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CO_2 Emissions, Foreign Direct Investments, Energy Consumption, and GDP in Developing Countries: A More Comprehensive Study using Panel Vector Error Correction Model

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This paper examines the causal relationships among carbon dioxide (CO_2) emissions, energy consumption, gross domestic product (GDP), and foreign direct investments (FDI) in 57 developing countries from 1980 to 2013. The results of the analysis based on panel vector error correction model (VECM) indicate no direct short-run causality exists from FDI to CO_2 emissions. These results are also confirmed by regional analysis, wherein the developing countries are divided into three regions. In the long run, a cointegrated relationship is found among CO_2 emissions, energy consumption, GDP, and FDI, which supports the environmental Kuznets curve hypothesis. However, the long-run elasticity of FDI on CO_2 emissions is very small even though it is statistically significant. These results do not support the pollution haven hypothesis of CO_2 emissions through inward FDI in developing countries.

JEL Classification: Q56, Q43
Keywords: CO_2 Emissions, Energy Consumption, GDP, FDI, Panel VECM, Cointegration

I. Introduction

As greenhouse gas (GHG) emissions have become more serious, causing unprecedented global problems, the need for a global reduction in their emissions is increasing. As a result, the United Nations Framework Convention on Climate Change concluded the Paris Agreement (2015) to establish a new climate change

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international response system to replace the Kyoto Protocol that expired in 2012.

In the Kyoto Protocol,[1] Annex I parties[2] comprising developed countries were obliged to reduce GHG emissions. The Kyoto Protocol either excluded the developing countries from the obligations or allowed them to decide the level of voluntary reduction. In comparison, both developing and developed countries were obliged to reduce GHG emissions[3] in the Paris Agreement, even though the degree of GHG reduction is significantly higher in developed countries than in developing countries.[4] Therefore, the transfer of the high GHG emission industries (or energy intensive industries) to the developing countries has steadily increased as a result of the stronger GHG mitigation policies of the developed countries.

Hence, finding whether foreign direct investments (FDI) act as a foreign migration conduit of the high GHG emission industries is an important issue in the international economy. However, significant empirical analyses of this issue have yet to be conducted. Therefore, the current paper empirically analyzes whether FDI inflows into developing countries increase GHG emissions in such countries. In addition, this paper analyzes the issue by using a framework on the causality relationships among carbon dioxide (CO_2) emissions, energy consumption, gross domestic product (GDP), and FDI.

The causality issues among these variables have been a subject of debate in the empirical and theoretical literature for the past 20 years and three types of literature have emerged in response. The first type of literature focuses on investigating the relationships between CO_2 emissions and economic growth using the environment Kuznets curve (EKC). This research demonstrates an inverted U-shaped relationship between economic growth and environmental pollution emissions.

[1] Under the Kyoto Protocol, only the Annex I parties had committed themselves to national or joint reduction targets (formally called "quantified emission limitation and reduction objectives" (QELRO) – Article 4.1). Parties to the Kyoto Protocol not listed in Annex I of the Convention (the non-Annex I Parties) are mostly low-income developing countries, and may participate in the Kyoto Protocol through the Clean Development Mechanism.

[2] Annex I parties include Australia, Austria, Belgium, Bulgaria*, Canada, Croatia, Czech Republic*, Denmark, Estonia*, European Community, Finland, France, Germany, Greece, Hungary*, Iceland, Ireland, Italy, Japan, Latvia*, Liechtenstein, Lithuania*, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland*, Portugal, Romania*, Russian Federation, Slovakia*, Slovenia*, Spain, Sweden, Switzerland, Ukraine*, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. "*" countries are undergoing the process of transition to a market economy.

[3] The contribution that each individual country should make in order to achieve the global goal is determined by all countries individually and is called the "nationally determined contributions" (NDCs). Article 3 of the Paris Agreement requires them to be "ambitious," "represent a progression over time," and set "with the view to achieving the purpose of this Agreement." Each further ambition should be more ambitious than the previous one, known as the principle of progression.

[4] In Article 4 of the Paris Agreement, developed country parties are expected to continue taking the lead by undertaking economy-wide absolute emission reduction targets. Developing country parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances.

Pollution increases along with national income and subsequently decreases once the national income crosses a certain level. Many empirical studies have verified the EKC hypothesis. Hettige et al. (1992), Cropper and Griffiths (1994), Selden and Song (1994), Grossman and Krueger (1995), Martinez-Zarzoso and Bengochea-Morancho (2004), Apergis (2016), and Bae (2018) all support the EKC hypothesis. However, some empirical studies do not support the EKC hypothesis. Holtz-Eakin and Selden (1995), and Shafik (1994) demonstrate a linear relationship between national income and environmental pollution levels.

