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Environmental Impact of the Shadow Economy, Globalisation, Trade and Market Size: Evidence Using Linear and Non-Linear Methods

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Abstract: The achievement of the Sustainable Development Goals (SDG) related to the environment requires identifying new sources of environmental degradation. In this research, we examine the impact of the underground economy on polluting gas emissions. This relationship was estimated, including the role of globalization, trade, and market size. Using annual data from the World Bank and the International Monetary Fund, we found that, in the short term, the underground economy had a negative effect on global environmental pollution and a long-term negative impact. In the long term, the cointegration results indicate a long-term relationship between the series included in the investigation. The existence of a long-term relationship between the variables implies that as the underground economy increases, the emissions of polluting gases also change. In the long term, policymakers can use the black economy as an instrument to influence environmental pollution. Likewise, we found a threshold effect in the index of globalization, trade, and market size. The existence of a threshold effect implies that from a threshold, the impact of globalization, trade, and the size of the market on polluting emissions is more significant. Therefore, the environmental policy must consider these aspects to achieve greater effectiveness of regulation in favor of the environment. The results were stable, including the dependence of the cross-sections and the heterogeneity in the slope of the panel. Actions to mitigate polluting gas emissions should regulate informal and clandestine activities and take advantage of globalization and trade to improve the practices of companies and individuals.

Keywords: environmental degradation; shadow economy; globalization; trade; market size

1. Introduction

Globalization has substantially impacted economic, social, and political aspects in all countries of the world through trade, capital flows, and technology transfer [1]. Since the industrial revolution, governments, to increase their income, have continuously increased the extraction and consumption of renewable and non-renewable resources [2]. Accompanied by the globalization process and the commercial exchange that the industry developed, the natural resources have become an indispensable material base for all production and consumption activities [3]. There is a close relationship between economic development, trade, urbanization, and the use of natural resources [4,5]. Therefore, there has been an escalation in consumption, and therefore in production to meet demand, which directly impacts the environment [6,7]. In the postulates of Müller–Fürstenberger & Wagner [8]

and Andreoni & Levinson [9] on the validity of the environmental Kuznets curve, considering the technological increase and productivity, the evidence is not conclusive on the functional form of the environmental Kuznets curve (EKC). The empirical evidence shows that the use of variables used to measure environmental damage, the output, and the level of development affect the EKC hypothesis's fulfillment [10,11]. This fact raises the need to investigate new determinants of pollution since the identification of new sources of environmental degradation can be used for the analysis of mitigation measures [12,13].

On the one hand, the empirical evidence also shows that emissions' main determinant is economic growth [14]. However, there are also factors such as urbanization, which also cause an expansion of the market and generate emissions through increased production, infrastructure, energy consumption, and others [15–17]. In addition, there are also several other factors such as trade openness, financial development, and foreign direct investment, which also significantly impact the environment [18,19]. However, several of these determinants are quantified in the legally established commercial and productive activities regulated and not regulated in terms of environmental impact, although they generate polluting gas emissions [20]. Most studies explain the ecological deterioration of formal and official activities. In practice, hidden environmental degradation sources are ignored [5,14]. Although companies generate value and exchange, they are not part of the national accounts subject to regulation and control [21,22]. In this sense, the shadow economy constitutes a source of contamination of the countries' environment regardless of the level of development. The shadow economy includes all unrecorded activities outside the framework of public and private sector establishments [23,24]. Thus, the shadow economy can be a hidden determinant of polluting gas emissions due to its ability to avoid environmental regulation policies [25]. In this sense, the shadow economy as a source of pollution persists despite the internationalization of production that has fostered globalization and the growth of the market's size.

In addition to the importance of analyzing the economy submerged by the absence of regulations and the environmental impact [26], the growing shadow economy worldwide also is important for policy makers due to its consequences, such as tax evasion, the alteration of income distribution, and the distortion of resource allocation [27]. Given that the shadow economy includes many pollution-intensive activities, (e.g., brick-making, metalworking, resource extraction, urban transport with old and inefficient vehicles, and production in small-scale or family-owned factories), if these effects (and also the drivers of shadow economy) are not included in the creation of fiscal policies, the objective of reducing contamination will not be achieved [28,29].

Biswas et al. [28] argued that the growing shadow economy is accompanied by higher and increasing levels of pollution given the evasions of environmental regulations. Therefore, the governments of various countries, especially those of developing countries, are looking for effective ways to deal with the large shadow economy, understanding its drivers and also trying to reduce high levels of pollution derived from this activity [30].

In this context, this research aims to examine the environmental impact of the shadow economy, globalization, trade, and the market size using a sample of 134 countries during 1980–2018. Unlike previous research, in this article, we evaluate the results using linear and non-linear methods and compare the results obtained in light of new econometric panel data methodologies. Specifically, we use panel data threshold regressions, cointegration techniques, and we estimate the long-run elasticities. Besides, our research differs from previous empirical works due to our study using a new measure of globalization: the informational globalization index. The main motivation for using this measure of globalization is that there has been a sustained increase in the use of the Internet, technological development measured by patent applications from non-residents, and exports of high technology and intensity in research and development. This indicator of globalization better captures current globalization processes that occur significantly through information and communication flows regardless of distances.

This research has the following sections. Section 2 contains a systematic review of relevant previous theoretical and empirical literature that measures independent variables' impact on polluting gas emissions. In Section 3, we describe the data sources and descriptive statistics. In Section 4, we propose the methodological strategy. Section 5 contains the results and the discussion with the previous literature. Section 6 has the conclusions and policy implications.

2. Literature Review

2.1. Nexus between the Shadow Economy and Environmental Pollution

The adverse effects of environmental deterioration, such as climate change, have promoted the study of the determinants of environmental quality, normally measured through carbon dioxide emissions [18,31]. The literature shows that greenhouse emissions' main determinants are the real per capita output and energy consumption from fossil sources [32,33]. Research in this field offers evidence for and against the environmental Kuznets curve hypothesis [9,34]. Likewise, other explanations for the increase in polluting gas emissions are energy consumption, urbanization, trade liberalization, financial development, and foreign direct investment [35,36]. Based on the above, we find that most of the determinants of environmental deterioration are explained in activities of the formal sector of the economy. From the shadow economy perspective, the literature on environmental deterioration and all those productive activities that are not part of the national accounts is limited [22,37,38]. Companies that operate informally and clandestinely have fewer restrictions to pollute, and therefore do not pay taxes on pollution [39]. In particular, the shadow economy poses a significant challenge regarding environmental regulation, especially in developing countries with higher levels of corruption and more informal activity (artisanal mining, clothing bleaching, and dyeing, brick making, automotive repair, and metallurgy), which generates negative environmental impacts [40]. In this sense, the policymakers of developing countries suggest that environmental policy is stricter to regulate the shadow economy's economic activities' negative ecological impacts. Countries with weak institutions must avoid shifting from the formal to the informal sector due to stricter environmental regulations [41–43].

