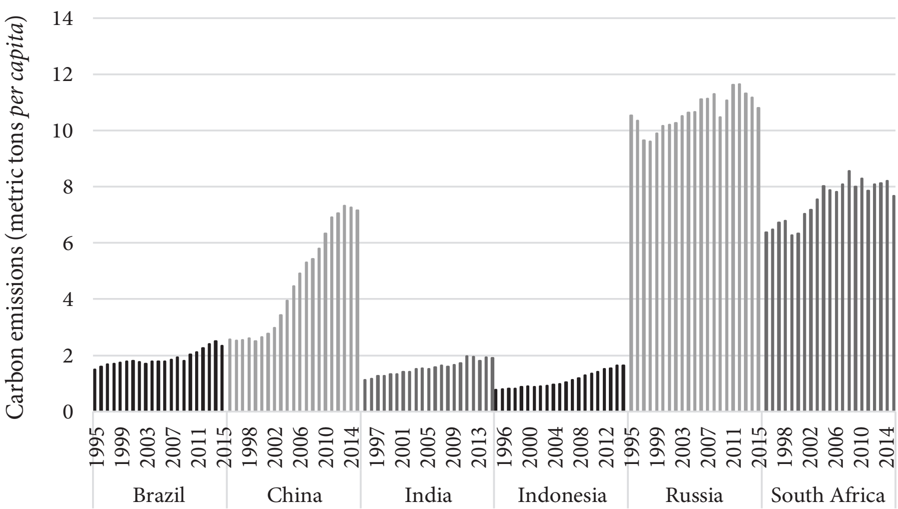

Figure 1. CO_2 emissions (metric tons *per capita*) over time

Note: CO_2 emissions (metric tons *per capita*), yearly data.
Source: Own elaboration based on (World Bank, 2021).

To test the effects of environmental policies this study benefits from a new quantitative index of environmental policy stringency constructed by Botta and Kozluk (2014). The authors used selected environmental policy instruments that relate to climate and air pollution, and they define the index as "a higher, explicit or implicit cost of polluting or environmentally harmful behaviour" (Botta & Kozluk, 2014, p. 14). Based on the dual distinction of De Serres, Murtin and Nicoletti (2010) on environmental regulation tools the index includes market-based and non-market instruments. While market-based instruments aim at addressing market failures through price signals (e.g., environmentally-related taxes, charges and fees), non-market tools include environmental regulations, active technology support policies, and voluntary approaches such as information-based instruments (De Serres et al., 2010, p. 15). Although market-based policies are used more in BRIICS countries in general it is observed that the stringency of non-market-based policies has increased relatively in certain years in some countries. Figure 2 shows the course of environmental policy stringency index values over the years in the countries included in the sample.