The second type of literature investigates the relationship between energy consumption and economic growth. This relationship has important implications for energy policy (Shiu and Lam, 2004; Jumbe, 2004; Yoo, 2005; Chen et al., 2007; Mozumder and Marathe, 2007; Apergis and Payne, 2009a). Ozturk (2010) categorizes the hypothesis about the causal relationship between energy consumption and economic growth into the following four types: neutral, conservative, growth, and feedback hypotheses. Recent studies have comprehensively considered the causal relationship between energy consumption and economic growth, as well as that between GHG emissions and economic growth. Since the publication of Ang's (2007) work, several papers have been written about the dynamic causal relationship, and the results vary according to target countries (Halicioglu, 2008; Zhang and Cheng, 2009; Apergis and Payne, 2009b; Soytas and Sari, 2009; Pao and Tsai, 2010; Arouri et al., 2012).

The third type of literature comprehensively investigates the relationships among CO_2 emissions, energy consumption, GDP, and inward FDI. The impact of FDI on the host country's environment has also been a subject of debate. Some papers investigated whether the inward FDI of the host country increases due to the high cost incurred by the GHG mitigation policy in the home country. Two conflicting hypotheses have been presented in previous studies: the pollution haven and the halo effect hypotheses. According to the latter, the presence of inward FDI will spur positive environmental spillovers in the developing country, as multinational companies have more advanced technologies and tend to disseminate cleaner technology which emits less GHG. In contrast, the pollution haven hypothesis posits that the stringent GHG mitigation policy in developed countries causes the energy-intensive industries (or firms/production facilities) to relocate their production bases to other countries with weaker mitigation policies.

The lower cost of resources and labor in developing countries leads to their use of less stringent GHG mitigation policies than developed countries; conversely, operating in developed countries with stricter GHG mitigation policies becomes more expensive for companies as a result of the costs associated with meeting the stringent national mitigation targets. Thus, the companies that choose to physically invest in a foreign country tend to relocate to countries with weaker mitigation policies. Furthermore, inward FDI in developing countries could cause an increase in the GHG emissions in such countries.

Nevertheless, the empirical results for the effects of inward FDI on the CO_2 emissions of the host country are mixed. Merican et al. (2007) investigated the long-run relationship between FDI and CO_2 emissions on five Association of Southeast Asian Nations (ASEAN) countries by employing an autoregressive distributed lag method. According to their results, FDI increased emissions in Malaysia, Thailand, and the Philippines; whereas FDI was inversely related to CO_2 emissions in Indonesia and Singapore, where it proved insignificant. Hoffmann et al. (2005) conducted Granger causality tests on the relationship between only two variables, FDI and CO_2 emissions, and found unidirectional causality running from FDI to CO_2 emissions in middle income countries. Their model did not consider the relationship under the link between GDP and energy consumption. Pao and Tsai (2011) examined the causal links between CO_2 emissions, energy consumption, FDI, and GDP in the BRIC (Brazil, Russian Federation, India, and China) countries using a multi-variate Granger causality approach. Their results demonstrated the bi-directional causality between CO_2 emissions and FDI as well as a one-way causality from GDP to FDI. Baek (2016) estimated the effects of FDI inflows, income, and energy consumption on CO_2 emissions using the pooled mean group estimator of dynamic panels in five ASEAN countries during the 1981–2010 period, and showed that FDI increased CO_2 emissions, thus supporting the pollution haven hypothesis. His research only focused on the long-run relationships between variables.

The previous literature mainly focused on a single country or specific regions when analyzing the causal relationships among CO_2 emissions, energy consumption, GDP, and FDI. Pao and Tsai (2011) and Baek (2016) focused on the BRIC and the ASEAN members, respectively. Moreover, Baek (2016) only focused on the long-run relationships among variables. In comparison, the present research expands the scope of analysis to 57 developing countries and conducts both short- and long-run analyses, particularly the causal relationship between inward FDI and CO_2 emissions. This paper also investigates the existence of the EKC hypothesis and the causal relationship between GDP and energy consumption. In addition, the developing countries are divided into three regions, namely, Asia, Africa and America, to verify whether the pollution haven and halo effect hypotheses exist in each region. Methodologically, the panel vector error correction model (VECM) is used to test the causality among CO_2 emissions, energy consumption, GDP, and inward FDI in developing countries in the short-run. Then, the fully modified ordinary least squares (FMOLS) estimation method to identify the long-run relationships among these variables and the existence of the EKC hypothesis.

