Causal interactions between CO2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models

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Causal interactions between CO_2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models

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Abstract

In this article, we investigate the causality links between CO_2 emissions, foreign direct investment, and economic growth using dynamic simultaneous-equation panel data models for a global panel of 54 countries over the period 1990–2011. We also implement these empirical models for 3 regional sub-panels: Europe and Central Asia, Latin America and the Caribbean, and the Middle East, North Africa, and sub-Saharan Africa. Our results provide evidence of bidirectional causality between FDI inflows and economic growth for all the panels and between FDI and CO_2 for all the panels, except Europe and North Asia. They also indicate the existence of unidirectional causality running from CO_2 emissions to economic growth, with the exception of the Middle East, North Africa, and sub-Sahara panel, for which bidirectional causality between these variables cannot be rejected. These empirical insights are of particular interest to policymakers as they help build sound economic policies to sustain economic development.

Keywords: CO_2 emissions, FDI inflows, economic growth
JEL Classifications: C33, C51, E22, O13, Q43, Q56

1. Introduction

Foreign direct investment (FDI) inflows have rapidly increased during the past two decades in almost every region of the world, thus revitalizing the long debate in both academic and policy spheres about their advantages and related costs. Indeed, FDI inflows may provide direct capital financing, generate positive externalities, and consequently stimulate economic growth through technology transfer, spillover effects, productivity gains, and the introduction of new processes and managerial skills (Lee, 2013). By contrast, they are also considered as one of the major factors that could lead to environmental degradation. Therefore, a better understanding of the complex interactions between environmental pollution, FDI inflows, and economic growth should be the basis for making sound economic policies.

The nexus between economic growth, environmental pollution, and FDI inflows has been intensively analyzed by a number of studies, but the empirical evidence more often than not remains controversial and ambiguous. The related past studies may be categorized into three research strands. The first strand focuses on the validity of the environmental Kuznets curve (EKC) hypothesis, which postulates that the relationship between economic output and CO_2 emissions conforms to an inverted-U curve. That is, the environmental degradation levels increase as a country develops but decrease when a certain level of average income is reached. This hypothesis, which predicts that economic growth is a solution to environmental problems in the future with no policy intervention, was first posited by Grossman and Krueger (1991) and a large number of subsequent studies have examined it using various data sets and econometric approaches. The empirical results are, however, inconclusive. For example, the studies by Selden and Song (1994) and Grossman and Krueger (1995) provide empirical evidence to support the validity of the EKC hypothesis. However, Holtz-Eakin and Selden (1995) establish a monotonic rising curve, while an N-shaped curve is found by Friedl and

Getzner (2003). In a more recent work, Saboori et al. (2012) find mixed results when examining the causal links between income and CO_2 emissions.

The second strand of research examines the nexus between economic growth and FDI inflows. Most of the past studies are concerned with the questions of whether a higher level of FDI inflows leads to higher additional economic growth and likewise whether higher economic growth sends positive signals to attract further FDI (e.g., Ekanayake and Vogel, 2003; Hermes and Lensink, 2003; Nguyen and Nguyen, 2007; Tsang and Yip, 2007; Batten and Vo, 2009; Anwar and Nguyen, 2010). Their findings often fall into one of the following categories: i) a causal relationship from FDI to GDP; ii) a causal relationship from GDP to FDI; iii) a feedback relationship between FDI and GDP; and iv) no causal relationship between FDI and GDP (neutrality).

The third strand of research is concerned with the nexus between CO_2 emissions and FDI inflows. This issue has received much less attention from academic researchers compared with the extensive literature investigating the nexus between economic growth and CO_2 emissions and between economic growth and FDI. Earlier studies, such as those by Smarzynska and Wei (2001), Xing and Kolstad (2002), Eskeland and Harrison (2003), He (2006), and Zhan (2011) document a positive relationship that runs from FDI to pollutant emissions in the host countries. It is, however, worth noting that most of the existing studies have paid heed to the causal effects from FDI inflows to CO_2 emissions. Only a few empirical studies have focused on the two-way causation between FDI and CO_2 emissions (Pao and Tsai, 2010).

The above-related literature shows that economic growth requires more FDI inflows, but these FDI inflows may, in turn, increase the CO_2 emissions and lead to environmental degradation. The bivariate links between these variables are not only complex to model, but they can also interact and be estimated simultaneously.

Our study thus contributes to the existing literature in the following two ways. First, we use a dynamic simultaneous-equation modeling approach to investigate the three-way causation between CO_2 emissions, FDI inflows, and economic growth. This modeling approach relies on the GMM (generalized method of moment) estimators and allows us to examine simultaneously the following combined causality effects: i) from CO_2 emissions and FDI inflows to economic growth; ii) from economic growth and CO_2 emissions to FDI inflows; and iii) from economic growth and FDI to CO_2 emissions. Second, compared with the previous studies that deal with the CO_2 emissions–FDI–growth nexus, we do not use panel cointegration and panel unit root approaches, but we rather resort to dynamic simultaneous-equation models (DSEMs) with panel data specifications. Since the DSEMs belong to the conventional "growth model" framework, we estimate the short-run elasticities instead of the long-run elasticities. As expected, our results for a global panel of 54 countries and three subpanels show evidence of simultaneous and rich interactions between CO_2 emissions, FDI inflows, and economic growth. They also indicate some specific patterns of causal links across the three subpanels.