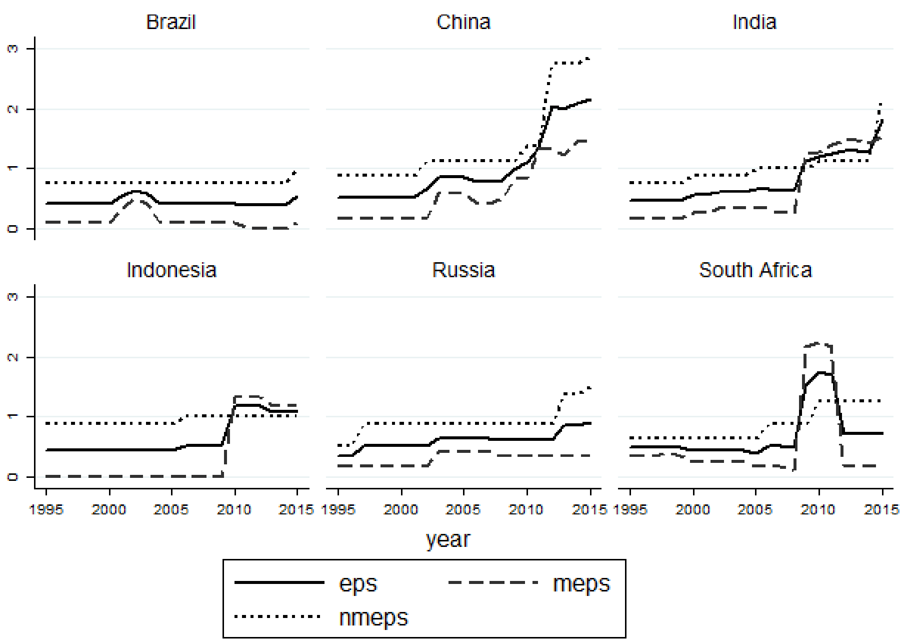

Figure 2. Environmental policy stringency indices over time

Notes: *eps* indicates environmental policy stringency index of OECD. *meps* indicates market-based environmental policy stringency index and *nmeps* indicates market-based environmental policy stringency index. The index ranges from 0 (not stringent) to 6 (highest degree of stringency).
Source: Own elaboration based on (OECD, 2021; Environmental Policy Stringency Index, yearly data).

While examining the role of environmental regulations in the relationship between CO_2 emissions and their determinants there are different reasons for choosing the panel threshold regression method developed by Hansen (1999) as an analysis method. First of all this analysis avoids the problem of multicollinearity that can arise from using the products or squares of the explanatory variables. In addition a specific threshold value can be calculated for the threshold variable taken with the method in question. This enables countries to determine which regime they are in and to produce more concrete environmental policies accordingly.

In the first stage of the analysis, the fixed-effects model was used to determine the determinants of the CO_2 emission variable. As a sample, in line with maximum data availability, the data of BRIICS countries for the period of 1995–2015 were used. The structural equation under consideration can be represented as follows:

$$y_{it} = \mu_i + \alpha X_{it} + e_{it}, e_{it} \approx iid(0, \sigma^2) \quad (1)$$

X_{it} in equation (1) consists of explanatory variables that are thought to affect CO_2 emissions. Based on the literature, these variables are; GDP *per capita*, the rate of urbanization, the share of the services sector in the economy, the share of foreign direct investments and the number of patents related to the environment. Information on the explanations and sources of these variables is presented in Table A1 and the descriptive statistics are presented in Table A2 in the appendix. As a result of the fixed effects model analysis; it has been observed that the variable of GDP *per capita*, the share of the services sector in the economy and foreign direct investments have statistically significant effects on the level of CO_2 emissions (Empirical findings for readers are presented in the fourth section).

However, if the possible non-linear relationships between the variables are not taken into account, the results of the analysis will lead us to the values with a downward bias (Foster, 2006). For this reason while testing the effects of GDP *per capita* the share of the services sector and foreign direct investments which are accepted as the determinants of CO_2 emissions, the panel threshold regression model developed by Hansen (1999) was used in the second step. Thus the effects of control variables on emission values were tested by considering the role of environmental policies.

The panel threshold regression of Hansen (1999) divides the observations into two regimes depending on whether the threshold variable is smaller or larger than the threshold. The regimes are distinguished by differing regression slopes (Hansen, 1999). Let represents the CO_2 emissions *per capita*, PS_{it} represents one of the policy stringency variables as environmental policy stringency, market environmental policy stringency and non-market environmental policy stringency. Z_{it} represents one of the explanatory variables from the set of control variables (X_{it}) including GDP *per capita* (gdp), urban population as a percentage of total population (urban), services sector to GDP (services), foreign direct investment to GDP (fdi) and the number of patents in environmental-related technologies (patents). Then the single threshold model for CO_2 emissions can be shown as follows:

$$y_{it} = \mu_i + X_{it} + \beta Z_{it} + e_{it},\ e_{it} \sim iid\left(0, \sigma^2\right)$$
$$y_{it} = \begin{cases} \mu_i + \alpha X_{it} + \beta_1 Z_{it} + e_{it}, PS_{it} \leq \lambda \\ \mu_i + \alpha X_{it} + \beta_2 Z_{it} + e_{it}, PS_{it} > \lambda \end{cases} \tag{2}$$
$$\alpha = \left(\alpha_1, \alpha_2, \alpha_3\right)' X_{it}$$

where $\{y_{it}, X_{it}, Z_{it}, PS_{it}: 1 \leq i \leq n, 1 \leq t \leq T\}$ is an observed panel data set of BRIICS economies. PS_{it} is the threshold variable with an estimated threshold value, λ. While μ_i is the fixed effect, the error term e_{it} is assumed to be independent and identically distributed with mean zero and finite variance σ^2.

