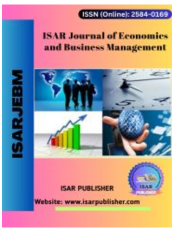

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Carbon dioxide emissions in the United States: A determinant analysis

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Abstract: This study examined the connection between intra-industry trade (IIT) and its impact on United States carbon dioxide (CO2) emissions. The research also delves into the influence of foreign direct investment (FDI) on CO2 emissions, considering the arguments presented by the pollution haven hypothesis and the halo hypothesis. Employing econometric techniques, specifically panel data analysis, this investigation utilized a Pooled Mean Group (PMG) of an Autoregressive Distributed Lag (ARDL) model.

The initial phase of the analysis involved conducting unit root tests, which revealed that IIT, United States renewable energy, and United States FDI are integrated when examined at the first differences level. Subsequently, the study conducted tests to assess cross-dependence among variables. The results of the variance inflation factor test indicated that FDI and IIT do not exhibit multicollinearity issues.

In terms of cross-sectional dependence, the investigation concluded that there is no dependence among the variables. In the econometric findings obtained through the ARDL estimator, it was observed that IIT displays a negative correlation with United States CO2 emissions, implying that this type of trade promotes environmental improvements. Moreover, United States renewable energy is adversely affected by CO2 emissions, suggesting that renewable energy initiatives aim to reduce pollution. Finally, United States FDI is found to reduce CO2 emissions, a trend attributed to factors such as product differentiation, innovation, and monopolistic competition.

Keywords: Intra – Industry Trade, foreign direct investment, trade theory, carbon dioxide emissions, panel ARDL model.

1. INTRODUCTION

The study of intra-industry trade (IIT), foreign direct investment (FDI), and renewable energy has been a focal point in international economics and energy economics. Theoretical models for understanding IIT emerged during the 1980s and 1990s, aiming to elucidate product differentiation. These models were proposed by scholars like Krugman (1979), Lancaster (1980), Falvey and Kierzkowski (1987), Shaked and Sutton (1987). However, it was only in later years that empirical research on horizontal and vertical IIT gained prominence in the academic landscape, notably with the investigations conducted by Greenaway et al. (1995) and others. These researchers utilized both country-specific and industry-specific characteristics to shed light on the determinants of IIT. Various studies, such as those by Faustino and Leitão (2007), Leitão and Faustino (2013), Jambor and Leitão (2016), Doanh and Heo (2018) delved into these determinants, considering factors like geographical distance, borders, economic dimensions, industrial concentration, product differentiation, scale economies, and FDI, often employing gravity models for explanation.

Another field of research pertains to the exploration of marginal intra-industry trade (IIT) and its implications for labor market structural adjustments. Scholars such as Brülhart and Thorpe (2000), Thorpe and Leitão (2012) and Leitão et al. (2022) have delved into this topic. In these empirical studies, various independent variables, including wages, productivity, apparent consumption, and marginal IIT, are analyzed concerning their role in labor market adjustments. Furthermore, these studies posit that adjustments in the labor market tend to be more seamless when there is a negative correlation between marginal IIT and changes in employment.

Recent empirical research conducted by Roy (2017), Leitão and Balogh (2020), Leitão (2021), and Kazemzadeh et al. (2022) has provided evidence suggesting that intra-industry trade (IIT) and increased trade intensity can have a mitigating effect on environmental damage, contribute to improved air quality, and help slow down climate change. This proposition is grounded in the notion that IIT is closely linked to innovation and the differentiation of products. Additionally, the internalization process of multinational enterprises has been developed based on theories of international investments, including organizational theories, localization theories, internalization theories, and considerations of transaction costs, as exemplified by the works of Dunning and Lundan (2008).

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When examining the factors influencing Foreign Direct Investment (FDI), empirical studies employ the gravity model and consider organizational, localization, and internalization advantages and characteristics. These studies incorporate various explanatory variables such as economic dimensions, border proximity, geographical distance, production costs, exchange rates, and more recently, the impact of corruption and democratization on the host country's FDI environment (Egger and Pfaffermayr, 2004; Leitão, 2021).

