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The Long Run Relationship between Economic Growth and Environmental Quality

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Authors' contributions

This work was carried out in collaboration among all authors. Author RA designed the study, managed the literature searches, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GS managed and reviewed the discussion of the study. Author MH is the corresponding author who revised and examined the conceptual framework of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAEES/2019/v32i330153

Editor(s):

(1) Dr. Sule Isin, Professor, Department of Agricultural Economics, Ege University, Turkey.

Reviewers:

(1) Nwani, Stanley Emife, Lagos State University, Nigeria.

(2) Romer C. Castillo, Batangas State University, Philippines.

Complete Peer review History: <http://www.sdiarticle3.com/review-history/48454>

Original Research Article

Received 16 February 2019

Accepted 24 April 2019

Published 30 April 2019

ABSTRACT

One of the controversial debates in environmental economics, which began in the 1980s, is the relationship between environmental pollution and economic growth. The study investigated the relationship between per capita carbon dioxide emissions and gross domestic product per capita in 63 countries over 51 years during 1960 to 2010. Using a graphical analysis approach, the results of this study showed that the relationship between per capita carbon dioxide emissions and gross domestic product per capita amongst the sample data followed a sigmoid curve indicating that the per capita carbon dioxide emissions of a country increased when its economy transitioned from a labor-intensive technology to a capital-intensive one caused by an increase in the rate of economic growth. The results also showed that the amount of relative emissions varied amongst the countries.

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The variability could be imputed to the following reasons: (i) the heterogeneity in the structure of the economies, and (ii) the disparity in the mode of production used in the countries' manufacturing processes.

Keywords: *Sigmoid curve; carbon dioxide emissions; economic growth; economic structure; mode of production.*

JEL classification: O40, Q50, Q56.

1. INTRODUCTION

The industrial revolution resulted not only in rapid economic growth but also in increased environmental pollution [1]. The effects of the revolution, however, influence the quality of human life in different ways. While global warming, climate change and the negative impact of environmental pollution can bring many complications to human life, economic growth is the most important precondition for economic development [2,3]. As a result, researchers have been interested in discovering the relationship between economic growth and environmental pollution since the 1980s [4,5,6].

Carbon dioxide (CO₂) is considered one of the major pollutants contributing to climate change [5,7,8], which has recently caused widespread impacts on the natural and human systems [9]. The impacts include, but are not limited to, altering hydrological systems, affecting water resources in terms of quantity and quality, impacting the biological activities of many species, and crop yields. It has been forecasted that there will be an increase in global temperatures - from 1.1 to 6.4 degrees Celsius due to increases in CO₂ and other greenhouse gases (GHG) emissions. As a result, sea levels are projected to rise from 16.5 cm to 53.8 cm by the year 2100, which will cause diverse socio-economic complications in many coastal areas [5,10]. Though CO₂ emissions originate from both anthropogenic and natural sources, it is believed that human activities are responsible for altering the carbon cycle – both by increasing the concentration of CO₂ in the atmosphere and by lowering the earth's capacity to absorb CO₂ from the atmosphere [8,11]. The level of anthropogenic CO₂ emissions of a country depends on different factors such as the intensity of economic activity and the mode of production, the consumption level of the population, and the stringency of environmental regulations [12].

Countries vary in their modes of production, the level of output and consumption, and the level of CO₂ emissions. Economic growth is often accompanied by an increased demand for durable goods, which results in even more CO₂ emissions [13]. It could be further extended that the relationship between consumption and CO₂ emissions implies that the more durable and non-durable goods a nation consumes, the higher is the level of its CO₂ emissions. The consumption level of a country depends primarily on its own production and partially on its imports from the rest of the world [14]. When a country specializes in export-based growth, it will have a comparative advantage in producing pollution-intensive output if its level of environmental regulations is weaker than the average [15]. Since there is a strong positive correlation between the per capita income level of a country and the stringency of its environmental regulations developing countries will specialize in pollution-intensive production whilst developed countries will specialize in clean production due to comparative advantage [15]. The same conclusion was supported by Shahbaz et al. [16] who explained how environmental quality in Nigeria decreased substantially due to higher levels of pollution-intensive output production under the trade openness regime. In addition, many developing countries are addressing their pollution problems through formulating effective environmental policies, with or without the help of developed countries and/or international organizations like the United Nations Environment Program [17]. By adopting standards that exist in developed countries and by implementing them in society, these countries often perform better than developed countries [17,18]. For example, Costa Rica received the 2010 Future Policy Award issued by the World Future Council for pioneering legal protection of biodiversity, which served as a model for other nations to follow [19]. Therefore, it cannot be maintained that all developing countries are lagging in formulating effective environmental policies.