To the best of our knowledge, this present paper is the first study to explore the causal relationships among GHG emissions, energy consumption, economic development, and inward FDI in all developing countries using panel VECM from

1981–2013. Understanding the causality relationships among the variables can help policy-makers in designing appropriate policies to address climate change. The remainder of the paper is structured as follows: Section II presents the methodologies employed in this study, Section III reports on the data, Section IV discusses the empirical findings, and Section V concludes the paper.

II. Empirical Model

Following the previous literature (Jalil and Mahmud, 2009; Pao and Tsai, 2011; Kivyiro and Arminen, 2014; Baek, 2016), the long-run relationships among CO_2 emissions, energy consumption, GDP, and FDI are modeled, as indicated by Equation (1) below. According to the EKC hypothesis, an inverted U-shaped relationship exists between environmental pollution and national outcome. The present paper applies this relationship to the one between CO_2 emissions and GDP, and expresses it mathematically by including the squared value of GDP per capita in the set of regressors

$$CO_{2,it} = \alpha_0 + \alpha_1 EN_{it} + \alpha_2 FDI_{it} + \alpha_3 Y_{it} + \alpha_4 Y_{it^2} + \theta_i + \varepsilon_{it} \quad (1)$$

where $i\,(i=1,2,\cdots,N)$ denotes the country, $t\,(t=1,2,\cdots,T)$ denotes the period, CO_2 denotes the log of CO_2 emissions per capita, EN is the log of energy consumption per capita, and FDI denotes the log of inward FDI. In addition, Y denotes the log of GDP per capita, Y^2 denotes the log GDP per capita squared, θ represents the individual fixed country effects, and ε denotes the stochastic error term.

First, we test whether these time series have unit roots. If they do, panel cointegration method is used to investigate the relationship. Panel estimation techniques are appropriate, because models estimated from cross-sections of time series have more degrees of freedom and efficiency in comparison to models estimated from individual time series. These techniques are particularly useful if the time series dimension of each cross-section is short. A number of authors recently used panel cointegration techniques to investigate the relationship between energy consumption and output.[5]

If each time series is I (1) and the variables are cointegrated, a panel VECM can be used to estimate causality, similar to that followed by Engle and Granger (1987). Finding the cointegration between variables is important as it ensures that an error

[5] e.g. Lee, 2005; Chen et al., 2007; Mahadevan and Asafu-Adjaye, 2007; Narayan et al., 2007; Mehrara, 2007; Lee and Chang, 2008; Lee et al., 2008; Narayan and Smyth, 2008; Apergis and Payne, 2009; Narayan and Smyth, 2009; Sadorsky, 2009a, 2009b; Apergis and Payne, 2010; Sadorsky, 2011.

correction mechanism exists, according to which changes in the dependent variable are modelled as a function of the level of the equilibrium in the cointegration relationship and changes in other explanatory variables. Thus, Equation (1) can be written as the following VECM model:

$$\Delta CO_{2,it} = c_{1i} + \sum_{j=1}^{q} \gamma_{11ij} \Delta CO_{2,it-j} + \sum_{j=1}^{q} \gamma_{12ij} \Delta EN_{it-j} + \sum_{j=1}^{q} \gamma_{13ij} \Delta FDI_{it-j}$$

$$+ \sum_{j=1}^{q} \gamma_{14ij} \Delta Y_{it-j} + \sum_{j=1}^{q} \gamma_{15ij} \Delta Y^2_{it-j} + \gamma_{16i} \varepsilon_{it-1} + \upsilon_{1it},$$

$$\Delta EN_{it} = c_{2i} + \sum_{j=1}^{q} \gamma_{21ij} \Delta CO_{2,it-j} + \sum_{j=1}^{q} \gamma_{22ij} \Delta EN_{it-j} + \sum_{j=1}^{q} \gamma_{23ij} \Delta FDI_{it-j}$$

$$+ \sum_{j=1}^{q} \gamma_{24ij} \Delta Y_{it-j} + \sum_{j=1}^{q} \gamma_{25ij} \Delta Y^2_{it-j} + \gamma_{26i} \varepsilon_{it-1} + \upsilon_{2it},$$