Based on the literature review, we conclude that a limited number of investigations have analyzed the effects of the shadow economy on environmental degradation. Some results of these studies indicate that the shadow economy causes the increase in polluting gas emissions. For example, Biswas et al. [28] showed that an increase in the size of the shadow economy increases per capita carbon dioxide emissions. This fact can reduce this effect with policies aimed at controlling levels of corruption. Likewise, Elgin & Oztunali [44] studied the relationship between the shadow economy and environmental pollution and found an inverted-U-shaped relationship. Zhou [38] analyzed the effect of the shadow economy on polluting gas emissions and showed that the U-shaped environmental Kuznets curve is maintained. In this same direction, Wang et al. [45] studied the effect of the shadow economy and corruption on pollution for a provincial spatial panel and pointed out that the expansion of the shadow economy's size significantly increases pollutants' discharge nature. Also, Canh et al. [46] investigated the effect of public spending, economic integration, and the shadow economy on greenhouse gas emissions. The findings indicate that an increase in the share of the shadow economy leads to an increase in all emissions, with some exceptions. More recently, Huynh [47] studied the impact of the shadow economy and fiscal policy on air pollution from CO_2 emissions. These authors conclude that the shadow economy directly impacts air pollution, and an expansive fiscal policy can reduce pollution. In practice, the effectiveness of environmental policy depends on the institutional framework of the countries. Institutional quality influences environmental degradation due to the effectiveness of environmental policies, innovation in design and application, and the credibility of the economy's rules.

2.2. Nexus between Trade in Polluting Gas Emissions

Since the late 1980s, trade flows have grown steadily due to regional and bilateral trade agreements, which have significantly impacted the environment [47]. Although there is growing literature examining the nexus between trade and environmental degradation, the findings are not conclusive, and the evidence is ambiguous. In some recent works, the results indicate that trade facilitates more environmentally friendly technology from developed countries to developing countries [39]. On the contrary, other research suggests that trade has a negative impact on the emission of polluting gases, mainly trade in manufactured products [48–51]. Likewise, some countries will have losses in environmental terms as a function of their regulation of trade due to the pollution generated by the production process of goods for trade [51,52]. Various studies have analyzed the trade between the United States and China and conclude that their trade relations influence national pollutant emissions inventories [53,54]. The United States and China are the two countries with an enormous trade flow and multiple investments, trade, infrastructure, and cooperation agreements worldwide. Therefore, the decisions made by the two countries have a significant impact on environmental pollution. Machado, Schaeffer & Worrell [55] evaluated the effects of international trade on energy use and CO_2 emissions. These authors argue that trade promotes energy use and increases greenhouse gas emissions. Ozturk & Acaravci [56] explore the causal relationship between financial development, trade, economic growth, energy consumption, and carbon emissions in Turkey during 1996–2007. The authors found an increase in the relationship between economic growth and trade increases pollutant emissions per capita. In general, trade generates positive and negative impacts on environmental quality, the balance of which will depend on each country's regulations and the environmental awareness of the population and those responsible for the companies.

2.3. Nexus between Market Size and Polluting Emissions

The transition from rural areas to urban concentration has generated sustained growth in the number of consumers. In practice, the market's size has increased across the board, causing a significant impact on environmental sustainability and upsetting the balance of nature. Market size as a proxy for urban concentration is helpful to explain changes in CO_2 emissions. Urbanization causes urban infrastructure growth to meet the new demand for energy-intensive goods, which contributes to pollution [19]. Various authors have analyzed this relationship, and their conclusions are scattered. Zhang, Yu & Chen [3] found an inverted U-shaped relationship between urbanization and carbon dioxide emissions. Yao et al. [57] showed that urbanization could reduce the polluting gas emissions, although this effect decreases with deeper urban concentration. However, most studies found that the impact of urbanization on CO_2 emissions differs between groups of countries or regions [15,58–60]. Findings from other similar investigations broaden the analysis framework by offering more recent methodological approaches [61,62]. In general, from the literature review, we conclude that most studies explain environmental deterioration from formal activities that are accounted for in official accounts, omitting the analysis of other hidden sources of environmental degradation such as the underground economy. Therefore, our research offers two significant contributions to the literature on environmental degradation.

2.4. Evidence Using Nonlinear Regressions

The literature has focused on the use of linear methods to explain the determinants of polluting gas emissions. However, the possibility of a non-linear effect has led researchers to use non-linear techniques in estimating the parameters. Based on the pioneering work of Hansen [63], some research has been published on the existence of non-linear effects of the independent variables on the dependent one. In environmental economics, Liu & Peng [64] indicate that the relationship curves between urbanization and energy consumption increase but decrease after the threshold. Hao et al. [65] obtained similar results. They

found that urbanization increases environmental pollution; however, it has decreased as the tertiary industry proportion has increased due to technology and industrial policies' improvements. Wang & Wang [66] conclude that urbanization on carbon emissions has a significant and positive double-threshold effect. While Du & Xia [67] found that the relationship between the urbanization index and emissions is positive, although the relationship is heterogeneous according to the countries' urbanization levels. Various investigations have shown that the levels of development influence the conclusions of the investigations. In the EKC logic, the level of development determines society's preferences concerning the environment. Jiang et al. [12] evaluated the role of globalization in carbon emissions in countries with different income levels and showed that globalization has a non-linear connection with CO_2 emissions. Shahbaz et al. [68] showed that globalization changes increase carbon emissions and that globalization increases emissions after crossing the threshold level. Recently, Huang & Duan [69] suggested the presence of non-linear effects of the threshold variables, which have asymmetric impacts on the negative relationships between income inequality and carbon emissions.