In formulating environmental policies, the main objective of policy makers varies by country. For instance, while reducing energy consumption as a means to reduce CO₂ emissions is important in developed countries, it is unrealistic to expect all developing nations to have the same goal, as their primary objective is to raise their standard of living rather than environmental quality [20]. Once a developing country starts its industrial development process, it will continue struggling to sustain its sustainable economic development as its ultimate goal. It is evident that the nature of a country's economy changes from a traditional economy (i.e., based on labor intensive technology) to a modern one (i.e., based on capital intensive technology). For each country, the transition period implies a change in the pattern of the relationship between CO₂ emissions and economic growth. Such a relationship is important in the domain of environmental policy where it allows policy makers to judge the impacts of economic activities on the environment, thereby enabling them to formulate effective conservation policies for sustainable development [21].

The main objective of this research is to demonstrate the most likely pattern of the long run relationship between economic growth and CO₂ emissions of a country as it changes its mode of production from a labor intensive technology to a factor neutral economy (i.e. neither more labor nor more capital employed into the production process), and, ultimately, to a capital intensive technology because of its economic progress. The findings of the paper may benefit policy makers in formulating policies to facilitate long run sustainable development.

The paper is organized as follows: after a survey of existing literature, the research methods are introduced followed by data analysis and a discussion, and a conclusion.

2. LITERATURE REVIEW

It is a general consensus that human economic activities appear to be the main reason for deteriorating environmental quality through emissions of anthropogenic GHGs such as CO₂. However, it is an interesting but unsettled debate in environmental economics whether economic growth is deteriorating or ameliorating the quality of the earth's environment [22]. On one hand, researchers argue that environmental pollution comes in many shapes and forms (e.g. SO₂, CO₂ emissions) and is positively correlated with

economic growth [23,24,25,26,27]. On the other hand, several researchers consider that economic growth is necessary to conserve the long run sustainability of the natural environment meaning that economic resources must be invested in research and development to discover pollution abatement technologies and in sustainability programs aimed at conserving the environment. In order to understand the debate, proper specification and justification of the relationship between environmental pollution and economic growth is required [21,28,29].

Using various methods, researchers have attempted to estimate the relationship between environmental pollution and economic growth by taking into account some figures such as GDP, GDP per capita and/or per capita national income and information on various pollutants such as emissions of CO₂, nitrogen oxide (NO_x), sulfur dioxide (SO₂) and suspended particulate matter [22,30]. As mentioned earlier our focus will be on CO₂ emissions in this paper. The findings of most researches show no consistent relationship between CO₂ emissions and economic growth. However, in numerous studies the nexus is found as an inverted *U*-shaped curve that is known as the Environmental Kuznets Curve (EKC). The EKC shows that at the beginning of a country's economic development, environmental degradation rises and then it levels off and, eventually, falls with continuous economic growth [28,31]. The findings imply that poorer nations, as they begin their economic growth process, pollute more while richer nations are cleaner due to their ongoing economic development. Chen and Huang [27] described the relationship as a monotonically increasing or a non-declining one implying that higher levels of economic activity require the use of more natural resources (e.g. coal, oil, gas, etc.) which results in more CO₂ emissions. On the other hand, Sengupta [32] and De Bruyn and Opschoor [33] found the relationship to be a *N*-shaped curve meaning that environmental quality started falling again after an improvement to a certain level, Roy and van Kooten [34] discovered the relationship followed a non-inverted *U*-shaped curve, and finally, Lacheheb et al. [5] did not find the existence of any inverted *U*-shaped curve.