The remainder of this article is organized as follows. Section 2 briefly reviews the related literature. Section 3 outlines the econometric modeling approach and describes the data used. Section 4 reports and discusses the empirical results. Section 5 concludes the article and offers some policy implications.

2. Literature Review

The environment–FDI–growth nexus has mainly been examined with respect to the following three competing hypotheses: the feedback hypothesis, the unidirectional hypothesis, and the neutrality hypothesis. The validation of the unidirectional hypothesis implies that there is unidirectional causality running from one or two particular variables to the remaining variable (i.e., from CO_2 emissions and FDI inflows to economic growth; from economic growth and

CO_2 emissions to FDI inflows; and from economic growth and FDI inflows to CO_2 emissions), whereas the acceptation of the feedback and neutrality hypotheses entails the existence of bidirectional causality between these variables, respectively. In the following, we review the most important works in this literature.

2.1. Unidirectional hypothesis

Ang (2008) and Menyah and Wolde-Rufael (2010) employ different estimation techniques to examine the causal relationships between CO_2 emissions and economic growth for Malaysia and for South Africa, respectively. They report evidence of unidirectional causality running from CO_2 emissions to economic growth. Jaunky (2010) investigates the environmental Kuznets curve (EKC) hypothesis for a sample of 36 high-income economies, including Bahrain, Oman, and the UAE, over the period 1980–2005. Unidirectional causality running from per capita GDP to per capita CO_2 emissions is uncovered in both the short and the long run. Fodha and Zaghdoud (2010), Nasir and Rehman (2011), and Pao and Tsai (2010) also examine the causal relationship between CO_2 emissions and economic growth using VECM-based Granger causality tests, and they find evidence of unidirectional causality running from economic growth to CO_2 emissions.

In more recent research, Lee (2013) adopts a panel cointegration approach to examine the nexus between renewable CO_2 emissions, FDI, and economic growth for 19 of the G20 countries from 1971 to 2009. The empirical evidence supports the existence of unidirectional causality from FDI to economic growth and from economic growth to CO_2 emissions.

2.2. Feedback hypothesis

Tsai (1994) uses Granger causality tests to identify the two-way linkages between FDI and economic growth for 62 countries over the period 1975–1978 and for 51 countries over the period 1983–1986. The author shows that FDI promotes economic growth and, in turn, economic growth is viewed as a tool to attract FDI. This finding is thus consistent with the feedback hypothesis.

Halicioglu (2009) investigates the causal relationship between CO_2 emissions and economic growth for Turkey by means of an ARDL bounds test and a Granger causality test based on a VECM over the period 1960–2005. The obtained results validate the feedback hypothesis because the bidirectional causality between the variables cannot be rejected in both the short and the long run. Soytas and Sari (2009) use the Toda and Yamamoto (1995) test to examine the causality relationship between CO_2 emissions and economic growth for Turkey over the period 1960–2000, and find evidence to support the feedback hypothesis. Ghosh (2010) also documents two-way links between CO_2 emissions and economic growth in India over the period 1971–2006.

Pao and Tsai (2010) look at the causal links between FDI and CO_2 emissions for a panel of BRIC countries. The results from their Granger causality tests indicate the existence of strong bidirectional causality between these variables over the period 1992–2007.

2.3. Neutrality hypothesis

Several studies have found no causality between CO_2 emissions, FDI inflows, and economic growth. For example, Richmond and Kaufmann (2006) find no significant causality between carbon emissions and economic growth for 36 nations over the period from 1973 to 1997, which validates the neutrality hypothesis. Similarly, the results reported by Lee (2013) are also in favor of the neutrality hypothesis for FDI inflows' and CO_2 emissions' interactions, using panel data of 19 nations in the G20 over the period from 1971 to 2009.

2.4. Some mixed results

Some studies have found mixed empirical evidence about the causal relationship between income and CO_2 emissions (e.g., Zhang, 2001 for East Asian and Latin American countries; Coondoo and Dinda, 2002 for a sample of developed countries; Apergis and Payne, 2009 for

6 Central American countries; Lee and Lee, 2009 for a panel of 109 countries; and Narayan and Narayan, 2010 for a panel of 43 developing countries.