$$\Delta FDI_{it} = c_{3i} + \sum_{j=1}^{q} \gamma_{31ij} \Delta CO_{2,it-j} + \sum_{j=1}^{q} \gamma_{32ij} \Delta EN_{it-j} + \sum_{j=1}^{q} \gamma_{33ij} \Delta FDI_{it-j}$$

$$+ \sum_{j=1}^{q} \gamma_{34ij} \Delta Y_{it-j} + \sum_{j=1}^{q} \gamma_{35ij} \Delta Y^2_{it-j} + \gamma_{36i} \varepsilon_{it-1} + \upsilon_{3it},$$

$$\Delta Y_{it} = c_{4i} + \sum_{j=1}^{q} \gamma_{41ij} \Delta CO_{2,it-j} + \sum_{j=1}^{q} \gamma_{42ij} \Delta EN_{it-j} + \sum_{j=1}^{q} \gamma_{42ij} \Delta FDI_{it-j}$$

$$+ \sum_{j=1}^{q} \gamma_{44ij} \Delta Y_{it-j} + \sum_{j=1}^{q} \gamma_{45ij} \Delta Y^2_{it-j} + \gamma_{46i} \varepsilon_{it-1} + \upsilon_{4it},$$

$$\Delta Y^2_{it} = c_{5i} + \sum_{j=1}^{q} \gamma_{51ij} \Delta CO_{2,it-j} + \sum_{j=1}^{q} \gamma_{52ij} \Delta EN_{it-j} + \sum_{j=1}^{q} \gamma_{53ij} \Delta FDI_{it-j}$$

$$+ \sum_{j=1}^{q} \gamma_{54ij} \Delta Y_{it-j} + \sum_{j=1}^{q} \gamma_{55ij} \Delta Y^2_{it-j} + \gamma_{56i} \varepsilon_{it-1} + \upsilon_{5it}, \quad (2)$$

where Δ is the first difference operator, q is the lag length, ε is the error correction term, and υ is the random error term. The VECM is estimated using a seemingly unrelated regression (SUR) technique, which allows for cross-sectional specific coefficient vectors and cross-sectional correlations in the residuals.

III. Data

The data on developing countries are the annual time series covering the period from 1980–2013. Developing countries were selected according to the criteria of the United Nations Conference on Trade and Development (UNCTAD). Eastern European countries and the Russian Federation are not included in the developing countries as these countries are in transition to market economies. This paper also excludes some least developed countries, which do not have sufficient time series data for the entire period. The 57 developing countries are selected based on the data availability and certain economic aspects.[6] For the regional analysis, the countries are divided into three regions: Asia, America, and Africa.[7] The Middle-East countries are excluded in the regional analysis, because their cross-sections are small and some time series data are missing.

CO_2 emissions per capita (measured in metric tons), energy consumption per capita (measured in kilograms of oil equivalent), and GDP per capita (measured in constant 2010 USD) are sourced from the World Bank (2017) World Development Indicators online database. The FDI stock (measured in millions USD) for all countries are taken from UNCTAD (2017).

IV. Empirical Findings

4.1. Unit Root Tests

In this paper, we conduct four types of panel unit root tests that assume cross-sectional independence (Dickey and Fuller, 1979; Phillips and Perron, 1988; Levin et al., 2002; Im et al., 2003). In these tests, the null hypothesis is that there is a unit root while the alternative hypothesis is that there is no unit root. Levin et al. (2002) assume a common unit root process and the other tests assume an individual unit root process. In this paper, the unit root is tested, which assumes the individual unit root process. Table 1 shows the results of panel unit root tests. In addition, the null

[6] The following list of developing countries is covered in this analysis: Bahrain, Brunei Darussalam, China, India, Indonesia, Iran, Jordan, South Korea, Kuwait, Lebanon, Malaysia, Mongolia, Oman, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Thailand, Turkey, United Arab Emirates, Vietnam, Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, Algeria, Botswana, Cameroon, Congo, Cote d'Ivoire, Egypt, Gabon, Ghana, Kenya, Mauritius, Morocco, Nigeria, South Africa, Tunisia, and Zimbabwe.

[7] Developing countries included in the Asian region are Brunei Darussalam, China, India, Indonesia, South Korea, Malaysia, Mongolia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Turkey, and Vietnam. Developing countries included in the American region are Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela. Developing countries included in the African region are Algeria, Botswana, Cameroon, Congo, Cote d'Ivoire, Egypt, Gabon, Ghana, Kenya, Mauritius, Morocco, Nigeria, South Africa, Tunisia, and Zimbabwe.