Alternatively, it can be written as follows:

$$y_{it}^{*} = \theta' h_{it}^{*}(\lambda) + e_{it}^{*} \tag{3}$$

where $\theta = (\alpha', \beta')'$, $h_{it} = (X_{it}', Z_{it}(\lambda)')'$, $y_{it}^{*} = y_{it} - \bar{y}_i$, $h = h_{it}(\lambda) - \bar{h}_i(\lambda)$, $e_{it}^{*} = e_{it} - \bar{e}_i$

Let

$$y_i^{*} = \begin{bmatrix} y_{i2}^{*} \\ \cdot \\ \cdot \\ \cdot \\ y_{iT}^{*} \end{bmatrix},\quad h_i^{*}(\gamma) = \begin{bmatrix} h_{i2}^{*}(\lambda) \\ \cdot \\ \cdot \\ \cdot \\ h_{iT}^{*}(\lambda) \end{bmatrix},\quad e_i^{*} = \begin{bmatrix} e_{i2}^{*} \\ \cdot \\ \cdot \\ \cdot \\ e_{iT}^{*} \end{bmatrix}$$

denote the stacked data and errors for an individual, with one time period deleted and Y^{*}, X^{*} and ε^{*} denote the data stacked overall individuals:

$$Y^{*} = \begin{bmatrix} y_1^{*} \\ \cdot \\ \cdot \\ \cdot \\ y_n^{*} \end{bmatrix}, H^{*}(\lambda) = \begin{bmatrix} h_1^{*}(\lambda) \\ \cdot \\ \cdot \\ \cdot \\ h_{it}^{*}(\lambda) \end{bmatrix},\quad e^{*} = \begin{bmatrix} e_1^{*} \\ \cdot \\ \cdot \\ \cdot \\ e_n^{*} \end{bmatrix}$$

Then equation (3) will be equivalent to:

$$Y_{it}^{*} = \theta' H_{it}^{*}(\lambda) + e^{*} \tag{4}$$

For any given threshold λ, the slope coefficients can be estimated by using OLS:

$$\hat{\theta}(\lambda) = \left(H^*(\lambda)'H^*(\lambda)\right)^{-1} H^*(\lambda)'Y^* \quad (5)$$

The vector of the residuals is expressed as:

$$\hat{e}^*(\lambda) = Y^* - H(\lambda)\hat{\theta}(\lambda) \quad (6)$$

The sum of squared errors (SSE) is expressed as:

$$SSE_1(\lambda) = \hat{e}^*(\lambda)\hat{e}^*(\lambda)' = Y^{*\prime}\left(I - H^*(\lambda)'\left(H^*(\lambda)'H^*(\lambda)\right)^{-1} H^*(\lambda)'\right)Y^* \quad (7)$$

According to Chan (1993) and Hansen (1999), the threshold can be easily estimated by minimization of the concentrated sum of squared errors. Therefore, the estimator of is

$$\hat{\lambda} = \underset{\lambda}{\operatorname{argmin}}\, SSE_1(\lambda) \quad (8)$$

Once $\hat{\lambda}$ is obtained, the slope coefficient estimate is $\hat{\theta} = \hat{\theta}(\lambda)$. The residual vector is $\hat{e}^* = \hat{e}^*(\lambda)$, and the estimator of residual variance is:

$$\hat{\sigma}^2 = \frac{1}{n(T-1)}\hat{e}^{*\prime}\hat{e}^* = \frac{1}{n(T-1)} SSE_1(\hat{\lambda}) \quad (9)$$

where n represents the number of countries and T represents the number of years in the sample.

Lastly, it is important to test whether the threshold effect is statistically significant. At that stage Hansen (1996) suggested a bootstrap to stimulate the asymptotic distribution of the likelihood ratio test. The null hypothesis of no threshold effect can be represented by a linear constraint such as . If the p-value is smaller than the critical value, the null hypothesis is rejected and the existence of the threshold effect is confirmed.

3. Empirical results

In the first step to test for cross-sectional dependency several tests have been used including the Breusch-Pagan (1980) Lagrange Multiplier (LM) test, the Pesaran, Ullah and Yamagata (2008) bias-adjusted LM test and the Pesaran (2004) Cross-sectional Dependence (CD) test. Under the null hypothesis of no relationship between the residuals of cross sections, the findings of all tests point to the cross-sectional independence. The results can be seen in Table 1.

Table 1. Residual Cross-sectional Independence

Test	Statistic	*p*-value
LM	16.67	0.3391
LM adj.	–0.6879	0.4915
LM CD	0.8232	0.4104

Source: Own calculations.