Table 1
Summary of existing empirical studies

No.	Author(s)	Objective	Countries	Methodology	Conclusion
Panel A: country-specific studies					
1.	Ang (2008)	CO_2–GDP nexus	Malaysia	Granger causality based on VECM	C → Y
2.	Halicioglu (2009)	CO_2–GDP nexus	Turkey	Granger causality based on VECM	Y ↔ C
3.	Soytas and Sari (2009)	CO_2–GDP nexus	Turkey	Toda and Yamamoto (1995)	Y ↔ C
4.	Anwar and Nguyen (2010)	FDI–GDP nexus	Vietnam	Granger causality test	F ↔ Y
5.	Fodha and Zaghdoud (2010)	CO_2–GDP nexus	Tunisia	Granger causality based on ECM	Y → C
6.	Ghosh (2010)	CO_2–GDP nexus	India	Granger causality based on VECM	Y ↔ C
7.	Menyah and Wolde-Rufael (2010)	CO_2–GDP nexus	South Africa	Toda and Yamamoto (1995)	C → Y
8.	Zhang (2011)	FDI–CO_2 nexus	China	Johansen cointegration	F→ C
9.	Saboori et al. (2012)	CO_2–GDP nexus	Malaysia	EKC hypothesis	C → Y Inverted-U-shape curve
Panel B: multi-country studies					
10.	Tsai (1994)	FDI–GDP nexus	62 countries	Granger causality test	F ↔ Y
11.	Richmond and Kaufmann (2006)	CO_2–GDP nexus	36 countries	Panel cointegration	Y ≠ C
12.	Apergis and Payne (2009)	CO_2–GDP nexus	6 central American countries	EKC hypothesis, panel VECM	Y ↔ C ; Y → C
13.	Jaunky (2010)	CO_2–GDP nexus	36 high-income economies	Panel unit root and cointegration tests	Y → C
14.	Narayan and Narayan (2010)	CO_2–GDP nexus	43 developing countries	Panel cointegration	Y → C (in the short-run)
15.	Pao and Tsai (2011)	CO_2–FDI–GDP nexus	19 countries	Granger causality based on VECM	Y → F ; F ↔ C Y ↔ C
16.	Lee (2013)	CO_2–FDI–GDP nexus	BRIC countries	Panel cointegration	F → Y ; Y → C F ≠ C

Notes: Y, C, and F indicate the per capita GDP, per capita carbon dioxide emissions, and FDI inflows. VECM refers to the vector error correction model, ECM refers to the error correction model, and EKC refers to the environmental Kuznets curve. →, ↔, and ≠ indicate the unidirectional causality hypothesis, feedback hypothesis, and neutral hypothesis, respectively.

We summarize the country-specific and multi-country studies in Table 1. Overall, our literature review suggests that the empirical results of the previous studies are inconclusive. A potential reason is that the past studies have not considered the three-way linkages between CO_2 emissions, FDI inflows, and economic growth, the joint dynamics of which can be simultaneously determined. In this article, we address this issue by applying dynamic simultaneous-equation models to a panel data set of 54 countries over the period from 1990 to 2011.

3. Econometric Method and Data

3.1. Econometric method

We examine the causality between CO_2 emissions, FDI inflows, and economic growth by using the Cobb–Douglas production function whereby the gross domestic product (GDP) depends on endogenous variables including FDI inflows and CO_2 emissions. This extended production function provides a meaningful framework in which to explore the three-way linkages between the three variables.

The Cobb–Douglas production functions including capital and labor as additional factors of production. Income or output depends also on energy consumption, which is directly related to CO_2 emissions (see, e.g. Ang, 2008; Sharma, 2010; and Omri (2013). Similarly, Anwar and Nguyen (2010), Anwar and Sun (2011), among others, include FDI in the production function to examine the impact of this variable on economic growth. They find that FDI stimulates economic growth. Specifically, we consider a Cobb-Douglas type production function:

$$\mathrm{Y} = e^{\varepsilon}\mathrm{AK}^{\alpha}E^{\lambda}\left(\mathrm{FDI}\right)^{\psi}\mathrm{L}^{\beta} \tag{1}$$

where *Y* is the real GDP, A the total factor productivity, K the capital stock, E the energy consumption, and L the labor force. ε is the error term. α, λ, ψ and β are the production elasticities with respect to domestic capital, energy consumption, foreign direct investment (FDI) and labor force, respectively. This model indeed augments the standard Cobb-Douglas production function by taking into account the fact that energy consumption and FDI are inputs required to generate national output. Given the technology level at given point in time, there is a direct linear relationship between energy consumption and CO_2 emissions (Pereira and Pereira, 2010) such as $E = bCO_2$. Then, we have

$$Y = b^{\lambda} e^{\varepsilon} AK^{\alpha} CO_2^{\lambda} (FDI)^{\psi} L^{\beta} \tag{2}$$

We then divide both sides of Eq. (2) by L to get per capita GDP. We further assume that the production function exhibits constant returns to scale, i.e., α + λ + ψ + β = 1. These arrangements lead to

$$\frac{Y}{L} = b^{\lambda} e^{\varepsilon} A \left(\frac{K}{L}\right)^{\alpha} \left(\frac{CO_2}{L}\right)^{\lambda} \left(\frac{FDI}{L}\right)^{\psi} \tag{3}$$

The production function in Eq. (3) can be written in the log-linear form as follows

$$log\left(\frac{Y}{L}\right) = \log(b^{\lambda}A) + \alpha\log\left(\frac{K}{L}\right) + \lambda\log\left(\frac{CO_2}{L}\right) + \psi\log\left(\frac{FDI}{L}\right) + \varepsilon \tag{4}$$

Let $a = \log(b^{\lambda}A)$, we have

$$log\left(\frac{Y}{L}\right) = a + \alpha\log\left(\frac{K}{L}\right) + \lambda\log\left(\frac{CO_2}{L}\right) + \psi\log\left(\frac{FDI}{L}\right) + \varepsilon \tag{5}$$