3. Materials and Methods

Statistical Sources

Our interest is to study the environmental impact of the shadow economy, globalization, trade, and market size in 134 countries. The period analyzed in this research is between 1990–2018. We use the World Bank Atlas method to group them into four groups according to the level of per capita gross national income: high income countries (HIC), middle-upper income countries (MHIC), middle-low income countries (MLIC), and low-income countries (LIC). The environmental impact is measured through polluting gases in metric tons per person (PEG). The independent variables are the black economy as a percentage of real product per capita (SE), the KOF globalization index, trade as a percentage of real product per capita (T), and the size of the market measured by the population between 15 and 64 years. Table 1 shows the detailed description of each variable as a data source. The selection of variables is based on an exhaustive review of the literature, highlighting new environmental impact determinants.

Table 1. Variables and statistical sources.

Variable	Symbol	Description	Measure	Data Source
Shadow Economy	SE	It includes all economic activities that are hidden from official authorities for monetary, regulatory, and institutional reasons.	% of GDP	International Monetary Fund
Pollution Gas Emissions	PGE	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	Metric tons per capita	The World Bank
Information Globalization Index	IGI	It measures the economic, social, and political dimensions of globalization.	Index	KOF Swiss Economic Institute
Trade	TR	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	Percentage of total	The World Bank
Market Size	MS	The total population that is in the age group 15–64.	Total (log)	The World Bank

Table 2 shows the descriptive statistics of the variables used. The four variables form a balanced panel in time and space. The correlation between the shadow economy and pollution gas emissions is −0.11, with trade at 0.06, both statistically significant at 1%, and market size at −0.03. All the variables present less variability within countries than

between countries, except for the urbanization rate, which is more stable between countries than within countries. The sample size and temporal coverage ensure that the conclusions are robust and applicable in various countries. In the use of variables, our research includes the informational globalization index and the market size to the population that potentially has a high level of consumption. The empirical results presented in the following sections justify the use of the variables used in this research.

Table 2. Descriptive statistics and correlation matrix.

	Polluting Gases Emissions	Shadow Economy	Informational Globalization Index	Trade	Market Size
Mean	0.003	−0.019	−0.0006	0.094	−0.0002
Std. Dev [Overall]	0.627	2.534	6.010	14.904	0.004
Std. Dev [Between]	0.023	0.104	0.079	0.601	0.005
Std. Dev [Within]	0.626	2.522	6.010	14.892	0.004
Min.	−7.977	−0.284	−0.621	−3.115	−0.001
Max.	7.191	0.546	0.211	2.56	0.001
Observations	3886	3886	3886	3886	3886
Countries [N]	134	134	134	134	134
Time [T]	29	29	29	29	29
Pollution Gas Emissions	1.00				
	-				
Shadow Economy	−0.11 [a]	1			
	[0.00]	-			
Informational Globalisation Index	0.009	0.02	1		
	[0.87]	[0.86]	-		
Trade	0.066 [a]	−0.276	0.026	1	
	[0.00]	[0.00]	[0.23]	-	
Market size	−0.037 [a]	−0.018	0.003	−0.012	1
	[0.24]	[0.653]	[0.23]	[0.12]	-

Note: [a] Denotes the statistical significance at 5%.

4. Econometric Strategy

The literature on environmental pollution is aimed at identifying polluting sources using linear models. For comparative analysis, our estimates combine non-linear and linear methods. There are two arguments for using non-linear regressions. First, in the EKC logic, the effect of regressors on contamination is different before and after the threshold. In order to capture that non-linear effect, you need to apply a method that captures that theoretical aspect. Second, in the particular case of our research, regressor variables can have a heterogeneous effect on polluting gas emissions. The tests on the existence of threshold effects show that the variables: information globalization index, trade, and market size have a threshold effect. Therefore, in subsequent econometric estimates, we include all three variables as thresholds, and the results confirm the importance of using non-linear methods to identify sources of contamination.

Furthermore, to reduce the intrinsic heterogeneity between countries due to development, we classified the total sample into four groups. It is well known that the level of development of countries influences the institutional and regulatory quality of pollutants.

4.1. Threshold Regression Approach

Following Hansen [63], we employed a panel threshold regression approach to explore the non-linear effects between the threshold variables and the dependent variable. In this study, the panel threshold model was used to analyze the impact of three threshold variables, informational globalization index (IGI), trade (T), and market size (MS). The main argument supporting the use of threshold regressions is that, from a point, the impact of the regressors on the dependent is different. This hypothesis is based on the theory of the environmental Kuznets curve. In environmental economics, various investigations use

threshold regressions to assess the nonlinear link between factors that influence pollution and emissions [70,71]. The panel threshold regression model was constructed as follows:

$$PGE_{it} = \beta_0 + \beta_1 IGI_{it} I(q_{it} \leq \gamma) + \beta_2 T_{it} I(q_{it} \leq \gamma) + \beta_3 MZ_{it}(q_{it} \leq \gamma) + \varepsilon_{it} \quad (1)$$

where i and t represent the region and time respectively, q_{it} represents the threshold variable, and γ is the specific threshold value. $I[.]$ is the exponential function when the condition is true, the value is 1, and 0 in another case, and, finally, ε_{it} is the random error term.

4.2. Short and Long-Run Relationship

To examine the long-run relationship between pollutant gas emissions, shadow economy, informational globalization index, trade, and market size, we divided the econometric strategy into six stages at the world level and by groups of countries. Each stage was applied for the 134 countries and by groups according to income levels. In the first stage, we estimated a generalized ordinary least squares (GLS) regression model that generates consistent estimators in the presence of heteroskedasticity and autocorrelation in panel data. Equation (2) formalizes this relationship:

$$PGE_{it} = \lambda_0 + \lambda_1 IGI_{i,t} + \lambda_1 T_{it} + \lambda_1 MS_{it} + \varphi_{it}, \ for \ i = 1, 2, \ldots, N; t = 1, 2, \ldots, T \quad (2)$$

where PGE_{it} is the shadow economy, IGI_{it} is the informational globalisation index, T_{it} is the trade, and MS_{it} is the market size of country i in period t, respectively. Finally, φ_{it} represents the error term. In the second stage, we checked the presence of cross-sections dependence among the countries. We applied two cross-sectional dependency tests proposed by Pesaran [72] that are better adapted to data with heterogeneity and large N, and the Bailey, Kapetanios & Pesaran test [73]. The exponent α-test of Bailey, Kapetanios & Pesaran [73] allows testing the weak versus the strong transverse dependence, or vice versa. For its part, the null hypothesis of the Pesaran test [72] assumes that the errors of the model have weak cross-sectional dependence. We show the Pesaran test statistic [72] in Equation (3):