[Table 1] Panel unit root tests

	CO_2		EN		Y		Y^2		FDI	
Method	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
Null: Unit root (assumes common unit root process)										
Levin, Lin & Chu t*	-2.58	0	0.23	0.59	0.06	0.52	1.53	0.94	1.71	0.96
Null: Unit root (assumes individual unit root process)										
Im, Pesaran and Shin W-stat	1.54	0.94	4.99	1	6.24	1	7.13	1	11.16	1
ADF - Fisher Chi-square	104.57	0.73	64.92	1	91.27	0.94	85.7	0.98	47.63	1
PP - Fisher Chi-square	132.83	0.11	79.86	0.99	90.87	0.95	85.02	0.98	68.04	1

	ΔCO_2		ΔEN		ΔY		ΔY^2		ΔFDI	
Method	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
Null: Unit root (assumes common unit root process)										
Levin, Lin & Chu t*	-18.17	0	-13.57	0	-12.35	0	-12.28	0	-14.33	0
Null: Unit root (assumes individual unit root process)										
Im, Pesaran and Shin W-stat	-24.68	0	-20.43	0	-16.58	0	-16.31	0	-16.45	0
ADF - Fisher Chi-square	774.95	0	629.15	0	506.05	0	497.03	0	484.86	0
PP - Fisher Chi-square	1,310.90	0	1,137.35	0	689.15	0	686.56	0	861.92	0

Note: *Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

hypothesis cannot be rejected at the 5% significance level for each series in the level. For each series in the first differences, the null hypothesis can be rejected at the 1% significance level. Therefore, we can conclude that these time series are I (1), as each variable has unit root in the level and do not have unit root in the first differences.

4.2. Cointegration Tests

We test whether these **I** (1) variables are cointegrated or not using the tests used in Pedroni (1999, 2004). The Pedroni panel cointegration tests are used to test the residuals from the following equation for unit root variables.

$$\hat{\varepsilon}_{it} = \rho_i + \hat{\varepsilon}_{it-1} + \delta_{it}$$

Overall, Pedroni (1999, 2004) provides seven statistics for testing the null hypothesis of no cointegration in heterogeneous panels. These tests can be classified as either within-dimension (panel tests) or between-dimension (group tests). Considering within-dimension approach, the null hypothesis of no cointegration ($\rho_i = 1$ for all i) is tested against the alternative hypothesis ($\rho_i < 1$ for all i). The group means that the approach is less restrictive as it does not require a common value of ρ under the alternative hypothesis ($\rho_i < 1$ for all i).

According to Table 2, five out of eight statistics indicate cointegration at the 5% level in the within-dimension case and two out of three statistics indicate cointegration at the 1% level in the between-dimension case. Hence, we can conclude that the variables in the model are cointegrated.

[Table 2] Panel cointegration tests

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	0.327	0.372	-1.993	0.977
Panel rho-Statistic	-0.756	0.225	-3.269***	0.001
Panel PP-Statistic	-8.000***	0	-11.880***	0
Panel ADF-Statistic	-10.110***	0	-12.904***	0
Alternative hypothesis: individual AR coefs. (between-dimension)				
		Statistic		Prob.
Group rho-Statistic		-0.268		0.394
Group PP-Statistic		-13.809***		0
Group ADF-Statistic		-13.435***		0

Note: Null Hypothesis: No cointegration. Trend assumption: Deterministic intercept and Trend. Automatic lag length selection based on SIC with a max lag of 5. Newey-West automatic bandwidth selection and Bartlett kernel. *** denotes the acceptance of the null hypothesis at 1%.

4.3. VECM

4.3.1. Short-run Dynamics

The short-run dynamics for equations with exports are estimated following Engle and Granger (1987). First, the short-run causalities for all developing countries are estimated, and a regional analysis is conducted. The vector auto regression lag length q is set at 2, and is determined by using the Schwarz and Hannan-Quinn information criteria in all cases. Table 3 shows the results of the short-run Granger causality test.

The main interest of this paper is the short-run causality among CO_2 emissions, GDP, energy consumption, and inward FDI. The first part of Table 3 shows the short-run Granger causality results for all developing countries. First, no direct short-run causality from FDI to CO_2 emissions exists, indicating that one of the two FDI hypotheses (the pollution haven or halo effect hypotheses) does not dominate in the estimation for all developing countries. Even if the pollution haven hypothesis holds in some countries, the halo hypothesis holds in other countries. However, an indirect short-run causality exists from FDI to CO_2 emissions (FDI causes GDP, and GDP causes CO_2 emissions).