Therefore, in the next step all variables are tested for stationarity with the Levin-Lin-Chu unit root test. Bayesian information criterion was used to determine the appropriate lag length. Results of stationarity tests can be seen in Table A3 in appendix. Non-stationary series at 5% significance level were made stationary by taking their differences. After obtaining the stationary series at the second stage the determinants of CO_2 emissions were tested using fixed-effects panel data model[3]. The results are summarized in Table 2. Among the possible

Table 2. Fixed effect regressions

Dependent variable: d(carbon)	
d(gdp)	0.0005*** (0.0001)
dd(urban)	–0.4090 (0.3453)
d(services)	–0.0305* (0.0162)
d(patents)	–0.0001 (0.0001)
fdi	0.0282* (0.0167)
d(eps)	–0.0416** (0.0439)
cons	–0.0416 (0.0439)
Num. of Obs.	114
F-stat.	9.27
R-square	0.3528

Note: ***, **, and * denote statistically significance at 1%, 5%, and 10% level, respectively. Standard errors are in parentheses. d indicates first difference, dd indicates second difference.

Source: Own calculations.

[3] According to the Hausman (1978) test, the null hypothesis-that the random effects estimator is consistent—has been rejected at 5% level of significance with Chi-square value of 22.64 and probability value of 0.0009.

determinants GDP *per capita*, services sector to GDP and the foreign direct investments to GDP were found to be significant at a 10% level of significance.

The coefficient of GDP *per capita* was found to be positive which means that the increase in *per capita* income increases the level of CO_2 emissions. Considering that the sample here includes developing economies. This finding is in line with theoretical expectations. The income levels of the countries in the sample are likely below the income level corresponding to the maximum pollution level of the environmental Kuznets curve.

The coefficient of the share of the services sector in GDP was found to be negative in line with the expectations. Accordingly, as the share of the relatively less pollutant services sector increases CO_2 emission values decreases. Additionally, the coefficient of the share of the foreign direct investment in GDP was found to be positive. This finding is in line with theoretical expectations, too. The sample consists of developing economies and these countries are likely to attract polluting foreign direct investments from highly developed countries. The findings of this study support the pollution haven hypothesis. Finally, the coefficient of the environmental policy stringency index was found to be negative. Therefore, it has been observed that increasing environmental policy stringency has a decreasing effect on CO_2 emissions.

In the next step threshold models were estimated for three determinants of CO_2 emissions. The results can be seen in Table 3. GDP *per capita*, services to GDP ratio and foreign direct investments to GDP ratio were used as the regime dependent variables in three separate models. The environmental policy stringency index was used as the threshold variable in all three models. In this way the non-linear relationships conditioning on policy stringency were considered. The structural models of this relationship for a single threshold can be shown as below:

$$y_{it} = \mu_i + \alpha X_{it} + \beta_1 Z_{it} I(PS_{it} \leq \lambda) + \beta_2 Z_{it} I(PS_{it} > \lambda) + e_{it} \tag{10}$$

Regardless of the regime dependent variable the coefficients of the explanatory variables in all three models were found to be quite similar according to the sign and the magnitude. While the environmental policy stringency index has no threshold effect on the relationship between GDP *per capita* and CO_2 emissions. A threshold effect is observed when the share of the services sector and FDI are used as regime-dependent variables. This effect is especially significant (at 5%) for the share of the services sector in GDP. Accordingly, in the low policy stringency regime the share of the services sector in GDP has no significant effect on the level of CO_2 emissions, however in the high policy stringency regime it reduces the CO_2 emissions.

In the next step, the paper focuses on the type of environmental policy. As indicated before environmental policies can be divided into two groups as market-based policies and non-market-based policies. To test the relative effectiveness of these two policy types they were used as a threshold variable in

