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Environmental degradation and economic growth: Investigating linkages and potential pathways

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ABSTRACT

Concerns about the incessant rise in emissions and their attendant effects on climate change, which is ravaging the globe, are on the ascendency. The literature has almost concluded that economic activities and growth contribute significantly to environmental degradation. Despite the plethora of studies on the effect of economic growth on environmental degradation, empirical studies examining the reverse – i.e., how environmental degradation affects economic growth – are limited. However, the associated literature postulates that attaining economic growth is accompanied by increased environmental degradation. To guide the development of non-conflicting environmental and structural policies, this study examines whether the rise in environmental degradation is associated with economic growth. It also examines the potential channels through which environmental degradation could affect economic growth. Using a global panel comprising 140 countries from 1980 to 2021 and the two-step dynamic system-generalized method of moment technique to control endogeneity, the findings generally indicate a retarding effect of environmental degradation on economic growth. Further analysis, however, reveals that emissions exhibit an inverted U-shaped relationship with economic growth. However, ecological footprint indicators of environmental degradation have a U-shaped relationship with economic growth. Pathway analysis highlighted that health, foreign direct investment, and technological innovation are the potential channels through which environmental degradation could retard economic growth. The policy implications are discussed.

1. Introduction

This paper examines the effect of environmental sustainability/degradation on economic growth. Demand for environmental sustainability in the 21st century has heightened like never before. This follows an excessive increase in environmental risks Osuntuyi et al., 2023). The World Economic Forum (WEF) posits that environmental risks constitute four of the top five risks the world is facing, and the five most likely global long-term risks are environmental (WEF, 2021). Environmental risks resulting from environmental degradation are considered the greatest threats to attaining the Sustainable Development Goals (SDGs). This is the case as environmental risks affect every society, company, and individual (SRI, 2021). It is the risk in which no one is immune, nor can the world vaccinate against it (WEF, 2021). The major cause of these risks has been carbon dioxide emissions, which form the main grounds for climate change. The Fourth National Climate Assessment report of the United States, published in 2018, cautioned that if greenhouse gases are not reduced, climate change could severely interrupt the world's economies (USGCRP, 2018). The report indicates that climate change negatively affects agriculture, forestry, fisheries, and tourism sectors. The report further suggests that "… climate change creates new risks and exacerbates existing vulnerabilities in communities…, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth …" (USGCRP, 2018, p. 25). Without significant and continued global alleviation measures, climate change is expected to cause increasing losses to infrastructure and property and impede economic growth over this century (USGCRP, 2018).

The rising concerns of climate change and environmental degradation have attracted enormous attention in the literature and policy discussions. In the economics literature, the focus has mainly been on the effect of economic growth on environmental degradation, mainly within the framework of the Environmental Kuznets Curve hypothesis (Asif

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et al., 2023a; Cole, 2003, 2004a; Dinda, 2004; He, 2006; Copeland, 2008; Awaworyi et al., 2018; Bouchoucha, 2021; Osuntuyi et al., 2023). The Environmental Kuznets Curve hypothesis postulates an inverted "U"-shaped relationship between economic growth and environmental degradation (Cole, 2003, 2004a). Specifically, it postulates that environmental degradation increases at the initial stages of economic growth; as growth increases, environmental degradation peaks (reaches a maximum) and starts to fall after further economic growth. Thus, environmental quality sets in with the advent of higher economic growth. In the literature, this higher economic growth rate/level (where environmental degradation peaks) has varied depending on an array of factors (methodology, sample, type of pollutant, etc.). For example, Grossman and Krueger (1991) find a turning point of $4000–$5000 for the United States, and Cole (2004b) finds a range of $25,100–$62,700 for the same United States depending on the model employed. Awaworyi et al. (2018) also find a range of $18,955- $89,540 for 20 OECD countries.

Despite the enormous literature on the economic activity-environmental nexus, the empirical examination of the reverse –whether environmental degradation affects economic growth– is elusive. Several pathways through which environmental degradation can affect economic growth can be identified. Ricci (2007) argues that environmental pollution affects economic growth when considered as input and a by-product of production. Ricci (2007) further asserts that policies to control environmental pollution could limit economic growth since it serves as an additional cost to or constrains production. Similarly, in the face of increasing environmental degradation, Albrizio et al. (2017) argue that stringent environmental policies may impose an additional cost on firms and, thus, induce firms to re-allocate resources from productive sectors towards pollution reduction sectors, thereby impeding economic growth. Also, given the importance of health in improving economic growth, Stern et al. (1996) argue that environmental pollution could impede economic growth by deteriorating human health. Numerous studies have indicated that environmental pollution is associated with poor health conditions (Bouchoucha, 2021; Donohoe, 2003; WHO, 2017). Contrarily, consistent with Porter's hypothesis, environmental degradation can enhance economic growth when it results in the development of stringent environmental regulations. Porter's hypothesis argues that in the face of environmental degradation, strict environmental regulations promote efficiency and induce firms to invest in technological innovations that would lead to higher productivity (Porter, 1991a, 1991b). Similarly, Soytas and Sari (2009) further argue that environmental degradation could drive economic growth when policies to address environmental degradation stimulate technological development and improve factor productivity.

Considering that the effect of environmental degradation is inconclusive despite the fact that it is deleterious to the countries pursuing degrading strategies and all other countries, we empirically examine the effect of environmental degradation on economic growth. This study is vital as it emphasizes factors important to attaining the SDGs. Choosing between the environment and economic growth could present a dilemma to stakeholders; whether protecting the environment should be given priority, even if it leads to slower economic growth and some job losses, or economic growth and generating jobs should be given priority, even if they worsen the environment. In line with this, in this present study, we attempt to answer the following questions:

1. *Does environmental degradation constrain or drive economic growth?*
2. *Is the effect of environmental degradation on economic growth non-monotonic?*
3. *Does environmental degradation explain the variation in economic growth between geographical regions and countries at different stages of economic development?*
4. *What are the potential channels through which environmental degradation affects economic growth?*

In answering the questions above, the current study makes four main contributions to the literature. Firstly, we empirically examine the potential channels through which environmental degradation affects economic growth. Identifying the potential channels through which environmental degradation influences economic growth is critical by enabling policymakers to appreciate that the economic growth effect of environmental degradation is complex; therefore, designing and implementing an integrative or holistic policy approach that would ensure a balance between environmental sustainability and economic development are consequential. Doing this also enables us to ascertain that the effect of environmental degradation on economic growth may not only be direct, but it may work through other channels. This study is the first to do this. Secondly, we contribute to the literature by determining whether there exists potential thresholds by which environmental degradation could affect economic growth. Unlike the test of the Environmental Kuznets Curve hypothesis that the turning point of economic growth (i.e., the point where environmental quality starts to set in) has been examined for various samples (Awaworyi et al., 2018; Cole, 2004b; Grossman and Krueger, 1991), this has not yet been done in the literature when examining the effect of environmental degradation on economic growth. This present study determines whether the relationship between environmental degradation and economic growth is linear or nonlinear. If nonlinear, whether the relationship is "U-" or inverted "U-shaped" and the turning point for environmental degradation. Thirdly, this study makes a case for a global panel of countries buttressed by a subsampling analysis. This is a deviation from the very few existing related studies. These studies have performed an analysis based on a handful of countries that do not give a detailed picture of the situation for more constructive inferences; for example, 11 Asian countries in the case of Azam et al. (2016), 4 countries in the case of Azam et al. (2016), a single country for both Tiwari (2011) and Rehman et al., 2021. We employ data from 140 countries in the present study and further conduct income and regional groups analysis. Our study augments the existing literature by examining if the level of economic development and regional disparity matters for the effect of environmental degradation. Lastly, we employ a more comprehensive measure of environmental degradation relative to the existing related studies. The related studies (see, for example, Azam, 2016; Azam et al., 2016; Rehman et al., 2021; Tiwari, 2011) have used carbon dioxide emission as the proxy for the environment. Though carbon dioxide emission has been the major proxy in the literature, it measures just an aspect of environmental degradation and is not encompassing enough (Acheampong et al., 2022). As a result, focusing on this proxy may give a one-sided story. To circumvent this, in addition to carbon dioxide, we employ total greenhouse gas, methane, and other greenhouse gas emissions. In addition, ecological footprint (as a proxy for environmental degradation) is employed as a robustness check. Another strand of the literature close to the present study attempts to calculate/estimate the cost of climate change (mainly temperature rise) on the economy (Dell et al., 2008, 2009; Fisher et al., 2021). Our study differs from this in that we focus on actual indicators of environmental degradation rather than the effect of environmental degradation, climate change (or temperature rise).

From an analytical perspective, a two-stage approach is adopted to examine the potential channels through which environmental degradation affects economic growth. For a variable to act as a mediator through which environmental degradation affects economic growth, the first-stage condition requires that such a variable has a significant relationship with environmental degradation. After fulfillment of the first-stage condition, the second-stage condition requires that the mediating variable, if included as an additional explanatory variable in the regression linking environmental degradation to economic growth, should decrease the magnitude of the coefficient on environmental degradation or render it statistically insignificant. This standard approach to conducting mediation analysis has been applied in some studies, such as Awaworyi Churchill and Smyth (2020) and Acheampong et al. (2021b). Further, to address the endogeneity issue that could result from reverse causality between economic growth and environmental degradation or variable omission, we apply the Blundell and Bond (1998) two-step dynamic system-generalized method of moment as the main estimator in this study. The fundamental condition that needs to be met before applying the two-step dynamic system-generalized method of moment is that the number of countries should be larger than the number of years. In this study, the number of countries ($N = 140$) exceeds the number of years ($T = 42$).

The remainder of the paper is as follows: the second section presents a brief literature review on the topic. The third, fourth, and fifth sections present the paper's methodology, analyses, and conclusion, respectively.

2. Literature

The major focus of previous literature highlights the impact of economic growth on the environment within the context of the Environmental Kuznets Curve hypothesis, which postulates that initial stages of economic growth are noted to be associated with increased environmental degradation (Grossman and Krueger, 1991; Cole, 2003; Dinda, 2004) due to increased exploitation of natural resources, production, and industrialization. Hence, environmental degradation may be inevitable in the developing region where countries have either set off or are on the path of setting off to development. For many countries at this stage of development, the cost of environmental degradation may be juxtaposed with the accruing benefits associated with increased trade, foreign direct investment, and economic growth. To some countries, an increase in environmental degradation may propel economic growth, and to some, it may serve as deterrence. In propelling economic growth and the associated economic activities, the use of enormous energy is inescapable. Since most of the energies used previously and even now are fossil-based, excessive energy use comes with excessive emissions. Burning fossil fuels (coal, oil, and natural gas) is the major source of carbon dioxide emissions. Carbon dioxide emission is the major contributor to climate change (Asif et al., 2023b; Ali et al., 2022; SRI, 2021; WEF, 2021;). In the 21st century, climate change is considered the utmost threat to both sustainable and human development (Baloch et al., 2019). The effects of climate change are enormous, for example, increasing heat waves, rising sea levels, floods, drought, wildfires, food insecurity (due to adverse effects on food production), biodiversity destruction, natural capital depletion, human health deterioration, conflicts, migration, physical (infrastructural) destruction, etc. (Asif et al., 2023b; Asif et al., 2023c; Ali et al., 2022, 2023; Butt et al., 2005; Fritsche et al., 2012; Kogo et al., 2021; Kurane, 2010; Tong and Ebi, 2019; Wheeler and Von Braun, 2013). Undoubtedly, these consequences threaten economic growth and development (Dell et al., 2008, 2009; Fisher et al., 2021). Climate change leads to hot temperatures, and hot countries tend to be poorer (Dell et al., 2008, 2009; Nordhaus, 2006). Dell et al. (2009) estimate that national income per capita falls on average about 8.5% for every degree Celsius increase in temperature. The Swiss Re Institute (SRI) also estimates that the largest impact of climate change could be the wiping off of nearly 18% of global GDP by 2050 if the temperature rises by 3.2 degrees Celsius (SRI, 2021). The Institute warns that climate change is a systemic risk that must be tackled now, as the effect will be fast and catastrophic. The economic cost of emissions (particularly air pollution) coming from the consumption of unclean cooking energy sources is, for example, estimated to cost about 3.3% of the global GDP (nearly $2.9 trillion) annually (IEA, 2020).

