Environmental Sustainability Through Aggregate Demand Behavior – Does the Knowledge Economy have Global Responsibility?

Abstract

Purpose – Considering environmental sustainability, a global challenge under the preview of sustainable development goals, the present study aims to highlight the significance of the knowledge economy in attaining sustainable aggregate demand behavior globally. For this purpose, 155 countries that have data available from 1995-2021 were selected. The purpose of selecting these countries is to test the global responsibility of the knowledge economy to attain environmental sustainability.

Design/methodology/approach – Results are estimated with the help of Panel Quantile Regression. The empirical existence of aggregate demand-based environmental Kuznets curve (EKC) was tested using non-linear tests. Moreover, principal component analysis (PCA) has been incorporated to construct the knowledge economy index.

Findings – U-shaped aggregate demand-based EKC at global level is validated. However, environmental deterioration increases with an additional escalation after 497.945 million US dollars in aggregate demand. As a determinant, the knowledge economy is reducing CO_2 emissions. The knowledge economy has played a significant role in global responsibility, shifting the EKC downward, and extending the CO_2 reduction phase for every selected country. Further, urbanization, energy intensity, financial development, and trade openness significantly deteriorate the environmental quality.

Originality and research limitations/implications – This study contains the empirical existence of aggregate demand-based EKC. The role of the knowledge economy is examined through an index which is calculated using four pillars of the knowledge economy (technology, innovations, education, and institutions). This study is based on a combined panel of all the countries for which the data was available.

JEL Codes: Q5, Q4, E6, D8

Keywords: EKC, knowledge economy, STIRPAT

1. Introduction

Addressing the growing environmental degradation is a global responsibility; sustainable development goals (SDGs) play an essential role in this context[1]. Looking at the past, environmental pollution started with the industrial revolution (Berry and Rondinelli, 1998). Resultantly, energy consumption increased tremendously and lead to increased environmental pollution (Chen and Kan, 2008). The reaction is emissions of CO_2, a greenhouse gas that drives global climate change and follows a persistently increasing trend[2]. It leads to global warming, the effects of which can be seen everywhere[3]. Since 1906, the Earth's average surface temperature has amplified by more than 1.6 degrees Fahrenheit (0.9 degrees Celsius) globally[4]. However, this increasing temperature is responsible for melting glaciers and sea ice, transforming precipitation patterns, and causing animals to migrate further.

This relationship between economic activities and environmental quality can be better understood through the environmental Kuznets curve (EKC). It states that environmental deterioration first increases and then decreases with continuous expansion in economic growth and vice versa (Iqbal and Kalim, 2023). As EKC is a quadratic phenomenon, environmental sustainability can be assured by using a suitable moderator in the model (Haans *et al.*, 2016). In other words, the spending patterns of economic agents can be transformed by spreading awareness among the economic agents through the knowledge economy (Kalim *et al.*, 2023).

The knowledge economy comprises four pillars: technology, innovations, education, and institutional quality (World Bank Report, 2008). A knowledge economy is an economic system where the production, distribution, and consumption of goods and services rely heavily on knowledge, information, and technology. In this system, innovation, creativity, and learning are critical for economic success and high-value-added products and services are based on advanced

[1] https://sdgs.un.org/goals
[2] https://www.nationalgeographic.com/environment/article/greenhouse-gases
[3] https://climate.nasa.gov/effects/
[4] https://www.nationalgeographic.com/environment/article/global-warming-effects

knowledge and expertise. Industries in the knowledge economy include software development, biotechnology, research and development, consulting, and education. It is closely tied to the concept of the information society where digital technologies and the internet play a vital role in economic and social life (Powell and Snellman, 2004).

This study will answer two main questions. Firstly, does aggregate demand based EKC exist? Secondly can the knowledge economy mitigate CO_2 emissions and moderate the EKC downward? Therefore, the objective of this study is to find out the existence of aggregate demand-based EKC by applying non-linear tests in the presence of control variables. It is also aimed at identifying the determining and moderating role of the knowledge economy in minimizing the intensity of environmental degradation. Another objective of this study is to comparatively analyze the percentile-wise and country-wise turning points with initial turning points to ensure environmental sustainability. Considering SDGs, this study is aligned with the 12th and 13th goals because the authors emphasize the knowledge economy's global responsibility for attaining matured consumption and production behavior. Moreover, the study will also propose practical policy implications to pave the way for sustainable environmental quality. Lastly, this study aims to test the role of urbanization and energy intensity in determining environmental quality.