Eq. (5) can then be rewritten in the growth and panel data form as

$$g\left(\frac{Y}{L}\right)_{it} = a + \alpha_{1i} g\left(\frac{K}{L}\right)_{it} + \lambda_{2i} g\left(\frac{CO_2}{L}\right)_{it} + \psi_{3i} g\left(\frac{FDI}{L}\right)_{it} + \varepsilon_{it} \tag{6}$$

where the subscript $i = 1,...,N$ denotes the country (N = 54 in our study) and $t = 1,...,T$ denotes the time period, and $g\left(\frac{Y}{L}\right)$ represents the growth rate of per capita GDP, $g\left(\frac{K}{L}\right)$ the growth rate of capital stock, $g\left(\frac{CO_2}{L}\right)$ the growth rate of per capita CO_2 emissions in metric tons, and $g\left(\frac{FDI}{L}\right)$ the growth rate of per capita foreign direct investment.

We then use the production function in Eq. (6) to derive the empirical models to simultaneously examine the interactions between per capita CO_2 emissions, FDI inflows, and GDP. These simultaneous-equation models are also constructed on the basis of the theoretical and empirical insights from the previous literature and allow the investigation of the three-way linkages between our variables of interest.

$$g\left(\frac{\mathrm{Y}}{\mathrm{L}}\right)_{i,t} = \beta_0 + \beta_{1i} g\left(\frac{\mathrm{CO_2}}{\mathrm{L}}\right)_{i,t} + \beta_{2i} g\left(\frac{FDI}{\mathrm{L}}\right)_{i,t} + \beta_{3i} g\left(\frac{\mathrm{K}}{\mathrm{L}}\right)_{i,t} + \varepsilon_{i,t} \quad (7)$$

$$g\left(\frac{\mathrm{FDI}}{\mathrm{L}}\right)_{i,t} = \psi_0 + \psi_{1i} g\left(\frac{Y}{\mathrm{L}}\right)_{i,t} + \psi_{2i} g\left(\frac{\mathrm{CO_2}}{\mathrm{L}}\right)_{i,t} + \psi_{3i} g\left(\frac{K}{\mathrm{L}}\right)_{i,t} + \psi_{4i} FD_{i,t} + \psi_{5i} RER_{i,t} + \varepsilon_{i,t} \quad (8)$$

$$g\left(\frac{CO_2}{\mathrm{L}}\right)_{i,t} = \lambda_0 + \lambda_{1i} g\left(\frac{Y}{\mathrm{L}}\right)_{i,t} + \lambda_{2i} g\left(\frac{FDI}{\mathrm{L}}\right)_{i,t} + \lambda_{3i} URB_{i,t} + \lambda_{4i} OPN_{i,t} + \varepsilon_{i,t} \quad (9)$$

In the above equations, Eq. (7) states that the FDI inflows, CO_2 emissions and capital stock are the driving forces of economic growth (e.g., Bruno and Easterly, 1998; Ang, 2008; Menyah and Wolde-Rufael, 2010; Anwar and Sun, 2011). Eq. (8) postulates that the FDI flows can be influenced by economic growth, environmental degradation, and capital stock, financial development level (*FD*) as measured by the ratio of total credit of the private sector to GDP, and the real effective exchange rate (RER) (e.g., Anwar and Nguyen, 2010; Anwar and Sun, 2011; Lee, 2013; and Omri, 2013). With respect to Eq. (9), the factors including economic growth, FDI inflows, urbanization, and trade openness (*OPN*) as measured by the ratio of exports plus imports to GDP can potentially affect CO_2 emissions (e.g., Lotfalipour et al., 2010; Hossain, 2011; Lee, 2013; and Omri, 2013). As we will show later, the *FD*, *RER*, *OPN*, and *URB* variables are stationary in their levels, hence no transformation is needed. The remaining variables are stationary in their first difference.

3.2. Estimation procedure

At the empirical level, we allow our dynamic simultaneous-equation models in Eqs. (7)-(9) to have a dynamic panel specification where the one-period lagged levels of the dependent variables (i.e., growth rate of per capita GDP, per capita FDI inflows, and per capita CO_2 emissions) can affect their current levels. Our dynamic models with panel data are then simultaneously estimated by using the Arellano and Bond (1991) GMM estimator. This approach uses a set of instrumental variables to solve the endogeneity problem of the regressors. It also avoids the estimation biases that can arise from the correlation between the lagged dependent variables and the error terms when the ordinary least squares (OLS) method is used.

3.3. Data

We use annual data for the GDP (constant 2005 US$), CO_2 emissions in metric tons, FDI inflows, capital stock (constant 2005 US$), trade openness (total of exports and imports as a share of GDP), financial development (total credit to the private sector as a ratio of GDP), urbanization (the urban population as a share of the total population), and real exchange rate (value of the domestic currency per unit of foreign currency). All the data, collected for the period 1990–2011, are sourced from the World Bank's World Development Indicators. To estimate our models, we divide the variables by the population to get the variables in per capita terms.