On the empirical front, Azam et al. (2016) found that environmental degradation (measured by carbon dioxide emissions) negatively affects economic growth using the fixed effect method and data from 11 Asian countries from 1990 to 2011. Within the vector correction model framework, Tiwari (2011) found that carbon dioxide emissions are negatively related to India's economic growth using data from 1971 to 2005. Also, in India, using a different year sample (1971–2006) and cointegration methods (autoregressive distributed lag (ARDL) and Johansen cointegration)), Ghosh (2010) found that in the short-run, reducing carbon dioxide emissions would decrease national income. Using data from 1990 to 2011 and the ARDL method in China, Zhai and Song (2013) found that carbon dioxide emissions positively affect economic growth in both the short and long runs. Similarly, Rehman et al. (2021) found carbon dioxide emissions (in the transportation sector) to positively influence economic growth in Pakistan using data from 1971 to 2017 and the ARDL method. In 9 Association of Southeast Asian Nations (ASEAN) countries, Lee and Brahmasrene (2014) found a negative relationship between carbon dioxide emissions and economic growth using data from 1991 to 2009 and panel cointegration methods. In a panel made up of high-emitting countries (China, the United States, India, and Japan), Azam et al. (2016) found that carbon dioxide emissions negatively affect economic growth using the fully modified OLS method and data over the period 1971–2013. For individual country analyses, they found that except for India (showing a negative outcome), carbon dioxide emissions positively affected economic growth.

Scrutiny of the extant literature reveals little about the impact of environmental degradation on economic growth, and the few existing studies have covered just a handful of countries and have mainly measured environmental degradation narrowly with carbon dioxide emissions. In this study, we broadly measure environmental degradation (carbon dioxide, total greenhouse gas, methane, other greenhouse gas emissions, and ecological footprint) and expand the sample size (140 countries) to examine its impact on economic growth. We also identify potential thresholds/turning points for which environmental degradation affects economic growth. In addition, we examine some possible channels through which the environment could affect economic growth. Specifically, we determine if health, foreign direct investment, and technological innovation mediate the effect of environmental degradation on economic growth. In what follows, we describe these channels as follows:

2.1. *The health channel*

The endogenous growth theories accentuate productivity as a key source of long-term growth and further explore how productivity fluctuates from within the economy (Arora, 2001). Health is considered an important element of productivity and economic growth. Well (2007) narrates that healthier people are considered better workers and contribute more to productivity as they can work longer and harder and contribute more intellectually. Well (2007) also argues that health improvement can indirectly affect economic growth through its positive impact on skill formation, especially through raising the incentive to obtain schooling. All other things being equal, healthier students receive better education and benefit more from the educational system. As Bhargava et al. (2001) noted, economic development depends on the extent of skills attained by the population and capital formation. They explain that as health factors partly influence skills acquisition, capital formation is contingent on the savings rate, which is also influenced by adult health. Well (2007) explains that improvements in health gauged by improvements in mortality may cause people to save for retirement, increasing the levels of investment and physical capital per worker.

Considering the importance of health to economic growth, factors that affect health may indirectly affect economic growth. Although environmental degradation may directly affect economic growth, it could also affect growth through several channels. One of the major channels is human health. Environmental risks pose a great danger to human health. Environmental risks to health can be defined as "all the physical, chemical and biological factors external to a person, and all related behaviours, but excluding those natural environments that cannot reasonably be modified" (Prüss-Üstün et al., 2016, p. 3). Human resource remains a significant asset to every economy. Good quality natural environments deliver the basic needs of humans, such as clean air and water. Clean environments also produce fertile land for food production and biodiversity protection (EEA, 2022). However, environmental degradation and resulting climate change threaten and affect biodiversity, air quality, clean water availability, food, and shelter. These contribute tremendously to the health of humans. Human health and well-being are closely connected to the state of the environment (EEA, 2022). Anything affecting human health reduces labour quality (productivity) and quantity. Environmental degradation or pollutants can cause health problems like stroke, heart disease, chronic obstructive pulmonary disease, diarrhea, eye problems, and lung cancer (Prüss-Üstün et al., 2016; WHO, 2021). In their report (Prüss-Üstün et al., 2016), out of the 133 diseases or injuries considered, 101 had a direct linkage with the environment. Prüss-Üstün et al. (2016) indicate that in 2012, about 23% of global deaths and 26% of deaths among children under five were environmentally related. In Europe, for example, air pollution is considered the utmost environmental risk health factor leading to over 400,000 premature deaths (EEA, 2022). In Africa, Fisher et al. (2021) estimate that air pollution accounts for close to 1.1 million deaths. The WHO estimates that the direct cost (without costs in health-determining sectors such as agriculture and water and sanitation) of climate change to health is estimated to be between US\$2-US\$4 billion annually by 2030 (WHO, 2021). In relation to economic loss, Fisher et al. (2021) estimated that environmentally related health issues and deaths contributed to a loss of 1.19%, 1.16%, and 0.95% of GDP in Rwanda, Ethiopia, and Ghana, respectively, in the year 2019. A cleaner and healthier environment could prevent/reduce all these health-related conditions and deaths and reduce the impact on the economy.

2.2. The foreign direct investment channel

Foreign direct investment is also considered an important channel through which environmental degradation could affect economic growth. The Pollution Haven Hypothesis hypothesizes that developing countries are more likely to be polluted/environmentally degraded due to the openness of their economies (Eskeland and Harrison, 2003; Javorcik and Wei, 2003; Levinson, 2020). This hypothesis asserts that due to non-stringent environmental regulations in developing countries, polluting industries in advance countries (with strict environmental regulations) will relocate to developing countries by bringing in foreign direct investment. Developing countries hence become pollution havens. Consequently, pollution will be imported from advanced countries to developing countries. In a theoretical model of two countries in the world, Copeland and Taylor (1994) show that the rich (higher income) country chooses tougher environmental protection and specializes in comparatively less pollution (clean) goods. A strand of the literature (examining the Pollution Haven Hypothesis) has shown that in some countries (particularly developing ones), lax environmental regulations and increased environmental degradation lure trade and foreign direct investment (Cole, 2003, 2004a; Copeland, 2008), and this serves as ways of opening economies up for environmental degradation.

Empirically, Opoku et al. (2022) revealed that environmental degradation plays a significant role in determining the inflow of foreign direct investment in developing countries. Using a global sample of 103 countries and the Lewbel two-stage least squares, the authors highlighted that environmental degradation mostly increases foreign direct investment flow in developing countries. In their study, they further indicated that the effect of environmental degradation on foreign direct investment depends on the stages of economic development and geographical regions. For instance, Opoku et al. (2022) showed that environmental degradation increases foreign direct investment in low-income and lower-middle-income countries, while environmental degradation impedes foreign direct investment in upper-middle-income countries. From a regional perspective, environmental degradation is associated with increasing inflows of foreign direct investment in sub-Saharan Africa, South Asia, Latin America, and the Caribbean, while the opposite effect occurs in Europe and Central Asia and the Middle East and North Africa regions. From this study, we argue that the heterogenous effect of environmental degradation on foreign direct investment among income groups and regions reflects the difference in the stringency of their environmental policies used to regulate environmentally polluting firms. Environmental degradation attracts more foreign direct investment to low-income, lower-middle-income countries, sub-Saharan Africa, South Asia, Latin America, and the Caribbean because they have lax environmental policies and regulations compared to upper-middle-income countries, Europe and Central Asia and the Middle East and North Africa regions.

The literature has shown that foreign direct investment is a significant conduit to economic growth (Brueckner and Lederman, 2015; Dollar and Kraay, 2003, 2004; Liu et al., 2009). In the same manner, environmental degradation plays a significant role in determining the inflow of foreign direct investment. We, therefore, suggest that foreign direct investment could mediate the effect of environmental degradation on economic growth.

2.3. The technological innovation channel

The role of environmental degradation in driving technological development to influence economic productivity can be traced back to Porter's hypothesis. Porter (1991a, 1991b) and Porter et al. (1995) argue that environmental degradation involves incomplete utilization of environmental resources, and thus, reducing environmental degradation could improve productivity with which resources are used. As formally known as Porter's hypothesis, it posits that well-designed environmental regulation seeking to address environmental degradation could drive technological innovation that could minimize the costs of complying with such regulation (Porter & Linde, 1995). As summarized in the work of Jaffe and Palmer (1997) and Lanoie et al. (2008), due to environmental degradation, environmental regulation could facilitate environmental innovation, incentivize firms to innovate, and induce cost-saving innovation, thereby boosting productivity. From Porter's hypothesis, technological innovation is one channel through which environmental degradation could affect economic growth.

The neoclassical and endogenous growth theories uphold innovation or technological advancement as the main driver of economic growth (King and Levine, 1993; Romer, 1990). Innovation intensifies the possibilities of developing better and current technologies that lead to new and superior goods, services, and processes, resulting in greater economic growth (Bilbao-Osorio and Rodríguez-Pose, 2004). Innovation can affect the economy through manifold conduits: improving domestic and global competitiveness of firms, financial systems, quality of life, infrastructural development, employment, openness, etc. (Aghion et al., 2009; Nickell, 1996; Pradhan et al., 2020; Thompson, 2018). Improvement in these factors enhances economic growth. Innovation could also enable firms to increase their revenues and profits due to the cost reduction benefits that innovation may come with (Nickell et al., 1997). Innovation enhances competition (Nickell, 1996), and Ahn (2002) emphasizes that competition leads to both productive and dynamic efficiency. Productive efficiency comes from innovation enhancing productivity through the introduction of new and better methods of production. As productive efficiency is attained, the level and growth rate of productivity will eventually increase, hence realizing dynamic efficiency.

Despite the many benefits of innovation, its effect is normally two-edged: on the one hand, enhancing economic growth through new technologies and, on the hand, posing a danger to the environment. Its effect on the environment could either be environmentally enhancing, further improving economic growth, or detrimental, thus militating against sustainable economic growth. Innovation could reduce the negative effect of environmental exploitation, utilization, and degradation on economic growth if it is environmentally friendly (Fernández et al., 2018). Innovative processes could ensure that resource exploitation is done more sustainably and waste production is reduced. Innovation also can potentially transform a country's energy consumption structure. Fisher-Vanden et al. (2004) maintain that innovative effort is a factor that significantly leads to a decline in energy intensity. Innovative processes could also be less resource-consuming, reducing resource exploitation and its environmental impact (Chen and Lei, 2018; Fernández et al., 2018). In contrast, innovation could lead to greater energy consumption and emissions of pollutants. If unguarded, firms in the quest to increase profit can pursue innovations that generate labor and capital gains but are detrimental to the environment (Zhang et al., 2018). This may lead to overexploitation and wastage of resources and environmental pollution. Zhang et al. (2018) recount that as the introduction of chemical fertilizers and pesticides enhance agricultural productivity, their usage deteriorates water quality. Besides, though the consumption of some products may be environmentally friendly, their production may generate tremendous environmental deterioration.