Table 3. Threshold regressions for environmental policy

Dependent variable: d(carbon)	Regime dependent variable (rx)		
	d(gdp)	**d(services)**	**fdi**
d(gdp)		0.0005*** (0.0001)	0.0005*** (0.0001)
dd(urban)	–0.3251 (0.34255)	–0.2370 (0.3358)	–0.3298 (0.3364)
d(pat)	0.0001 (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)
fdi	0.0219 (0.0166)	0.0298* (0.0161)	
d(services)	–0.0261 (0.0161)		–0.0237 (0.0159)
rx($eps \leq \lambda$)	0.0006*** (0.0001)	–0.0203 (0.0159)	0.0260 (0.0162)
rx($eps > \lambda$)	–0.0002 (0.0002)	–0.2686*** (0.0690)	–0.0934** (0.0399)
c	–0.0419 (0.0435)	–0.0569 (0.0425)	–0.0436 (0.0427)
R-square	0.3647	0.3961	0.3863
Threshold	1.5208	1.2792***	1.3542*
p-value	0.2667	0.0067	0.0567
Confidence region	1.3542–1.7083	1.2146–1.2958	1.1896–1.5208
F-Statistics	9.76	11.15	10.70
F-probability	0.0000	0.0000	0.0000

Note: ***, **, and * denote statistically significance at 1%, 5%, and 10% level, respectively. Standard errors are in parentheses. The number of repetition of the bootstrap method is equal to 300. d indicates first difference, dd indicates second difference.

Source: Own calculations.

separate models. Table 4 shows the results obtained from the regression that includes market-based policies as the threshold variable.

As can be seen from Table 4 the environmental policy stringency index has again no threshold effect on the relationship between GDP *per capita* and CO_2 emissions, however, a threshold effect has been observed when the share of the services sector and FDI has been used as regime-dependent variables. Accordingly, in the low policy stringency regime the share of the services sector in GDP has no significant effect on the level of CO_2 emissions however in the high policy stringency regime it reduces the CO_2 emissions. On the other

Table 4. Threshold regressions for market-based environmental policy

Dependent variable: d(carbon)	Regime dependent variable (rx)		
	d(gdp)	d(services)	fdi
d(gdp)		0.0005*** (0.0001)	0.0005*** (0.0001)
dd(urban)	–0.2694 (0.0167)	–0.1960 (0.3403)	–0.2201 (0.3373)
d(pat)	0.0001 (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)
fdi	0.0262 (0.0167)	0.0337** (0.0164)	
d(services)	–0.0268 (0.0163)		–0.0208 (0.0159)
rx($meps \leq \lambda$)	0.0005*** (0.0001)	–0.0206 (0.0160)	0.0381** (0.0165)
rx($meps > \lambda$)	–0.0001 (0.0004)	–0.2587*** (0.0708)	–0.0807** (0.0348)
c	–0.0523 (0.0440)	–0.0651 (0.0430)	–0.0659 (0.0428)
R-square	0.3519	0.3873	0.3932
Threshold	1.4344	1.4333**	1.4333**
p-value	0.3000	0.0233	0.0200
Confidence region	1.4000–1.4500	1.3250–1.4500	1.3333–1.4500
F-Statistics	9.23	10.75	11.02
F-probability	0.0000	0.0000	0.0000

Note: ***, **, and * denote statistically significance at 1%, 5%, and 10% level, respectively. Standard errors are in parentheses.

Source: Own calculations.

hand, the threshold effect of regulation for foreign direct investments became more obvious when market-based regulations were used. In the low policy stringency regime foreign direct investments as a share of GDP have a significant and positive effect on the level of CO_2 emissions but in the high policy stringency regime, it reduces the CO_2 emissions. Therefore, these countries may attract foreign direct investments with clean technologies by making the market-based environmental regulations more stringent.

In the next step, the paper focused on the role of non-market-based regulations. Table 5 shows the results obtained from the regression that includes non-market-based policies as the threshold variable.

According to Table 5, the threshold effect of non-market-based regulation emerges only for the share of the services sector. Accordingly, in the low policy stringency regime the share of the services sector in GDP has no significant effect on the level of CO_2 emissions however in the high policy stringency regime it reduces the CO_2 emissions. No threshold effect was found for the other two variables. This indicates that the role of non-market-based environmental policies in the relationship between CO_2 emission and these two economic determinants is relatively insignificant.