In order to empirically validate the existence of EKC and to highlight the determining and moderating role of the knowledge economy, this study is divided into several parts after the introductory remarks. Section 2 consists of a literature review to understand the work done so far on the subject matter and to highlight the required gap. Data and methodology are discussed in Section 3. Empirical results and their interpretations are presented in Section 4. Some concluding remarks and policy implications are given in Section 5.

2. Literature Review

2.1 Literature on EKC and STIRPAT

EKC is derived from Kuznets curve which describes the relationship between economic growth and income inequality (Todaro, 2015). However, EKC is about economic growth and environmental quality. Several studies, including Grossman and Kruger (1991), Selden and Song (1994), and Stern *et al*. (1996), have provided a sound base for EKC. From a quadratic point of view, the literature on EKC is divided into finding U-shaped and inverted U-shaped EKC. Some recent studies are discussed below in Table 1.

Table 1 goes about here

Further, Altıntaş and Kassouri (2020) have found U-shaped and inverted U-shaped EKC using ecological footprints and carbon emissions. Hassan *et al*. (2021), for 80 development-wise categorized countries, have validated U-shaped, inverted U-shaped, and linear relationships between environmental quality and disaggregated GDP. Moreover, studies from Allard *et al*. (2018) for a panel of 74 countries, Benedek and Fertő (2020) for the countries where forest cover increased, and Gyamfi et al. (2021), for E7 countries, have confirmed N-shaped EKC. Studies from Ganda (2018) for South Africa, Pata and Caglar (2021) for China, Ciarlantini *et al*. (2021) for five European countries, and Massagony and Budiono (2022) have not validated the EKC. The stochastic impacts by regression on population affluence and technology (STIRPAT) framework also tests the impact of economic activities on environmental quality. Many studies, including Liu and Xiao (2018), Zhang and Zhao (2019), Chekouri *et al*. (2020), Arshed *et al*. (2021), Jiang *et al*. (2022), and Iqbal *et al*. (2023b) have mutually analyzed EKC and STIRPAT analysis.

2.2 Literature on Control Variables

Among other determinants of environmental quality, urban migration increases the population pressure in urban areas due to ecological disturbance increases. Several studies are validating this phenomenon such as Sun and Huang (2020), Musah *et al*. (2021), Huang *et al*. (2021), Erdoğan *et al*. (2022), and Sun *et al*. (2022). Moreover, in many countries the share of energy in producing a certain quantity is increasing hence continuous pressure on the energy demand is felt and is leading to environmental deterioration. Many recent studies (Khan *et al*., 2022; Yang *et al*., 2022; Iqbal and Kalim, 2023)have validated this situation.

Domestic credit to the private sector by banks represents financial development and is responsible for environmental breakdown through economic activities. Many recent studies have found it responsible for environmental deterioration. For example: Acheampong (2019), Ganda (2021), Petrović and Lobanov (2022), and Xu *et al*. (2022) have found domestic credit responsible for environmental deterioration. Moreover, trade liberalization enlargement represents an increase in production and limitless expansion in output represents ecological deterioration. However, trade liberalization has a wide-reaching influence on environmental quality. Studies such as Ali *et al.* (2019), Dou *et al.* (2021), Ibrahim (2022), and Iqbal and Kalim (2023) have found trade liberalization responsible for environmental damage.

2.3 Literature on the Knowledge Economy

Several studies empirically tested the role of the knowledge economy in combating the issue of environmental degradation. A brief summary of this literature is presented in Table 2 below.

Table 2 goes about here

2.4 Literature Gap

As discussed, studies have incorporated economic growth to validate EKC representing aggregate supply. This study has utilized Keynes' aggregate demand or the spending pattern. It also reflects aggregate expenditure from consumers, investors, government, and foreign consumers. In an ideal state of affairs, aggregate demand and supply are equal. However, in real life, it is rare for this to be the case hence economies bear inflationary and deflationary gaps. The present study uniquely combines the proposed knowledge indicators as an index and as a determinant and moderator to ensure environmental sustainability. Against this, several studies (Doğan *et al.*, 2021; Leitão *et al.*, 2021; Khezri *et al.*, 2022) have utilized the economic complexity index which refers to the diversity, interconnectedness, and sophistication of an economy's components. In comparison, the knowledge economy is a complete system for running the economy.