Another focal point in FDI research centers on the question of its impact on economic growth, entailing an exploration of the relationship between FDI and economic development. This topic has been addressed by academics and scholars, as seen in the works of Alfaro et al. (2004) and Alfaro and Charlton (2013). Additionally, scholars have delved into the debate surrounding FDI's role in the "pollution haven hypothesis" versus the "pollution halo hypothesis," as evident in studies by Cole et al. (2006), Singhania and Saini (2021), and Kisswani and Zaitouni (2021). Copeland and Taylor (2017) introduced a theoretical model outlining the Pollution Haven Hypothesis (PHH). Their model revolves around two countries, referred to as the North and the South. In this model, the North primarily engages in industries with lower pollution intensity, while the South specializes in industries that are more pollution intensive.

Several empirical studies have explored the relationship between pollution and trade, with recent research contributions outlined as follows (Antweiler et al., 2001; Copeland and Taylor, 2003; Cole and Elliot, 2003; Kahn and Yoshino, 2004; Cole et al., 2010; Grether et al., 2010; Aggarwal, 2017a, 2017b, 2020). Antweiler et al. (2001) and Copeland and Taylor (2003) focused on assessing the impact of sulfur oxides on trade dynamics. In contrast, Cole and Elliot (2003) identified a negative correlation between intra-industry trade and environmental regulations, indicating that intra-industry trade tends to involve less pollution-intensive emissions.

Kahn and Yoshino (2004) employed sulfur dioxide, carbon monoxide, and nitrogen dioxide to investigate how trade liberalization influences the environment, highlighting negative externalities. Cole et al. (2010) conducted a study that demonstrated the statistical significance of environmental and industrial regulations as determinants of Japanese net imports, both from the rest of the world and specifically from non-OECD countries and China.

Furthermore, Grether et al. (2010) explored the role of trade in global SO_2 manufacturing. Their findings revealed that trade activities and reallocation efforts contributed to a reduction of approximately 2 to 3% in global SO_2 emissions.

This study makes valuable contributions to the existing literature in several keyways. First, it delves into the relationship between Intra-Industry Trade (IIT) and its effects on climate change, air quality, and CO_2 emissions. This analysis combines both theoretical and empirical approaches, which traditionally indicate a negative correlation between IIT and CO_2 emissions, showcasing its potential to reduce greenhouse gas emissions and mitigate global warming.

Second, the study assesses the connection between Foreign Direct Investment (FDI) and pollution emissions, considering two distinct perspectives. On one hand, empirical evidence suggests that FDI has a positive impact on CO_2 emissions, a phenomenon explained by the Pollution Haven Hypothesis. Essentially, countries may use FDI to circumvent strict domestic environmental regulations, resulting in the relocation of polluting activities to countries with laxer regulations.

On the other hand, empirical research indicates that FDI is associated with factors promoting innovation, which, in turn, reduces greenhouse gas emissions, thus contributing to efforts to combat climate change. This perspective aligns with the Pollution Halo Hypothesis, where transnational enterprises transfer green technology through FDI to their host countries.

The primary objective of this research is to evaluate the influence of IIT and FDI on pollution and environmental conditions. Additionally, the study considers the role of renewable energy in relation to CO_2 emissions. Typically, empirical studies suggest that renewable energy initiatives aim to mitigate climate change and global warming (Aggarwal and Chakraborty, 2020a, 2020b; Usman et al., 2022; Yu et al., 2022).

Lastly, this investigation holds significant importance as its empirical findings contribute to the advancement of existing literature and have far-reaching implications for the environmental policies of complex economies with diverse export profiles. Moreover, the results and insights from this study can provide invaluable support to policymakers and governments in crafting coherent strategies and initiatives that promote clean energy, reduce energy consumption, and facilitate sustainable development.

The subsequent sections of this paper are structured as follows: Section 2 will provide an overview of the literature review followed by methodology and empirical studies in Section 3. Section 4 will present the empirical results, and the study will conclude with Section 5, summarizing the key findings and implications.

2. Literature Review

The initial theoretical models of Intra-Industry Trade (IIT) were formulated in Helpman and Krugman's model (1985), which combines elements of monopolistic competition with the Heckscher-Ohlin (HO) theory. This model considers variations in factor endowments, horizontal product differentiation, and the presence of increasing returns to scale. In essence, it merges the ideas of Chamberlin and Heckscher-Ohlin.