3. Methodology and data

3.1. Specification of empirical models

Following existing studies such as Azam et al. (2016), Lee and Brahmasrene (2014), Rehman et al. (2021), we use the dynamic reduced-form model to estimate the impact of environmental degradation on economic growth. Eq. (1) is the log-linear form of the empirical equation.

$$lnrgdpc_{i,t}=\alpha_0 lnrgdpc_{i,t-1}+\beta_1 lngfcf_{i,t}+\beta_2 lnsec_{i,t}+\beta_3 lnenv_{i,t}+\theta_1 ln\boldsymbol{X}_{i,t}+\mu_t+\varepsilon_{it} \tag{1}$$

Where $\boldsymbol{lnrgdpc_{i,t}}$ is economic growth (GDP per capita) of country i at year t. $\boldsymbol{lnrgdpc_{i,t-1}}$ is lagged GDP per capita of country i at year t; $\boldsymbol{lngfcf_{it}}$ is the physical capital of country i at year t; $\beta_2\boldsymbol{lnsec_{i,t}}$ is secondary school enrolment (a proxy for human capital) of country i at year t; $\boldsymbol{lnenv_{i,t}}$ is the measure of environmental degradation variables of country i at year t; $\boldsymbol{ln\ X_{i,t}}$ is a vector of control covariates that affect economic growth, which include trade openness, government expenditure, access to electricity, and urbanization. μ_t is the year-specific effect and ε_{it} is the unobserved error term. a_0 coefficient of lagged GDP per capita; β_i are coefficients to be estimated while $\theta_1$is the coefficient of the set of control variables.

In this study, we also test the hypothesis that the effect of environmental degradation is nonlinear. To examine the nonlinear effect of environmental degradation on economic growth, we augment Eq. (1) with the squared term of environmental degradation. Eq. (2) is the empirical model for capturing the nonlinear effect on economic growth.

$$\begin{aligned} lnrgdpc_{i,t} =& \alpha_0 lnrgdpc_{i,t-1}+\beta_1 lngfcf_{i,t}+\beta_2 lnsec_{i,t}+\beta_3 lnenv_{i,t}+\beta_4 lnenv_{i,t}^2 \\ &+\theta_1 ln\boldsymbol{X}_{i,t}+\mu_t+\varepsilon_{it} \end{aligned} \tag{2}$$

From Eq. (2), the relationship between environmental degradation and economic growth is an inverted U-shaped if $\beta_3 > 0$ *and* $\beta_4 < 0$. This expression shows that the environmental degradation variables have a significant inverse U-shaped relationship with GDP per capita, indicating that economic growth rises at a lower level of environmental degradation, but after certain thresholds of the environmental degradation variables, economic growth declines. Contrarily, the relationship between environmental degradation and economic growth is U-shaped if $\beta_3 < 0$ *and* $\beta_4 > 0$. The expression indicates that economic growth decreases at a lower level of environmental degradation, but after certain thresholds of the environmental degradation variables, economic growth increases.

From Eq. (2), we calculate the turning points using the axis of symmetry approach, given as: $x = -\frac{\beta_3}{2\beta_4}$, where x, is the turning point value.

3.1.1. Models for estimating the potential pathways

Studies on economic growth have established that health, foreign direct investment, and technological innovation play crucial roles in economic growth. From the literature, both theoretical and empirical studies have revealed that environmental degradation influences foreign direct investment (Opoku et al., 2022; Shaari et al., 2022), health (Bouchoucha, 2021; Donohoe, 2003; WHO, 2017) and technological innovation (Albrizio et al., 2017; Porter, 1991a, 1991b). Therefore, another contribution of this study is to examine the potential pathways through which environmental degradation affects economic growth. Regarding this, this study follows Awaworyi Churchill and Smyth (2020) and Acheampong et al. (2021b) to use the mediation analysis approach, which involves a two-staged approach, to examine if variables such as foreign direct investment, health, and innovation serve as potential channels through which environmental degradation affects economic growth. For these variables to act as the potential channels (mediators) through which environmental degradation affects economic growth, first, they must be correlated with environmental degradation variables. Therefore, Eqs. (3)–(5) are used to examine the effect of environmental degradation variables on foreign direct investment, health, and technological innovation.

$$lnfdi_{i,t} = \alpha_1 lnfdi_{i,t-1} + \varnothing_1 lnenv_{i,t} + \varnothing_2 lnX_{i,t} + \mu_t + \varepsilon_{it} \tag{3}$$

$$lnhealth_{i,t} = \alpha_2 lnhealth_{i,t-1} + \gamma_1 lnenv_{i,t} + \gamma_2 lnX_{i,t} + \mu_t + \varepsilon_{it} \tag{4}$$

$$lnRD_{i,t} = \alpha_3 lRD_{i,t-1} + \delta_1 lnenv_{i,t} + \delta_2 lnX_{i,t} + \mu_t + \varepsilon_{it} \tag{5}$$

In the second stage, the environmental degradation variables found to have a statistically significant relationship with foreign direct investment, health, and technological innovation would be included as an additional explanatory variable in the growth regression (Eq. (1)). If foreign direct investment, health, and technological innovation are mediators, including them as additional explanatory variables in the economic growth regression should decrease the magnitude of the coefficient on environmental degradation variables or render them statistically insignificant.

From Eqs. (3)–(5), $\boldsymbol{lnfdi_{i,t}}$ is a foreign direct investment of country i at year t. $\boldsymbol{lnfdi_{i,t-1}}$ is lagged foreign direct investment of country i at year t. $\boldsymbol{lnhealth_{i,t}}$ is the health variable of the country i at year t. $\boldsymbol{lnhealth_{i,t-1}}$ is lagged health variable of country i at year t. $\boldsymbol{lnRD_{i,t}}$ is an indicator of technological innovation of country i at year t. $\boldsymbol{lnRD_{i,t-1}}$ is lagged technological innovation of country i at year t. $\boldsymbol{lnenv_{i,t}}$ is the measure of environmental degradation variables of country i at year t; $\boldsymbol{lnX_{i,t}}$ is a vector of control covariates that affect foreign direct investment, health, and technological innovation. μ_t is the year-specific effect and ε_{it} is the unobserved error term. a_1 coefficient of lagged foreign direct investment; a_2 coefficient of lagged health; a_3 coefficient of lagged innovation; $\varnothing_1 - \varnothing_2$, $\gamma_1 - \gamma_2$ and $\delta_1 - \delta_2$ are coefficients to be estimated.

3.2. Econometric estimation strategy

Even though environmental degradation affects economic growth, economic growth can also affect environmental degradation. For instance, economic growth affects the environment through the scale effect. The scale effect indicates that without changes in the economy's structure or technological change, increasing economic growth could jeopardize the environment (Stern, 2004). Environmental resources serve as an essential input in the production process. Therefore, boosting economic growth requires intensive exploitation of these environmental resources. In addition, many bye products in the form of waste and greenhouse gas emissions are generated during the production process, which deteriorate the environment. These serve as sources of endogeneity. This endogeneity issue could result from reverse causality or omitted variable bias. To cater for endogeneity, the study employs the Blundell and Bond (1998) two-step dynamic system-generalized method of moment (system-GMM) to estimate the above dynamic models. In the presence of unobserved country and time-fixed effect in the above equations, Arellano and Bond (1991) argue that estimating such equations with a conventional econometric technique such as OLS could lead to bias results since the lag of the independent variable correlated with the unobserved effects. The above-specified equations are differenced to eliminate the unobserved country and time effects to present unbiased estimates. Therefore, Arellano and Bond (1991) developed the first difference generalized method of moment (GMM) estimators that use the first differencing transformation to remove these unobserved country and time effects. However, in a simulation study, Blundell and Bond (1998, p. 115) argue that the Arellano and Bond (1991) first difference GMM estimator has poor precision and large finite sample bias, especially when the time series observation is small, and the autoregressive parameter is relatively large. Therefore, Blundell and Bond (1998) developed the system-system-GMM to address the weakness of the first difference GMM. Blundell and Bond (1998) system-GMM uses the lagged differences of the dependent variable as instruments for equations in levels and includes the lagged levels of the dependent variable as instruments for equations in first differences. To present reliable results, the Hansen test is used to check for the validity of the instruments. Additionally, this study also tests for first and second-order autocorrelation.

3.3. Data description

Based on data availability, this study uses a comprehensive panel dataset for 140 countries between 1980 and 2021. Economic growth is represented using GDP per capita (constant 2015 US$). Environmental degradation is measured with carbon dioxide emissions (kt),[1] which serves as the main indicator of environmental degradation in the literature (Opoku et al., 2022; Pal and Mitra, 2017; Sadorsky, 2009; Zheng et al., 2019). In addition to this, environmental degradation is also proxied with total greenhouse gas emissions (kt of CO2 equivalent), methane emissions (kt of CO_2 equivalent), and other greenhouse gas emissions, which include HFC, PFC, and SF6 (thousand metric tons of CO_2 equivalent). Apart from the emissions variables, the ecological footprint of consumption and production are also used. Both are measured in total global hectares to test the robustness of our results. The ecological footprint of consumption defines the consumption of biocapacity by a country's inhabitants, while the ecological footprint of consumption indicates the consumption of biocapacity resulting from the production process within a given geographical area (York University Ecological Footprint Initiative, 2022). Ecological footprint captures environmental degradation more broadly than the use of pollutant emissions. Ecological footprint generally indicates the degree to which the activities of humans, such as crop and livestock production, grazing, fishing, mining, construction, and absorption of wastes, particularly CO_2 emissions, affect the amount of biologically productive area of a country (Opoku and Aluko, 2021).

Consistent with the literature, we control for physical capital measured using gross fixed capital formation (% of GDP), human capital measured with school enrolment (secondary (% gross)), trade openness measured with trade (% of GDP), government expenditure measured with general government final consumption expenditure (constant 2015 US$), electricity measured with access to electricity (% of population), urbanization measured with urban population (% of total population). We glean these variables from studies such as Li et al. (2015), Acheampong et al. (2021a), and Pablo-Romero and Gómez-Calero (2013), Best and Burke (2018) and Acheampong et al. (2021b). Regarding the mediating variables, technological innovation is measured with research and development expenditure (% of GDP), foreign direct investment with foreign direct investment, net inflows (% of GDP), and health with a maternal mortality rate (modeled estimate, per 100,000 live births). The sources and the descriptive statistics for the variables are presented in Table 1. All the variables used for the analysis are log-transformed, and the descriptive statistics in Table 1 are log-transformed values.

Table 1
Variable descriptive statistics.

Variable	Description	Mean	Std. Dev.	Min	Max	Sources
lnrgdpc	GDP per capita	8.475	1.481	5.119	11.630	WDI
lngfcf	Physical capital	3.071	0.353	−0.309	4.493	WDI
lnsec	Human capital	4.169	0.664	0.910	5.099	WDI
lntra	Trade openness	4.213	0.630	−3.863	6.093	WDI
lngovc	Government expenditure	22.975	2.020	15.830	28.219	WDI
lnelect	Access to electricity	4.276	0.691	−0.628	4.605	WDI
lnurbp	Urbanization	3.899	0.550	1.468	4.605	WDI
lnmatdm	Health	3.826	1.599	0.693	7.090	WDI
lnfdi	Foreign direct investment	0.475	1.687	−13.122	6.107	WDI
lnrdpp	Innovation	−0.612	1.177	−5.214	1.693	WDI
lntgr	Total greenhouse gas emissions	10.590	1.967	4.094	16.380	WDI
lnco2kt	Carbon dioxide emissions	9.801	2.264	2.303	16.213	WDI
lnmet	Methane emissions	9.182	1.940	2.303	13.998	WDI
lnoghg	Other greenhouse gas emissions	7.024	2.471	−1.926	14.346	WDI
lnefcons	Ecological footprint of consumption	16.987	1.722	11.346	22.391	YUEFI
lnefprod	Ecological footprint of production	16.888	1.822	11.167	22.333	YUEFI

Note: WDI is World Development Indicators.

4. Results and discussion

We first estimated the linear effect of the environmental degradation variables on GDP per capita. These linear estimates are presented in Models 1, 3, 5, and 9 (Table 2). The estimates show that the coefficients of total greenhouse gas emissions (Model 1), carbon dioxide emissions (Model 3), methane emissions (Model 5), and other greenhouse gas emissions (Model 7) are negative, but the impact is statistically significant only for the total greenhouse, carbon dioxide, and methane emissions. Specifically, the results imply that a 1% increase in total greenhouse gas, carbon dioxide, and methane emissions is associated with a 0.053%, 0.023%, and 0.041% reduction in GDP per capita, ceteris paribus, respectively. These estimates are consistent with some theoretical arguments that environmental degradation hinders economic growth. The adverse effect of environmental degradation on economic growth supports previous studies such as Azam et al. (2016), Tiwari (2011), Lee and Brahmasrene (2014), and Azam et al. (2016), which highlighted that environmental degradation measured by carbon dioxide emissions retards economic growth.