3. Data and Methodology

3.1 Variables and Sample

For the empirical analysis, secondary data is selected from world development indicators (WDI) and the International Country Risk Guide (ICRG) from 1995 to 2021 for 155 countries. The time frame and countries are selected considering the availability of data. This study is based on a large data panel highlighting the knowledge economy's role in attaining sustainable environmental quality.

The World Bank produces the WDI which contains data on various development indicators while the ICRG, on the other hand, provides risk assessments and other information related to political and economic risk factors for countries around the world. Further, these data sources provide a comprehensive and objective picture of economic and social conditions in different countries because they are widely used and recognized in academic and policy communities. Additionally, the WDI and ICRG datasets are publicly available and updated regularly, making them an attractive data source for research purposes.

Except for the knowledge economy index, all variables are in natural log form. For the environmental quality, carbon dioxide emissions metric tonnes per capita are incorporated as a proxy and its symbol is CO_2. Keynes (1937) proposed aggregate demand as the summation of consumption, investment, government expenditures, and net exports (AD = C + I + G + NX). The present study has incorporated the same and its square with the symbols AD and AD^2 to validate the EKC. For this purpose, all series follow constant 2015 US$ in calculating aggregate demand. Moreover, urbanization represents the percentage increase in the urban population compared to the rural population and its symbol is UB. Energy intensity shows the total energy required to produce a certain quantity of a product; its symbol is EI. Banks' domestic credit to the private sector (% of GDP) is included as a proxy for financial development and its symbol is FD. The total volume of trade (% of GDP) is used as a proxy for trade liberalization.

The combined impact of the knowledge economy is captured with four pillars in the form of an index with the symbol KN. Principal component analysis (PCA) has been integrated into an index calculation. This method develops an index using these common variances among the variables (Boivin and Ng, 2006). This method helps reduce high dimensions of data to fewer but critical dimensions (Hameed *et al.*, 2021). Further, PCA uses the covariance structure to allocate heterogeneous weights based on their relative importance.

3.2 Theoretical Model

EKC designates the non-linear relationship between economic activities and environmental quality. It is based on the Kuznets curve theory. As Todaro (2015) discussed, it describes an initial increase and later decrease in income inequality through a continuous increase in economic growth. Grossman and Kruger (1991), Selden and Song (1994), and Stern *et al*. (1996) are the baseline studies that have transformed this relationship using environmental quality instead of income inequality. It states that environmental deterioration initially increases and later decreases through continuous economic growth. It describes the inverted U-shaped relationship. However, evidence of U-shaped also exists. Some notable studies on EKC include those by Kalim *et al*. (2023), Xing *et al*. (2023), and Iqbal *et al*. (2023a).

Figure 1 is constructed to comprehend the theoretical relationship between aggregate demand and environmental quality through U-shaped and inverted U-shaped curves. There is a framework of several economic reasons behind these two phenomena. Inverted U-shaped EKC infers that initial economic expansion through industrialization and urbanization may lead to increased pollution but, as economies mature, the service sector expands, reducing environmental impact. Technological progress and the implementation of stricter environmental regulations also play a role along with outsourcing pollution-intensive production processes to developing countries. In comparison, the U-shaped EKC reflects an opposite scenario. It shows that in the beginning economies adopt sustainable growth paths leading to minimizing climate challenges through innovative production techniques and matured aggregate demand behavior. However, the desire to attain immeasurable economic growth endorses economies towards environmental deterioration. According to research by Iqbal and Kalim (2023), the knowledge economy has the potential to contribute globally to promoting environmental sustainability by moderating the EKC. This effect applies to both U-shaped and inverted U-shaped EKC.

Figure 1 goes about here

3.3 Models to be Estimated

This study has proposed two regression models. Model 1 contains three equations to validate EKC while Model 2 contains the role of the knowledge economy. Each regression equation contains i and t as a subscript where i represents the cross sections and t represents time. Where β_0 is the intercept term, it represents the dependent variable in the non-existence of independent variable(s). In equation 1 of the first model, β_1 and β_2 are the coefficients of aggregate demand and its square respectively. While β_3, β_4, β_5, and β_6 are the coefficients of urbanization, energy intensity, financial development, and trade liberalization. Equations 1.1 and 1.2 are also the same while the square term is eliminated to validate the EKC empirically. The second model comprises Equation 2 where all the coefficients are the same as in Equation 1, while β_7 and β_8 are the coefficients of the knowledge economy index and interaction term with aggregate demand respectively. Further, ε_i is the normally distributed error term.