In the context of trade, Intra-Industry Trade (IIT), also known as two-way trade, refers to the simultaneous occurrence of exports and imports of a specific product within a country or within a particular industry. IIT is shaped by several key factors, including economies of scale, industrial concentration, and product differentiation. This type of trade primarily occurs within the same sector or branch, as evidenced by studies such as Grubel and Lloyd (1975) and Greenaway and Milner (1983). The theoretical models of IIT, such as those proposed by Krugman (1979), Lancaster (1980), Falvey and Kierzkowski (1987), and Shaked and Sutton (1987) are grounded in the concept of monopolistic competition. These models consider factors like geographical proximity, similarities or differences in factor endowments, and consumer preferences as essential explanatory variables.

As a result, this investigation will explore the link between IIT and environmental concerns within the framework of monopolistic competition. It's worth noting that before delving into the connection between IIT and ecological issues, there exists a body of empirical research that examines the determinants of IIT. This research often employs the gravity model, utilizing country-specific characteristics or industry-specific attributes, as seen in studies by Hasim et al. (2018), Vidya and Prabheesh (2019), and Jošic and Žmuk (2020).

A variety of theoretical and empirical models have been developed to examine the relationship between international trade (IIT), export quality, trade intensity, and their impact on air quality and the environment. These models include works by Gürtzgen and Rauscher (2000), Copeland and Taylor (2017), Roy (2017), Echazu and Heintzelman (2018), Gallucci et al. (2019), Leitão and Balogh (2020), Leitão (2021), Shapiro (2021) and Kazemzadeh et al. (2022).

These studies collectively suggest that IIT, along with improved export quality and increased trade intensity, can contribute to enhancing air quality and environmental conditions. In the following sections, this investigation will provide further insights and conclusions based on empirical research in this area, with a specific focus on the studies conducted by Roy (2017), Gallucci et al. (2019), Leitão and Balogh (2020), Leitão (2021) and Kazemzadeh et al. (2022).

For instance, Roy (2017) conducted an empirical analysis of the determinants of IIT, employing the gravity model framework. The study assessed the impact of IIT, marginal IIT, and trade intensity on air quality and pollution emissions using panel data. The results of the regression analysis indicated that IIT endeavors to reduce the environmental impact by contributing to improvements in climate change mitigation.

Similarly, Gallucci et al. (2019) found that IIT can serve as an indicator of innovation, and this form of trade has a positive influence on the environment through the adoption of cleaner and more sustainable technologies.

Examining the European context, Leitão and Balogh's research (2020) employed fixed effects and generalized method of moments estimators to explore various facets of international trade (IIT) and its environmental implications. Their study yielded several noteworthy conclusions. Firstly, they found a negative correlation between IIT and CO2 emissions, suggesting that increased international trade is associated with reduced carbon dioxide emissions. Additionally, employing a fixed effects model, the same authors concluded that the adoption of renewable energy sources is linked to a decrease in pollution emissions. Furthermore, they observed a positive relationship between CO2 emissions and both income per capita and agricultural land productivity.

In a comprehensive empirical analysis focusing on Portugal, Leitão's study (2021) utilized the autoregressive distributed lag (ARDL) model with time series data. This investigation revealed that heightened trade intensity is linked to a reduction in CO2 emissions. However, it also highlighted those variables related to energy consumption and income per capita tend to contribute to increased pollution emissions, particularly CO2 emissions.

Shifting the focus to a global perspective, Kazemzadeh and colleagues (2022) investigated the effects of economic complexity and export quality on pollution emissions across 98 countries during the period from 1990 to 2014, employing panel quantile regressions (PQRs). Their findings indicated that trade openness and export quality have a positive impact on environmental quality, as they were associated with reduced pollution emissions. Conversely, factors such as income per capita, population size, and reliance on non-renewable energy sources exhibited a positive correlation with climate change and ecological harm. However, when panel cointegration regressions were applied, the results consistently demonstrated that urban population and economic complexity were negatively correlated with CO2 emissions, suggesting that urbanization and economic diversification may contribute to environmental improvements.

