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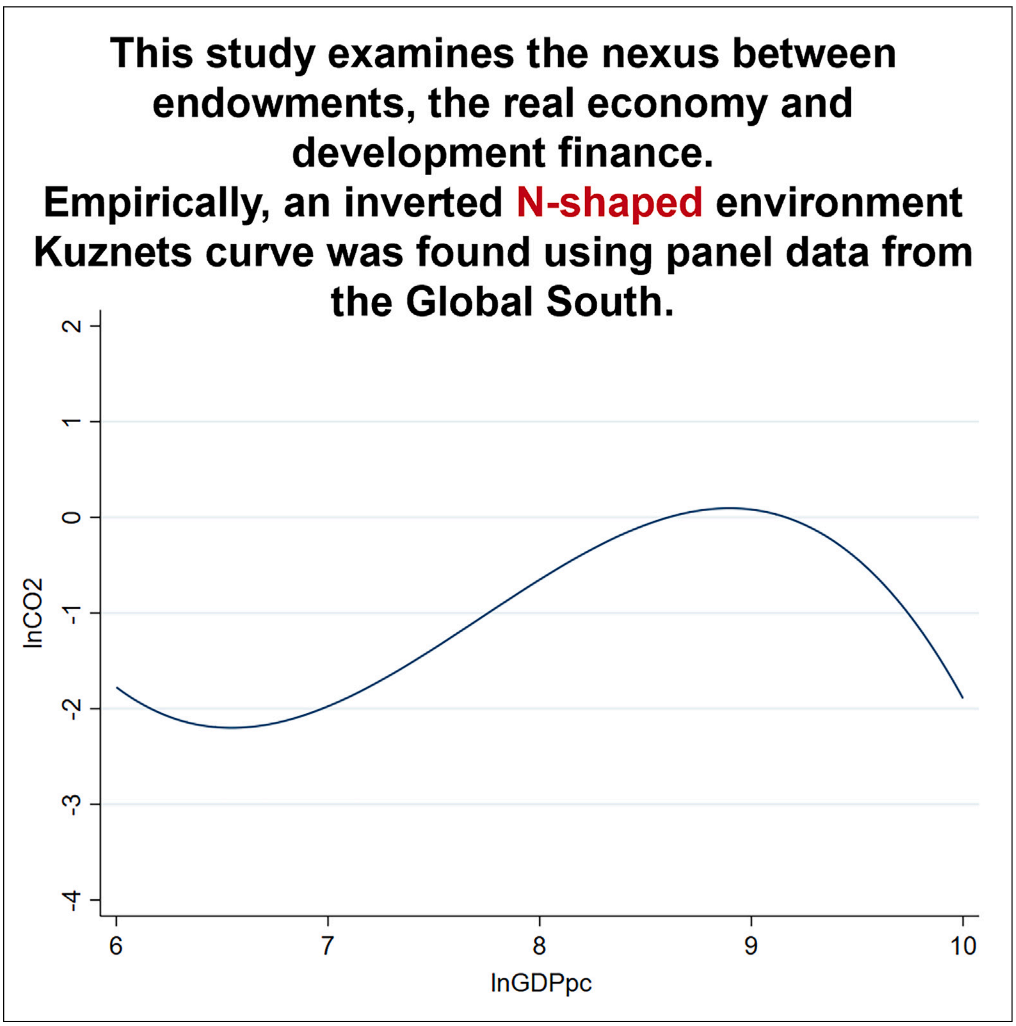

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Highlights

Development finance's impact on carbon emission reduction is not significant

Future development finance should aim at scalable renewable energy adoption

Developing countries need to pay attention to renewable natural capital preservation

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Green natural capital, the environmental Kuznets curve and development financing in the Global South

Yan Wang[1] and Yinyin Xu[2,3,*]

SUMMARY

This study investigates the nexus between carbon dioxide emissions, economic development, and development finance in seeking an empirical answer to the conundrum at the intersection of development and environmental economics. Employing a theoretical framework that incorporates three dimensions of endowments, the real economy, and the financial sector, our empirical model accounts for the bi-directional causality of environmental degradation and economic growth in the Global South by adopting the simultaneous equations model. Our results confirm an inverted N-shaped environment Kuznets curve which is statistically significant and robust, and consistent with the conceptualized theoretical framework. The results provide insights to enhance the effectiveness of future development finance and policy design by promoting sustainable growth and green transformation through facilitating renewable energy adoption, investing in human capital, and preserving renewable natural capital.

INTRODUCTION

Developing countries, home to the most economically disadvantaged population vulnerable to climate change, are under pressure to reduce carbon dioxide (CO_2) emissions to minimize the damage from the environmental externalities. The amount of CO_2 emissions is highly unequal among countries, both in historically cumulative terms and in current per capita terms. Historically, rich and developed countries have been the largest contributors to CO_2 emissions. The respective shares of low-income and most middle-income countries in global historical accumulation are negligible. Along with the call for climate justice, promoting green transformation for sustainable growth and minimizing the trade-off between environmental degradation and economic growth has been on top of the development agenda in the Global South.

However, the environment development dilemma in the Global South is largely unsolved. There is an apparent conundrum at the intersection of development and environmental economics. Empirical evidence shows that the marginal willingness to pay for environmental quality in developing countries is lower than it should be considering the negative externalities such as health-related productivity and welfare loss.[1] The governments in developing countries face different development problems in less favorable circumstances from their industrialized counterparts. What are the feasible policies to minimize the negative environmental externalities without harming economic development? In this case, the traditional development or the environmental economics tools alone cannot provide a credible and straightforward answer to this seemingly contradictory policy question. A country's economic and endowment structures matter in seeking a potential pathway through the complex maze.

From a practical and macro perspective, what factors contribute to the "growing up" and "cleaning up" in developing countries? This study investigates the circular relationship between CO_2 emissions, economic development, and development financing in developing countries by re-examining the Environmental Kuznets Curve (EKC) hypothesis using a panel dataset for 76 developing countries from 1995 to 2018. The EKC hypothesis suggests that various pollutants rise with income at low-income levels and decline after reaching a certain higher income threshold (i.e., an inverted U-shaped relationship), which is named after the Kuznets hypothesis on income inequality.[2,3] This stylized fact has been tested using cross-sectional data from developed and developing countries in the past two decades while reporting different turning points and yielding different policy implications.

The EKC analysis has been evolving frequently with a massive amount of literature. The validation of the EKC relationship is based on the researchers' choice of model specification, elements to enter the empirical equations, and the understanding of the real-world environment-development relationship.[4] This paper contributes to the EKC literature by filling the gaps in empirical testing in the following three ways.