$$CO_{2it} = \beta_0 + \beta_1 AD_{it} + \beta_2 AD_{it}^2 + \beta_3 UB_{it} + \beta_4 EI_{it} + \beta_5 FD_{it} + \beta_6 TO_{it} + \varepsilon_i \text{ --- } (1)$$

$$CO_{2it} = \beta_0 + \beta_1 AD_{it} + \beta_2 UB_{it} + \beta_3 EI_{it} + \beta_4 FD_{it} + \beta_5 TO_{it} + \varepsilon_i \text{ --- } (1.1) \text{ (Before Turning Point)}$$

$$CO_{2it} = \beta_0 + \beta_1 AD_{it} + \beta_2 UB_{it} + \beta_3 EI_{it} + \beta_4 FD_{it} + \beta_5 TO_{it} + \varepsilon_i \text{ --- } (1.2) \text{ (After Turning Point)}$$

$$CO_{2it} = \beta_0 + \beta_1 AD_{it} + \beta_2 AD_{it}^2 + \beta_3 UB_{it} + \beta_4 EI_{it} + \beta_5 FD_{it} + \beta_6 TO_{it} + \beta_7 KN_{it} + \beta_8 KN_{it}^{*} AD_{it} + \varepsilon_i \text{ --- } (2)$$

Carbon dioxide emission oppositely represents environmental quality. Studies (including Liu and Xiao (2018), Danish *et al.* (2019), Altıntaş and Kassouri (2020), Hassan *et al.* (2021) and Yang *et al.* (2022)) have proxied CO_2 for environmental quality. Further, Keynes' aggregate demand is incorporated as an instrument for environmental quality along with its square term. Following Wainwright (2005), Iqbal *et al.* (2019), and Salem *et al.* (2021), signs of a square term will help in analyzing the non-linear impact of aggregate demand from an EKC perspective. Though, the U-shaped existence of EKC has been found in several recent studies (Destek *et al.* (2018), Akadiri *et al.* (2019), Dogan and Inglesi-Lotz (2020), Arshed *et al.* (2021), and Karahasan and Pinar (2022)), Akadiri *et al.* (2019), Altıntaş and Kassouri (2020), and Bilgili *et al.* (2022) have found it to be an inverted U-shape.

Urbanization, energy intensity, financial development and trade openness are incorporated in the study, assuming environmental deteriorating factors. However, urbanization is part of the model aligning with Huang *et al.* (2021) and Sun *et al.* (2022). Afterwards, Yang *et al.* (2022) and Iqbal and Kalim (2023) validated energy intensity as a determinant of environment quality. Keeping in mind the findings of Omri *et al.* (2021) and Khan *et al.* (2022), this study considers domestic credit to the private sector by banks as a deteriorating environmental factor. Parallel to the findings of Cheikh and Zaied (2021) and Shah *et al.* (2022), trade openness is also considered an environmental polluting agent.

This study has assumed that maturity in economic activities can bring about environmental sustainability. However, it assumes that the joint venture of knowledge pillars will pave the way for sustainable environmental quality. Following Arshed *et al*. (2021, 2022) and Kalim *et al*. (2023), this study has also captured the moderating effect of the knowledge economy index. This index has a portion of the technology so research partially covers the STIRPAT framework.

3.4 Methodology

The study has adopted several methods to respond to the proposed research questions. Firstly, to empirically test the existence of EKC a non-linear test will be applied. Secondly, the role of the knowledge economy is incorporated in dual ways. As a determinant, its role in mitigating carbon emissions will be tested. At the same time, its moderating role will ease understanding of the EKC's shifting pattern. In this context, the panel quantile regression (PQR) model proposed by Powel (2016) is considered a suitable approach.

The non-existence of unit root and non-normal series justifies the PQR. In order to estimate the regression coefficients, unit root tests will be applied to check whether the series is stationary. As the median is used as a measure of central tendency this technique provides robust estimates in skewed data or when variables are not distributed normally. At the same time, the unobserved heterogeneity is solved through fixed effect specification. As discussed by Wang *et al*. (2021), and Iqbal and Kalim (2023), this technique is proper when variables are non-normally distributed.