After the linear estimates, we tested for the nonlinear effect of the environmental degradation variables on GDP per capita, and the estimates are presented in Models 2, 4, 6, and 8 (Table 2). While the coefficients of total greenhouse gas, carbon, methane, and other greenhouse gas emissions are positive and statistically significant, the squared terms of these variables are negative and statistically significant. These outcomes imply an inverted U-shaped relationship between the environmental degradation variables and GDP per capita. Thus, GDP per capita rises at lower levels of environmental degradation, but after certain thresholds of the environmental degradation variables, GDP per

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[1] kt is kiloton.

Table 2
Effect of environmental degradation variables on GDP per capita (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.GDP per capita	0.897***	0.930***	0.932***	0.938***	0.899***	0.926***	0.985***	0.959***
	(0.013)	(0.013)	(0.013)	(0.012)	(0.015)	(0.011)	(0.011)	(0.005)
Physical capital	0.025**	0.047***	0.014	0.043***	0.013	0.018***	−0.019*	0.010***
	(0.011)	(0.009)	(0.010)	(0.010)	(0.008)	(0.007)	(0.011)	(0.004)
Human capital	−0.006	0.030*	0.029	0.026	0.029	0.018	0.056***	−0.047***
	(0.020)	(0.016)	(0.019)	(0.017)	(0.018)	(0.013)	(0.019)	(0.014)
Trade openness	0.038***	0.018**	0.045***	0.032***	0.021	0.020***	0.010	0.057***
	(0.013)	(0.009)	(0.013)	(0.010)	(0.013)	(0.007)	(0.011)	(0.004)
Government expenditure	0.062***	0.040***	0.034***	0.047***	0.042***	0.025***	−0.004	0.032***
	(0.014)	(0.013)	(0.013)	(0.014)	(0.013)	(0.009)	(0.006)	(0.003)
Access to electricity	0.078***	0.051***	0.077***	0.042***	0.056***	0.070***	0.088***	0.119***
	(0.013)	(0.010)	(0.014)	(0.009)	(0.011)	(0.009)	(0.022)	(0.011)
Urbanization	0.102***	−0.002	0.018	−0.005	0.073***	0.023	−0.158***	−0.101***
	(0.029)	(0.033)	(0.038)	(0.037)	(0.026)	(0.026)	(0.050)	(0.022)
Total GHG emissions	−0.053***	0.222***						
	(0.013)	(0.060)						
Total GHG emissions Sq		−0.012***						
		(0.003)						
Carbon dioxide emissions			−0.023*	0.179***				
			(0.012)	(0.042)				
Carbon dioxide emissions Sq				−0.011***				
				(0.002)				
Methane emissions					−0.041***	0.084*		
					(0.011)	(0.045)		
Methane emissions Sq						−0.006**		
						(0.002)		
Other GHG emissions							−0.002	0.006**
							(0.001)	(0.003)
Other GHG emissions Sq								−0.001**
								(0.000)
Constant	−0.903***	−1.865***	−0.710***	−1.763***	−0.492***	−0.795***	0.288	−0.546***
	(0.187)	(0.375)	(0.235)	(0.401)	(0.166)	(0.223)	(0.179)	(0.060)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Threshold		**9.25 [10,404.566]**		**8.136 [3415.230]**		**7 [1096.633]**		**3 [20.086]**
Observations	2317	2317	2314	2314	2317	2317	737	737
Hansen	59.071	72.101	57.508	62.419	55.820	72.465	32.666	50.681
P(Hansen)	0.178	0.136	0.217	0.390	0.265	0.130	0.753	0.799
AR (1)	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.01
AR (2)	0.581	0.943	0.567	0.877	0.602	0.651	0.183	0.487
No. of countries	140	140	140	140	140	140	140	140
No. of instruments	88	99	88	99	88	99	74	96

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

capita declines. We determine thresholds at which the environmental degradation variables would be detrimental to economic growth using the axis of symmetry approach. Specifically, the turning points analysis suggests that the threshold after which total greenhouse gas emissions deteriorate GDP per capita is 10,404.566kt of CO_2 equivalent. Also, carbon, methane, and other greenhouse gas emissions would deteriorate GDP per capita after reaching 3415.230kt, 10,96.633kt of CO_2 equivalent, and 20.086 thousand metric tons of CO_2 equivalent, respectively.[2] These threshold estimates suggest that some level of environmental degradation might be needed to increase economic growth; however, too much degradation would be harmful.

The estimates for the control variables are mostly consistent with the literature. For instance, consistent with previous studies such as Li et al. (2015), Acheampong et al. (2021a), and Pablo-Romero and Gómez-Calero (2013), gross fixed capital formation as a proxy of physical capital has a positive and statistically significant effect on GDP per capita. Also, the coefficient of trade openness is positive and statistically significant, suggesting that increasing trade openness among countries drives economic growth. This result aligns with the findings of Raghutla (2020), Awokuse (2008), and Udeagha and Ngepah (2021). The coefficient on the government expenditure variable is positive and statistically significant, suggesting that government spending generally drives economic growth. Consistent with Best and Burke (2018) and Acheampong et al. (2021a), access to electricity has a statistically significant positive effect on GDP per capita. The lagged GDP per capita coefficients are positive and statistically significant, indicating that past economic growth is associated with increased current economic growth.

We further extend the analysis by incorporating income and regional dummy variables in the estimations.[3] For the income dummies, low-income is the baseline category. The results are reported in Table 3, and they show that the coefficients of the dummy variables of lower-middle, upper-middle, and high-income countries are positive and statistically significant. The implication is that lower-middle, upper-middle, and high-income countries have higher GDP per capita relative to low-income countries (baseline category). Interestingly, it is observed that the linear estimates for the environmental degradation variables become largely insignificant. However, except for the nonlinear effect of

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[2] We calculated the turning point using the axis of symmetry approach, given as $x = -\frac{b}{2a}$, where x is the turning point value, b is the coefficients of the main terms of the environmental degradation variables, and a is the coefficients of the squared terms of the environmental degradation variables. Because the natural logarithms of GDP per capita and the environmental degradation variables were used for the estimation, the exponential function given as $y = e^x$ can be used to calculate the raw values of the turning points.

[3] The income and regional groupings are based on the World Bank's classification of countries.

Table 3

Effect of environmental degradation variables on GDP per capita, including income groups dummies (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.GDP per capita	0.876***	0.926***	0.866***	0.917***	0.881***	0.905***	0.869***	0.918***
	(0.019)	(0.015)	(0.021)	(0.018)	(0.024)	(0.019)	(0.030)	(0.014)
Physical capital	0.016*	0.043***	0.019*	0.050***	0.013	0.028***	−0.007	0.017***
	(0.009)	(0.010)	(0.011)	(0.011)	(0.013)	(0.011)	(0.013)	(0.004)
Human capital	0.081***	0.041***	0.089***	0.027***	0.095***	0.063***	0.117***	−0.023*
	(0.019)	(0.012)	(0.019)	(0.011)	(0.021)	(0.018)	(0.022)	(0.012)
Trade openness	−0.006	0.016	−0.007	0.028**	0.015	0.009	−0.023	0.052***
	(0.011)	(0.011)	(0.012)	(0.012)	(0.014)	(0.010)	(0.021)	(0.006)
Government expenditure	0.008	0.001	0.013	0.022	−0.016	−0.023*	−0.003	0.033***
	(0.015)	(0.014)	(0.015)	(0.016)	(0.019)	(0.013)	(0.011)	(0.002)
Access to electricity	−0.013	0.003	−0.009	−0.002	−0.017	0.001	0.064**	0.081***
	(0.009)	(0.007)	(0.009)	(0.006)	(0.011)	(0.008)	(0.028)	(0.014)
Urbanization	0.042	−0.018	0.058	0.008	0.041	0.048	−0.173***	−0.052**
	(0.031)	(0.030)	(0.036)	(0.039)	(0.038)	(0.029)	(0.049)	(0.025)
LMIC	0.078***	0.048**	0.086***	0.024	0.064**	0.038	0.063**	0.007
	(0.025)	(0.021)	(0.027)	(0.023)	(0.032)	(0.027)	(0.031)	(0.012)
UMIC	0.169***	0.118***	0.180***	0.085***	0.171***	0.123***	0.210***	0.055***
	(0.036)	(0.027)	(0.037)	(0.028)	(0.049)	(0.039)	(0.058)	(0.019)
HIC	0.334***	0.204***	0.352***	0.158***	0.371***	0.304***	0.443***	0.120***
	(0.059)	(0.049)	(0.062)	(0.050)	(0.080)	(0.066)	(0.094)	(0.035)
Total GHG emissions	−0.006	0.239***						
	(0.013)	(0.074)						
Total GHG emissions Sq		−0.010***						
		(0.004)						
Carbon dioxide emissions			−0.012	0.167***				
			(0.016)	(0.052)				
Carbon dioxide emissions Sq				−0.009***				
				(0.003)				
Methane emissions					0.030*	0.035		
					(0.016)	(0.073)		
Methane emissions Sq						−0.000		
						(0.004)		
Other GHG emissions							−0.002	0.011***
							(0.001)	(0.002)
Other GHG emissions Sq								−0.001***
								(0.000)
Constant	0.321	−1.141**	0.214	−1.061**	0.356	0.331	1.046***	−0.430***
	(0.196)	(0.502)	(0.263)	(0.501)	(0.241)	(0.436)	(0.363)	(0.082)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Threshold		**11.95 [154,817.15]**		**9.278 [10,700.01]**		**–**		**5.5 [244.692]**
Observations	2317	2317	2314	2314	2317	2317	737	737
Hansen	48.752	64.516	51.770	61.688	41.611	57.517	36.692	52.991
P(Hansen)	0.523	0.322	0.405	0.416	0.795	0.567	0.576	0.727
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.001
AR(2)	0.712	0.994	0.738	0.955	0.740	0.840	0.172	0.456
No. of countries	140	140	140	140	140	140	140	140
No. of instruments	91	102	91	102	91	102	77	99

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

methane emission being statistically insignificant, the remaining environmental degradation variables retain their statistically significant nonlinear impact on GDP per capita. Thus, total greenhouse gas, carbon, and other greenhouse gas emissions maintained their statistically significant inverted U-shaped relationship with GDP per capita. After accounting for the level of economic development among countries, the turning points analysis suggests that total greenhouse gas, carbon dioxide, and other greenhouse gas emissions would likely have a decreasing effect on economic growth after reaching 15,4817.150kt of CO_2 equivalent, 10,700.010kt, and 244.692 thousand metric tons of CO_2 equivalent, respectively.

Table 4 displays the estimates after the inclusion of regional dummy variables. South Asia (SAR) serves as the baseline category. The results show that the dummy variables of Sub-Saharan Africa (SSA), East Asia & Pacific (EAP), Middle East and North Africa (MENA), Europe and Central Asia (EAC), and Latin America & Caribbean (LAC) have positive and statistically significant coefficients (Table 4). The implication is that SSA, EAP, MENA, and LAC have, on average higher GDP per capita than SAR, the baseline category. After including the regional dummy variables, total greenhouse gas, carbon dioxide, and other greenhouse gas emissions lost their significant levels but maintained their negative signs. Thus, methane emissions retained its statistically significant negative effect on GDP per capita. On the other hand, the environmental degradation variables retain their statistically significant nonlinear impact on GDP per capita. In other words, total greenhouse gas, carbon dioxide, methane, and other greenhouse gas emissions maintained their statistically significant inverted U-shaped relationship with GDP per capita after including the regional dummy variables. Controlling for regional differences, the turning points estimates show that total greenhouse gas, carbon dioxide, methane, and other greenhouse gas emissions would likely have a decreasing effect on economic growth after reaching 20,516.814kt of CO_2 equivalent, 5569.163kt, 3967.931kt of CO_2 equivalent and 20.086 thousand metric tons of CO_2 equivalent, respectively. The results imply that income and regional differences in GDP per capita may differ based on environmental degradation. In the next section, we examine if the level of economic development and regional disparity in GDP per capita varies based on environmental degradation.