Copeland and Taylor (2017) examined a scenario involving two countries, North and South, each characterized by different levels of pollution intensity and possessing a single factor of production, namely labor. Both countries share an identical utility function among their consumers. According to their model, economies with higher income tend to adopt cleaner environmental practices and regulations. When international trade occurs between these North and South countries, it leads to an increase in global environmental challenges, which the authors term "world pollution." In this context, when the North increases its production, pollution levels rise accordingly. However, the growth of production in the South has the opposite effect, reducing pollution. The introduction of international trade enables the transfer of pollution to the South, resulting in an overall decrease in world pollution.

Gürtzgen and Rauscher (2000) delve into the relationship between environmental policies and trade restrictions between these two nations. They employ a Dixit–Stiglitz-type model characterized by monopolistic competition within the market structure. The introduction of international trade in this model leads to increased production and a rise in negative externalities, such as gas emissions, in the host country. However, countries that implement more stringent environmental policies tend to experience less environmental damage.

Haupt (2006) explores the connection between trade and the environment, drawing on the concept of externalities associated with production taxes. The model encompasses two countries, their respective governments, household consumption, and business enterprises. The model adopts a perspective of monopolistic competition and unfolds in a sequential game. In the initial phase, governments decide to implement measures that promote environmental sustainability. In the subsequent phase, companies choose to introduce product differentiation, ultimately transitioning to a free market environment. With the introduction of competitive markets and market liberalization, household utility functions decline, primarily due to a reduction in the availability of imported product varieties. The author concludes that the impact of international trade on the environment remains ambiguous. While free trade can lead to increased economic efficiency and support ecological objectives, market liberalization may result in higher opportunity costs, which can discourage anti-pollution measures.

Echazu and Heintzelman (2018) employ a monopolistic competition framework to analyze intra-industry trade and environmental regulation. They highlight that a country's decisions regarding emissions are influenced by their strategic considerations. In closed economies, these decisions can function as strategic substitutes in a Nash equilibrium. However, when markets are opened up to international trade, countries can opt for either stricter or more flexible environmental regulations, depending on their product preferences.

Mehra and Kohli's (2018) model investigated the intricate connections between trade and environmental pollution, building upon Krugman's theoretical framework. Within this model, they examine how an exogenous increase in environmental taxation affects production levels. Notably, this analysis reveals that such a tax increase leads to decreased production. Consequently, in cases where the home country is a net exporter, this heightened environmental regulation has a negative impact on exports, a phenomenon referred to by the authors as the "negative scale effect." This effect implies an increased demand for imports.

Empirical studies in this field often rely on panel data to assess the influence of trade intensity and intra-industry trade on the environment. Some studies, such as Roy (2017), Leitão and Balogh (2020) and Leitão and Lorente (2020), argued that trade liberalization promotes a reduction in environmental harm. These studies reveal a negative correlation between trade intensity or intra-industry trade and carbon dioxide emissions. However, a distinct perspective is presented by studies like Dasgupta and Mukhopadhyay (2018), Chin et al. (2018), and Yazdani and Pirpour (2020). They suggest that intra-industry trade is positively associated with CO2 emissions. The outsourcing or fragmentation of production processes, involving the relationship between component parts and the final product, is implicated in this context, contributing to increased global pollution levels.

Chin et al. (2018), for instance, employed an autoregressive distributed lag (ARDL model) to analyze the determinants of Malaysia's carbon dioxide emissions. Their long-term empirical findings indicated a positive impact of foreign direct investment, income per capita, and vertical intra-industry trade on CO2 emissions, underscoring the complexity of the relationship between trade and environmental outcomes.

Another study, conducted by Aggarwal et al. (2023a) and focused on India, sheds light on the nature of India's international trade (IIT), highlighting the prevalence of low-quality products due to differences in environmental regulations. The authors suggest that India could potentially address this issue by forging trade agreements with European Union countries and the United Kingdom to enhance product quality and environmental standards.

In a separate investigation, Khan et al. (2020) examined the connections between international trade, renewable energy adoption, and CO2 emissions within the Group of Seven (G7) economies. Their findings revealed that over the long term, imports and income per capita were associated with increased pollution emissions. In contrast, exports, environmental innovations, and the adoption of renewable energy sources were found to be factors that led to a reduction in CO2 emissions.