Second, evidence suggest that short-run causalities from GDP to CO_2 emissions and CO_2 emissions to GDP exist. Therefore, bi-directional causality can be observed between GDP to CO_2 emissions, indicating that the GHG mitigation policy affected economic growth and vice versa.

As shown in Table 3, there are no direct short-run causalities from FDI to CO_2 emissions and from FDI to energy consumption in any regional analysis. The changing pattern of FDI in these regions may affect these causalities. In the past, the trend observed was that the proportion of manufacturing industry in the Greenfield FDI was decreasing, whereas the proportion of service industry was increasing. According to the World Investment Report 2017 (UNCTAD, 2017), the proportion of the manufacturing industry was 52.8% in 2003 and this decreased to 39.2% in 2013. However, the proportion of service industry was 30.0% in 2003 and this increased to 56.2% in 2013.

In addition, no indirect short-run causality exists from FDI to CO_2 emissions. In the Asian and American regions, short-run causality is observed from economic growth to CO_2 emissions, but FDI does not cause economic growth in these regions. The countries included in the Asian region are China, India, South Korea, Mongolia, Pakistan, Turkey, Brunei Darussalam, Sri Lanka, and the ASEAN countries (Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam). The countries included in the American region are Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela. FDI may cause economic growth during the period considered in some countries. However, it may not be the case for the above panel data and its corresponding period due to the characteristics of FDI and the composition of the industry receiving investment.

In the African region, no short-run causality was observed from either FDI to economic growth or from economic growth to CO_2 emissions. The countries included in the African region are Algeria, Botswana, Cameroon, Congo, Cote d'Ivoire, Egypt, Gabon, Ghana, Kenya, Mauritius, Morocco, Nigeria, South Africa, Tunisia, and Zimbabwe. Specifically, the majority of the current Greenfield FDI into the African region is focused on the service industry, and the share of this industry has steadily increased over the period.

Meanwhile, GDP causes CO_2 emissions in the Asian and American regions, but does not cause CO_2 emissions in the African region. One of the distinct characteristics is the existence of bi-directional causality between GDP and energy consumption in case of the African region.

[Table 3] Short-run Granger causality results for all developing countries

All Developing Countries

	To				
From	ΔCO_2	ΔEN	ΔY	ΔY^2	ΔFDI
ΔCO_2		0.92	10.88***	10.78***	3.82
ΔEN	14.25***		2.09	2.82	1.01
ΔY	27.51***	1.33		17.12***	1.26
ΔY^2	15.88***	0.86	23.60***		0.49
ΔFDI	0.85	4.22	8.04**	9.67	
ε_{t-1}	-2.29**	0.54	-2.88***	-3.98***	5.65***

The Asian Region

	To				
From	ΔCO_2	ΔEN	ΔY	ΔY^2	ΔFDI
ΔCO_2		12.70***	1.30	2.37	1.04
ΔEN	1.57		3.08	4.23	7.12**
ΔY	13.36***	17.34***		19.04***	1.71
ΔY^2	9.80***	16.17***	19.41***		0.92
ΔFDI	1.89	0.43	3.92	5.95	
ε_{t-1}	0.004	0.007**	0.003***	0.028***	-0.008***

The American Region

	To				
From	ΔCO_2	ΔEN	ΔY	ΔY^2	ΔFDI
ΔCO_2		0.06	1.05	1.40	2.07
ΔEN	27.92***		1.40	1.80	4.13
ΔY	6.97**	1.80		0.55	2.06
ΔY^2	5.18*	0.69	1.13		1.72
ΔFDI	1.29	0.97	3.78	4.05	
ε_{t-1}	-0.0068***	0.001	0.001**	0.012**	-0.006*

The African Region

	To				
From	ΔCO_2	ΔEN	ΔY	ΔY^2	ΔFDI
ΔCO_2		0.39	5.82	5.01*	0.10
ΔEN	6.08**		6.89**	8.62**	0.43
ΔY	3.29	11.55***		12.14***	2.28
ΔY^2	2.17	11.21***	13.71**		2.24
ΔFDI	0.54	0.029	0.67	0.99	
ε_{t-1}	-0.006	-0.005***	-0.003**	-0.020***	0.014

Note: The value of this table reports Chi-sq statistics. The Chi-sq tests for the short-run Granger causality have two degrees of freedom for each analysis. The system of equation is estimated using OLS with the SUR technique. *, **, and *** refer to the 10%, 5%, and 1% significance levels, respectively.