Table 4
Effect of environmental degradation variables on GDP per capita, including regional dummies (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.GDP per capita	0.928***	0.951***	0.943***	0.945***	0.915***	0.942***	0.979***	0.954***
	(0.014)	(0.013)	(0.014)	(0.012)	(0.012)	(0.011)	(0.012)	(0.007)
Physical capital	0.027***	0.045***	0.018	0.041***	0.014**	0.033***	−0.016	0.016***
	(0.008)	(0.008)	(0.011)	(0.010)	(0.006)	(0.006)	(0.012)	(0.004)
Human capital	0.073***	0.028	0.047**	0.004	0.049***	0.021*	0.078***	−0.048**
	(0.021)	(0.018)	(0.019)	(0.016)	(0.014)	(0.013)	(0.021)	(0.019)
Trade openness	0.075***	0.027***	0.061***	0.021*	0.037***	0.044***	0.000	0.064***
	(0.015)	(0.010)	(0.015)	(0.011)	(0.011)	(0.010)	(0.013)	(0.007)
Government expenditure	0.046***	0.043***	0.020	0.043***	0.057***	0.030***	−0.004	0.033***
	(0.014)	(0.013)	(0.015)	(0.012)	(0.012)	(0.010)	(0.005)	(0.003)
Access to electricity	0.044***	0.061***	0.075***	0.042***	0.064***	0.077***	0.064**	0.132***
	(0.017)	(0.012)	(0.013)	(0.009)	(0.010)	(0.009)	(0.026)	(0.015)
Urbanization	−0.121***	−0.073**	−0.095**	0.008	−0.098***	−0.062**	−0.149**	−0.098***
	(0.040)	(0.030)	(0.041)	(0.036)	(0.027)	(0.027)	(0.061)	(0.036)
SSA	0.111***	0.049	0.098***	0.021	0.065***	0.073***	0.084	0.096***
	(0.025)	(0.043)	(0.033)	(0.039)	(0.019)	(0.024)	(0.071)	(0.025)
EAP	0.115***	0.050	0.068*	0.042	0.105***	0.051**	0.101	0.064**
	(0.026)	(0.039)	(0.036)	(0.033)	(0.022)	(0.023)	(0.071)	(0.025)
MENA	0.100***	0.003	0.049	−0.016	0.071***	0.020	0.114	0.062*
	(0.031)	(0.044)	(0.040)	(0.035)	(0.026)	(0.026)	(0.086)	(0.033)
ECA	0.107***	−0.000	0.075**	0.002	0.076***	0.043*	0.097	0.073***
	(0.024)	(0.040)	(0.035)	(0.032)	(0.021)	(0.025)	(0.072)	(0.024)
LAC	0.131***	0.010	0.082**	−0.029	0.094***	0.047	0.106	0.081***
	(0.033)	(0.045)	(0.039)	(0.039)	(0.025)	(0.029)	(0.079)	(0.030)
Total GHG emissions	−0.005	0.278***						
	(0.014)	(0.074)						
Total GHG emissions Sq		−0.014***						
		(0.003)						
Carbon dioxide emissions			0.010	0.207***				
			(0.013)	(0.041)				
Carbon dioxide emissions Sq				−0.012***				
				(0.002)				
Methane emissions					−0.039***	0.116**		
					(0.011)	(0.054)		
Methane emissions Sq						−0.007**		
						(0.003)		
Other GHG emissions							−0.001	0.006**
							(0.001)	(0.003)
Other GHG emissions Sq								−0.001**
								(0.000)
Constant	−0.903***	−2.226***	−0.582**	−1.806***	−0.573***	−1.156***	0.236	−0.722***
	(0.183)	(0.407)	(0.239)	(0.319)	(0.152)	(0.243)	(0.170)	(0.070)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Threshold		**9.929 [20,516.814]**		**8.625 [5569.1627]**		**8.286 [3967.9307]**		**3 [20.086]**
Observations	2317	2317	2314	2314	2317	2317	737	737
Hansen	51.236	65.914	58.332	62.389	62.859	66.685	35.927	50.627
P(Hansen)	0.110	0.280	0.196	0.391	0.105	0.258	0.611	0.800
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
AR(2)	0.777	0.973	0.728	0.877	0.632	0.812	0.126	0.477
No. of countries	140	140	140	140	140	140	140	140
No. of instruments	83	104	93	104	93	104	79	101

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

4.1. Examining if the level of economic development and regional disparity in GDP per capita varies based on environmental degradation

Observation from both Tables 3 and 4 shows that the inclusion of income and regional dummy variables in the models rendered the linear effect of the environmental degradation variables mostly statistically insignificant. The implication is that differences in environmental degradation among countries according to the development status or geographical location could affect their economic growth differently. We, therefore, extend the analysis to examine the interactive effects among income and regional dummy variables and environmental degradation on GDP per capita.

In Table 5, the results show that the interaction between the lower-middle income county dummy variable and total greenhouse gas emissions has a statistically significant positive effect on GDP per capita. Similarly, the coefficients on the interaction between the upper-middle income country dummy variable and total greenhouse gas emissions are positive and statistically significant. Likewise, the coefficients on the interaction between an upper-middle-income country's dummy variable and total greenhouse gas emissions and between a high-income country's dummy variable and total greenhouse gas emissions are positive and statistically significant. The net effect analysis indicates that compared to low-income countries (baseline category), for every 1% increase in total greenhouse gas emissions, GDP per capita is expected to increase in lower-middle and high-income countries rise by an additional 0.07% and 0.148%, respectively, while upper-middle-income countries' GDP per capita reduces by an additional 0.06%. In addition, the results show that the interaction between lower-middle income countries and carbon dioxide emissions and high-income countries and carbon emissions have a statistically significant positive effect on GDP per capita compared to carbon dioxide emissions in low-income countries. Contrarily, the interactive results indicate that in upper-middle-income countries, carbon dioxide emissions have a statistically significant negative effect on GDP per capita compared to carbon dioxide

Table 5

Effect of environmental degradation variables on GDP per capita, including interactions of income groups dummies and environmental variables (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.GDP per capita	0.935***	0.981***	0.937***	0.863***
	(0.031)	(0.027)	(0.025)	(0.036)
LMIC	−2.720***	−0.976***	−1.185***	0.143
	(0.557)	(0.312)	(0.374)	(0.116)
UMIC	−1.260*	1.542***	−0.129	0.236*
	(0.741)	(0.375)	(0.426)	(0.141)
HIC	−3.452***	−1.251***	−0.453	0.514***
	(0.555)	(0.366)	(0.379)	(0.165)
Total GHG emissions	−0.200***			
	(0.049)			
LMIC × Total GHG emissions	0.270***			
	(0.055)			
UMIC × Total GHG emissions	0.140**			
	(0.070)			
HIC × Total GHG emissions	0.348***			
	(0.055)			
Carbon dioxide emissions		−0.100***		
		(0.029)		
LMIC × Carbon dioxide emissions		0.120***		
		(0.036)		
UMIC × Carbon dioxide emissions		−0.122***		
		(0.038)		
HIC × Carbon dioxide emissions		0.144***		
		(0.040)		
Methane emissions			−0.082**	
			(0.037)	
LMIC × Methane emissions			0.127***	
			(0.039)	
UMIC × Methane emissions			0.023	
			(0.046)	
HIC × Methane emissions			0.066	
			(0.041)	
Other GHG emissions				0.011
				(0.014)
LMIC× Other GHG emissions				−0.014
				(0.015)
UMIC × Other GHG emissions				−0.008
				(0.015)
HIC × Other GHG emissions				−0.012
				(0.015)
Constant	3.199***	1.066**	1.114***	1.031**
	(0.578)	(0.490)	(0.347)	(0.400)
Control variables	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Observations	2317	2314	2317	737
Hansen	51.012	53.655	47.886	33.584
P(Hansen)	0.319	0.234	0.437	0.584
AR(1)	0.000	0.000	0.000	0.005
AR(2)	0.751	0.563	0.454	0.195
No. of countries	140	140	140	140
No. of instruments	91	91	91	77

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

emissions in low-income countries. Thus, compared to low-income countries, for every 1% increase in carbon dioxide emissions, lower-middle and higher-income countries' GDP per capita is expected to increase by an additional 0.02% and 0.04%, respectively, while upper-middle-income countries' GDP per capita is expected to reduce by an additional 0.222%. Also, the interaction between upper-middle and high-income countries and methane emissions is positive but statistically insignificant. Contrarily, the coefficient on the lower-middle income countries and methane emissions is positive and statistically significant at the 1% level. Thus, relative to low-income countries, for every 1% increase in methane emissions, lower-middle countries' GDP per capita rises by an additional 0.045%. It is also observed that none of the interactions between the income dummy variables and other greenhouse gas emissions has a statistically significant effect on GDP per capita.

In Table 6, the results show that the coefficients of interaction terms between the regional dummy variables (SSA, EAP, MENA, ECA, and LAC) and total greenhouse gas emissions are negative and statistically significant. Thus, the net effect analysis indicates that relative to SAR GDP per capita, for every 1% increase in total greenhouse gas emissions, SSA, ECA, and LAC GDP per capita declines by 0.08%, 0.123%, and 0.068%, respectively, while EAP, and MENA GDP per capita increase by 0.016% and 0.005% respectively. The interaction term coefficient of ECA and carbon dioxide emissions is negative and statistically significant. In addition, the coefficients on the interaction between regional dummy variables (SSA, EAP, MENA, ECA, and LAC) and methane emissions are negative and statistically significant. Compared to SAR, the net effect analysis indicates that for every 1% increase in total greenhouse gas emissions, SSA, EAP, MENA, and LAC GDP per capita declines by 0.051%, 0.093%, 0.098%, and 0.083%, respectively, while ECA GDP per capita increases by 0.002%. It is also observed that none of the coefficients of the interaction terms between the regional dummy variables and other greenhouse gas emissions has a statistically significant effect on GDP per capita.

4.2. *Examining the potential pathways through which environmental degradation affects economic growth*

This section tests if foreign direct investment, technological innovation, and health mediate the effect of environmental degradation on economic growth. Two-stage approaches are used here. For the first stage, for foreign direct investment, technological innovation, and health to act as the potential channels through which environmental degradation affects economic growth, they must be correlated with environmental degradation variables. Based on Eqs. (3)–(5), we have presented the relationship between environmental degradation variables and the potential mediators (foreign direct investment, technological innovation, and health) in Tables 7-9.

Table 7 shows the impact of environmental degradation variables on foreign direct investment. The results show that the coefficients of total greenhouse gas, carbon dioxide, and methane emissions have a negative and statistically significant effect on foreign direct investment, while other greenhouse gas emissions have an insignificant effect on foreign direct investment. Specifically, a 1% increase in total greenhouse gas, carbon dioxide, and methane emissions significantly is respectively associated with a 0.274%, 0.329%, and 0.312% reduction in foreign direct investment inflows. This result is consistent with Opoku et al. (2022) findings that environmental degradation can deter foreign direct investment flows to certain regions and income groups. The negative effect of environmental degradation on foreign direct investment may suggest that countries are implementing stringent environmental regulations in the face of increasing global environmental degradation. These stringent environmental regulations are costly to profit-driven multinational corporations and deter foreign investment (Opoku et al., 2022; Stavropoulos et al., 2018). For total greenhouse gas, carbon dioxide, and methane emissions having statistically significant effects, in the second stage of mediation analysis, we shall include these variables in the regression model linking foreign direct investment to economic growth, while other greenhouse gas emissions variables will not be included.