The relationship varies across countries, especially between developed and developing countries. Using different datasets collected by the Organization for Economic Cooperation and Development (OECD) and the non-OECD

countries, Galeotti et al. [31] examined the relationship between CO₂ emissions and income level and found that the inverted U-shaped curve only applied for the former group. Lapinskiene et al. [35] found the inverted U shaped nexus for 29 European countries whereas Huang et al. [36] could not provide any evidence to support the same relationship for developed countries. In order to test the validity of the inverted U shaped relationship for developing countries, Apergis and Ozturk [37] conducted empirical tests for 14 Asian countries, using data that were collected from 1990 to 2010 and found the relationship across these countries to be valid. Narayan and Narayan [21] tested the relationship for 43 developing countries and found an inverted U shaped relationship for only a few Middle Eastern and South Asian countries. The pattern of the relationship between pollution and economic growth that is mostly reported in the literature is an inverted U shape. According to the pattern, environmental degradation in a country starts to fall when its per capita GDP reaches a turning point at 3,137 USD [38] or a per capita income of less than 8,000 USD [22]. In recent years, the GDP per capita of developed or high-income countries (HICs) has increased beyond the turning point. However, both real GDP per capita as well as per capita CO₂ emissions continue to increase [39], disproving the hypothesis of *pollution-income progression of agrarian communities (clean) to industrial economies (pollution intensive) and to service economies (cleaner)* [40]. More importantly, as Holtz-Eakin and Selden [24] and Roberts and Grimes [41] stressed out the EKC or the inverted U shape relationship does not describe CO₂ emissions in a meaningful way, as these emissions have been commonly used as the proxy for the level of pollution in the existing literature. Furthermore, the EKC does not exist in the long run [42,43]. Therefore, an attempt is necessary to estimate the long run relationship between CO₂ emissions and economic growth, which may enable policy makers to formulate policies facilitating long run sustainable development.

3. RESEARCH METHODOLOGY

The study used a graphical method and a line chart to explore the long run relationship between economic growth and CO₂ emissions [44]. The economic growth variable, measured by GDP per capita, was placed on the horizontal axis, whereas the CO₂ emissions variable, measured by per capita CO₂ emissions, was placed on the vertical axis. Countries were

classified on the grounds of low, middle, and high annual national income [45]. Economic growth was the core of the classification that justifies transition from a low-income country (LIC) to a middle-income country (MIC) and, ultimately, to a high-income country (HIC).

For exploring the pattern of the long run relationship, data on both variables are required over a period long enough to cover an entire transitional phase. An entire transitional phase can be explained as a period when a previously low-income country managed to transform its traditional economy based on labor power mostly to a modern economy based on machineries because of the economic growth. What has generally been a time-frame for a LIC to become a HIC? At present, no database provides time series data on per capita CO₂ emissions and GDP per capita for any country before 1960 [20,44]. Literature shows that such limitation can be waived if researchers assume that LICs should pursue the strategies used by HICs to develop their economies status [46]. Fig. 1 shows trends in per capita CO₂ emissions of LICs, MICs and HICs over the last five decades. Per capita CO₂ emissions are plotted against the corresponding per capita GDP for all three categories of countries. The first segment of the graph represents the relationship between these two variables for a LIC whose mode of production is labor intensive. The second segment of the graph shows the same relationship for a MIC which follows a factor neutral mode of production. The third segment of the graph depicts the relationship between these two variables for a HIC with a capital intensive mode of production. The resulting combined line chart will specify the most likely pattern of the long run relationship between economic growth and CO₂ emissions of a country when it improves its economic status from a LIC to a MIC and ultimately to a HIC following a change in its mode of production from labor intensive to factor neutral and then to a capital intensive type of technology, respectively.