$$CD = \left[\frac{TN(N-1)}{2} \right]^{1/2} \hat{\rho}_N \quad (3)$$

In the third stage, we checked the presence of heterogeneity in the slope. We applied the Pesaran & Yamagata [74] slope homogeneity test to compare whether the slope coefficients were homogeneous between the panels. This approach is based on estimating delta $[\Delta]$ and adjusted delta $[\Delta_{\text{adj}}]$ to test the null hypothesis of the slope's homogeneity. In the fourth stage, to test the stationarity of the data and verify the order of integration and avoid spurious regressions, we applied two second-generation unit root tests in the presence of cross-sectional dependence and heterogeneity, the IPS test of augmented cross-section (CIPS) by Pesaran [74] and Herwartz and Siedenburg [75]. The first test consisted of using cross-section averages $\bar{y}_{t-1}$ and $\Delta\bar{y}_t$ of y_{it-1} and y_{it}, respectively, as a proxy for the common component of the data, which were then included in the regression of the ADF test as additional regressors. The null hypothesis of the CIPS test was that all data series contain unit root whose statistic is:

$$CIPS(N, T) = t - bar = N^{-1} \sum_{i=1}^{N} t_i(N, T) \quad (4)$$

The term $t_i(N, T)$ is the Dickey–Fuller statistic increase in the cross-section. In addition, we applied a second test, which, more than being resistant to cross-sectional dependence, considers non-stationary volatility in a panel. Equation (5) proposes this test:

$$t_{Wh} = \frac{\sum_{t-1}^{T} y'_{t-1} \Delta y_t}{\sum_{t-1}^{T} y'_{t-1} \breve{u}_t \breve{u}'_t y_{t-1}} \quad (5)$$

where, $\breve{u}_t$ are the residuals obtained under the null hypothesis of the regression. In the fifth stage, we established whether there is cointegration between the variables using the Westerlund test [76]. The advantage of the test is that it allowed to have consistent and solid estimates [43]. The test considers the problems of heterogeneity and cross-sectional dependence and uses structural dynamics rather than residual dynamics to analyze the long-term relationship. In the Equation (6), $\hat{\alpha}_{ij}$ is the error correction parameter that can be estimated through ordinary least squares. The conditional error correction model for Y_{it} fitted for the cross-dependency assumption with the bootstrap proposal is:

$$\Delta Y_{it} = \sum_{J=1}^{p_i} \hat{\alpha}_{ij} \Delta Y_{it-j} + \sum_{J=0}^{p_i} \hat{\gamma}_{ij} \Delta X_{it-j} + \hat{e}_{it} \tag{6}$$

From the previous equation, Westerlund [76] constructed four tests, two were designed to test the alternative hypothesis that the panel is cointegrated as a whole (panel statistics: P_t and P_a). The last two tests pose the alternative that there is at least one element that is cointegrated (statistics of the group mean: G_t and G_a). We calculate the statistics of the group mean according to Equations (7) and (8):

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE\hat{\alpha}_i} \tag{7}$$

$$G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{8}$$

where $SE\hat{\alpha}_i$ is the conventional standard error of $\hat{\alpha}_i$. Dashboard statistics are calculated as follows in the Equations (9) and (10).

$$P_t = \frac{\hat{\alpha}}{SE\hat{\alpha}} \tag{9}$$

$$P_a = T\hat{\alpha} \tag{10}$$

Finally, in the sixth stage, we estimated the parameters associated with long-term cointegration with two heterogeneous panel data techniques with fixed effects: completely modified OLS (FMOLS) and dynamic OLS (DOLS). Based on Pedroni [77], the FMOLS and DOLS estimator is given by Equation (11):

$$\hat{\beta}_{GFM}^* = N^{-1} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} (p_{it} - \overline{p}_i)^2 \right)^{-1} \left(\sum_{t=1}^{T} (p_{it} - \overline{p}_i) s_{it}^* - T\hat{\gamma}_i \right) \tag{11}$$

Figure 1 illustrates the econometric process used in this research. We started with the threshold models and then estimated the linear models.
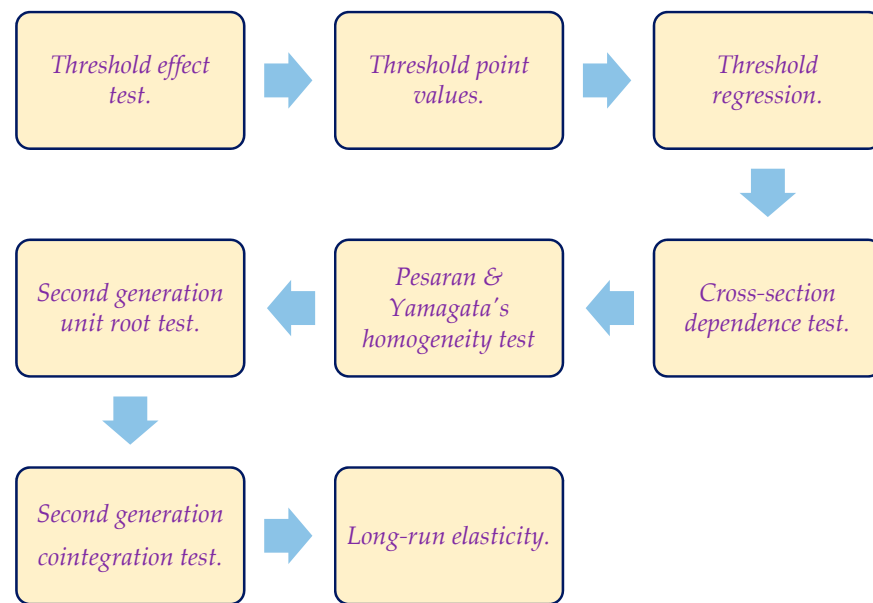
Figure 1. Diagram of the econometric strategy.

5. Results and Discussion

This research aims to examine the environmental impact of the shadow economy, globalization, trade, and market size in 134 countries during 1980–2018. Based on this objective, this section reports the results obtained due to the development of the econometric strategy. Table 3 reports the hypothesis test results of the existence of thresholds through an interactive process of 300 repetitions. The F obtained parameters are contrasted with the critical values of F at a significance level of 1%, 5%, and 10%. However, the hypotheses are verified using a significance level of 5%. The results show a single threshold effect of the informational globalization index in trade and market size. In other words, these variables have a non-linear impact on polluting gas emissions in the countries analyzed. This suggests the need to use the three variables as thresholds in the regression analysis. Furthermore, the threshold implies an effect before the threshold and another impact after the threshold. The omission of this heterogeneous impact generates biased estimators.