Table 8 shows the impact of environmental degradation variables on health (captured by maternal mortality). It can be observed in Table 8

Table 6
Effect of environmental degradation variables on GDP per capita, including interactions of regional dummies and environmental variables (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L. GDP per capita	0.972***	0.992***	0.917***	0.999***
	(0.018)	(0.019)	(0.026)	(0.029)
SSA	2.910***	0.839	2.133**	0.905
	(1.079)	(0.670)	(0.959)	(1.060)
EAP	1.881*	0.325	1.664*	1.042
	(1.106)	(0.834)	(0.958)	(1.043)
MENA	2.030*	0.547	2.613***	1.295
	(1.212)	(0.881)	(1.009)	(1.063)
ECA	3.443***	1.657**	2.601***	1.175
	(1.028)	(0.755)	(0.908)	(1.088)
LAC	2.814***	0.730	2.509***	0.771
	(1.008)	(0.722)	(0.907)	(1.072)
Total GHG emissions	0.189**			
	(0.087)			
SSA × Total GHG emissions	−0.269***			
	(0.095)			
EAP × Total GHG emissions	−0.173*			
	(0.094)			
MENA × Total GHG emissions	−0.184*			
	(0.103)			
ECA × Total GHG emissions	−0.312***			
	(0.088)			
LAC × Total GHG emissions	−0.252***			
	(0.086)			
Carbon dioxide emissions		0.062		
		(0.055)		
SSA Carbon dioxide emissions		−0.085		
		(0.063)		
EAP × Carbon dioxide emissions		−0.034		
		(0.077)		
MENA × Carbon dioxide emissions		−0.051		
		(0.079)		
ECA × Carbon dioxide emissions		−0.156**		
		(0.070)		
LAC × Carbon dioxide emissions		−0.065		
		(0.067)		
Methane emissions			0.158*	
			(0.087)	
SSA × Methane emissions			−0.209**	
			(0.089)	
EAP × Methane emissions			−0.156*	
			(0.087)	
MENA × Methane emissions			−0.251***	
			(0.095)	
ECA × Methane emissions			−0.256***	
			(0.083)	
LAC × Methane emissions			−0.241***	
			(0.083)	
Other GHG emissions				0.109
				(0.143)
SSA × Other GHG emissions				−0.105
				(0.141)
EAP × Other GHG emissions				−0.117
				(0.138)
MENA × Other GHG emissions				−0.146
				(0.142)
ECA × Other GHG emissions				−0.138
				(0.145)
LAC × Other GHG emissions				−0.072
				(0.143)
Constant	−3.130***	−1.056	−2.652***	−0.598
	(1.057)	(0.808)	(0.904)	(1.123)
Control variables	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Observations	2317	2314	2317	737
Hansen	53.649	54.322	50.037	29.098
P(Hansen)	0.177	0.161	0.280	0.707
AR(1)	0.000	0.000	0.000	0.002
AR(2)	0.792	0.581	0.874	0.116
No. of countries	140	140	140	140
No. of instruments	93	93	93	79

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7
Effect of environmental degradation on foreign direct investment (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.Foreign direct investment	0.253***	0.256***	0.224***	0.169***
	(0.022)	(0.033)	(0.032)	(0.054)
Physical capital	0.052	0.457***	0.159	−0.023
	(0.104)	(0.169)	(0.154)	(0.119)
Human capital	0.650**	−0.339	−0.473*	0.149
	(0.286)	(0.244)	(0.285)	(0.329)
Trade openness	0.497***	0.341***	0.262	0.910***
	(0.150)	(0.112)	(0.175)	(0.160)
Government expenditure	0.212	0.236*	0.192*	−0.003
	(0.129)	(0.139)	(0.113)	(0.053)
Access to electricity	−0.068	0.057	0.297	0.711*
	(0.115)	(0.249)	(0.265)	(0.402)
Urbanization	−0.590	0.723*	−0.130	−1.186*
	(0.380)	(0.414)	(0.394)	(0.666)
Total GHG emissions	−0.274**			
	(0.136)			
Carbon dioxide emissions		−0.329**		
		(0.146)		
Methane emissions			−0.312**	
			(0.133)	
Other GHG emissions				0.036
				(0.030)
Constant	−3.480***	−5.748***	−0.890	−2.000*
	(1.318)	(2.191)	(1.032)	(1.084)
Time fixed effect	YES	YES	YES	YES
Observations	2078	2075	2078	702
Hansen	82.931	49.624	50.879	33.434
P(Hansen)	0.138	0.142	0.116	0.759
AR(1)	0.000	0.000	0.000	0.000
AR(2)	0.063	0.045	0.067	0.192
No. of countries	140	140	140	140
No. of instruments	108	78	78	75

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

that the coefficients of total greenhouse gas, carbon dioxide, and methane emissions are positive and statistically significant. At the same time, other greenhouse gas emissions have an insignificant effect on health. Specifically, a 1% increase in total greenhouse gas, carbon dioxide, and methane emissions is respectively associated with a 0.051%, 0.029%, and 0.069% deterioration in health. This result implies that increasing environmental degradation poses a severe challenge to health, confirming Mahalik et al. (2022) and Steinberger et al. (2012) results that environmental pollution is associated with poor health. The significant effect of total greenhouse gas, carbon dioxide, and methane emissions suggest that in the second stage of mediation analysis, these environmental degradation variables will be included in the regression model linking health to economic growth, while other greenhouse gas emissions variable will not.

Table 9 shows the impact of environmental degradation variables on technological innovation. It can be observed that the coefficients of total

Table 8
Effect of environmental degradation on health (maternal mortality) (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.Health	0.985***	0.972***	0.941***	0.948***
	(0.012)	(0.010)	(0.018)	(0.022)
Physical capital	−0.004	0.003	0.005	0.074***
	(0.014)	(0.015)	(0.014)	(0.025)
Human capital	0.049	0.010	0.033	−0.062
	(0.030)	(0.032)	(0.029)	(0.044)
Trade openness	0.031	0.009	0.033*	−0.040
	(0.020)	(0.020)	(0.019)	(0.040)
Government expenditure	−0.032	−0.013	−0.051**	0.004
	(0.025)	(0.017)	(0.026)	(0.016)
Access to electricity	−0.008	−0.011	−0.027	−0.237***
	(0.018)	(0.019)	(0.021)	(0.047)
Urbanization	−0.084**	−0.125***	−0.075*	0.235***
	(0.034)	(0.040)	(0.040)	(0.087)
Total GHG emissions	0.051**			
	(0.022)			
Carbon dioxide emissions		0.029**		
		(0.014)		
Methane emissions			0.069***	
			(0.021)	
Other GHG emissions				−0.004
				(0.005)
Constant	0.236	0.543	0.854*	0.406
	(0.435)	(0.386)	(0.474)	(0.611)
Time fixed effect	YES	YES	YES	YES
Observations	1570	1570	1570	623
Hansen	52.919	45.103	45.145	30.699
P(Hansen)	0.362	0.670	0.668	0.826
AR(1)	0.000	0.000	0.000	0.004
AR(2)	0.080	0.080	0.089	0.666
No. of countries	140	140	140	140
No. of instruments	75	75	75	63

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
Effect of environmental degradation on RD (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.Innovation	0.714***	0.854***	0.533***	0.993***
	(0.038)	(0.035)	(0.048)	(0.055)
Physical capital	0.075	0.074	−0.085	0.085
	(0.049)	(0.052)	(0.058)	(0.063)
Human capital	0.132	0.231	0.619***	−0.178
	(0.169)	(0.203)	(0.203)	(0.566)
Trade openness	−0.140***	−0.086*	−0.196***	0.182***
	(0.051)	(0.049)	(0.067)	(0.043)
Government expenditure	0.496***	0.385***	0.433***	0.089**
	(0.072)	(0.050)	(0.065)	(0.037)
Government expenditure	0.805***	0.993***	0.643**	−0.208
	(0.188)	(0.175)	(0.252)	(0.595)
Urbanization	−1.365***	−1.233***	−1.792***	−0.011
	(0.276)	(0.195)	(0.381)	(0.252)
Total GHG emissions	−0.538***			
	(0.068)			
Carbon dioxide emissions		−0.423***		
		(0.045)		
Methane emissions			−0.480***	
			(0.061)	
Other GHG emissions				0.028**
				(0.012)
Constant	−4.075***	−4.938***	−3.121***	−1.574**
	(0.951)	(0.958)	(1.026)	(0.723)
Time fixed effect	YES	YES	YES	YES
Observations	1204	1204	1204	358
Hansen	40.263	43.782	48.046	28.287
P(Hansen)	0.836	0.720	0.552	0.898
AR(1)	0.002	0.002	0.004	0.117
AR(2)	0.743	0.790	0.767	0.594
No. of countries	140	140	140	140
No. of instruments	81	81	81	67

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

greenhouse gas, carbon dioxide, methane, and other greenhouse gas are negative and statistically significant. Thus, a 1% increase in total greenhouse gas, carbon dioxide, and methane emissions reduces innovation by 0.538%, 0.423%, and 0.480%, respectively. Contrarily, other greenhouse gas has a statistically significant positive effect on technological innovation, suggesting that a 1% increase in additional greenhouse gas emissions would increase technological innovation by 0.028%. The significant effect of total greenhouse gas, carbon dioxide, methane, and other greenhouse gas emissions suggests that these environmental degradation variables in the second stage of mediation analysis will be included in the regression model linking technological innovation to economic growth.

In the second stage, we examine if the inclusion of the potential mediators (foreign direct investment, health, and technological innovation) either render the environmental degradation variables statistically insignificant or reduce the magnitude of the coefficients. In Table 10, comparing the coefficient of total greenhouse gas in Model 1 to its coefficient in Model 2 shows that including the foreign direct investment variable causes total greenhouse gas emissions to be statistically insignificant. Comparing the coefficient of carbon dioxide emissions in Model 3 to its coefficient in Model 4 shows that the inclusion of the foreign direct investment variable causes increases in the magnitude and level of significance of carbon dioxide emissions; hence foreign direct investment does not mediate the effect of carbon dioxide emissions on economic growth. Also, comparing the coefficient of methane emissions in Model 5 to its coefficients in Model 6 indicates that including the foreign direct investment variable renders methane emissions statistically insignificant. Generally, these results show that foreign direct investment mediates the effect of total greenhouse gas and methane emissions on economic growth.

In Table 11, comparing the coefficient of total greenhouse gas in Model 1 to its coefficient in Model 2 shows that the inclusion of the health variable reduces the magnitude of total greenhouse gas emissions coefficient. Similarly, comparing the coefficient of carbon dioxide emissions in Model 3 to its coefficient in Model 4 shows that the inclusion of the health variable reduces the magnitude of the carbon dioxide emissions coefficient. Also, comparing the coefficient of methane emissions in Model 5 to its coefficients in Model 6 indicates that the health variable's inclusion renders methane emissions statistically insignificant. These findings highlight that health mediates the effect of environmental degradation variables (total greenhouse, carbon, and methane emissions) on economic growth.

In Table 12, comparing the coefficient of total greenhouse gas in Model 1 to its coefficient in Model 2, shows that the inclusion of the technological innovation variable renders total greenhouse gas emissions statistically insignificant. Similarly, comparing the coefficient of carbon dioxide emissions in Model 3 to its coefficient in Model 4 shows that the inclusion of the technological innovation variable renders carbon dioxide emissions statistically insignificant. Also, comparing the coefficient of methane emissions in Model 5 to its coefficients in Model 6 indicates that the inclusion of the technological innovation variable renders methane emissions statistically insignificant. Finally, comparing the coefficient of other greenhouse gas in Model 7 to its coefficient in Model 8 shows that the inclusion of the technological innovation variable reduces the magnitude of other greenhouse gas emissions coefficient. These findings highlight that technological innovation mediates the effect of environmental degradation variables (total greenhouse, carbon, methane, and other greenhouse emissions) on economic growth.