Table 5. Threshold regressions for nonmarket-based environmental policy

Dependent variable: d(carbon)	Regime dependent variable (rx)		
	d(gdp)	**d(services)**	**fdi**
d(gdp)		0.0005*** (0.0001)	0.0006*** (0.0001)
dd(urban)	–0.3262 (0.3440)	–0.2594 (0.3408)	–0.3713 (0.3451)
d(pat)	0.0001 (0.0001)	0.0001 (0.0001)	–0.0001 (0.0001)
fdi	0.0227 (0.0166)	0.0269 (0.0164)	
d(services)	–0.0262 (0.0162)		–0.0298* (0.0162)
rx($nmeps \leq \lambda$)	0.0006*** (0.0001)	0.0216 (0.0161)	0.0860*** (0.0319)
rx($nmeps > \lambda$)	–0.0002 (0.0003)	–0.2268*** (0.0668)	0.0118 (0.0179)
c	–0.0446 (0.0437)	–0.0528 (0.0431)	–0.0268 (0.0448)
R-square	0.3595	0.3775	0.3528
Threshold	1.500	1.2500**	0.6250
p-value	0.1333	0.0433	0.2500
Confidence region	1.3750–2.1250	1.000–1.3750	–
F-Statistics	9.54	10.31	9.27
F-probability	0.0000	0.0000	0.0000

Note: ***, **, and * denote statistically significance at 1%, 5%, and 10% level, respectively. Standard errors are in parentheses. d indicates first difference, dd indicates second difference.

Source: Own calculations.

Conclusions

Considering the vital importance of environmental quality it is important to find out the determinants of environmental degradation and to determine policy tools for their elimination. Today many different policy tools such as taxes, trading schemes and feed-in tariffs are being used to reduce environmental pollution. However, the impact of stringency of environmental policies on the level of environmental pollution has only been empirically addressed in recent years. Some of the aforementioned studies have tested the relationship with the help of different methods taking into account that environmental policies can create non-linear effects on pollution. The general result of these studies states that if environmental policy stringency rises above a certain level it gives more positive results, in other words, it takes time for environmental policies to create effective results.

In this study, unlike the previous literature, the role of environmental policy stringency on the relationship between CO_2 emissions and their economic determinants has been tested. For this purpose panel threshold regression which calculates the role of a third variable by determining a certain threshold value for this variable was used in testing the effect between the variables. The obtained findings confirm that the relationships should be handled in terms of environmental policy stringency. First, no significant threshold effect was observed on GDP *per capita* but it was observed that the CO_2 emission effects from foreign direct investment and the share of the services sector were significantly affected by environmental policy stringency. In the low policy stringency regime the share of the services sector in the economy and the share of foreign direct investments in GDP do not have a statistically significant effect on emissions but in the high regime these variables affect emission levels in a statistically significant and negative way. Thus increasing environmental policy stringency contributes to reducing emissions.

It is difficult to compare the results with the previous literature since there is no preliminary study that tests the role of mediating effects of environmental policies by directly addressing them within the model. However, it can be said that the findings are consistent with the studies (e.g., Ahmed, 2020; Neves et al., 2020; Wolde-Rufael & Weldemeskel, 2021) that draw attention to the reducing effects of environmental policies on carbon emissions. Differences in findings with previous studies (e.g., Demiral et al., 2021) may be due to differences in sample and method selection.

Another important analysis handled in the study is; to test the effects by separating policy instruments into market-based and non-market-based policy instruments. The analysis results obtained confirm the importance of this distinction for some variables. First, no significant threshold effect on GDP *per capita* was observed in either policy instrument option but pollution levels of foreign direct investment and the services sector are significantly affected by both types of environmental policy stringency. While the use of non-market-based policy instruments eliminates the threshold effect on foreign direct investments the use of market-based policy instruments creates significant threshold effects on both foreign direct investments and the share of the services sector. If market-based policy stringency is below the threshold (1.4333), foreign direct investment increases emission levels while if it is above the threshold it reduces emission levels. This is thought to be since countries with relatively high market-based environmental policy stringency attract foreign direct investments involving more environmentally friendly technologies as advocated by the pollution halo hypothesis. Countries with relatively low market-based environmental policy stringency as advocated by the pollution haven hypothesis will be able to attract polluting investments from developed countries with high policy stringency.

How the share of the services sector in the economy affects emission levels varies according to the stringency of both market-based and non-market-based environmental policy implementations. In both cases changes in the share of the services sector do not have a significant effect on emission levels when policy stringency is below the threshold. However, if market-based or non-market-based environmental policy stringency is above the thresholds of 1.4333 and 1.2500, respectively the emission level will decrease as the share of the services sector in the economy increases. It is thought that this may be due to the sector's tendency towards more environmentally friendly technologies (e.g., green buildings in construction, noise and pollution control in transportation, using renewable sources of energy in tourism, green hospitals in health care services). In addition it is noteworthy that the reduction in emissions is more effective if market-based policy instruments are used. This finding is consistent with the findings of Neves and others (2020) study which proposes market-based regulations to reduce carbon emissions.