Table 3. Threshold effect test.

Threshold Variable	Threshold Effect	F	*p*-Value	Critical Value of F		
				1%	**5%**	**10%**
Informational Globalisation Index	Single	97.95	0.03	112.15	80.21	65.99
	Double	33.47	0.36	200.56	129.09	84.80
Trade	Single	63.11	0.05	80.11	60.13	48.38
	Double	18.02	0.52	113.00	64.24	41.24
Market Size	Single	160.60	0.03	191.84	136.80	109.43
	Double	92.59	0.15	202.12	136.40	109.95

From the results reported in Table 3, in the next stage we estimate the exact value of the threshold for each variable. The calculation of the threshold makes it possible to analyze how the change in the effect of the independents variables on polluting gases emissions occurs. The calculation of the threshold measures the value of the informational globalization index of trade and of the market size where the impact of the regressors on the polluting gases emissions is heterogeneous. In the recent literature on environmental degradation, various authors have noted the need to use this non-linear method to capture the dependent one's impacts accurately. For example, Shahbaz et al. [68] and Jiang et al. [78]

used the instrumental framework of threshold regressions to measure globalization's non-linear impact on environmental pollution. It is well known in the econometric literature that changes in the dependent variables to changes in the independent variables are not fixed throughout the distribution. Therefore, threshold regressions allow us to capture this behavior of the data according to the number of thresholds. Table 4 reports the results of the threshold verification.

Table 4. Threshold point values.

Threshold Variable	Model	Threshold Estimation Value	Interval	
			Lower	Upper
Informational globalization index	Th-1	93.45	93.45	93.45
	Th-21	93.45	93.45	93.45
	Th-22	81.92	81.34	82.13
Trade	Th-1	208.26	188.02	217.57
	Th-21	208.26	188.02	217.57
	Th-22	80.58	80.00	80.79
Market size	Th-1	13.72	13.44	13.75
	Th-21	13.72	13.70	13.75
	Th-22	13.16	13.12	15.29

Table 5 presents the results obtained when estimating Equation (1) for the global panel. In the first model, the threshold variable is the informational globalization index. The results show that below the threshold, the effect of the IGI is positive and significant. In contrast, above the threshold, the IGI is not significant, although it is positive. In this model, the shadow economy, trade, and market size increase the emissions of polluting gases. The effect of these variables is statistically significant. In the second model, when the trade is a threshold variable, the impact below and above the threshold is positive and significant, but the intensity of the effect is different. The IGI also has a positive and significant effect on polluting gas emissions, while the shadow economy and market size have a negative impact on emissions. In the third model, market size is the threshold variable and we found that the shadow economy, the informational globalization index, and market size have a negative impact on greenhouse gas emissions. In general, the global panel level results indicate that the shadow economy has a greater weight in the output and the emissions of polluting gases decrease. One possible explanation for this result is that the countries with the highest informal and clandestine activity are the least developed countries [79]. However, the effect is minimal. Besides, these results require a contrast with the results of the linear models and the short- and long-term elasticities to obtain a more solid conclusion. The change in impact before and after the threshold is extremely small. This raises the need for a robustness analysis to determine the sensitivity of the parameters obtained.

The non-linear model results are consistent with recent conclusions [68,69,78,80]. These authors used the variable of political and economic globalization as a threshold variable. They determined that globalization has a non-linear connection with polluting gas emissions, although it depends on the countries' income level. However, the measures of globalization are different. Regarding the negative impact of market size as a threshold variable in model 3, the results do not agree with Ulucak et al. [80]. Their study for 28 EU countries covers the period 2000–2017. These authors mentioned that higher levels of globalization help reduce the consumption of materials and thus contribute to the sustainable management of resources and the reduction of polluting gas emissions. The results are closer to those of Hao et al. [65] since the negative effect of urbanization on pollution emissions may be due to the policies adopted in recent years by increasing the tertiary industry due to technology improvement and the adjustment of industrial policies. However, it is clear that the effect of urbanization is not uniform, and this result is probably more observable in high-income countries. Du & Xia [67] found that the incidence of the urbanization index on emissions is positive. Trade is also important in determining

pollution emissions, although this study found the effect of trade on emissions to be small and negative. Yuan et al. [81] and Du et al. [67] obtained similar conclusions.

Table 5. Coefficient estimates of threshold regression.

Model 1: Threshold = IGI		Model 2: Threshold = Trade		Model 3: Threshold = Market Size	
Single Threshold Model	**Coef.**	**Single Threshold Model**	**Coef.**	**Single Threshold Model**	**Coef.**
$IGI_{it} < 93.45$	0.01 [a]	$TR_{it} < 208.26$	−0.01 [a]	$MS_{it} < 13.72$	1.42 [a]
	[5.33]		[−6.24]		[7.94]
$IGI_{it} > 93.45$	0.01 [a]	$TR_{it} > 208.26$	−0.01 [a]	$MS_{it} > 13.72$	1.21 [a]
	[3.51]		[−5.99]		[7.07]
Shadow Economy	−0.02 [a]	Shadow economy	−0.01 [b]	Shadow economy	−0.02 [b]
	[−3.42]		[−3.13]		[−3.11]
Informational Globalisation Index		Informational globalisation index	0.01 [b]	Informational globalisation index	−0.001
			[3.08]		[−0.29]
Trade	−0.01 [a]	Trade		Trade	−0.01 [a]
	[−7.75]				[−10.57]
Market size	−0.24	Market size	−0.11	Market size	
	[−1.60]		[−0.70]		
Constant	9.392 [a]	Constant	7.596 [a]	Constant	−10.67 [a]
	[4.09]		[3.30]		[−4.20]
Observations	3886	Observations	3886	Observations	3886
Adjusted R^2	0.03	Adjusted R^2	0.02	Adjusted R^2	0.06
Countries	134	Countries	134	Countries	134

Note: t statistics in parentheses, [a] $p < 0.001$, [b] $p < 0.01$.