Tables 10 and 12 show that the coefficients on foreign direct investment and technological innovation are positive and statistically

Table 10
Inclusion of FDI variable in GDP per capita models (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
L.GDP per capita	0.897***	0.964***	0.932***	0.987***	0.899***	0.951***
	(0.013)	(0.014)	(0.013)	(0.016)	(0.015)	(0.013)
Physical capital	0.025**	0.004	0.014	−0.006	0.013	0.004
	(0.011)	(0.009)	(0.010)	(0.012)	(0.008)	(0.008)
Human capital	−0.006	0.012	0.029	0.010	0.029	0.014
	(0.020)	(0.017)	(0.019)	(0.021)	(0.018)	(0.015)
Trade openness	0.038***	0.045***	0.045***	0.034***	0.021	0.043***
	(0.013)	(0.010)	(0.013)	(0.013)	(0.013)	(0.009)
Government expenditure	0.062***	0.008	0.034***	−0.014	0.042***	0.026***
	(0.014)	(0.014)	(0.013)	(0.015)	(0.013)	(0.009)
Access to electricity	0.078***	0.082***	0.077***	0.069***	0.056***	0.076***
	(0.013)	(0.013)	(0.014)	(0.014)	(0.011)	(0.012)
Urbanization	0.102***	−0.083***	0.018	−0.136***	0.073***	−0.074***
	(0.029)	(0.030)	(0.038)	(0.037)	(0.026)	(0.028)
Total GHG emissions	−0.053***	0.014				
	(0.013)	(0.014)				
Foreign direct investment		0.008***		0.011***		0.008***
		(0.002)		(0.002)		(0.001)
Carbon dioxide emissions			−0.023*	0.032**		
			(0.012)	(0.013)		
Methane emissions					−0.041***	−0.005
					(0.011)	(0.010)
Constant	−0.903***	−0.297*	−0.710***	0.194	−0.492***	−0.407***
	(0.187)	(0.167)	(0.235)	(0.271)	(0.166)	(0.108)
Time fixed effect	YES	YES	YES	YES	YES	YES
Observations	2317	2164	2314	2161	2317	2164
Hansen	59.071	56.440	57.508	55.935	55.820	59.855
P(Hansen)	0.178	0.247	0.217	0.262	0.265	0.160
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.581	0.867	0.567	0.960	0.602	0.809
No. of countries	140	140	140	140	140	140
No. of instruments	88	89	88	89	88	89

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 11
Inclusion of maternal health variables in GDP per capita models (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
L.GDP per capita	0.897***	0.914***	0.932***	0.926***	0.899***	0.910***
	(0.013)	(0.010)	(0.013)	(0.010)	(0.015)	(0.012)
Physical capital	0.025**	0.016*	0.014	0.012	0.013	0.025***
	(0.011)	(0.008)	(0.010)	(0.008)	(0.008)	(0.007)
Human capital	−0.006	0.067***	0.029	0.054***	0.029	0.039***
	(0.020)	(0.013)	(0.019)	(0.013)	(0.018)	(0.014)
Trade openness	0.038***	0.014	0.045***	0.019*	0.021	0.012
	(0.013)	(0.012)	(0.013)	(0.010)	(0.013)	(0.012)
Government expenditure	0.062***	−0.033**	0.034***	−0.023**	0.042***	−0.026*
	(0.014)	(0.014)	(0.013)	(0.010)	(0.013)	(0.014)
Access to electricity	0.078***	−0.036***	0.077***	−0.030***	0.056***	−0.030***
	(0.013)	(0.007)	(0.014)	(0.008)	(0.011)	(0.006)
Urbanization	0.102***	0.199***	0.018	0.152***	0.073***	0.208***
	(0.029)	(0.018)	(0.038)	(0.017)	(0.026)	(0.021)
Total GHG emissions	−0.053***	0.024**				
	(0.013)	(0.011)				
Health (maternal mortality)		−0.026***		−0.017***		−0.037***
		(0.007)		(0.006)		(0.008)
Carbon dioxide emissions			−0.023*	0.018**		
			(0.012)	(0.007)		
Methane emissions					−0.041***	0.015
					(0.011)	(0.011)
Constant	−0.903***	0.343	−0.710***	0.244	−0.492***	0.400*
	(0.187)	(0.220)	(0.235)	(0.176)	(0.166)	(0.214)
Time fixed effect	YES	YES	YES	YES	YES	YES
Observations	2317	1653	2314	1653	2317	1653
Hansen	59.071	79.882	57.508	77.692	55.820	76.950
P(Hansen)	0.178	0.044	0.217	0.062	0.265	0.069
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.581	0.013	0.567	0.008	0.602	0.015
No. of countries	140	140	140	140	140	140
No. of instruments	88	87	88	87	88	87

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 12
Inclusion of R&D variable in GDP per capita models (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.GDP per capita	0.897***	0.870***	0.932***	0.925***	0.899***	0.882***	0.985***	0.920***
	(0.013)	(0.020)	(0.013)	(0.014)	(0.015)	(0.016)	(0.011)	(0.005)
Physical capital	0.025**	0.043***	0.014	0.022**	0.013	0.047***	−0.019*	0.024***
	(0.011)	(0.012)	(0.010)	(0.011)	(0.008)	(0.012)	(0.011)	(0.009)
Human capital	−0.006	0.079**	0.029	0.061**	0.029	0.024	0.056***	0.066***
	(0.020)	(0.038)	(0.019)	(0.025)	(0.018)	(0.031)	(0.019)	(0.017)
Trade openness	0.038***	0.039***	0.045***	0.016**	0.021	0.013	0.010	0.014
	(0.013)	(0.011)	(0.013)	(0.008)	(0.013)	(0.012)	(0.011)	(0.009)
Government expenditure	0.062***	−0.053*	0.034***	−0.033	0.042***	−0.004	−0.004	−0.004
	(0.014)	(0.028)	(0.013)	(0.021)	(0.013)	(0.017)	(0.006)	(0.005)
Access to electricity	0.078***	−0.094**	0.077***	−0.046	0.056***	−0.014	0.088***	0.063***
	(0.013)	(0.046)	(0.014)	(0.043)	(0.011)	(0.037)	(0.022)	(0.016)
Urbanization	0.102***	0.444***	0.018	0.182***	0.073***	0.287***	−0.158***	−0.000
	(0.029)	(0.070)	(0.038)	(0.053)	(0.026)	(0.061)	(0.050)	(0.040)
Total GHG emissions	−0.053***	0.042						
	(0.013)	(0.028)						
Innovation		0.056***		0.036***		0.048***		0.045***
		(0.006)		(0.004)		(0.007)		(0.004)
Carbon dioxide emissions			−0.023*	0.026				
			(0.012)	(0.021)				
Methane emissions					−0.041***	−0.010		
					(0.011)	(0.017)		
Other GHG emissions							−0.002	−0.011***
							(0.001)	(0.001)
Constant	−0.903***	−0.023	−0.710***	0.280	−0.492***	−0.090	0.288	0.236*
	(0.187)	(0.296)	(0.235)	(0.292)	(0.166)	(0.194)	(0.179)	(0.132)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2317	1387	2314	1387	2317	1387	737	419
Hansen	59.071	50.686	57.508	51.588	55.820	52.796	32.666	34.132
P(Hansen)	0.178	0.446	0.217	0.411	0.265	0.367	0.753	0.691
AR(1)	0.000	0.002	0.000	0.002	0.000	0.001	0.001	0.030
AR(2)	0.581	0.929	0.567	0.659	0.602	0.694	0.183	0.839
No. of countries	140	140	140	140	140	140	140	140
No. of instruments	88	83	88	83	88	83	74	69

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

significant at a 1% level. This indicates that foreign direct investment inflows and higher innovation investment would contribute significantly to economic growth. On the other hand, Table 11 shows that the coefficients on the health variable are negative and statistically significant at a 1% level. This indicates that deterioration in health could reduce productivity and economic growth. Given the effect of the environmental degradation variables on the potential mediators, it can be asserted that environmental degradation could lessen global economic growth by impeding foreign direct investment, technological innovation, and health.

4.3. Robustness check using ecological footprint as a proxy for environmental degradation

The linear and nonlinear effects of ecological footprint[4] variables on economic growth are presented in Table 13. As presented in Table 13, Models 1 and 3 show that ecological consumption and production footprint have statistically significant negative effects on GDP per capita. From the estimates, a 1% increase in ecological consumption footprint reduces GDP per capita by 0.030% ceteris paribus. Also, a 1% increase in ecological consumption footprint reduces GDP per capita by 0.050% ceteris paribus. The implication is that environmental degradation, in a broader sense, is associated with lower GDP per capita. These results collaborate with the earlier findings that greenhouse gases as a proxy of environmental degradation decrease GDP per capita. Evidence from the nonlinear specifications (see Models 2 and 4) shows that the main terms of ecological consumption footprint and ecological production footprint have a statistically significant negative effect on GDP per capita, while their squared terms have a statistically significant positive effect on GDP per capita. This relationship shows that ecological footprint has a U-shaped relationship with GDP per capita, suggesting that GDP per capita decreases at a lower level of ecological footprint; however, after certain higher thresholds of the ecological footprint variables, GDP per capita increases. From the threshold estimates, after a turning point of 1.174482 in total global hectares, the ecological footprint of consumption and production would eventually increase GDP per capita. The policy implication is that environmental degradation in the form of an ecological footprint would eventually increase economic growth in the long term. Environmental resources are needed to produce goods and services, which need to be consumed to increase production further and boost economic growth.

It is further tested if foreign direct investment, health, and technological innovation mediate the effect of ecological footprint on GDP per capita. Following the same approach presented in section 4.2, the first-stage results are presented in Table 14. In Table 14, the ecological consumption footprint has a statistically insignificant effect on foreign direct investment (see Model 1), while the ecological production footprint has a statistically significant negative effect on foreign direct investment (see Model 2). This evidence suggests that environmental degradation, proxied with ecological production footprint, deters foreign direct investment. Also, in Models 3 and 4, ecological consumption and production footprint have a statistically significant positive effect on health. Consistently, this result supports the earlier findings that environmental degradation is detrimental to health and can increase maternal mortality. In Model 5, the ecological consumption footprint has a statistically significant negative effect on innovation, while in Model 6, the ecological production footprint has an insignificant effect on innovation. This shows that environmental degradation

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[4] The ecological footprint variables used for the analysis span from 1980 to 2016.

Table 13

Effects of ecological footprint on GDP per capita (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.GDP per capita	0.934***	0.959***	0.918***	0.948***
	(0.015)	(0.015)	(0.017)	(0.012)
Physical capital	0.011	0.055***	0.019*	0.058***
	(0.011)	(0.012)	(0.011)	(0.008)
Human capital	0.062***	0.059***	0.058**	0.024
	(0.023)	(0.018)	(0.023)	(0.017)
Trade openness	−0.039***	0.009	−0.035**	0.023**
	(0.015)	(0.009)	(0.015)	(0.010)
Government expenditure	−0.005	−0.037***	0.021	−0.025*
	(0.013)	(0.012)	(0.020)	(0.014)
Access to electricity	0.060***	0.018	0.057***	0.040***
	(0.013)	(0.011)	(0.014)	(0.009)
Urbanization	0.090***	0.109***	0.086***	0.120***
	(0.031)	(0.037)	(0.030)	(0.029)
Ecological footprint of consumption	−0.030***	−1.166***		
	(0.011)	(0.192)		
Ecological footprint of consumption Sq.		3.625***		
		(0.576)		
Ecological footprint of production			−0.050***	−1.111***
			(0.018)	(0.147)
Ecological footprint of production Sq.				3.458***
				(0.435)
Constant	0.501**	−8.978***	0.375*	−8.821***
	(0.199)	(1.381)	(0.196)	(1.025)
Time fixed effect	YES	YES	YES	YES
Threshold	–	**0.161 [1.174482]**	–	**0.161 [1.174482]**
Observations	2002	2002	2002	2002
Hansen	56.937	61.914	56.412	68.174
P(Hansen)	0.233	0.408	0.248	0.219
AR(1)	0.000	0.000	0.000	0.000
AR(2)	0.409	0.857	0.508	0.921
No. of countries	140	140	140	140
No. of instruments	85	96	85	96

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

(ecological consumption footprint) does not increase technological development, indirectly contradicting Porter's hypothesis.