Our study covers 54 countries selected on the basis of data availability. They include: (a) the European and North Asian region, consisting of 22 countries, namely: Albania, Belgium, Bulgaria, Denmark, France, Germany, Greece, Hong Kong, Korea, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom; (b) the Latin American and Caribbean region, consisting of 15 countries, namely: Argentina, Bolivia, Brazil, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Jamaica, Mexico, Panama, Paraguay, Peru, Uruguay, and Venezuela); and (c) the Middle Eastern, North African, and sub-Saharan region, consisting of 17 countries, namely: Algeria, Botswana, Cameroon, Congo, Egypt, Ghana, Iran, Kenya, Morocco, Mozambique, South Africa, Senegal, Sudan, Syrian Arab Republic, Togo, Tunisia, and Zambia.

The descriptive statistics of the different variables for the three sub-panel regions are presented in Table 2. On average, the highest level of per capita CO_2 emissions is found for the European and North Asian region, followed by the Latin American and Caribbean region and the Middle Eastern, North African, and sub-Saharan region with 8.393, 4.243, and 1.038 metric tons, respectively. This variable exhibits the greatest variability in the case of the Middle Eastern, North African, and sub-Saharan region.

The highest average of per capita GDP is obtained for the European and North Asian region. It is also worth highlighting that this region's overall economic output is almost 3 times higher than that of the Latin American and Caribbean region, and almost 17 times higher than the Middle Eastern, North African, and sub-Saharan region. The Middle Eastern, North African, and sub-Saharan region is the most volatile compared with the other regions in terms of economic output. It has the highest coefficient of variation (0.623) as measured by the standard deviation-to-mean ratio, followed by the Latin American and Caribbean region and the European and North Asian region.

The same pattern is found for FDI inflows as the European and North Asian region receives the highest level of FDI inflows, while the Middle Eastern, North African, and sub-Saharan region experiences the greatest variability. Note also that the Middle Eastern, North African, and sub-Saharan region is the most volatile in terms of FDI inflows. It has the highest coefficient of variation of 2.132 compared with the other regions.

Table 2
Descriptive statistics by panels of countries

Panels	Descriptive statistics	GDP per capita (constant 2005 USD)	CO_2 emissions (metric tons per capita)	FDI (net inflows)	Capital stock (constant 2005 USD)	Real exchange rate	Financial development (in %)	Urbanization (in %)	Trade openness (in %)
European and North Asian region	Mean	26237.04	8.393	1.73e+10	1.66e+11	86.678	103.322	77.546	83.075
	Standard deviation	11061.86	3.936	1.27e+10	1.40e+11	10.898	54.980	13.305	11.036
	CV	0.421	0.468	0.734	0.843	0.125	0.532	0.176	0.132
Latin American and Caribbean region	Mean	9095.605	4.243	2.93e+9	4.42e+10	79.981	88.367	76.219	80.418
	Standard deviation	4891.234	2.205	4.13e+9	3.27e+10	52.290	44.874	11.37	9.398
	CV	0.537	0.519	1.409	0.723	0.653	0.507	0.149	0.116
Middle Eastern, North African, and sub-Saharan region	Mean	1510.869	1.038	6.80e+08	5.68e+09	71.225	68.365	61.77	65.871
	Standard deviation	942.115	0.925	1.45e+09	4.00e+09	8.777	8.187	7.418	6.118
	CV	0.623	0.891	2.132	0.709	0.123	0.119	0.120	0.092

Notes: CV indicates the coefficients of variation (standard deviation-to-mean ratio), respectively.

4. Results and Discussions

We begin our analysis with the implementation of the panel unit root test proposed by Im et al. (2003). The objective is thus to decide which of the considered variables should enter into our empirical modeling in the growth rate form and which of them should be in their level form. Our results indicate that the null hypothesis of a unit root is rejected for financial development, real exchange rate, urbanization, and trade openness.[1] This finding holds effectively for all the four panels we consider: the European and North Asian panel; the Latin American and Caribbean panel; the Middle Eastern, North African, and sub-Saharan panel; and the global panel. These results imply that the above-mentioned variables are stationary in levels and no transformation is needed for further statistical analysis. On the other hand, the Im et al. (2003) test cannot reject the null hypothesis of a unit root for the four remaining variables (i.e., GDP, FDI, CO_2 emissions, and capital stock). Clearly, these four variables are not stationary in levels and they need to be first-differenced before they can be used in further statistical analysis. The use of their growth rates in our empirical modeling is thus suitable.