First, in terms of the structure of the model, this study attempts to include both the quadratic and cubic terms of the economic variable. The inverted U-shaped relationship is the most extensive in the existing literature. However, more recent studies provide evidence for the

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N-shaped relationship. The early empirical studies focused on testifying the inverted U-shaped relationship,[5–7] which were similar to the original Kuznets hypothesis on economic growth and inequality. In more recent studies, scholars have a growing interest in re-considering the EKC model specification and attempting to add the cubic form of economic variable to the model based on different theoretical reasoning.[8,9]

Second, this study investigates new sets of factors based on new findings in the recent publications such as the renewable natural capital (RNC), and renewable energy consumption, etc. In addition to the economic and environmental variables, researchers generally include multiple additional control factors that correlate with economic or environmental variables. These additional factors fall into the sectors of energy consumption structure, economic performance, government behavior, technological advancement, and sociodemographic development. Renewable energy consumption is the most often added energy variable, and it is found to reduce emissions, improve environmental quality, and increase environmental sustainability.[10–13] A few studies also account for the impact of natural resources using the natural resource rent as the proxy.[12,14]

In addition, development finance has often been neglected in previous studies on EKC. Although it is meant to play a critical role in mitigating negative environmental externalities based on institutional consensus, such as the Clean Development Mechanism under the Kyoto Protocol, few studies have combined the investigation of the effectiveness of development financing from multilateral development banks and bilateral creditors when testing the EKC hypothesis. Given the limitations of data availability and transparency from creditors, some researchers examine the impact of official development aid from a single country.[15] Apparently, the environmental and macro-development economics thinking and tools are not reconciled yet to address the empirical question.

Third, this study departs from existing research in accounting for simultaneity. The vast literature on EKC seldom addresses the endogeneity caused by the bi-directional causality. The endogeneity problem in the EKC empirical analysis using the Global South samples is largely ignored except for some studies in the field of Envirodevonomics, which recognize the endogeneity caused by omitted variables such as political power and simultaneity.[1,16] Most studies use single polynomial equations where the pollutant is the dependent variable and per capita income is the independent variable.[17,18] By construction, these studies see the pollutants as the products or byproducts of economic activities. Thus, these studies are less likely to address the two-way causality due to the feedback effect of environmental degradation on economic growth.[19,20] Intuitively, extreme weather and natural disasters caused by global warming hinder agricultural output and subsequently lower farmers' incomes.[21] Thus, this study attempts to address these weaknesses by formulating a two-equation simultaneous equations model (SEM) based on the theoretical implication.

RESULTS

Theoretical model

The primary concern in the Global South is to address broader environmental issues while simultaneously dealing with the pressing social and economic challenges such as economic growth and poverty reduction. Attempting to understand the intrinsic relationship between the environment and the broader socioeconomic structures, we develop the theoretical model based on the New Structural Environmental Economics (NSEE).[22,23]

Factor endowments: Human capital, renewable natural capital, and renewable energy

Human and natural capital are the factor endowments critical to economic growth and environmental degradation. Conventional economics has placed greater importance on accumulating physical capital for growth, leading to underinvestment in human capital and over-exploitation of natural capital, such as fossil fuels. We follow the definition of human capital and natural capital by the Changing Wealth of Nations (CWON) working group at the World Bank. For the natural capital, the CWON working group further divides it into RNCK and non-RNC. Given the difficulty in accounting for renewable energy as natural capital and other constraints, renewable energy resources are not included in the RNC discussed in the World Bank's accounting. RNC is defined as the monetary value of agricultural land, forests, protected areas, fisheries, and mangroves by the CWON working group. In order to differentiate renewable energy from the existing accounting framework, for the purpose of this study, we define "green natural capital" as the country's reserves of the World Bank-defined RNC and the potential renewable power resources of a country.

Structure of the economy and structure of the factor endowments

The structure of endowments determines the industrial structure and level of emissions. From a micro perspective, households and firms are not just consumers but also owners of factor endowments, producers of eco-services, and emitters of pollutants. Meanwhile, firms also serve as innovators of green technology. From a macro perspective, a country's endowment structure determines the industrial structure, which in turn influences the energy consumption pattern, leading to the heterogeneity of CO_2 emissions across economies. As the country's industrial structure transforms from the primary sectors to secondary industries, energy consumption patterns rely more heavily on non-renewable natural endowments, i.e., minerals, oil, coal and gas reserves, and hence CO_2 emissions increase. The industrialized country sees the rapid accumulation of produced capital and depletion of non-renewable natural endowments. Rapid economic growth leads to rapidly rising production costs (i.e., labor, land, and raw materials) in the country after years of accumulation of produced wealth, and the structure of the real economy gradually shifts from the second to tertiary sectors. In this stage, the economies rely more on technological advancement and human capital investment, which in turn changes the structure of energy consumption, along with the reduction in CO_2 emissions.

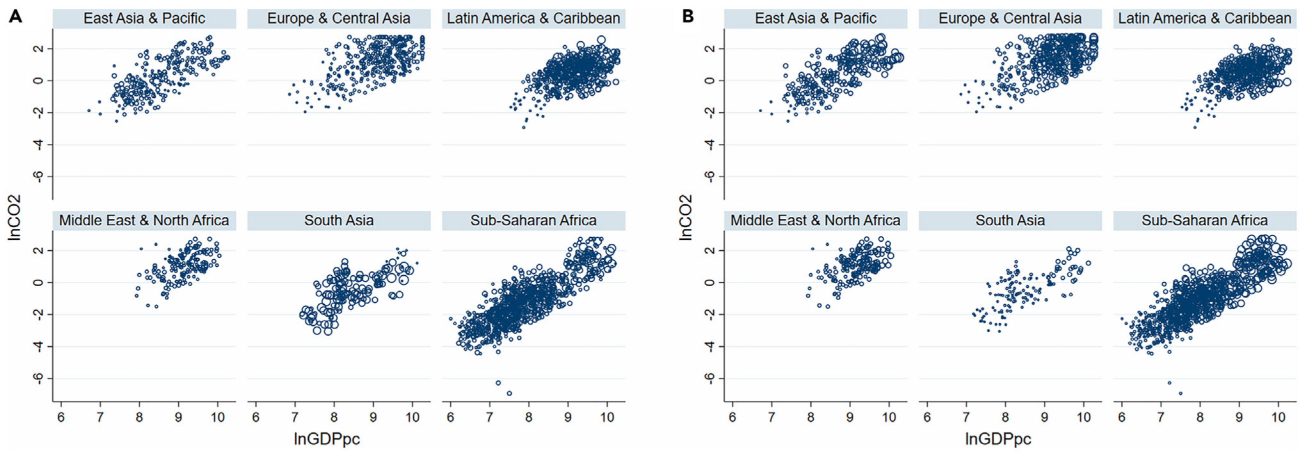

Figure 1. Relationship between CO2 and GDP per capita, circle size represents the comparative value of renewable natural capital (left) per capita and human capital (right) per capita over the observed period, by region

Source: Authors' calculation based on World Bank WDI, and Changing Wealth of Nations (CWON) database.