3.1 Data Description

Data on both GDP per capita and per capita CO₂ emissions have been collected from the World Data Bank website [47]. Data on both variables have been collected over 51 years from 1960 to 2010 and for 63 countries comprising 25 low-income, 16 middle-income, and 22 high-income countries which are as follows:

Low-income countries (LICs): Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Ghana, Guatemala, Honduras, Kenya, Liberia, Madagascar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Papua New Guinea, Philippines, Rwanda, Sierra Leone, Sri Lanka, Togo, and Uganda,

Medium-income countries (MICs): Algeria, Brazil, Chile, China, Costa Rica, Dominican Republic, Ecuador, Gabon, Jamaica, Mexico, Panama, Peru, South Africa, Suriname, Thailand and Turkey, and

High-income countries (HICs): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, Norway, Portugal, Singapore, Spain, Sweden, UK, and USA.

It is worth mentioning that the panel data have been converted into time series data by taking the average of values of the same category countries across the 51-year period.

4. RESULTS AND DISCUSSION

Table 1 shows a summary of statistics of GDP per capita and per capita CO₂ emissions for the sample data. It is evident that the per capita CO₂ emissions rose with per capita GDP overtime for all countries. Generally, HICs emitted higher levels of per capita CO₂ emissions than the MICs and LICs during the period of study. Table 1 shows that the rate of the per capita CO₂ emissions in both MICs and LICs was much higher in 2010 compared to that in 1960.

The increase in per capita CO₂ emissions in all groups of countries occurred primarily due to expanding economic activities, since output is positively correlated with pollution in the long run [20,39]. These results indicate that emissions

rise monotonically with output. Other precedent studies reported similar findings [23,24]. Among the three groups of countries, per capita CO₂ emissions in HICs experienced significantly more fluctuations, especially a continuous rise until 1973 and then an overall decline, with some modest fluctuations. The nature of the fluctuations in HICs' per capita CO₂ emissions rises the question what initiatives had been taken by developed countries before 1973 to reduce the overall per capita CO₂ emissions trend, or even to level it off in later periods? Developed countries began formulating and implementing environmental policies vigorously since the 1960s. It has been documented that the end of the 1960s could be marked as the beginning of the modern environmental policy-making era [48]. In the USA, the Environmental Protection Agency (EPA) was established in 1970 to protect all Americans from significant risk to human health and the natural environment [49]. The U.S. government signed the Clean Air Act in 1970 which marked another milestone for the environmental conservation in the USA. In Europe, the EU Council of Environmental Ministers adopted the very first Environmental Action Program in 1973 and since then the EU environmental policy has become a core area of European politics [50]. Other developed countries along with global organizations have undertaken initiatives to conserve the natural environment, aiming to protect all living beings from significant risk. All of these initiatives contributed to the leveling off or the falling trend in per capita CO₂ emissions in HICs in the 1980s and onwards.

Fig. 2 shows the long run relationship between per capita CO₂ emissions and GDP per capita. The trend line of the chart is a curve, similar to a sigmoid curve. The curve shows a monotonically increasing relationship between per capita CO₂ emissions and GDP per capita.

Table 1. Summary statistics of GDP per capita and per capita CO₂ emissions (1960-2010)

Country	Range of values							
	For GDP per capita (in US\$)				For per capita CO ₂ emissions (in metric tons)			
	1960	2010	Min	Max	1960	2010	Min	Max
LICs	122.99	1208.13	122.99	1208.13	0.15	0.39	0.15	0.41
MICs	307.70	7381.72	300.88	7381.72	1.10	3.54	1.10	3.56
HICs	1262.91	47313.74	1262.91	51420.19	6.95	9.60	6.95	11.46