The next section will discuss the methodology and econometric model. Further, research hypotheses are developed that need to be tested by applying the select economic model.

3. Methodology and Econometric Model

In the present study, we employ carbon dioxide emissions as the dependent variable. These emissions encompass the CO2 generated from the consumption of solid, liquid, and gaseous fuels, as well as gas flaring. The data source for this variable is the Carbon Dioxide Information Analysis Centre within the Environment Sciences Division of the United States. The present study uses IIT as an explanatory variable which is defined as the difference between the trade balance of country *j* for industry *i*. To make comparisons easier between industries or countries, the index is presented as a ratio, where the denominator is total trade:

$$\text{IIT} = \frac{\sum(X_{ij} + M_{ij}) - \sum|X_{ij} - M_{ij}|}{\sum(X_{ij} + M_{ij}) - |\sum X_{ij} - \sum M_{ij}|} \times 100$$

The IIT index varies between 0 and 1. When IIT = 1, all trade is intra-industry trade, but when IIT = 0, the trade is inter-industry trade.

The agriculture intra-industry trade between United States and NAFTA, European Union and ASEAN for the period between 2001 and 2020 are constructed from the OECD at the five-digit level of the standard international trade classification (SITC) in US dollars. The renewable energy consumption data and foreign direct investment (FDI) data as a percentage of GDP has been sourced from world bank database (WBD).

The dataset is structured as panel data, initially the investigation places its focus on the coefficients derived from the panel ARDL model, which were selected based on the Akaike information criterion (AIC), and the model's specifications are held constant. In the first phase, co-integration tests, including those by Kao et al. (1999), Kao and Chiang (2001), and Johansen (1991), are employed to assess the existence of a long-term relationship between the variables of interest. Additionally, this study examines panel unit roots and cross-sectional dependence tests.

Based on the existing empirical studies (Roy, 2017; Dogan and Ozturk, 2017; Zafar et al., 2019; Leitão and Balogh, 2020; Balsalobre-Lorente et al., 2021; Aggarwal and Chakraborty, 2022 and Aggarwal et al., 2023b), the current research formulates the following model:

$$\Delta LCO_{2it} = \alpha_{0it} + \beta_{1it} LCO_{2i(t-1)} + \beta_{2it}(LIIT)_{i(t-1)} + \beta_{3it} LRE_{i(t-1)} + \beta_{4it}(LRESP)_{i(t-1)} + \beta_{5it}(LFDI)_{i(t-1)} + \sum_{j=0} p\,\gamma_1 LCO_{2i(t-j)} + \sum_{j=0} p\,\gamma_2 IIT_{i(t-j)} + \sum_{j=0} p\,\gamma_3 LRE_{i(t-j)} + \sum_{j=0} p\,\gamma_4 LRESP_{i(t-j)} + \sum_{j=0} p\,\gamma_5 LFDI_{i(t-j)} + \varphi(ECT)_{i(i-t)} + \mu_{it}$$

where,

α represents the *constant* term

βs are *coefficients*

γ_s are *coefficients*

L represents logarithmic transformation of the variables

$LCO_{2(t-1)}$ represents a lagged variable of United States carbon dioxide emissions per capita

LIIT represents United States index of Intra-Industry Trade (IIT)

LRE represents United States renewable energy consumption as a percentage of total energy consumption

LFDI represents United States foreign direct investment, net inflows (% of GDP)

Based on the above derived model, we have developed the hypothesis based on the existing literature.

Hypothesis 1: Intra-industry trade is linked with environmental damage.

Hypothesis 2: FDI is positively related to CO_2 emissions and is explained by pollution haven hypothesis (PHH).

Hypothesis 3: Intra Industry trade is negatively related with CO_2 emissions.

Hypothesis 4: FDI aims to decrease pollution emissions by adopting innovation and product differentiation techniques.

4. Empirical Results

In this section, we start with empirical investigation and dependence of each variable on one another. To analyze the variables, we have deployed descriptive statistics, unit root test and cross-sectional dependence test. The summary statistics for the variables selected for the empirical analysis is provided in Table 1.