Environmental degradation, such as emissions of pollutants and extreme weather caused by climate change, can negatively impact the value of renewable natural endowments by lowering the quality and quantity of economic outputs. The depletion of RNC hinders poverty reduction and human welfare, since the poor rely heavily on renewable natural endowments as an input for production. Conversely, if governments want to reduce emissions of CO_2 and other pollutants, they could preserve and foster the growth of RNC along with other conventional environmental policies, resulting in appreciation in both land value and economic outputs.[24] Thus, a virtuous cycle to sustainable growth will likely emerge in the long run.

The accumulation of human capital and RNC is recognized as beneficial to green transformation in the Global South. The human and RNC represent a large share of the total wealth of developing countries. Human capital accounts for 65% of total wealth in the developing world. RNC accounts for 23% and 5% of total wealth in low- and middle-income countries, respectively (see Figure 1). Considering the large shares of these non-produced capitals of the total wealth, suppose a developing country has a better accounting of its natural and human capital and channels the developing resources to invest in these areas. These two often neglected capitals can increase investment returns and attract more physical/financial capital.[25]

Role of the development finance

Development finance in the financial sector is to be incorporated into the framework for the purpose of this study. Foreign direct investment (FDI) usually enters the EKC equations and is found to be positively associated with environmental degradation in developing countries, known as the pollution heaven hypothesis.[26] However, the role of development finance, which is essential to developing countries, is largely neglected in the EKC research in the Global South. As a substitution for FDI, this study alternatively focuses on the net transfers of development finance from bilateral and multilateral development banks (MDBs). The primary concern is to examine whether the public and public guaranteed (PPG) and often concessional debts from the bilateral and multilateral creditors are associated with economic growth and environmental degradation in the host countries (see Figure 2).

Differing from private investments with a profit motive, development finance is presumed to accelerate sustainable economic growth and promote social development in the host countries and is mission-driven. Concessional development finance also differs from grants since the lending needs to be paid back with a certain interest at a significantly lower rate than borrowing from commercial banks. The eligibility of concessional multilateral finance is predetermined by multilateral institutions such as the International Development Association (IDA), the International Bank for Reconstruction and Development (IBRD), and other MDBs. The eligibility of concessional bilateral finance is largely context-based, which could be affected by the creditor-debtor strategic interactions and specific development goals. Nevertheless, concessional lending represents a large share of capital inflow to the recipient country.

Following the spirit of the above-mentioned theoretical framework, the theoretical framework includes three dimensions: the natural endowments, the real economy, and the financial sector. The three sectors are intertwined (see Figure 3).

In the tradition of an extended Cobb-Douglas production function, the simultaneous equations model (SEM) is given as follows.

$$ln\ CO2_{it} = a_0 + a_1 lnGDP_{it} + a_2\ ln\ GDP_{it}^2 + a_3\ ln\ GDP_{it}^3 + a_4 lnRNK_{it} + a_5\ ln\ MLT_{it} + a_6\ ln\ BLT_{it} + a_7\ ln\ REN_{it} + T + \varepsilon_{it} \quad \text{(Equation 1)}$$

$$lnGDPpc_{it} = \beta_0 + \beta_1 lnRNK_{it} + \beta_2 lnCO2_{it} + \beta_3 lnMLT_{it} + \beta_4\ lnBLT_{it} + \beta_5 lnHK_{it} + \beta_6 lnwaged_{it} + \beta_7 lnInd_{it} + T + \mu_{it} \quad \text{(Equation 2)}$$

Where CO_2, $GDPpc$, RNK, MLT, BLT, REN, HK, $waged$, Ind, T denote CO_2 emissions (per capita, density and intensity), gross domestic product (GDP) per capita, RNC, concessional multilateral lending net transfer, concessional bilateral lending net transfer, the share of renewable

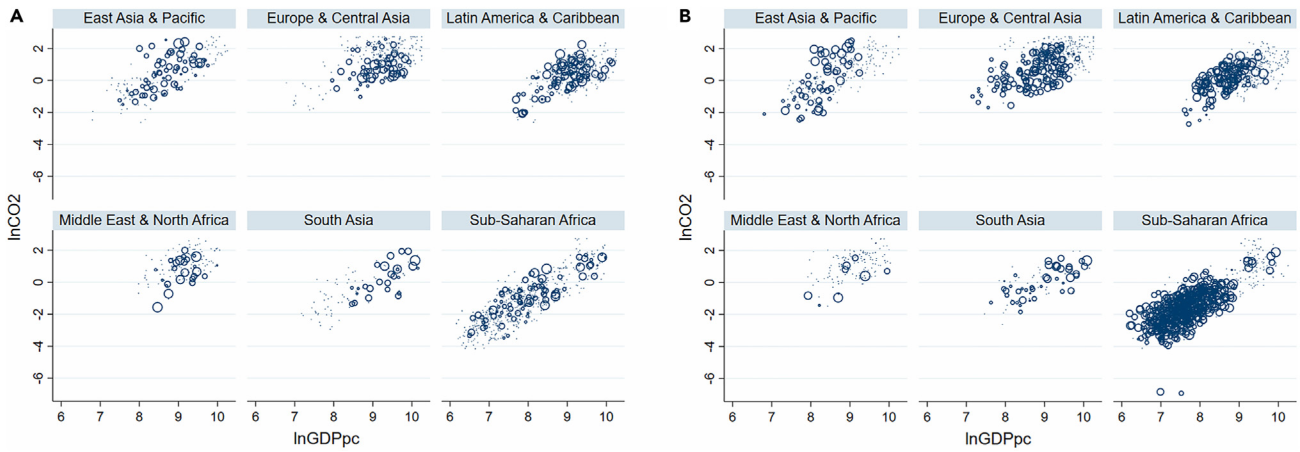

Figure 2. Relationship between CO2 and GDP per capita, circle size represents the comparative size of bilateral (left) and multilateral (right) net transfer per capita over the observed period, by region

Source: Authors' calculation based on World Bank World Development Indicators (WDI), and World Bank International Debt Statistics (IDS) database.

energy consumption (in total energy consumption), human capital per capita, the share of wage and salaried workers in total employment, the share of industry in GDP, and time trend, respectively. ε, μ are error terms, and i stands for a country index. All the variables enter the SEM in log form except for the time trend.

Different from previous literature, we use waged employment rate to account for the quality of employment in the developing world. Although previous studies have used employment rate as an important indicator for labor input, it is recognized by labor economists that the quality of employment weighs more, echoing the fact that the unemployment rate is usually low since most poor are in the informal and self-employed sectors.[27] Thus, this study examines the ratio of waged or salaried employment as a proxy for the quality of employment.