The main advantage of using the threshold method is that it allows you to capture the non-linearity of the relationship between pollutant gas emissions, globalization, trade, and market size. Furthermore, it makes it possible to know exactly the inflection point of the threshold variables. Figure 2 shows the LR statistics and the three variables' threshold values: IGI, trade, and market size.
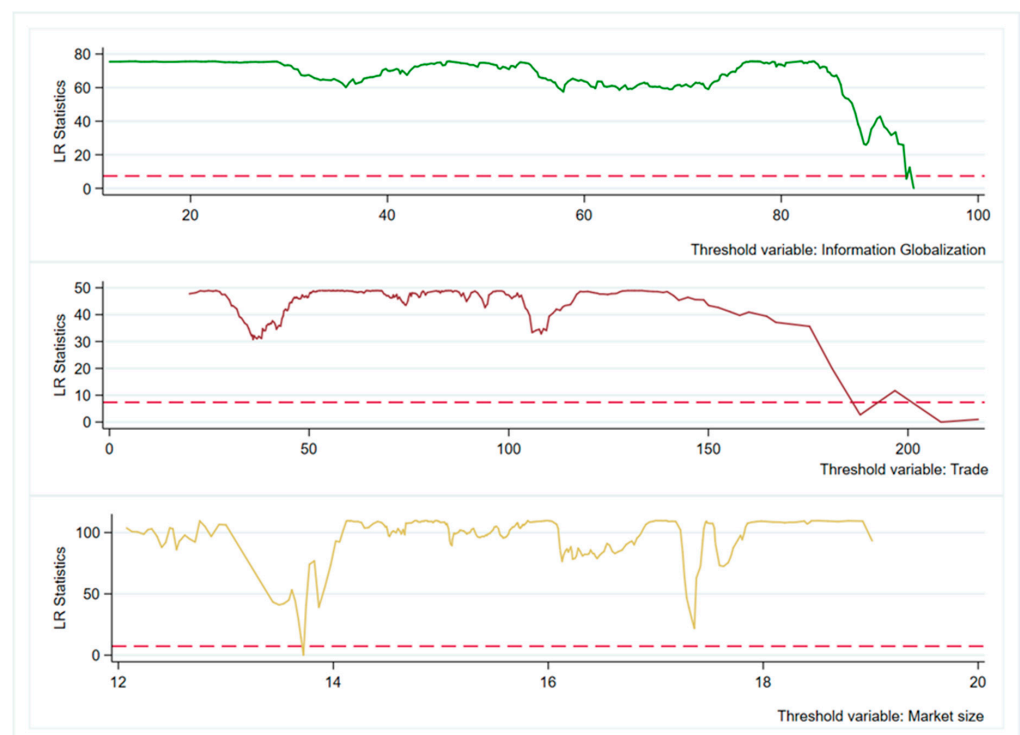

Figure 2. LR statistic of the thresholds.

Globalization and other integration and cooperation processes between countries have caused the interdependence between them to be high. The dependency between countries means that the values that the variables take in a country are a function of the values that the variables take in the rest of the countries. In particular, if the countries share a common border or have high mobility of people and capital flows [39]. In order to capture this fact, we used two dependency tests in the cross-sections: Pesaran [71] and Bailey, Kapetanios & Pesaran [72]. The results reported in Table 6 show that there is enough evidence to reject the hypothesis of null independence between the cross-sections in the global panel. Therefore, the dependency on the cross-sections must be incorporated into the long-term estimates.

Table 6. Results of cross-section dependence test.

Variables	Pesaran (2015)		Bailey, Kapetanios & Pesaran (2016)	
	Statistics	*p*-Value	Statistics	*p*-Value
Pollution Gas Emissions	30.55 [a]	0.00	477.23 [a]	0.00
Shadow Economy	258.65 [a]	0.00	503.91 [a]	0.00
Informational Globalisation Index	471.65 [a]	0.00	498.27 [a]	0.00
Trade	100.55 [a]	0.00	492.33 [a]	0.00
Market size	306.04 [a]	0.00	508.31 [a]	0.00

Note: [a] denote significance level at 0.1%.

Table 7 reports the results of the slope homogeneity test. It is well known that models with panel data adequately capture the average effect of temporal and cross-sectional variation. However, when there is high heterogeneity between panels, the average effect may be biased towards one of the two tails of the data distribution. This fact supports the need to estimate a formal test of the slope's homogeneity between the panels. We report the results of the delta and adjusted delta statistics. In both cases, the estimators are statistically significant at 1%, allowing rejecting the null hypothesis of homogeneity in the slope. It is concluded that there is enough evidence to accept the hypothesis of heterogeneity in the slope of the panels. Consequently, it is necessary to incorporate this characteristic of the data to estimate the linear models.

Table 7. Results from the Pesaran & Yamagata's homogeneity test.

Tests	Delta	*p*-Values
$-\Delta$	57.12 [a]	0.000
$-\Delta_{adj}$	64.14 [a]	0.000

Note: [a] denote significance level at 0.1%; and H0: slope coefficients are homogenous.

The time trend of a series can generates unbiased estimators in long-term estimates. To determine the data's unit root properties, we used unit root tests: Herwartz & Siedenburg [75] and Pesaran [82]. Table 8 reports the results of both tests. The null hypothesis of a unit root in the series cannot be rejected, as shown by the *p*-value with the second difference. Consequently, in subsequent estimations, we will use the series in the second difference. The null hypothesis is rejected for the four series in all tests and in all groups of countries using the levels of significance indicated in Table 8. In the environmental economics literature, empirical evidence on environmental degradation has used similar tests [10,49,83].

In recent decades, the world has been rapidly urbanizing, and cities have grown due to the influx of manufacturing and service jobs from developed economies and the immigration of workers displaced by agricultural adjustment [84]. The impact of trade reforms and liberalized foreign investment regimes has become vital when considering the effect of cross-reliance on the specified data set. Likewise, trade continues to play an important role in ensuring basic connectivity and access to gateways for most developing countries [85–88]. Likewise, Kolcava, Nguyen & Bernauer [89] mentioned that trade

liberalization and participation in international trade agreements influence pollution levels and ecological footprint. In terms of environmental policy, a significant period must elapse to design, apply, and evaluate a policy in favor of the environment, particularly if policies aim to mitigate environmental damage without putting economic growth at risk. Furthermore, the changes in the variables are observable and measurable in the long term. Consequently, once we verify the dependency in the cross-sections and that the series do not have the second difference trend, we verify the long-term relationship between the series. To verify the long-term relationship between the series, we used the second-generation cointegration test proposed by Westerlund [76]. One of the advantages of using this cointegration technique is that it allows to include the cross sections' average effect. Besides, the time trend can be added or omitted in the estimates.