4.3.2. Long-run Dynamics

The long-run output elasticities based on Equation (1) are estimated using panel FMOLS (Pedroni, 2001). Additional estimation using panel generalized least squares (GLS) with fixed effects is conducted to compare the estimation results. The estimated coefficients are elasticities as the variables are measured in logarithms. Tables 4 and 5 show the results of the long-run equilibrium for Equation (1) using panel FMOLS and panel GLS, respectively. As can be seen, the two estimation results are very similar, and all coefficients show similar signs.

According to the results of panel FMOLS for all developing countries, the long-run elasticity of GDP to CO_2 emissions is 2.425, indicating that a 1% increase in output increases CO_2 emissions by 2.42%. Moreover, the long-run elasticity of energy consumption to CO_2 emissions is 0.643, indicating that a 1% increase in energy consumption increases CO_2 emissions by 0.64%. However, a 1% increase in

FDI decreases CO_2 emissions by 0.033%, which is a very small value, even though it is statistically significant at the 1% level. Therefore, this result does not support the pollution haven hypothesis, but rather, the weekly the halo effect in all developing countries, even if the pollution haven hypothesis holds in some countries or regions as in the previous literature.

Furthermore, we can identify the EKC hypothesis. In the long run, economic growth and energy consumption play a major role in the increase of CO_2 emissions, whereas FDI does not induce the increase of CO_2 emissions in all developing countries.

The results for all developing countries show different results in the regional analysis. The elasticity of energy consumption to CO_2 emissions is the highest in the Asian region, whereas the elasticity of economic growth to CO_2 emissions is highest in the American region. The EKC hypothesis is observed in all three regions, but is mostly supported in the America region.

Even though the pollution haven hypothesis does not hold in the analysis for all developing countries, it holds somewhat in the Asian and American regions. The long-run elasticity of FDI to CO_2 emissions is 0.03 in the Asian region and is 0.027 in the American region. Furthermore, the halo effect hypothesis finds weak acceptance in the African region, where the elasticity of FDI to CO_2 emissions is -0.043. FDI has played a role in increasing CO_2 emissions marginally in the Asian and the American regions, but it has also played a role in reducing CO_2 emissions in the African region. These regional differences may be due to the nature of FDI. While the share of the manufacturing industry is relatively high in the FDI in the Asian and American regions, it is low in the case of the African region. However, the coefficients for all three regions are so small, making it difficult to prove that FDI has led to an increase in CO_2 emissions in the long run.

[Table 4] Long-run equilibrium for equations (FMOLS)

	All Developing Countries	The Asian Region	The American Region	The African Region
EN	0.643***(0.015)	1.232***(0.099)	0.783***(0.070)	0.359***(0.135)
Y	2.425***(0.013)	2.700***(0.261)	4.286***(0.602)	2.346***(0.567)
Y^2	-0.311***(0.009)	-0.417***(0.039)	-0.540***(0.080)	-0.196**(0.091)
FDI	-0.033***(0.013)	0.030***(0.010)	0.027***(0.009)	-0.043***(0.014)
R^2	0.989	0.980	0.981	0.977
Adjusted R^2	0.989	0.979	0.980	0.976
S.E. of Regression	0.060	0.074	0.054	0.089
Long-run Variance	0.002	0.015	0.007	0.018

# of observations	1,824	462	659	495
Cross sections	57	14	20	15
Periods included	33	33	33	33

Note: *, *, and *** refer to the 10%, 5%, and 1% significance levels, respectively. The panel methods is weighted estimation and long-run covariance estimates (Bartlett kernel, Newey-West fixed bandwith). Values in parenthesis show the standard errors.

[Table 5] Long-run equilibrium for equations (Panel GLS with Fixed effects)

	All Developing Countries	The Asian Region	The American Region	The African Region
EN	0.712***(0.014)	1.166***(0.042)	0.815***(0.042)	0.393***(0.047)
Y	2.664***(0.093)	2.134***(0.099)	4.748***(0.377)	2.967***(0.267)
Y^2	-0.312***(0.013)	-0.324***(0.014)	-0.603***(0.049)	-0.311***(0.042)
FDI	-0.016***(0.002)	0.031***(0.006)	0.016***(0.004)	-0.039***(0.006)
R^2	0.993	0.994	0.983	0.993
Adjusted R^2	0.993	0.993	0.982	0.993
S.E. of Regression	0.078	0.075	0.054	0.087
# of observations	1,824	476	679	510
Cross sections	57	14	20	15
Periods included	33	34	34	34
F-value (Fixed Effects)	302.16***	119.49***	211.40***	224.11***

Note: *, **, and *** refer to the 10%, 5%, and 1% significance levels. The Panel GLS methods is cross-section weighted estimation with fixed effects. Values in parenthesis show the standard errors.