Table 3
Results for the global panel

	Specification 1	Specification 2	Specification 3
Independent variables	GDP per capita	FDI	CO_2 emissions
GDP	-	0.214^{**} (0.023)	0.102 (0.038)
GDP(-1)	0.375^{*} (0.001)	-	-
FDI	0.442^{*} (0.009)	-	0.187^{***} (0.011)
FDI(-1)	-	0.198^{**} (0.019)	-
CO_2 emissions	-0.289^{*} (0.000)	-0.368^{*} (0.003)	-
CO_2 emissions (-1)	-	-	0.281^{*} (0.000)
Capital stock	0.263^{**} (0.042)	0.093 (0.245)	-
Financial development	-	0.236^{*} (0.001)	-
Real exchange rate	-	-0.114^{***} (0.089)	-
Urbanization	-	-	-0.356^{**} (0.039)
Trade openness	-	-	0.097 (0.342)
Constant	0.218^{*} (0.007)	0.199^{**} (0.022)	0.365^{**} (0.017)
Hansen J-test (p-value)	11.34 (0.202)	16.331 (0.199)	17.41 (0.185)
DWH test (p-value)	3.241 (0.011)	4.013 (0.008)	4.681 (0.002)
AR2 test (p-value)	0.089 (0.669)	0.191 (0.840)	- 0.103 (0.901)

Notes: Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. DWH test is the Durbin–Wu–Hausman test for endogeneity. The AR2 test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

[1] The results of the panel unit root test are not reported here to conserve spaces, but they can be made available upon request to the corresponding author.

We then use the Arellano and Bond (1991) GMM approach to estimate the three-way linkages between CO_2 emissions, foreign direct investment, and economic growth for all the four panels under consideration. For each panel, three specifications that correspond to Eq. (7)–(9) are simultaneously estimated. Tables 3–4 report the results for which diagnostic tests (the Hansen-J test for over-identification, Durbin–Wu–Hausman endogeneity test, and Arellano–Bond test for the existence of the second-order autocorrelation in first differences) provide good statistical performance.

Table 3 reports the estimated results for the global panel. The overall findings show evidence of a bidirectional causal link between CO_2 emissions and FDI inflows and between FDI inflows and economic growth. Moreover, they indicate the existence of a unidirectional causal link from CO_2 emissions to economic growth. The lagged values of GDP, FDI inflows and CO_2 emissions also have a significant and positive impact on their current values, suggesting an increasing tendency of these variables over time. In particular, the FDI level in the previous year provides a general indicator for new investors to come in the target countries.

More precisely, Specification 1 in Table 3 indicates that FDI inflows have positive and significant effects on economic growth at the 1% level. The results suggest that a 1% increase in foreign direct investment raises the economic growth for the global panel by around 0.44%, which is consistent with the results achieved by Anwar and Nguyen (2010). Economic growth is also affected negatively and significantly by CO_2 emissions as a 1% increase in CO_2 emissions decreases the economic growth by around 0.30%. Hence, the higher level of pollution emissions might lead to the reduction of the production capacity of a country. Jayanthakumaran et al. (2012) find similar results when analyzing these linkages for China and India. The capital stock also exerts positive and significant impacts on economic growth.

In Specification 2, we find that the effects of economic growth and CO_2 emissions on FDI inflows are statistically significant at the 5% and 1% levels, respectively. Economic growth has a positive impact on FDI inflows, whereas the CO_2 emissions have a negative impact. Accordingly, a 1% increase in economic growth results in a 0.21% increase in the FDI inflows for the global panel, meaning that higher economic growth does send positive signals to prospective foreign investors. Our empirical evidence is thus consistent with the results reported by Borensztein et al. (1998) and Bengoa and Sanchez-Robles (2003). On the other hand, a 1% increase in CO_2 emissions reduces the FDI inflows by around 0.37%. This implies that higher polluting emissions do send negative signals to prospective foreign investors. The financial development level and, to a lesser extent, the real exchange rate are found to be determinants of FDI inflows as their effect is statistically significant at the 1% and 10% levels. The capital stock does not drive the FDI inflows.

In Specification 3, only FDI inflows and urbanization have significant impacts on CO_2 emissions at the 10% and 5% levels, respectively. FDI inflows have positive impacts on CO_2 emissions. A 1% increase in FDI inflows raises the CO_2 emissions by 0.19%, suggesting that FDI flows may have resulted in pollution havens and that lowering the environmental regulations may help to attract and retain foreign investments. Similar results are documented by, among others, Pao and Tsai (2010) and Sharma (2011). The impact of an urban population on CO_2 emissions is negative, thus contrasting the view that the development of urbanization leads to degraded environmental quality (e.g., Duh et al., 2008; Kahn and Schwartz, 2008).

Table 4 presents the estimated results for panels of three different regions. The impact of the one-period lagged values of GDP, FDI inflows and CO_2 emissions on the dependent variables is still positive and significant. The findings for the Europe and North Asia panel indicate a bidirectional causal link between FDI inflows and economic growth, but a unidirectional causal link running from CO_2 emissions to economic growth and from CO_2 emissions to FDI inflows. Specification 1 shows that, similar to the results of the global panel, economic growth is affected positively by FDI inflows and negatively by CO_2 emissions.