From the first stage, the second stage results are presented in Table 15. The coefficients of ecological consumption footprint and ecological production footprint in Table 15 should be compared to their respective coefficients in Table 13 [Models 1 and 3] to determine whether the inclusion of foreign direct investment, health, and technological innovation as additional independent variables in the economic growth models render the ecological footprint variables statistically insignificant or reduce the magnitude of their coefficients. It can be observed in Table 15, Model 1, that the inclusion of the foreign direct investment variable does not render the ecological production footprint statistically insignificant or reduce the size of its coefficients, suggesting no evidence that foreign direct investment fully mediates the effect of ecological production footprint on GDP per capita. Also, in Model 2, the inclusion of health (maternal mortality) does not render the ecological consumption footprint statistically insignificant or reduce the size of its coefficients, suggesting that health does not fully mediate the effect of ecological consumption footprint on GDP per capita. However, in Model 3, including health reduces the magnitude of ecological production footprint statistically coefficients from 0.050 to 0.025, suggesting that health fully mediates the effect of ecological production footprint on GDP per capita. In addition, Model 4 suggests that including technological innovation reduces the magnitude of ecological consumption footprint statistically coefficients from 0.030 to 0.022, suggesting that technological innovation fully mediates the effect of ecological consumption footprint on GDP per capita. This evidence further substantiates the earlier claim that the impact of environmental degradation on GDP per capita could be mediated by foreign direct investment, health, and technological innovation.

5. Conclusion and policy implications

There is extensive literature on the contribution of economic growth to environmental pollution; however, limited empirical evidence exists on the reverse. To guide the development of non-conflicting environmental and structural policies, it is worthy of providing empirical knowledge on the economic growth effect of environmental degradation. This study deviates from the existing literature and contributes significantly to knowledge and practice by addressing the following research gaps. First, it contributes to the economic growth literature by examining if the effect of environmental degradation is nonlinear. Understanding the nonlinear impact of environmental degradation on economic growth is vital for policymakers in designing appropriate policies to tackle environmental degradation while promoting economic growth simultaneously. Therefore, this study quantifies the threshold values at which environmental degradation can promote or harm economic growth. Second, our study augments the existing literature by highlighting the potential channels through which environmental degradation affects economic growth. Identifying the potential channels through which environmental degradation influences economic growth is critical by enabling policymakers to appreciate that the economic growth effect of environmental degradation is complex; therefore, designing and implementing an integrative or holistic policy approach that would ensure a balance between environmental sustainability and economic development are consequential. In addition, the study utilized different measures of environmental degradation and applied a robust econometric technique to provide a policy-relevant recommendation.

In addressing the research gaps, this paper deployed the two-step dynamic system-GMM to investigate the impact of environmental degradation (proxied with total greenhouse gas, carbon dioxide, methane, and other greenhouse gas emissions) on economic growth. The findings showed that environmental degradation is significantly associated with the deterioration of economic growth. However, the nonlinear analysis revealed that the environmental degradation variables have an inverted U-shaped relationship with economic growth. The estimated values show that until threshold levels of 10,404.566 [kt of CO_2 equivalent], 3415.230kt, 1096.633 [kt of CO2 equivalent] and 20.086 [thousand metric tons of CO_2 equivalent], respectively of total greenhouse gas, carbon dioxide, methane, and other greenhouse gas emissions, environmental degradation could boost economic growth. However, environmental degradation would impede economic growth after these threshold values. These threshold values change if regional and income effects are considered. In addition, the ecological footprint of consumption and production support that environmental degradation is negatively associated with economic growth. However, the nonlinear evidence suggests that, unlike the pollutant emissions, the ecological footprint variables have a U-shaped relationship with economic growth, suggesting that at a threshold value of 1.174482 in total global hectares, the ecological footprint of production and consumption would eventually drive economic growth. Pathway analysis highlighted that health, foreign direct investment, and technological innovation are the potential channels through which environmental degradation could harm economic growth.

The findings are important for informing sustainable development policies. They highlight the need for policymakers to implement

Table 14

Effect of ecological footprint on FDI, health, and technological innovation (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Foreign direct investment		**Health (maternal mortality)**		**R&D**	
L.Foreign direct investment	0.231***	0.173***				
	(0.024)	(0.047)				
L.Health			0.974***	0.976***		
			(0.011)	(0.010)		
L.Innovation					0.964***	0.997***
					(0.023)	(0.024)
Physical capital	−0.176	0.200	0.012	0.003	0.029	−0.057
	(0.143)	(0.182)	(0.011)	(0.009)	(0.041)	(0.046)
Human capital	0.848**	−0.113	−0.025	−0.030	0.255	0.508***
	(0.341)	(0.348)	(0.027)	(0.025)	(0.186)	(0.168)
Trade openness	0.939***	0.349	0.051***	0.057***	−0.145***	−0.064
	(0.170)	(0.221)	(0.019)	(0.019)	(0.054)	(0.041)
Government expenditure	−0.046	0.465	−0.004	−0.007	0.214***	0.018
	(0.144)	(0.293)	(0.018)	(0.017)	(0.062)	(0.075)
Access to electricity	−0.011	0.258	−0.014	−0.006	0.400**	0.256
	(0.148)	(0.313)	(0.019)	(0.016)	(0.158)	(0.178)
Urbanization	−0.767*	−0.948	−0.057**	−0.051*	−1.143***	−0.993***
	(0.445)	(0.645)	(0.029)	(0.027)	(0.200)	(0.173)
Ecological footprint of consumption	0.132		0.040*		−0.252***	
	(0.176)		(0.021)		(0.075)	
Ecological footprint of production		−0.562*		0.039**		−0.022
		(0.332)		(0.017)		(0.081)
Constant	−4.311**	1.079	−0.392	−0.353	1.670**	1.123**
	(1.881)	(1.884)	(0.273)	(0.273)	(0.690)	(0.473)
Time fixed effect	YES	YES	YES	YES	YES	YES
Observations	1820	1820	1441	1441	1000	1000
Hansen	70.734	49.362	46.291	46.924	48.048	48.994
P(Hansen)	0.453	0.147	0.623	0.598	0.552	0.514
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.054	0.085	0.027	0.025	0.534	0.460
No. of countries	140	140	140	140	140	140
No. of instruments	105	75	74	74	78	78

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

proactive environmental policies to mitigate global environmental pollution. The environmental pollution variables emanate from the world's energy and food production systems (Tol, 2009). Reducing greenhouse gases, the main drivers behind climate change requires improving energy efficiency in the world energy mix. Also, strategies for assisting the transition towards a renewable energy economy would help mitigate environmental degradation's negative effect on economic growth. While countries need to use proactive policies to reduce environmental degradation, the nonlinear analysis suggests some form of environmental degradation is required to promote economic growth; therefore, global and national environmental policies should be implemented with care without causing closed-form relationships that can cause a decline in economic growth. As Tol (2009, p. 29) indicated, "One cannot have beef, mutton, dairy, and rice without methane emissions." Therefore, policymakers should also be mindful in the fight against environmental pollution since most instruments and strategies designed to mitigate greenhouse gas emissions could distort production and consumption activities and further hinder economic growth. Hence, sustainable ways, mitigation, and restoration strategies should guide policies that drive economic growth, especially in the early stages of development.

Another practical implication demonstrated in this study is that environmental degradation worsens health and reduces foreign direct investment and technological innovation. At the same time, health, foreign direct investment, and technological innovation are essential for sustaining global economic growth. These findings suggest that the role of environmental degradation in deteriorating health could increase the health cost for households and the government. These put a burden on household income and savings as well as government budget. National savings could be reduced, and the less loanable fund would be available for investment to drive economic growth. Also, environmental degradation could be a barrier to attracting more foreign investment to drive economic growth. Multinational corporations are paying more attention to environmental sustainability and are more likely to invest in countries with the best environmental sustainability practices. Additionally, environmental degradation could stifle competition and limit technological innovation in the long run. Countries with poor environmental quality are under pressure from international organizations and civil organizations to put in measures to improve their environment, especially mitigating greenhouse gas emissions. These have made some emerging economies develop and implement stringent environmental policies to enhance the quality of their environment. These stringent environmental regulations could act as a cost to production and reduce the ease of doing business, deterring foreign investment and limiting technological innovation and transfer. From these implications, it is suggested that policymakers consider the complexities involved in environmental degradation and economic growth linkage when designing policies to address environmental degradation.

CRediT authorship contribution statement

Alex O. Acheampong: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Eric Evans Osei Opoku:** Conceptualization, Methodology, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 15
Ecological footprint, potential mediators, and GDP per capita (Two-step dynamic-GMM results).

Variables	Model 1	Model 2	Model 3	Model 4
L.GDP per capita	1.011***	0.922***	0.907***	0.860***
	(0.018)	(0.010)	(0.009)	(0.012)
Physical capital	−0.007	−0.001	0.004	0.077***
	(0.011)	(0.006)	(0.005)	(0.010)
Human capital	0.002	0.061***	0.050***	0.025
	(0.022)	(0.013)	(0.012)	(0.032)
Trade openness	0.063***	0.018*	0.037***	0.056***
	(0.017)	(0.010)	(0.009)	(0.009)
Government expenditure	−0.080***	−0.050***	−0.024***	0.029**
	(0.016)	(0.010)	(0.008)	(0.011)
Access to electricity	0.077***	−0.014*	−0.018***	−0.111***
	(0.018)	(0.007)	(0.007)	(0.040)
Urbanization	−0.023	0.213***	0.199***	0.436***
	(0.041)	(0.022)	(0.018)	(0.073)
Foreign direct investment	0.006***			
	(0.002)			
Ecological footprint of production	0.108***		0.025***	
	(0.018)		(0.007)	
Health (maternal mortality)		−0.022***	−0.025***	
		(0.008)	(0.009)	
Ecological footprint of consumption		0.039***		−0.022*
		(0.009)		(0.012)
Innovation				0.032***
				(0.006)
Constant	−0.578***	0.122	−0.047	−0.875***
	(0.171)	(0.173)	(0.173)	(0.204)
Time fixed effect	YES	YES	YES	YES
Observations	1891	1522	1522	1162
Hansen	60.132	73.713	72.578	42.013
P(Hansen)	0.154	0.110	0.128	0.782
AR(1)	0.000	0.004	0.000	0.000
AR(2)	0.876	0.004	0.006	0.782
No. of countries	140	140	140	140
No. of instruments	86	86	86	80

Standard errors in parentheses. Hansen test refers to the over-identification test for the restrictions in system-GMM estimation. The AR (1) and AR (2) tests are the Arellano–Bond tests for first and second-order autocorrelation in first differences * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix A. Table 1: List of countries

Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, The, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Chile, China, Colombia, Comoros, Congo, Dem. Rep., Congo, Rep., Costa Rica, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, Arab Rep., El Salvador, Estonia, Ethiopia, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong SAR, China, Hungary, Iceland, India, Indonesia, Iran, Islamic Rep., Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Rep., Kuwait, Kyrgyz Republic, Latvia, Lesotho, Libya, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Rwanda, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, St. Kitts and Nevis, St. Lucia, Sudan, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkiye, Uganda, Ukraine, United Arab Emirates, United Kingdom, Uruguay, Uzbekistan, Vanuatu, Vietnam, Zambia, Zimbabwe.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106734.

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