The environmental Kuznets curve (EKC) is tested for validity by dividing data into two parts within the aggregate demand range. For a U-shaped EKC, the coefficient of aggregate demand and its square should be negative and positive respectively, plus statistically significant, and the quadratic plot should display similar patterns. Equations A and B are derived from Equations 1 and 4 to identify turning points using first-order derivative methods based on Wainwright's (2005) work.

$$\frac{\partial CO_{2it}}{\partial AD_{it}} = \beta_1 + 2\beta_2 AD_{it}$$

$$\beta_1 + 2\beta_2\, AD_{it} = 0$$

$$AD_{it}^{*} = \frac{-\beta_1}{2\beta_2} --- (A)$$

$$\frac{\partial CO_{2it}}{\partial AD_{it}} = \beta_1 + 2\beta_2\, AD_{it} + \beta_8\, KN_{it}$$

$$\beta_1 + 2\beta_2\, AD_{it} + \beta_8\, KN_{it} = 0$$

$$AD_{it}^{*} = \frac{-\beta_1 - \beta_8\, KN_{it}}{2\beta_2} --- (B)$$

4. Results and Discussion

4.1 Estimated Results

Table 3 below presents mean, median, minimum, maximum values and, additionally, the Jarque-Bera (JB) test is also presented. Further, Figures 2 and 3 are constructed to test the pattern of association. In order to avoid the problem of spurious regression, two-panel unit root tests are applied to disclose whether or not the series is stationary. Therefore, panel unit root tests developed by Levin *et al*. (2002) and Maddala and Wu (1999) are frequently used for stationarity examination, also applied in Table 4 below.

Table 3 goes about here

Figure 2 goes about here **Figure 3 goes about here**

Table 4 goes about here

Table 5 presents estimated results using the PQR approach. Further, using the derivative method the turning point is also presented in the same table. Figures 3 and 4 are constructed to validate the EKC and analyze the percentile-wise moderating effect while Figure 5 compares the turning point values on different percentiles. Figure 6 reflects the behavior of regression coefficients on different data percentiles.

Table 5 goes about here

Figure 4 goes about here **Figure 5 goes about here**

Figure 6 goes about here

Figure 7 goes about here

4.2 Discussion on the Results

In Table 3, the mean and median measure central tendencies while minimum and maximum are the range, and standard deviation shows the rate of difference from the mean. However, CO_2 is under-dispersed as the mean value is less than the standard deviation while the other variables are over-dispersed. The Jarque-Bera (JB) test is statistically significant and implies that the variables are not normally distributed. Therefore, it justifies the use of PQR. Figure 2 depicts a low association among the variables. Only a high coefficient of association ($\geq$ 0.94) indicates the existence of multicollinearity. Figure 3 shows the association of aggregate demand with carbon emissions using the knowledge economy's above and below mean values. A moderating effect is confirmed because changes in the knowledge economy are responsible for changing the EKC's association patterns.

Panel unit root tests developed by Levin *et al*. (2002) and Maddala and Wu (1999) are presented in Table 4. The null hypothesis for both tests states that the series contains a unit root and is rejected in the light of significant test statistics. In this situation an ordinary method to estimate regression coefficients should be adopted (Gujarati, 2022).

In Table 5, the negative and positive coefficients of aggregate demand and its square respectively point out the existence of a U-shaped EKC. Moreover, negative and positive coefficients of aggregate demand before and after turning point samples and a U-shaped quadratic plot validate the U-shaped EKC empirically. It denotes that an initial increase in aggregate demand improves the environmental quality. This is because, in the beginning, expansion in aggregate demand expands the size of the economy, not at the cost of environmental deterioration. Nevertheless, when aggregate demand crosses the limits production follows it and an immense increase in production starts hurting the environmental quality. Studies such as Dogan and Inglesi-Lotz (2020), Arshed *et al*. (2021), and Karahasan and Pinar (2022) have confirmed a U-shaped EKC. Further, with an increase in aggregate demand after 20.026 percent, environmental deterioration starts. In absolute terms, environmental deterioration emerges after an additional escalation of 497.945 million US dollars in aggregate demand. The turning point is obtained using Equation A. Thus, the value of the turning point can be increased, leading to the extended carbon reduction process. This research has empirically validated this scenario (see Figure 5). Comparing the turning point with the mean value of aggregate demand, 152 out of 155 countries have crossed this point. Further, an increase in the turning point value is detected by incorporating the knowledge economy in the model (see supplementary file).

Contradictory to the assumption of the authors, the knowledge economy is deteriorating ecological quality. It inspires economic activities by encouraging economic agents towards more spending. Studies such as Ullah *et al*. (2021), Anser *et al*. (2021), Zhang *et al*. (2022), and Obobisa *et al*. (2022) have validated that the role of technology, innovations, education, and institutions are worsening environmental quality. Nevertheless, the knowledge economy and aggregate demand simultaneously minimize environmental challenges by improving environmental quality as the interaction term's coefficient is negative. Though EKC is partially shifted down, it reflects ecological sustainability.