The key parameters to estimate in relevance to the EKC hypothesis are a_1, a_2 and a_3. If a_2 and a_3 are both zero, the EKC relationship becomes a single polynomial linear relationship between emission and economic growth. If a_2 is nonzero while a_3 is zero, then it turns to a quadratic function (U-shaped or inverted U-shaped EKC) depending on the signs of a_1, a_2. If a_3 is nonzero, then it is likely to see an inverted N-shaped relationship than the N-shaped relationship given that the latter is validated in the samples of developed countries. The expected signs of the estimates are given in Table 1.

Data description

Based on the discussions in Section Results, this study compiles a panel dataset of 76 countries between 1995 and 2018. This panel is not balanced; thus, we use the time trend variable to control for the year effect. Table 2 presents a descriptive analysis of the panel. The key dependent variables are CO_2 emissions per capita (metric tons per capita), CO_2 emissions intensity (kg per 2017 PPP dollars of GDP), and CO_2 emissions density (kt per squared km) from the World Bank's World Development Indicators. The key explanatory variables are RNC per capita (constant 2018 US dollars) and human capital per capita (constant 2018 US dollars) from the World Bank's Changing Wealth of Nations[28] (CWON); net transfer of public and publicly guaranteed concessional loans from multilateral and bilateral development institutions (current 2018 US dollars) from the World Bank's International Debt Statistics[29] (IDS) database; GDP per capita (constant 2017 international dollars), renewable energy consumption as a portion of total final energy consumption (%), industry (including construction) value-added as a percent of GDP (%), and the share of wage and salaried workers as a percent of total employment (%) from the World Bank's World Development Indicators.[30] All monetary terms are adjusted to the constant price.

Empirical methodology

The first concern is whether the economic variable's quadratic and cubic form shall be included in the function, regardless of the choice between the single polynomial equation and the simultaneous equations model. The necessity to include the quadratic and cubic terms is examined with the F test under the heteroscedasticity condition. Given that the F test results reject the null hypothesis that both or either of these two terms is zero, neither term is omitted in the continuing estimates.

The second concern is the endogeneity of the GDP per capita. That is, to test whether the single polynomial equation will be sufficient in empirically evaluating the EKC relationship. The Hausman specification test is executed to test the endogeneity of the GDP per capita and its quadratic and cubic terms. The test result rejects the null hypothesis that these economic variables are exogenous to the CO_2 emission equations in different model specifications. In other words, the estimations using the single polynomial equation might yield biased and inconsistent results given that the exogeneity condition is violated, which can be interpreted as estimates provided by the single polynomial equation being biased. In other words, the empirical results validate the bilateral causality between the economic growth and pollutant variables using

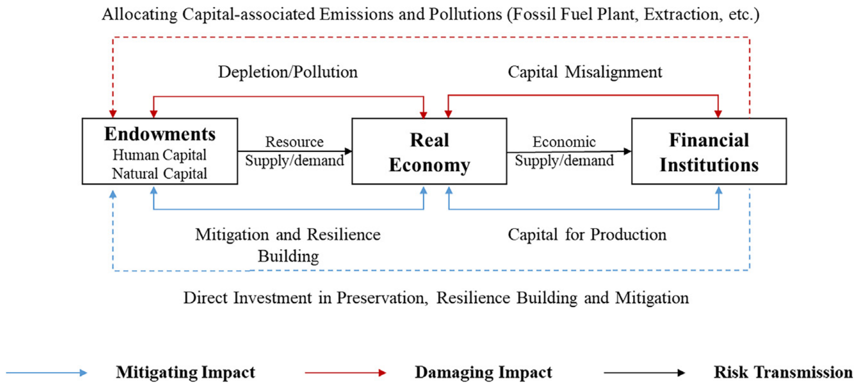

Figure 3. Three dimensions are intertwined: Endowments, the real economy, and the financial system
Source: Authors.

the selected sample. The following empirical analysis uses mainly the two-stage least squares (2SLS) method, while the three-stage least squares (3SLS) method is used for robustness check and as an extension for the estimation.

The third concern is the identification of the instrumental variables for the endogenous terms in the SEM estimation. Using all the exogenous variables in the SEM system as instrumental variables is conventional. Specifically, the instrumental variables for GDP per capita are RNC, concessional multilateral lending net transfer, concessional bilateral lending net transfer, renewable energy consumption share, human capital per capita, wage and salaried workers portion, industry share, and time trend. However, given that the Hausman specification says that the GDP per capita and its quadratic and cubic terms are all endogenous variables, it is required to find the instrumental variables for the three terms. Following Wooldridge,[31] this study attempts to use the quadratic and cubic terms of the exogenous variables in the equations. Several tests are applied to test the validity of the instrumental variables, reported in Table 3. The first test is the weak IV test, for which the Kleibergen-Paap rk Wald F statistic[32] is reported. The Hansen J statistic is not used since the estimation is under the heteroscedasticity condition. The second test is under-identification, for which the rank condition can fulfill the requirements. The third test is the over-identification test. The instrumental variables are to be validated via these three tests.

The last concern is over the estimation method for the panel data. The choice is among the pooled OLS, random, and fixed effects. The pooled OLS is rejected as the estimation method by the F test with the existence of the country effect in the sampled data. The Hausman test is employed and the test result confirms that using the fixed-effect model is preferred as reported in Table 3.

Main results

The empirical results show that the single polynomial equation estimation tends to yield biased and inconsistent results, and the simultaneous equations model with 2SLS provides consistent estimates. The F-test statistics validate the co-existence of the quadratic and cubic terms of the GDP per capita in the equation, which means there is no need to omit either. The Hausman specification tests prove the endogeneity of the GDP per capita and its quadratic and cubic terms. The identification tests of the instrumental variables have validated the chosen ones, despite the over-identification test for the emission density function. In both single polynomial equations and simultaneous equations models with 2SLS estimations, the null hypothesis of choosing the random effect model is rejected by the Hausman test. Thus, the fixed-effect model is adopted.

The following tables present the study's empirical results. Table 3 reports the fixed effect for both the single polynomial equation and simultaneous equations model (2SLS), along with the test statistics of those mentioned in Section Discussion, discussing the empirical methodologies. In addition, the turning points are calculated for the SEM estimations.

In the equation of CO_2 emission (Columns 2, 4, 6 in Table 4), the SEM model presents an inverted N-shaped relationship between the per capita emission and GDP per capita in the sample. The model pictures a trend where the CO_2 emission reduces until the first turning point and increases sharply until the second turning point, after which the CO_2 emission reduces again. Such an inverted N-shaped is not found in the single polynomial equation estimations (Columns 1, 3, 5 in Table 4). The estimated EKC using the CO_2 per capita emission is shown in Figure 4.