V. Conclusions

This paper analyzed the short-run causality and long-run equilibrium among CO_2 emissions, energy consumption, GDP, and inward FDI for 57 developing countries from 1980–2013. The analysis for all developing countries were analyzed and regional analyses were subsequently conducted. No causalities from FDI to CO_2 emissions were observed in the short-run for all developing countries, which were also confirmed by regional analyses. In other words, FDI inflows do not cause an increase in CO_2 emissions in the short run. Furthermore, the long-run results show that the long-run elasticities of FDI to CO_2 emissions are negative and the coefficients are very small, which means that FDI inflows do not induce the increase of CO_2 emissions in developing countries.

These results do not generally support the pollution haven hypothesis in GHG emissions in developing countries, yet they slightly support the halo effect. This means that one of the two FDI hypotheses (pollution haven or halo effect hypotheses) does not dominate in developing countries. Even if the pollution haven hypothesis holds in some regions, there are other regions, in which the halo hypothesis holds. The factors influencing firms' FDI include low labor costs, the size and proximity of demand markets, and ease of access to raw materials in addition to carbon costs. Although carbon costs are low in developing countries, exceeding the benefits of other factors is unlikely.

Consequently, the possibility of a halo effect will increase in the future as the GHG mitigation technology progresses. In other words, the proportion of FDI to advanced CO_2 reduction technologies is expected to increase due to the global GHG mitigation efforts. If the investment of multinational corporations is accompanied by new technologies that are more beneficial to reducing GHGs, the halo effect of reducing GHGs in the host countries will increase. Thus, overall inward FDI to developing countries cannot act as a conduit for the increase of GHG emissions in the future, though there may be differences in the analyses in terms of the country.

Furthermore, although economic growth causes CO_2 emissions in the short run, the long-run results support the EKC hypothesis. Therefore, there is a possibility of green growth, in which GHG mitigation and economic growth in developing countries are simultaneous.

Appendix

[Table A1] Summary of Statistics

	CO_2 emissions per capita	energy consumption per capita	GDP per capita	FDI inflows
All Developing Countries				
Mean	4.52	1,776.71	7,499.48	26,233.53
Median	1.84	801.41	3,730.41	4,123.69
Maximum	36.97	15,109.24	115,003.40	956,793.00
Minimum	0.02	264.08	257.11	0.14
Std. Dev.	6.79	2,543.28	11,474.54	75,807.01
Jarque-Bera Stat.	5,634***	6,775***	34,022***	264,988***
# of Observations	1885	1885	1885	1885
The Asian Region				
Mean	4.35	1,734.85	8,071.98	51,680.27
Median	2.26	854.07	2,298.79	9,675.07
Maximum	35.65	9,695.71	59,666.37	956,793.00
Minimum	0.21	269.3	347.89	0.14
Std. Dev.	5.28	2,053.48	12,155.28	119,581.30
Jarque-Bera Stat.	787***	412***	472***	13,025***
# of Observations	465	465	465	465
The American Region				
Mean	2.98	1,270.71	5,562.04	24,813.80
Median	1.62	744.34	4,727.75	3,908.53
Maximum	36.82	15,109.24	17,052.26	675,532.70
Minimum	0.33	341.49	1,068.31	2.2
Std. Dev.	4.82	1,869.34	3,507.45	69,868.61
Jarque-Bera Stat.	19,222***	32,039***	97***	54,971***
# of Observations	670	670	670	670
The African Region				
Mean	1.89	783.36	2,898.72	10,305.36
Median	1.09	638.06	1,716.43	2,282.57
Maximum	10.36	2,979.07	12,665.72	179,564.80
Minimum	0.02	264.08	257.11	25.69
Std. Dev.	2.39	593.2	2,682.67	22,231.09
Jarque-Bera Stat.	781***	810***	348***	12,451***
# of Observations	502	502	502	502

Note: *** means that the probability of the Jarque-Bera statistics is less than 1%. CO_2 emissions per capita is measured in metric tons per capita, Energy consumption per capita is measured in kilograms of oil equivalent per capita, GDP per capita is measured in constant 2010 USD, and FDI stock is measured in millions USD.

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