Table 4
Estimation results for the three sub-panels

	Europe and North Asia			Latin America and Caribbean			Middle East, North Africa, and sub-Sahara		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Independent variables	GDP	FDI	CO_2 emissions	GDP	FDI	CO_2 emissions	GDP	FDI	CO_2 emissions
GDP	-	0.314** (0.012)	0.087 (0.179)	-	0.220* (0.043)	0.202 (0.101)	-	0.443* (0.000)	0.255** (0.013)
GDP(-1)	0.356** (0.048)	-	-	0.402* (0.000)	-	-	0.224*** (0.061)	-	-
FDI	0.256** (0.012)	-	0.129 (0.226)	0.188* (0.005)	-	0.187** (0.018)	0.197** (0.022)	-	0.398* (0.004)
FDI(-1)	-	0.341** (0.014)	-	-	0.211*** (0.032)	-	-	0.281** (0.023)	-
CO_2 emissions	-0.221** (0.014)	-0.156 (0.108)	-	-0.277* (0.002)	-0.167***(0.092)	-	-0.239* (0.000)	-0.294* (0.004)	-
CO_2 emissions(-1)	-	-	0.295* (0.007)	-	-	0.324* (0.002)	-	-	0.231** (0.037)
Capital stock	0.253* (0.001)	0.167 (0.109)	-	0.345* (0.000)	0.159 (0.117)	-	0.222*** (0.010)	0.098** (0.047)	-
Financial development	-	0.324** (0.012)	-	-	0.267* (0.000)	-	-	0.123 (0.146)	-
Real exchange rate	-	-0.098 (0.279)	-	-	-0.151*** (0.055)	-	-	-0.139** (0.039)	-
Urbanization	-	-	-0.178 (0.201)	-	-	0.215*** (0.031)	-	-	-0.288** (0.026)
Trade openness	-	-	0.065 (0.468)	-	-	0.138 (0.107)	-	-	0.073 (0.221)
Constant	0.235*** (0.012)	0.331* (0.000)	0.291* (0.002)	-0.099*** (0.076)	0.189*** (0.093)	-0.201** (0.033)	0.486* (0.000)	-0.149** (0.019)	0.348** (0.045)
Hansen J-test (p-value)	19.91 (0.571)	26.22 (0.091)	25.44 (0.099)	15.67 (0.637)	18.96 (0.589)	21.22 (0.341)	20.31 (0.409)	24.87 (0.104)	22.36 (0.308)
DWH test (p-value)	3.85 (0.051)	4.12 (0.042)	4.42 (0.034)	6.81 (0.009)	6.97 (0.007)	5.42 (0.019)	5.05 (0.025)	6.13 (0.010)	4.66 (0.024)
AR2 test (p-value)	0.099 (0.941)	-0.272 (0.735)	0.185 (0.865)	0.139 (0.914)	0.644 (0.510)	0.077 (0.969)	0.389 (0.641)	0.134 (0.897)	0.111 (0.924)

Notes: Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. DWH test is the Durbin–Wu–Hausman test for endogeneity. The AR2 test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

In Specification 2, economic growth continues to affect FDI inflows significantly at the 5% level, but a 1% increase in economic growth leads to a lower increase in the FDI inflows (0.31%) compared with the global panel (0.44%). Another important finding is that CO_2 emissions do not have significant impacts on FDI inflows for the European and North Asian panel. Among the control variables, only the financial development variable has a positive and significant effect on FDI inflows. Finally, the results show that CO_2 emissions in the European and North Asian countries are affected neither by economic growth and FDI inflows nor by control variables.

Regarding the Latin American and Caribbean panel, our results are similar to those of the global panel as we find evidence of a bidirectional causal relationship between FDI inflows and economic growth and between FDI inflows and CO_2 emissions, but a unidirectional causal relationship from CO_2 emissions to economic growth. It is, however, important to note that the positive (negative) impact of FDI inflows (CO_2 emissions) on economic growth is smaller for the Latin American and Caribbean panel than for the global panel (0.19% and 0.28% versus 0.44% and 0.30%). Capital stock also affects economic growth in the opposite manner as the effect is positive for the former and negative for the latter. Economic growth, CO_2 emissions, financial development, and the real exchange rate also explain the evolution of FDI inflows (Specification 2) in the same manner as for the global panel, while the impact from capital stock is insignificant. While economic growth has no effect on CO_2 emissions, the positive causality running from FDI inflows to CO_2 emissions suggests that low environmental standards may have turned the developing countries in the Latin American and Caribbean panel into "pollution havens" (Specification 3). Finally, the urbanization variable is found to increase the level of pollution (CO_2 emissions) significantly. This finding, differing from the global panel, corroborates that of Hossain (2011), who examines this issue for newly industrialized countries.

As regards the Middle Eastern, North African, and sub-Saharan panel, our results point out the existence of bidirectional causal relationships among the three variables we consider. More precisely, the results from Specifications (1) to (3) for the causal relationships between dependent and independent variables are generally not different from those of the global panel. The unique difference with the results of the other subpanels is that economic growth significantly causes changes in the CO_2 emissions at the 5% level. Effectively, a 1% increase in economic growth raises the CO_2 emissions by around 0.26%. This result is somewhat consistent with the study by Pao and Tsai (2010), which provides evidence of an inverted U-shape for the growth–pollutant emissions nexus for a panel of the BRIC countries.

Overall, the above-discussed results regarding the emissions–FDI–growth links for the global panel as well as for the three sub-panels provide four interesting insights. First, FDI inflows have positive and significant impacts on economic growth in all the panels, while they significantly raise the CO_2 emissions in all the panels, except for Europe and North Asia. Past studies, including, among others, Aitken et al. (1997), Pao and Tsai (2010), Kahouli and Khadhraoui (2012), and Lee (2013), also document these strong causalities from FDI inflows to economic growth[2] and pollution[3]. In another hand, and accordingly, the pollution havens hypothesis has two empirical results. First, FDI outflows in developed countries have a positive relationship with the stringency of environmental laws in their countries. Second, pollution in developing countries is positively related to FDI Inflows.