Based on the findings the policy alternatives can be listed as follows. First of all, it is recommended to strengthen the said tool based on the finding that environmental policy stringency supports emission-reducing effects above the threshold. Especially in emerging countries environmental policy stringency remains lower than in developed countries. However, bringing policy stringency above the threshold value in these countries will have indirect and significant effects in terms of emission reduction. Secondly, according to the results obtained from the analysis findings, market-based environmental policy instruments have more positive indirect effects in reducing emissions than non-market-based policy instruments. In particular, how foreign direct investments will affect emissions is significantly affected by market-based policies. Therefore, market-based environmental policy instruments such as taxes, trading schemes and feed-in tariffs are suggested as a more effective alternative in the fight against emission-related environmental pollution. Thirdly, it is possible to state that environmental taxes can come to the forefront as an appropriate policy tool due to the public revenue they provide. The revenues obtained can be directed towards efficient public investments or new environmental regulations which are especially important for developing countries. Thus, the increase in environmental quality and economic development are supported.

Of course it is possible that the study can be improved in some aspects in the future. First of all, with the increase in data size it will be possible to make estimations on a country basis. Again with the increase in data size testing the effects of market-based and non-market-based instruments by sub-items will contribute to the literature. Finally, estimates made by other methods testing regime-switching effects such as smooth transition and Markov-switching models will be useful for comparison.

Appendix

Table A1. Data description

Variable	Description	Source
carbon	CO_2 emissions (metric tons *per capita*)	World Bank, WDI
gdp	GDP *per capita* (constant 2015 US $)	World Bank, WDI
urban	Urban population (% of the total population)	World Bank, WDI
services	Services, value added (% of GDP)	World Bank, WDI
fdi	Foreign direct investments, net inflows (% of GDP)	World Bank, WDI
patents	Patents in environment-related technologies	OECDStat
eps	Environmental policy stringency index	OECD.Stat

Source: Own elaboration.

Table A2. Descriptive statistics by quartiles

	N	Mean	Median
Carbon			
1	32	1.1891	1.2276
2	31	1.8655	1.7888
3	32	5.3969	6.3062
4	31	9.8507	10.2660
total	126	4.5551	2.5066
gdp			
1	32	1292.7	1268.594
2	31	3177.516	2980.61
3	32	5878.315	5737.48
4	31	8995.575	8814.001
total	126	4816.177	4693.699
urban			
1	32	31.3938	30.9455
2	31	47.2840	47.535
3	32	64.3499	62.482
4	31	79.6625	81.192
total	126	55.5487	54.7265
services			
1	32	38.8257	39.6833
2	31	44.6829	44.4067
3	32	53.8482	53.8306
4	31	59.8736	60.1254
total	126	49.2604	49.1113
fdi			
1	32	0.3315	0.6004
2	31	1.5501	1.6350
3	32	2.6222	2.5913
4	31	4.0773	3.7977
total	126	2.1347	2.1401
patents			
1	32	36.2933	19.2087

2	31	310.8665	322.0516
3	32	659.1218	644.9942
4	31	6220.145	2020.696
total	126	1783.45	427.2504
eps			
1	36	0.4161	0.4167
2	30	0.5007	0.5208
3	30	0.6361	0.625
4	30	1.2913	1.1667
total	126	0.6970	0.5208

Source: Own calculations.

Table A3. Levin–Lin–Chu unit root test results

Variable names	Adjusted *t*-Statistics	*p*–value
carbon	0.5187	0.6980
d(carbon)	−4.5488	0.0000
gdp	5.2278	1.0000
d(gdp)	−2.0306	0.0211
urban	−0.7017	0.2414
d(urban)	−0.9884	0.1615
dd(urban)	−5.9897	0.0000
services	−1.1802	0.1190
d(services)	−6.9250	0.0000
fdi	−2.4035	0.0081
patents	3.5351	0.9998
d(patents)	−3.4263	0.0003
eps	1.6341	0.9489
d(eps)	−6.6767	0.0000

Note: The letter d indicates first difference, while dd indicates second difference.

Source: Own calculations.

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