The inverted N-shaped relationship, as shown in Figure 4, fits within the structural transformation process described in Section Results. In brief, the first stage remarks on the development pattern where economic activities' negative environmental externalities are within the ecosystem-based mitigation capacity even without policy interventions or regulations. The second stage sees the monotonically increasing relationship between environmental degradation and economic growth with limited incentives for firms to reduce emissions or for the government to discourage the negative externalities at the cost of economic takeoffs. In the third stage, societal and structural changes evolve to promote more sustainable economic growth as emissions reduce with economic growth.

First Stage: Gradual Decrease

In the early stage of economic development, when the endowment structure is labor- and resource-intensive, the endogenously determined industrial structure is dominated by land- and labor-intensive sectors such as agriculture. Most ice-free and non-barren land areas are

Table 1. Expected signs for estimates in SEM (Equations 1 and 2)

CO_2 equation		GDP equation	
explanatory variables	expected signs	explanatory variables	expected signs
lnGDP	+	*lnRNK*	+
lnGDP^2	−	*lnCO2*	−
lnGDP^3	+	*lnMLT*	+
lnRNK	−	*lnBLT*	+
lnMLT	+ / −	*lnHK*	+
lnBLT	+ / −	*lnwaged*	+
lnREN	+	*lnInd*	+

Source: Authors.

occupied by agricultural production in a rather discrete pattern. The inconsistency in industrial land distribution and technological backwardness are causes for comparative disadvantages in market competition. The environmental characteristics of such industrial structures are low energy consumption and low pollution intensity. Regarding greenhouse gas emissions, agriculture is more often responsible for non-CO2 emissions, i.e., methane and nitrous oxide. CO_2 emissions as a byproduct of other human activities can be removed and stored through soil-based carbon sequestration. As a result, the environmental degradation due to human activities in this development stage is insignificant as the negative effects are still within the ecosystem-based mitigation capacity. Meanwhile, slow economic growth can be observed due to low productivity, and a steady decrease in emissions emerges until the economy reaches the first threshold when technological advancement in the agricultural sector takes place, such as the adoption of chemical fertilizers and pesticides in mass production.

Second Stage: Rapid Increase

With economic development and an evolved structure of endowments, the optimal sectoral structure becomes increasingly capital-intensive, where capital plays an increasingly essential role in development along with both a mitigating impact and a damaging impact on the real economy. Meanwhile, agricultural land, wild habitat, and forests are gradually squeezed out due to urbanization and rapid industrialization. The environmental characteristics of this kind of industrial structure are often high-energy and pollution-intensive, thereby leading to the depletion of natural endowments and the environment. CO_2 emissions from different kinds of industrial production and human activities gradually exceed nature's capacity to store, which requires the firms to invest in cleaner technologies and reduce emissions if possible. However, the mitigating expense of environmental externalities is a great burden for firms without subsidies from the government and technological spillovers from more developed regions. Also, the government rarely finds it legitimate to discourage negative externalities by taxing when it prioritizes economic growth. Meanwhile, subsidizing the positive externalities, such as clean energy adoption and technological upgrading, requires the government to give up other policy goals on the development agenda. Thus, the emissions show an almost monotonically increasing relationship with economic growth.

Table 2. Descriptive analysis

	Sample Mean	Standard Deviation	Sample Minimum	Sample Maximum	Observations
CO2pc	1.082	1.276	0.029	6.484	677
CO2D	0.112	0.149	0.000	0.566	677
CO2I	0.210	0.233	0.023	1.080	677
GDP	4488.301	3066.063	822.611	14082.240	677
RNK	4353.768	1996.041	903.347	8737.036	677
MLT	2.359	2.154	0.009	12.042	677
BLT	1.799	6.104	0.001	57.942	677
REN	53.290	30.020	1.750	97.030	677
HK	11810.340	7336.341	818.415	36056.500	677
Ind	28.168	13.433	8.877	66.121	677
waged	31.99718	18.98605	4.617385	87.3222	677

Source: Authors.

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Table 3. Estimated results for Equation 1 with fixed effect

	CO_2 Emission per capita		CO_2 Emission Density		CO_2 Emissions Intensity	
	(1) Single Polynomial Equation	(2) Simultaneous Equations Model (2SLS)	(3) Single Polynomial Equation	(4) Simultaneous Equations Model (2SLS)	(5) Single Polynomial Equation	(6) Simultaneous Equations Model (2SLS)
lnGDP	−11.834 (7.832)	−64.493*** (13.989)	−7.030 (4.788)	−69.095*** (14.650)	−12.860 (8.084)	−65.025*** (14.022)
lnGDP^2	1.769* (0.982)	8.490*** (1.754)	1.225** (0.601)	9.081*** (1.845)	1.777* (1.014)	8.438*** (1.757)
lnGDP^3	−0.082** (0.041)	−0.364*** (0.073)	−0.062** (0.025)	−0.390*** (0.077)	−0.083** (0.042)	−0.362*** (0.073)
lnMLT	−0.002 (0.014)	−0.019 (0.012)	0.006 (0.009)	−0.011 (0.069)	−0.003 (0.014)	−0.020 (0.012)
lnBLT	−0.006 (0.009)	−0.009 (0.012)	0.004 (0.006)	0.001 (0.010)	−0.007 (0.010)	−0.010 (0.013)
lnRNK	−0.043 (0.058)	−0.062 (0.068)	−0.101*** (0.035)	−0.127** (0.007)	−0.044 (0.060)	−0.063 (0.068)
lnREN	−0.332*** (0.065)	−0.262*** (0.072)	−0.290*** (0.040)	−0.206*** (0.081)	−0.331*** (0.067)	−0.262*** (0.072)
T	0.021*** (0.003)	0.013*** (0.005)	0.040*** (0.002)	0.031*** (0.004)	0.021*** (0.004)	0.013** (0.005)
Intercept	−17.291 (23.092)	134.434*** 49.087	−72.176*** (14.122)	108.152*** (31.432)	−10.956 (23.835)	139.407*** (50.578)
Overall R^2	0.746	0.949	0.394	0.985	0.003	0.843
F Test for Quadratic and Cubic Terms	3.27*	38.14***	4.23**	67.06***	3.10*	23.13***
Hausman Test for Exogeneity	–	8.713*** (3,589)	–	10.801*** (3,587)	–	8.563*** (3,589)
Weak IV Test	–	7.423	–	7.417	–	7.423
Over-Identification Test	–	23.479 (15)	–	39.104 (15)	–	23.539 (15)
F Test for Country Effect	18.20*** (77, 618)	15.29*** (76, 592)	209.04*** (77, 616)	164.68*** (76, 590)	17.24*** (77, 616)	14.54*** (76, 592)
Hausman Test for FE vs. RE	94.01*** (7)	119.82*** (7)	517.76*** (7)	28.25*** (7)	102.47*** (7)	95.51*** (7)
Turning Point	–	1st, 732.893 2ND, 7723.323	–	1st, 790.764 2ND, 6981.367	–	1st, 1172.625 2ND, 4783.845
Observations	704	677	702	675	704	677