[2] The inflow of FDI makes several contributions to the economies of host countries. Such contributions include: (a) foreign firms are making important contributions to the technological capacity of host countries; (b) the competition, standards and knowledge of foreign markets that foreign firms bring to the domestic market can have important spillover effects; and (c) many firms in developing countries have increased their access to cutting-edge technology by purchasing technologically sophisticated firms domiciled in developed countries.

[3] Accordingly, the pollution havens hypothesis has two empirical results. First, FDI outflows in developed countries have a positive relationship with the stringency of environmental laws in their countries. Second, pollution in developing countries is positively related to FDI Inflows.

Second, CO_2 emissions affect significantly and negatively economic growth in all the panels and FDI inflows in three out of the four panels, with the European and North Asian panel being the exception. These findings, which are in line with those of Halicioglu (2009) and Pao and Tsai (2010), suggest that environmental damage can prevent potential foreign investors from committing, and thereby slow down economic growth. Third, we find evidence that CO_2 emissions are positively linked to economic growth only for the Middle Eastern, North African, and sub-Saharan panel. One potential explanation is that countries in the early stages of economic development are more polluting. This finding seems to validate the EKC hypothesis, which is also confirmed by the results of Narayan and Narayan (2010) and Sharma (2011). Finally, our evidence shows that fast-growing countries attract more FDI inflows, regardless of the panels under consideration. Borensztein et al. (1998), Bengoa and Sanchez-Robles (2003), Pao and Tsai (2010), and Soltani and Ochi (2012) reach the same conclusions.

5. Concluding remarks

Though the nexus between economic growth, FDI inflows, and carbon emissions has been extensively investigated in the past literature, their dynamic interactions may not be modeled appropriately because they can simply be determined simultaneously. In this article, we propose to examine their simultaneous causal relationships by using simultaneous-equation models that rely on a growth framework. We tackle this issue empirically for a global panel of 54 countries around the world as well as for three regional sub-panels: the regions of Europe and North Asia, Latin America and the Caribbean, and the Middle East, North Africa, and sub-Sahara.

The main findings over the period 1990–2011 show evidence of bidirectional causality between economic growth and FDI inflows for all the four panels we consider, bidirectional causality between FDI inflows and CO_2 emissions for all the panels with the exception of Europe and North Asia, and unidirectional causality running from CO_2 emissions to economic growth with the exception of the Middle Eastern, North African, and sub-Saharan panel, for which we find bidirectional causality between CO_2 emissions and economic growth.

The main policy implications arising from our study can be presented as follows. First, the presence of bidirectional and positive causality links between FDI inflows and economic growth implies that an increase in the stock of FDI contributes to promoting economic growth, and that economic growth, in turn, creates favorable conditions for attracting and retaining further FDI flows into the considered regions. Accordingly, governments, essentially those in developing countries, should implement sound economic policies to eliminate legal and non-legal barriers that prevent local firms from establishing economic linkages as well as access to technology and financing conditions from the foreign markets. Improving local conditions may also be an appropriate solution to attract foreign investors and to enable host economies to maximize the economic benefits from foreign direct investments (Alfaro et al., 2006).

Second, the feedback causal relationship between FDI inflows and CO_2 emissions for all the panels, except the European and North Asian panel, implies that environmental pollution and FDI inflows are jointly determined and affected at the same time. The negative causality from CO_2 emissions to FDI inflows suggests that, apart from the countries in Europe and North Asia, the remaining countries in our panels need to implement more environmental regulation policies in order to control carbon emissions and to prevent FDI capital flights. At the same time, the positive causality direction from FDI inflows to CO_2 emissions typically evinces that policymakers should pay heed to the "environmental quality" of foreign direct investments in order to avoid "pollution haven" traps through encouraging the coordinated know-how and "clean" technological transfer with foreign companies. Previous studies have shown that the green technological progress accompanied by FDI inflows may lead to a rapid improvement in the efficient use of energy and thus result in a reduction of CO_2 emissions (Dincer and Rosen, 2011; Lee, 2013). All in all, the increased amount of pollution emissions produced by the entry of multinational corporations should be compensated for by the transfer of developed green technologies.

Finally, the unidirectional and positive causality from economic growth to CO_2 emissions in the countries of the Middle Eastern, North African, and sub-Saharan panel entails that high economic growth leads to damage to the environmental quality. However, to the extent that the decline in economic growth may put strong pressure on the public finances and employment in these countries, important efforts should be made in order to encourage industries to adopt clean development mechanisms and environmentally friendly technologies. Moreover, these countries have to embrace energy conservation policies and seek to increase their energy efficiency; otherwise, they will pollute more as their incomes grow. The negative causality from CO_2 emissions to economic growth for all the panels seems to suggest that policymakers should implement policies that encourage environmentally friendly energy production and utilization as well as green technologies in order to reduce carbon emissions and to promote economic growth simultaneously.

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