Table 8. Second generation unit root test.

Groups	Variables	Herwartz & Siedenburg (2008)		Pesaran (2007)	
		Levels	Second Difference	Levels	Second Difference
134 countries	Pollution gas emissions	0.12	−3.57 [a]	6.27	−43.59 [a]
	Shadow economy	1.56	−3.89 [a]	−3.24 [a]	−42.78 [a]
	Informational globalization index	3.08	−3.81 [a]	−7.43 [a]	−46.06 [a]
	Trade	−0.23	−3.57 [a]	−5.18 [a]	−41.87 [a]
	Market size	0.16	−1.74 [c]	−9.53 [a]	−16.50 [a]
HIC	Pollution gas emissions	−0.76	−3.49 [a]	−0.87	−24.85 [a]
	Shadow economy	1.11	−2.68 [b]	0.71	−22.73 [a]
	Informational globalization index	1.92	−3.18 [b]	−3.87 [a]	−25.42 [a]
	Trade	1.07	−2.75 [b]	−3.94 [a]	−23.88 [a]
	Market size	1.28	−2.19 [b]	−0.39	−12.04 [a]
UMIC	Pollution gas emissions	0.43	−3.25 [a]	−4.04 [a]	−22.41 [a]
	Shadow economy	0.96	−3.23 [a]	0.66	−21.41 [a]
	Informational globalization index	2.28	−3.19 [b]	−3.92 [a]	−24.07 [a]
	Trade	−0.07	−3.21 [b]	−1.95 [c]	−22.77 [a]
	Market size	−0.19	−1.69 [c]	-4.88 [a]	−6.52 [a]
LMIC	Pollution gas emissions	2.51	−2.53 [b]	−0.57	−23.18 [a]
	Shadow economy	2.06	−4.00 [a]	−4.30	−22.95 [a]
	Informational globalization index	2.70	−3.82 [a]	−4.65 [a]	−22.43 [a]
	Trade	−1.56	−3.39 [a]	−0.34	−22.94 [a]
	Market size	−1.65 [c]	−0.55	−8.22 [a]	−4.04 [a]
LIC	Pollution gas emissions	1.76	−3.44 [a]	−0.17	−18.26 [a]
	Shadow economy	0.88	−3.56 [a]	−1.87 [c]	−19.25 [a]
	Informational globalization index	2.44	−2.86 [b]	−3.28 [a]	−18.24 [a]
	Trade	−1.78 [c]	−3.11 [b]	−1.25	−18.00 [a]
	Market size	−0.89	−0.73 [c]	−8.59 [a]	−5.05 [a]

Note: *t* statistics in parentheses: [a] $p < 0.001$, [b] $p < 0.01$, and [c] $p < 0.05$.

The results in Table 9 show the results of the Westerlund [76] cointegration test. The findings reveal that when the cross sections' mean effect is included, there is a long-run cointegration relationship between polluting gas emissions, the shadow economy, globalization, trade, and market size. This result is consistent when the average effect of the cross-sections is not included. Therefore, it is concluded that there is an equilibrium relationship between the five series, denoting that the regressor variables change them, and they will generate changes in the emissions of polluting gases. In all cases, the *p*-value is statistically significant at 0.1%. Based on these results, the estimators in Table 9 show that the shadow economy, globalization, trade, and market size are valid instruments to impact greenhouse gas emissions significantly. Some recent empirical research used this methodological framework to estimate the long-term relationship between the series [49].

Table 10 reports the results of the long-term elasticities. Specifically, we employ a fully modified ordinary least squares model (FMOLS) and a dynamic panel model (DOLS). The main advantage of the FMOLS model proposed by Pedroni [77] is that it allows correcting endogeneity bias and serial correlation. The results are heterogeneous between countries

according to the level of development. In the global panel of 134 countries, the shadow economy has a negative impact on polluting gas emissions. In high-income countries, the effect of the Shadow economy on emissions is stronger. As countries' development decreases, the effect of the informal and clandestine economy on emissions also decreases. The impact is consistent at all levels of development. That is, although the size of the estimator changes, the negative effect is stable in all the estimations. Regarding the informational globalization index, we find that the vector's force is not overwhelming. In high-income countries, the strength of the correlation vector between IGI and pollutant gas emissions is significant in most countries. In the global panel of 134 countries, trade increases greenhouse gas emissions significantly. The result is stable in groups of countries classified according to the level of development they have reached. Most of the vectors are forceful as the level of development of the countries decreases. Finally, the size of the market reduces the emissions of polluting gases in most groups of countries.

Table 9. Results of the Westerlund (2005) cointegration test.

Variance Ratio	Without Cross-Sectional Averages				With Cross-Sectional Averages			
	Without Time Trend		With Time Trend		Without Time Trend		With Time Trend	
Test Some Panels	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value
	−10.37 [a]	0.00	−13.26 [a]	0.00	−10.37 [a]	0.00	−13.18 [a]	0.00
Test All Panels	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value
	−5.71 [a]	0.00	−9.68 [a]	0.00	−5.71 [a]	0.00	−9.71 [a]	0.00

Note: *t* statistics in parentheses and [a] $p < 0.001$.

Table 10. Long-run elasticity.

	Panel-FMOLS		Panel-DOLS	
	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic
134 Counties				
Shadow Economy	−0.05 [a]	−35.36	−0.10 [a]	−19.04
Informational Globalisation Index	−0.00	−1.41	0.001	0.34
Trade	0.01 [b]	16.84	0.01 [b]	8.80
Market Size	−7.88 [c]	−2.44	−11.75 [c]	−2.18
High Income Countries				
Shadow Economy	−0.11 [a]	−19.92	−0.21 [b]	−10.92
Informational Globalisation Index	0.01 [c]	4.02	−0.01 [c]	5.00
Trade	0.02 [a]	25.	0.03 [c]	3.80
Market size	−26.84 [c]	−5.11	−32.87 [c]	−2.77
Middle-High Income Countries				
Shadow Economy	−0.04 [a]	−26.50	−0.10 [b]	−12.64
Informational Globalisation Index	−0.01 [b]	−7.21	0.01	1.26
Trade	0.00 [c]	5.54	0.01 [b]	9.89
Market Size	4.33	0.32	−5.94 [c]	−2.01
Middle-Low Income Countries				
Shadow Economy	−0.01 [b]	−11.18	−0.02 [b]	−7.82
Informational Globalisation Index	0.00	−0.25	0.01	0.95
Trade	0.00	1.48	0.00	3.32
Market Size	−2.08	0.75	0.13	−0.11
Low Income Countries				
Shadow Economy	−0.00 [b]	−12.42	−0.001 [c]	−6.19
Informational Globalisation Index	−0.00	0.25	0.00 [c]	4.86
Trade	−0.00 [c]	−2.07	0.00	−0.01
Market size	−0.13	−0.30	0.13	1.06

Note: *t* statistics in parentheses and [a] $p < 0.001$, [b] $p < 0.01$, and [c] $p < 0.05$.