Source: The World Bank

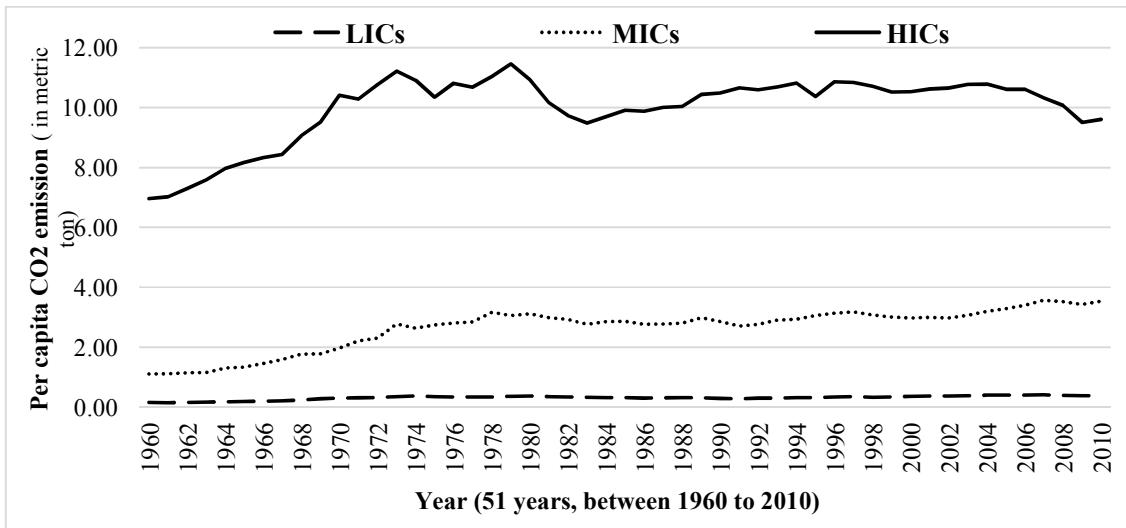


Fig. 1. Trends in per capita CO2 emissions of LICs, MICs and HICs over the last five decades

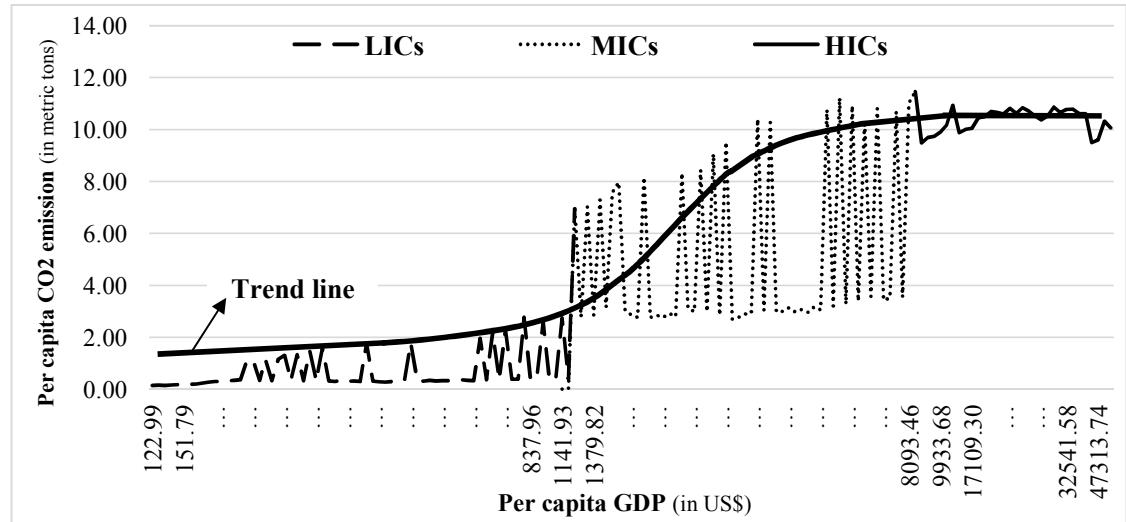


Fig. 2. The long run relationship between per capita CO2 emissions and GDP per capita

This is compatible with the findings of Shafik [23] and Holtz-Eakin and Selden [24]. However, the distinctive feature of the curve is its two wiggles, which split it into three segments. The first segment represents the per capita CO₂ emissions of LICs, which was at a lower level with a gradual increase. The traditional economies of the LICs were mostly dependent on agricultural activities, which employed more labor than capital [20]. Less capital use in the production processes consumed less fossil fuel, which resulted in lower levels of per capita CO₂ emissions. Structural change is essential for these traditional economies, without which modern economic growth would not be possible