***$p < 0.01$, **p<;0.05, *p<;0.1; standard errors in parentheses. *Note: The weak IV test statistics reported in this table is Kleibergen-Paap rk Wald F statistics.*

Table 4. Estimated results for Equation 2 with fixed effect

	lnGDPpc		
	(1)	(2)	(3)
lnCO2pc	−0.087*** (0.042)		
lnCO2 Density		−0.177*** (0.043)	
lnCO2 Intensity			−0.211*** (0.037)
lnRNK	0.167** (0.026)	0.152*** (0.026)	0.136*** (0.027)
lnMLT	0.003 (0.005)	0.005 (0.005)	0.003 (0.005)
lnBLT	−0.005 (0.003)	−0.005 (0.003)	−0.006** (0.003)
lnHK	0.621*** (0.032)	0.641*** (0.031)	0.536*** (0.031)
lnInd	0.144*** (0.025)	0.141*** (0.025)	0.103*** (0.026)
lnwaged	0.042 (0.039)	0.095** (0.040)	0.126** (0.039)
T	0.017*** (0.001)	0.022*** (0.002)	0.017*** (0.001)
Intercept	−32.792*** (3.087)	−43.840*** (4.276)	−32.747*** (2.138)
Overall R^2	0.984	0.984	0.983
Observations	677	675	677

***$p < 0.01$, **p<;0.05, *p<;0.1; standard errors in parentheses.

Third Stage: Rapid Decrease

In the third stage, with the tightening of environmental constraints devaluing the quality of economic growth and human welfare, there is a strong demand for green transformation to shift away from a pollution-intensive industrial structure through mitigation and resilience-building. The land shortage leads to the emergence of populated cities and their suburbs. The energy consumption in this period primarily comes from motorized transportation and power generation to support the functioning of cities or other populated industrial centers. Meanwhile, the economy has accumulated considerable wealth during the economic takeoff period and has more fiscal space for public spending. Consequently, governments or planners are more motivated to encourage positive externalities such as subsidizing clean technology, promoting public transit and clean energy transition, and to discourage negative externalities by taxing or environmental regulations. Thus, the economy reaches the second turning point where the emissions start to decline.

Regarding development finance, both concessional bilateral lending and multilateral lending have a negative relationship with CO_2 emissions, but neither is statistically significant at any level. Considering that most of the concessional multilateral lending comes from IDA and IBRD, the ultimate goal of these net transfers is to build economic resilience rather than mitigate environmental externalities. Thus, the insignificant coefficient for concessional multilateral lending is understandable. Concessional bilateral lending, for which the unknown lending purposes can be very different among creditors, has an even more uncertain relationship with the environmental degradation due to its complexity in nature. To answer the reasons behind our result, we also tested the endogeneity of borrowing behavior of the recipient countries, in other words, whether they might be able to borrow more from the bilateral and multilateral banks when facing economic difficulties. However, it turns out that the relatively richer countries in our panel have been receiving more concessional bilateral and multilateral lending than the less developed counterparts. The empirical result is robust when using the lagged term of GDP per capita. To some extent, it is safe to assert that concessional lending from bilateral and multilateral banks is not directly associated with environmental degradation.

The remaining explanatory variables generally have the same signs as expected. RNC is only negatively and statistically significantly associated with the CO_2 emissions density, consistent with "biological carbon sequestration" and empirical findings.[12,14] The share of renewable energy consumption is negatively and statistically significantly associated with CO_2 emission and its variations, as expected.

In the equation of GDP per capita (Columns 1–3 in Table 4), CO_2 emission has a statistically significant negative association with economic growth. Neither concessional bilateral nor multilateral lending has a statistically significant relationship with GDP per capita. Although it is not the focus of this study, some possible reasons might be rooted in the misfunctioning of some structural adjustment programs (or the nature of the structural adjustment lending).[33] Both RNC and human capital are positively and statistically significantly associated with GDP per capita. As expected, the estimates for the waged employment portion and the industry share are both positive and statistically significant.

Robustness checks and extensions

The robustness of the empirical finding is based on examining different forms of CO_2 emission, including per capita emission, emission density, and emission intensity. The results shown in Table 3 prove the existence of an inverted N-shaped relationship between emission and economic growth, which is validated by the statistically significant parameters of the same signs. The second attempt to check the robustness of the estimates is by using an alternative estimation method. Table 5 shows the estimation of the CO_2 emission equations using the three-stage least square (3SLS) compared to the 2SLS. 3SLS takes care of the correlation between the error terms in each equation of the SEM and is more asymptotically efficient than the 2SLS estimates.[34]

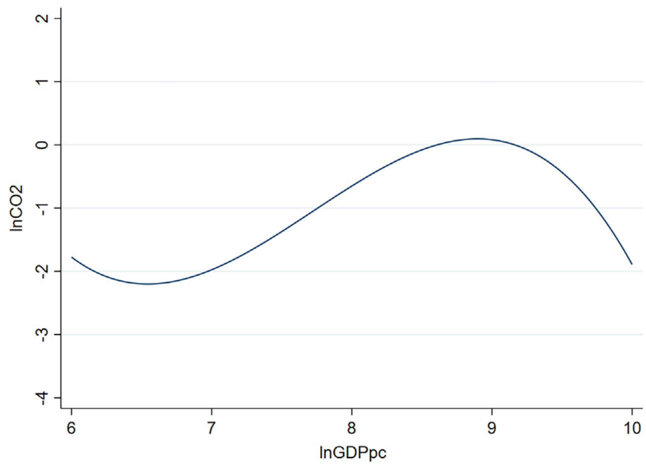

Figure 4. An inverted N-shaped relationship between CO2 emissions per capita and GDP per capita, both in logarithmic form
Source: Authors based on Regression in Table 3, Column (2).

The 2SLS and 3SLS estimates have the same parameter signs, and each parameter's magnitude changes are reasonable except for the emission intensity equation. The close numeric values reflect that the estimation of the parameters is consistent. The 3SLS estimation validates the existence of an inverted N-shaped relationship between economic development and environmental degradation in three specifications. In addition, the value of turning points in each EKC estimation is generally close and robust to changes in specification. The signs for concessional bilateral and multilateral lending remain insignificant. The relationship between renewable energy adoption and emission reduction is robust using a more rigorous estimation approach.