Some results are intuitive, while other findings are contrary to what was expected a priori. In the case of the shadow economy, the result is opposed to the previous literature and is consistent with the results of the threshold regressions presented in Table 5. In developed countries, the cointegration vector's strength is stronger, and the vector loses power in developing countries. This result leaves two interesting lessons. First, it is possible to intuit that the activity associated with the shadow economy is high in developing countries, but they are low-skilled activities. It is clear that, if informal and clandestine activities are low-skilled, the impact on polluting emissions must also be small. On the contrary, it is possible that in developed countries, the activities of the underground economy generate greater added value. Consequently, the pollution generated by informal economic agents must be high. In this sense, there must be other aspects where the environmental pollution caused by the shadow economy is reflected. In developing countries, shadow economy activities must be more visible in the ecological footprint than in polluting emissions.

The strength of the vector for the cointegration of trade with environmental degradation is positive. This result is expected according to the logic of the environmental Kuznets curve. The goods that are traded are predominantly manufactured products and, to a lesser extent, natural resources. Therefore, as trade increases, environmental degradation must also increase. The vectors of the informational globalization index and market size are those expected according to the previous literature. At least two arguments explain the positive relationship between the two variables. First, the patterns of globalization reflect the consumption of energy-consuming technological goods. Therefore, the contamination is greater. Various empirical investigations have noted that variables associated with the number of consumers, such as urbanization, increase environmental degradation [3,15,58].

The comparison between the linear and non-linear approaches improves the understanding of the problem of environmental pollution and reinforces the robustness of the findings to raise the policy implications. In particular, concerning the shadow economy, the lessons drawn from a broad sample of countries allow the recommendations to mitigate growing environmental pollution in an effective form.

6. Conclusions and Policy Implications

The present study provides a significant contribution to both the literature, empirical analyses, and policymakers, since the first contribution is the inclusion of the shadow economy as a determinant of environmental pollution. Activities that moved from the formal to the informal economy to evade environmental regulations or payment of environmental taxes were included and are clandestinely damaging the environment. In environmental economics, global polluting gas emissions continue to be under solid attention and analysis; the larger the shadow economy, the greater the increases in total emissions from emissions, although this will depend on time and each country's economies [18,90,91]. Such observations result from the fact that the shadow economy is not constrained by environmental regulations, making controls almost impossible and therefore impacting the environment to a greater extent [47]. The environmental Kuznets curve offers a robust theoretical framework for analysis that allows guiding the search for new sources of environmental pollution. The idea that environmental pollution is a problem that will be resolved with economic development does not necessarily have empirical support in all contexts and particularly in developed countries, which continue to pollute to maintain the economic growth necessary to achieve the social objects.

The second contribution of this research is analyzing the combined effect of the shadow economy, globalization, trade, and market size using linear and non-linear methods. This aspect has not yet been jointly addressed in the existing literature. Therefore, it extends the current literature to previous studies by further documenting the differences in the effects of globalization, trade, and market size on emissions. The results show that when the threshold is the informational globalization index, below the threshold, the IGI on emissions is positive and significant. On the contrary, above the threshold, the effect of

the IGI on emissions is not significant, although it is positive. The IGI and the market size increase the polluting gases emissions, and the trade reduces them. Likewise, we find that when the threshold variable is the trade, the effect below and above the threshold is also positive and significant. The IGI also has a positive and significant impact on pollution emissions. Similar results are obtained to the previous model regarding trade and market size in effect, but not significance. When the market size is the threshold variable, negative but significant impacts are obtained only below the threshold. Evidence shows that the globalization index, trade, and market size can predict pollutant gas emissions globally but vary according to income level. For policymakers, this information is relevant for designing policies to reduce environmental pollution based on countries' heterogeneity. Some actions to mitigate environmental pollution are fair trade and regulations on the shadow economy's activities [48]. Another public policy is providing incentives and payments for environmental services that can balance long-term trade and reduce polluting gas emissions [89]. Fiscal policy instruments must be aligned with environmental reforms since the results have established different economic activities' environmental effects. Governments of income-dependent economies should save more funds for green projects in their fiscal reforms for sustainable development. However, the constant macroeconomic indicators' constant changes limit the state's capacity to apply this type of pro-environmental policy [92].

Finally, institutional quality must be internalized within the macroeconomic policy framework to preserve the environment [93]. This policy recommendation is crucial to reduce the shadow economy that causes changes in environmental quality. Similar studies can be carried out for other economies using different approaches and delve into local pollution problems. The nexus' micro-foundations between the shadow economy and pollution require further analysis to understand the causal mechanisms that relate the two variables. Thus, we will include those activities that moved from the formal to the informal economy to evade environmental regulations or payment of environmental taxes, damaging the environment. Specifically, to reduce polluting emissions from the underground economy, we suggest increasing the frequency of accounting audits to avoid displacement from the formal to the informal sector, and also, reduce taxes on companies that incorporate clean technologies, to reduce their production costs. This information is relevant to policymakers seeking to identify ways to reduce environmental pollution globally. It is necessary to develop international cooperation initiatives to reduce regional disparities in the levels of environmental degradation. Globalization determines the emission levels of polluting gases. It is clear that the effect varies by country, and those who continue to lag cannot hope to reduce pollution if the environmental burdens induced by trade continue. The geographical and temporal coverage of the research is limited to statistical information on the variables. One of the challenges for those responsible for international development organizations and national statistical institutions is to improve the quality of the data and expand the temporal coverage. Without access to open and reliable data, the search for the sources of environmental degradation will be limited to outdated analyses with little application to the actual context.

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