Table 1. Descriptive statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
LCO_2	4.65	0.04	4.45	4.92
LIIT	-0.55	0.38	-1.64	-0.01
LRE	1.35	0.08	1.16	1.58
LRESP	1.07	0.16	0.75	1.32
LFDI	0.54	0.28	-0.36	0.87

Source: Author's estimation

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity has been conducted next. The chi-square value (χ^2 = 3.13, Prob > χ^2 = 0.0769) indicates that no heteroskedasticity is present. Estimated mean VIF is 2.27, which lies within the tolerance limit of multicollinearity. Table 2. reports the Levin, Lin and Chu (2002), which has a null of unit root versus an alternative with a single stationary value, is performed to detect the presence of unit root among the explanatory variables. As shown in Table 2 below, the variables under investigation are integrated into the first difference. However, the variables in IIT and FDI are simultaneously stationary in levels and the first differences.

Table 2. Levin, Lin & Chu Panel Unit Root Test

Variables (Levels)	Statistics	p-Value
LCO_2	0.178	0.578
LIIT	-3.156***	0.000
LRE	0.422	0.729
LRESP	2.876	0.992
LFDI	-6.245***	0.000
Variables (First Differences)	**Statistics**	**p-Value**
ΔLCO_2	-3.654***	0.000
ΔLIIT	-6.298***	0.000
ΔLRE	-4.362***	0.000
ΔLRESP	6.935***	0.000
ΔLFDI	-8.120***	0.000

Notes: *** denotes statistical significance at a 1% level. All variables are in logarithmic form.

To test whether unobserved components that create interdependencies across cross sections are correlated with included regressors, Pesaran (2004) CD test has been performed in R software. The null hypothesis of the CD test states that the residuals are cross-sectionally uncorrelated. The test of cross-sectional dependence in Table 3 shows that the variables considered in this research do not have any cross-sectional dependence between them.

Table 3. Diagnostic tests of cross-sectional dependence: Pesaran (CD test)

Variables	Statistic	p-Value
LCO_2	28.054***	0.000
LIIT	27.563***	0.000
LRE	25.489***	0.000
LRESP	26.541***	0.000
LFDI	15.872***	0.000

Source: Author's estimation

Table 4 presented below displays the econometric findings obtained through the PMG model. This model serves as an initial tool to evaluate the relationship between the variables under examination and their significance. Moreover, the Wald test, a diagnostic assessment of coefficients, is illustrated in Table 4, highlighting the statistical significance of all independent variables.

Table 4. Autoregressive distributed lag (ARDL) model

Independent variables	Coefficients	Standard Error	T-statistic
	Dependent variable: LCO_2		
Long Run Equation			
LIIT	-0.0289**	0.098	-2.584
LRE	-0.318***	0.017	-4.832
LRESP	-0.156***	0.068	-2.465
LFDI	-0.078***	0.005	-3.981
Short Run Equation			
ECT	-4.528***	0.176	-3.189
Δ (LIIT)	-0.016**	0.048	-1.094
Δ (LRE)	0.317***	0.040	4.258
Δ (LRESP)	-0.076**	0.025	-3.067
Δ (LFDI)	0.002*	0.003	0.783
C	2.486	0.645	2.542
Mean dependent var	-0.03	S.D. dependent var	0.027
S.E. of regression	0.028	Akaike info criteria	-4.308
Sum squared residuals	0.056	Schwarz criteria	-3.128
Log-likelihood	450.32	Hannan-Quinn criteria	-3.876
Wald test 279 (0.00)***			

Notes: ***, ** denotes statistical significance at 1% and 5% levels respectively

The panel ARDL estimator offers the advantage of accounting for both short- and long-term effects. In the long run, all independent variables exhibit statistical significance and align with the anticipated signs as per the formulated hypotheses. Consequently, this analysis examined the enduring impacts of the explanatory variables on CO2 emissions and validated the hypotheses established in the methodology. The error correction adjustment (ECT) is not only negative but also statistically significant at the 1% significance level. This finding is consistent with recent studies by Boufateh and Saadaoui (2020) and Teng et al. (2021).