DISCUSSION

An inverted N-shaped EKC relationship is found in the panel data of 76 developing countries during the period of 1995–2018, using the per capita CO_2 emission, CO_2 emission density, and CO_2 emission intensity. The estimation method takes into account the bi-directional causality of environmental degradation and economic growth by adopting the simultaneous equations model estimated via fixed effect 2SLS. The study focuses on the relationship between GDP per capita and CO_2 emission, and the indirect impact of the other explanatory variables is not investigated here. Nevertheless, the accumulation of RNC and the adoption of renewable energy have proven effective in improving the environmental condition. In addition, concessional lending from bilateral and multilateral banks was not found to be associated with CO_2 emission changes or economic growth in various model specifications during the sampled period.

This study contributes to the literature in three ways. First, it joined the recent studies on testing the nonlinear EKC relationship and validated an inverted N-shaped relationship with a sample from developing countries. Second, it provides a better proximation of reality by using the simultaneous equations model to construct the bi-directional relationship between environmental degradation and economic growth. Third, the study tests the impact of factors that are vital to sustainable growth in the Global South when examining the EKC relationship, which includes RNC, human capital, renewable energy adoption, quality of employment, bilateral and multilateral concessional development finance, etc.

The empirical results report the turning points, which are predicted values using the coefficients estimated with the sampled data over the observed period. Progress in environmental protection is notable in developing countries, and effective policies are in place, which could have flattened the upward-sloping part of the EKC but had not been captured by the data of this study (ending in 2018 due to unavailability of CWON data). The reporting of the turning points is not to encourage the policies that merely pursue a "faster" downturn, but to investigate how to "flatten the curve." As Munasinghe[35] notes, equal attention needs to be paid to "tunneling through" the curve by bridging the upward and downward parts of the curve. (Figure 5) In developing countries, if the environmental and climate problems are not taken seriously during the upward-sloping part of the curve, it could reach a point of being nonreversible.

Governments in developing countries need to be aware of what kinds of environmental regulations are needed and when to implement such policies. One practical implication of the EKC analysis is that it sheds light on the fact that the environmental regulations in developing countries need to take into account the economic structure and endowment structure to maintain the balance between environmental protection and economic development. For example, suppose the economy is at the first stage, where the society is mainly agrarian. In that case, the government should pay more attention to mitigating climate-induced negative impacts on agriculture production to avoid welfare loss due to income reduction. However, suppose the country is already in the second stage of the EKC curve. In that case, the optimal choice is to think about "flattening the curve" by discouraging negative externalities as soon as possible by adjusting the endowment structure that will facilitate the structural changes in the real economy.

Table 5. Estimated results for Equation 1: Robustness and extension, 2SLS vs. 3SLS

	CO_2 Emission per capita		CO_2 Emission Density		CO_2 Emissions Intensity	
	(1) Simultaneous Equations Model (3SLS)	(2) Simultaneous Equations Model (2SLS)	(3) Simultaneous Equations Model (3SLS)	(4) Simultaneous Equations Model (2SLS)	(5) Simultaneous Equations Model (3SLS)	(6) Simultaneous Equations Model (2SLS)
lnGDP	−61.575*** (15.763)	−64.493*** (13.989)	−66.033*** (10.141)	−69.095*** (14.650)	−45.434*** (14.278)	−65.025*** (14.022)
$lnGDP^2$	8.165*** (1.995)	8.490*** (1.754)	8.714*** (1.283)	9.081*** (1.845)	6.007*** (1.811)	8.438*** (1.757)
$lnGDP^3$	−0.353*** (0.083)	−0.364*** (0.073)	−0.375*** (0.054)	−0.390*** (0.077)	−0.264*** (0.076)	−0.362*** (0.073)
lnMLT	−0.020 (0.015)	−0.019 (0.012)	−0.011 (0.009)	−0.011 (0.069)	−0.017 (0.015)	−0.020 (0.012)
lnBLT	−0.009 (0.009)	−0.009 (0.012)	0.001 (0.005)	0.001 (0.010)	−0.009 (0.009)	−0.010 (0.013)
lnRNK	−0.044 (0.081)	−0.062 (0.068)	−0.117** (0.052)	−0.127** (0.007)	−0.002 (0.083)	−0.063 (0.068)
lnREN	−0.241 (0.066)	−0.262*** (0.072)	−0.191*** (0.042)	−0.206*** (0.081)	−0.127*** (0.059)	−0.262*** (0.072)
T	0.015*** (0.004)	0.013*** (0.005)	0.032*** (0.003)	0.031*** (0.004)	0.021*** (0.004)	0.013** (0.005)
Intercept	121.103** (45.275)	134.434*** 49.087	97.007** (29.113)	108.152*** (31.432)	70.427* (41.101)	139.407*** (50.578)
Overall R^2	0.949	0.949	0.988	0.985	0.845	0.843
Turning Point	1^{st}, 712.657 2^{ND}, 6981.367	1^{st}, 732.893 2^{ND}, 7723.323	1^{st}, 738.780 2^{ND}, 7230.041	1^{st}, 790.764 2^{ND}, 6981.367	1^{st}, 1319.489 2^{ND}, 2936.577	1^{st}, 1172.625 2^{ND}, 4783.845
Observations	677	677	675	675	677	677

***$p < 0.01$, **p<;0.05, *p<;0.1; standard errors in parentheses, the 3SLS standard errors are not robust.

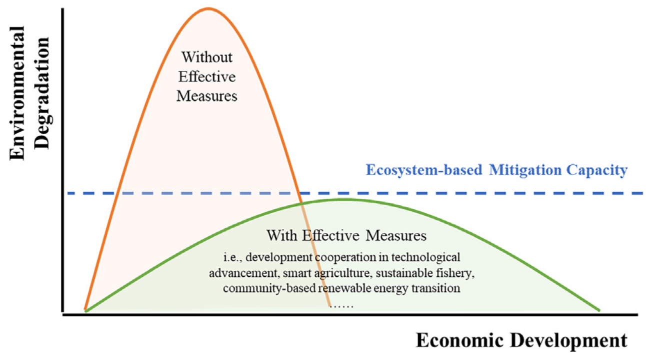

Figure 5. "Tunneling through" the curve by bridging the upward and downward parts of the curve
Source: Authors.

Renewable energy adoption, human capital accumulation, and natural resource conservation are key factors in green transitions in developing countries and can be among the potential policy choices. In order to "tunnel through" the curve, the targeting areas should include facilitating renewable energy adoption, investing in human capital, and preserving RNC. Many developing countries are home to abundant renewable energy resources while lacking the necessary gird capability for market integration to cope with the need for massive renewable adoption.[36] Farmland preservation policies are costly but essential for both poverty reduction and promoting green transformation. For example, smart agricultural technology can improve economic efficiency in production while providing job opportunities simultaneously. The North-South and South-South technological transfers are viable through mission-driven development cooperation.