[51]. However, the structural shift from a rural, and predominantly agricultural, economic base, to a manufacturing one resulted in increasing demand for energy [20], and therefore a gradually increasing rate of per capita CO₂ emissions. The middle segment shows a dramatic rise in the per capita CO₂ emissions of the MICs. Industrialization was emphasized highly in developing countries to accelerate economic growth aiming to improve the standard of living of the societies in the region [20]. The ongoing industrialization required a continuous process of capital formation for higher economic growth. According to Solow's theory of economic growth, countries invest more resources in their

physical capital aiming to realize their potential economic growth, since an increase in the stock of physical capital results in higher growth rate both in the short run and in the long run [52,53]. Since industrialization in the MICs resulted in a substitution of labor by machines, the MICs were becoming more and more energy intensive, and the corresponding per capita CO₂ emissions rate was rising in a higher rate. The last segment represents the higher level of per capita CO₂ emissions in the HICs which are highly industrialized. Industrial revolution in these countries transformed their economies from organic economies based on labor power to inorganic economies based on fossil fuels [1]. These countries use more physical capital techniques in manufacturing output [15]. Capital-intensive techniques are more pollution-intensive since more fossil fuels are necessary to operate machineries in the production process [54]. Therefore, the use of capital-intensive techniques was one of the main reasons for which the HICs emitted a higher level of per capita CO₂ emissions.

In examining how the findings of this research compare with other findings available in the large body of literature about the relationship under consideration, the study has found both similarities and dissimilarities. The most reported shape of the relationship is an inverted *U*-shaped curve. The left segment of an inverted *U*-shaped curve before its turning point expresses a monotonically increasing relationship between environmental pollution and economic growth of a country when it was a developing country. The first and second segments of the sigmoid curve depict a similar increasing relationship in the case of developing countries. On the other side, the right segment of the inverted *U*-shaped curve after its turning point, which implies environmental degradation, is declining when a country becomes developed. However, the last segment of the sigmoid curve depicts a leveling off in the pollution trend for developed countries. Other empirical findings had shown that the per capita CO₂ emissions of developed countries were much higher, but the trend was either leveling off or slightly declining [55]. As mentioned earlier, the findings of this study are compatible with other researches [23,24,25,26,27]. In comparison with the *N*-shaped curve precedent studies provided a similar relationship that is increasing [32,33]. After that, these findings vary with each other. In fact, the sigmoid curve shows a significantly unique relationship between the per capita CO₂

emissions and the GDP per capita in the long run. The sigmoid curve indicates that all three categories of countries emitted increasing amounts of per capita CO₂ overtime, but that the relative emissions varied by category or country. This can be explained by the fact that different countries adopted different modes of production and produced different levels of output. They also emitted different levels of CO₂ emissions. Limiting emissions while encouraging growth is necessary for sustainable development, but it is challenging. Investment in green technologies and in human capital rather than in fossil fuel technologies may be a good policy towards sustainable development. Green technologies consume less fossil fuels and more renewable energy, and are more labor-intensive. Formulating and implementing a consistent environmental policy is another factor facilitating the process towards sustainable development through limiting pollution. Therefore, investment in green technologies and human capital along with proper environmental policy design and implementation may make the curve flatter or change the direction of the curve and make it downward sloping, meaning that more output is being produced while limiting emissions.

5. CONCLUSION

The most likely pattern of the long run relationship between per capita CO₂ emissions and GDP per capita is a sigmoid curve. The curve shows that per capita CO₂ emissions begin rising gradually from an initial low level and then reach a higher level following a dramatic increase. According to the curve, all three categories of countries emit per capita CO₂ increasingly overtime, but their relative emissions vary. The variation in relative emissions is due to heterogeneity in both the structure of their economies as well as the mode of production used in their manufacturing processes. The findings of the paper are significantly unique; however, they are consistent, in varying degrees, with other findings of previous studies. Effective environmental policy implementation along with investment in green technologies and human capital may change the direction of the curve and make it downward sloping. Panel data in the study have been converted into time series data by using the average of values for same category countries. The average measure is convenient to provide a general view; however, it cannot provide an in-depth view of all countries under consideration. Development strategies vary by countries. For various reasons, developing

countries may not require fulfilling all of the five stages of Rostow's economic growth model to improve their economic status. Australia, Canada and the U.S. are good examples, because they did not pass through the five stages of the growth model.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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