The statistical significance of the coefficient for the IIT index (LIIT) is observed at the 5% significance level. This outcome underscores the role of intra-industry trade in reducing pollution emissions and enhancing environmental conditions. This finding aligns with previous empirical studies by Aggarwal and Chakraborty (2017), Roy (2017), Khan et al. (2020), Leitão and Balogh (2020), Aggarwal et al. (2021), Leitão (2021), Nag et al. (2021), Aggarwal et al. (2022), Kazemzadeh et al. (2022) and Aggarwal (2023b) which support the idea that the assumptions of monopolistic competition validate the theory that two-way trade promotes and adheres to environmental standards.

Next, LRE and LRESP are negatively correlated with CO2 emissions, suggesting that greater use of renewable energy is associated with reduced climate change impact. This relationship is consistent with findings from Dogan and Ozturk (2017), Zafar et al. (2019), Adebayo and Kirikkaleli (2021), Balsalobre-Lorente et al. (2021), Leitão et al. (2022), Aggarwal (2023d), Aggarwal (2023e) which also highlighted the connection between renewable energy usage and reduced CO2 emissions.

Additionally, the coefficient for FDI (LFDI) demonstrates a negative effect on pollution emissions (LCO2), indicating that foreign direct investment can be linked to product differentiation and innovation, thereby contributing to climate change mitigation and improved air quality. This result is in line with the pollution halo hypothesis, which posits that multinational enterprises export cleaner technology to host countries, reducing environmental harm. This perspective is supported by studies such as those conducted by Aggarwal and Chakraborty (2019), Demena and Afesorgbor (2020), Marques and Caetano (2020), Teng et al. (2021).

5. Conclusion

The initial test results showed that the variables in IIT and FDI remain stationary across all levels. Nevertheless, all the variables examined in this research exhibit integration at the first differences. The empirical results obtained from the PMG-ARDL model indicate that independent variables represented in natural logarithms, such as LIIT, LRE, LRESP, and LFDI, exert a negative influence on the dependent variable LCO2 in the long term. Additionally, independent variables presented as the first differences of natural logarithms, such as ΔLRE, exhibit a positive impact on the dependent variable ΔLCO2 in the short term, whereas ΔLRESP negatively affects the dependent variable. However, it's worth noting that the variables ΔLIIT and ΔLFDI do not show statistically significant effects.

The inverse relationship observed between IIT and climate change indicates that cleaner trade strategies, which emphasize innovation and product differentiation, aim to reduce CO2 emissions. This finding aligns with previous research findings (Roy, 2017; Leitão and Balogh, 2020; Leitão, 2021). Furthermore, in terms of the connection between renewable energy and CO2 emissions, this study supports the anticipated negative effect, suggesting that increased use of renewable energy reduces global warming and contributes to environmental improvement (Aggarwal, 2016; Dogan and Ozturk, 2017; Balsalobre-Lorente et al., 2021; Fuinhas et al., 2021; Ebrahimi et al., 2022). Lastly, the link between FDI and CO2 emissions displays a negative correlation, indicating that FDI is associated with innovation, as seen in previous studies by Demena and Afesorgbor (2020) and Marques and Caetano (2020), thereby confirming the pollution halo hypothesis.

Based on the existing literature, as exemplified by Roy (2017), it is widely accepted that marginal IIT, also referred to as trade intensity, as demonstrated by Leitão (2021) and Aggarwal and Chakraborty (2020c), plays a crucial role in enabling adjustments and reducing pollution emissions. This phenomenon occurs when this type of trade enhances productivity through innovation, particularly within the context of monopolistic competition. Furthermore, this methodology offers the flexibility to incorporate dynamic indicators and lagged variables over time, as highlighted by previous research (Leitão et al., 2022; Aggarwal, 2023a, 2023c).

Additionally, within the context of product differentiation and its correlation with consumer preferences for high- or low-quality products, it is imperative to evaluate the impact of both horizontal IIT and vertical IIT on CO2 emissions. For a more comprehensive exploration and differentiation between horizontal IIT-HIIT and vertical IIT-VIIT, refer to works such as Greenaway et al. (1995), Faustino and Leitão (2007), Jambor and Leitão (2016) and Aggarwal and Chakraborty (2021).

Theoretical models indicate that labor-intensive products tend to rely on less sustainable or cleaner energy sources, while capital-intensive products or sectors are more inclined to adopt sustainable practices. Furthermore, future research should delve into the effects of income inequality on economic growth and its impact on the environment, along with the implications of inflation rates and rising fuel consumption.

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