Our results imply that development finance should expand the goal and funding mechanism for environmental mitigation or climate change adaptation, especially in project-based financing. Concessional development finance is meaningful in unlocking the decarbonization potential and providing socioeconomic benefits in developing countries through capital mobilization and technological spillovers. The EKC relationship provides insights into some possible aspects for channeling future development finance for sustainable growth, i.e., investment in human capital and green natural capital. The development partners can consider investing in green natural capital such as forest, farmland, pastureland, mangroves, agriculture biomass, and scalable renewable energy adoption such as distributive solar and wind farms. At the same time, waged employment and technological spillover should be encouraged in these projects to enhance the human capital through recruitment and training. The advantage of these investments is that these projects are likely to be small, labor- and tech-intensive, and thus, more likely to reach results without incurring large amounts of debt.

Climate finance can be considered as partial debt relief operations led by major bilateral and multilateral creditors in debt restructuring negotiations. The ongoing sovereign debt crisis has exacerbated the poly-crisis in multiple developing countries, along with the global health crisis of COVID-19, sharp economic slowdown, and climate crisis. The slow debt relief process is insufficient to help the indebted countries achieve equal recovery and build resilience.[37] In addition to the proposal to provide more development finance through grants, developing country governments and international development communities need to work together on innovative approaches such as asset-based refinance, debt-to-nature swaps, debt-to-climate action conversions, and public-private partnerships (PPPs).

Limitations of the study

Several possible limitations that we are not able to address can be improved by future studies. First, concessional development finance is provided to achieve particular development goals through economic or social channels. Examining the impact of different types of development finance can validate the findings in this research and provide more direct policy advice. The annually updated IDS database does not reveal such information at this time. More transparency in global debt accumulation will provide a basis for more solid research works and further promote efficiency in debt relief and responsive lending behaviors. Second, environmental degradation is not limited to CO_2 emissions. For the purpose of this study, we only tested the EKC relationship using the CO_2 emission and its variants as the proxy for the environmental degradation. However, the negative environmental externalities brought by human activities are complicated, and studying the impact requires cooperation and knowledge sharing from multiple disciplines. Third, further study can improve by including the welfare analysis when studying the relationship between economic development and environmental degradation. Such analyses will further contribute to the environmental justice movements and just transition in developing countries.

STAR★METHODS

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AUTHOR CONTRIBUTIONS

Conceptualization and SEM methodology: Y.W.

Writing –Conceptualization, coordination, and conclusion: Y.W.

Writing – Methodology and empirical analysis: Y.X.

Review and editing –Y.W. and Y.X.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
CO2 emissions	World Bank, World Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Renewable natural capital per capita	World Bank, Changing Wealth of Nations	https://www.worldbank.org/en/publication/changing-wealth-of-nations/data
Human capital per capita	World Bank, Changing Wealth of Nations	https://www.worldbank.org/en/publication/changing-wealth-of-nations/data
Net transfer of public and publicly guaranteed multilateral concessional loans	World Bank, International Debt Statistics	https://www.worldbank.org/en/programs/debt-statistics/ids
Net transfer of public and publicly guaranteed bilateral concessional loans	World Bank, International Debt Statistics	https://www.worldbank.org/en/programs/debt-statistics/ids
GDP per capita	World Bank, World Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Industry (including construction) value-added as a percent of GDP	World Bank, World Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Renewable energy consumption as a portion of total final energy consumption	World Bank, World Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Share of wage and salaried workers as a percent of total employment	World Bank, World Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Software and algorithms		
Stata	Stata	Stata 17

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Dr. Yan Wang at ywang5@bu.edu.

Materials availability

No new materials were generated by this work.

Data and code availability

- This paper analyzes existing, publicly available data which are listed in the key resources table. All data reported in this paper will be shared by the lead contact upon request.
- Code for the analysis was written in STATA and is available from the lead contact upon request.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

METHOD DETAILS

We compiled a panel dataset of 76 developing countries between 1995 and 2018 using three publicly accessible databases, i.e., World Bank's World Development Indicators, World Bank's Changing Wealth of Nations and World Bank's International Debt Statistics database.

CO2 emissions per capita (metric tons per capita), CO2 emissions intensity (kg per 2017 PPP dollars of GDP), CO2 emissions density (kt per squared km), GDP per capita (constant 2017 international dollars), renewable energy consumption as a portion of total final energy consumption (%), industry (including construction) value-added as a percent of GDP (%), and the share of wage and salaried workers as a percent of total employment (%) were downloaded from the World Bank's World Development Indicators, available at: https://databank.worldbank.org/source/world-development-indicators. Renewable natural capital per capita (constant 2018 US dollars) and human capital per capita (constant 2018 US dollars) were downloaded from the World Bank's Changing Wealth of Nations, available at: https://www.worldbank.org/en/publication/changing-wealth-of-nations/data. Net transfer of public and publicly guaranteed concessional loans from multilateral and bilateral development institutions (current 2018 US dollars) were downloaded from the World Bank's International Debt Statistics database, available at: https://www.worldbank.org/en/programs/debt-statistics/ids.

QUANTIFICATION AND STATISTICAL ANALYSIS

We tested the Environmental Kuznets Curve hypothesis based on the simultaneous equations model in the traditional of an extended Cobb-Douglas production function. In particular, the model was gradually formalized with regard to the structure of the model, estimation method and robustness checks.

Structure of the model and factors

We validated the structure of the model by including both the quadratic and cubic terms of the economic variable. We adopted the F test under the heteroscedasticity condition and the test result rejected the null hypothesis that both of the coefficients of these two terms is zero. Thus, we kept both quadratic and cubic terms of the economic variable in the continuing estimation. In addition, we fitted the model by invesitgating the other factors such as development finance, renewable natural capital, and renewable energy consumption. We adopted the fix-effect estimation method to account for the country-fixed effect in our panel dataset. The country-fixed effect is validated by the Hausman test restuls as an alternative to the random effect model.

Estimation method

We used the simultaneous equations model to account for the bi-directional causality in the relationship between environmental degradation and economic growth. In particular, we ran the Hausman specficaition test and the test results validated the endogeneity of the GDP per capita and its quadratic and cubic terms. Empricially, we used the the two-stage least squares (2SLS) method in our estimations. In order to validate the choice of the instrumental varaibles(IVs), we further conducted the conventional test for IVs, i.e., the weak IV test, the under-identification test and the over-identification test.

Robustness checks

We tested the sensitivity of our estimations with different forms of dependent variables and an alternative estimation method. The different forms of the dependent variables were per capita emission, emission density, and emission intensity. In addition, we used the three-stage least squares (3SLS) method, a more asymptotically efficient way to estimate the parameters in the robustness check. Different specifications validated our empirical result of an inverted N-shaped relationship between emission and economic growth.

All statistical analyses were performed using STATA software (version 17). A two-sided P-value < 0.05 was considered statistically significant.