Positive coefficients of urbanization and energy intensity reflect that these are the polluting agents. Sun and Huang (2020) and Sun *et al*. (2022) have the same point of view about urbanization and recent studies such as Kahn *et al*. (2022), and Iqbal and Kalim (2023) have identical points of view about energy intensity. Due to migration population, the density of urban areas increases. Migrated people require shelter, food, and other basic needs thus putting environmental quality at risk. As a result, environmental depletion starts. Similarly, expansion in production may increase demand for energy consumption to fulfill the gradually increasing demand for goods and services. Its reaction is a polluted environment.

Moreover, the findings of Petrović and Lobanov (2022) and Xu *et al*. (2022) regarding financial development and those of Ibrahim (2022) and Iqbal and Kalim (2023) regarding the findings of trade liberalization are quite similar to the findings of this research. Both are responsible for environmental deterioration. However, banks' domestic credit to the private sector boosts economic activities more than required thus putting pressure on ecosystems. Environmental deterioration due to trade liberalization is common because an increase in the volume of international trade enhances aggregate production volume. Environmental pollution possibly emerges when environmental norms and regulations are not considered in the production process.

4.3 Theoretical and Practical Implications

The theoretical implications include the role of economic development, environmental awareness, regulation, and technological innovation in achieving environmental improvement. Practically, the EKC implies the need for policy prioritization, integrating environmental sustainability into development goals, promoting technology transfer, encouraging green investments, and implementing robust data monitoring systems. By understanding the EKC, policymakers can make informed decisions to balance economic growth with environmental protection, ultimately working towards achieving sustainable development.

The knowledge economy plays a vital role in achieving environmental sustainability. Theoretical implications include the emphasis on knowledge generation, systems thinking, and collaboration among stakeholders. Practical implications involve the development of green technologies, evidence-based policy making, education and awareness, utilization of information and communication technologies (ICT), and the promotion of circular economy and sustainable consumption. By leveraging knowledge, innovation, collaboration, and technology, the knowledge economy provides a pathway to address environmental challenges and promote sustainable development.

5. Conclusion and Implications

The key objective of this study was to test the existence of an aggregate demand based EKC and to analyze the role of the knowledge economy in determining and moderating EKC, something that was a gap in the existing literature on EKCs. The results validated a U-shaped EKC and confirmed the moderating role of the knowledge economy. Further, the countries have crossed the turning point border and suffered from environmental deterioration through escalating aggregate demand behavior. Significantly, work, progress, and global responsibility of the knowledge economy are crucial for sustainable environmental quality. With the knowledge economy in the EKC framework as a moderator, the carbon elimination phase can be extended as it paves the way for achieving sustainability goals. At the same time, urbanization, energy intensity, financial development, and trade openness are environmentally worsening factors.

To formulate suitable environmental policy, urban migration should be controlled by minimizing the difference in rural and urban sectors. Governments should allocate proper resources for rural areas as well. Through sufficient spending on Research & Development(R&D), energy-efficient production processes should be encouraged. Tight monetary policies should be adopted by the authorities to control the engorged economic activities. International trade ensures growth but is responsible for environmental deterioration. In this context, every country should follow the policies formulated by the World Trade Organization[5].

To achieve ecological sustainability, producers should adopt innovative technologies, developed countries should share experiences with developing countries, and governments should subsidize imports and allocate resources for research and development. Education plays a crucial role in changing consumer and producer behavior through awareness on climate change in textbooks. Efficient institutional quality and careful selection of qualified public representatives are necessary for implementing proposed policies for sustainable environmental quality.

This study provides many theoretical and practical implications. The study highlights the connection between how the production process follows the aggregate demand behavior of the economic agents and how aggregate demand affects environmental quality from an EKC perspective. From this perspective, the knowledge economy's global responsibility is highlighted to accomplish sustainable environmental quality. As a result, several policy implications are also presented, highlighting that the knowledge economy is beneficial in transforming aggregate spending patterns. However, this study is only able to cover some things. Other researchers and scholars can accommodate the four knowledge pillars separately to confront environmental challenges for other development and region-wise country groups in different EKC frameworks.

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[5] https://www.wto.org/english/tratop_e/envir_e/climate_intro_e.htm

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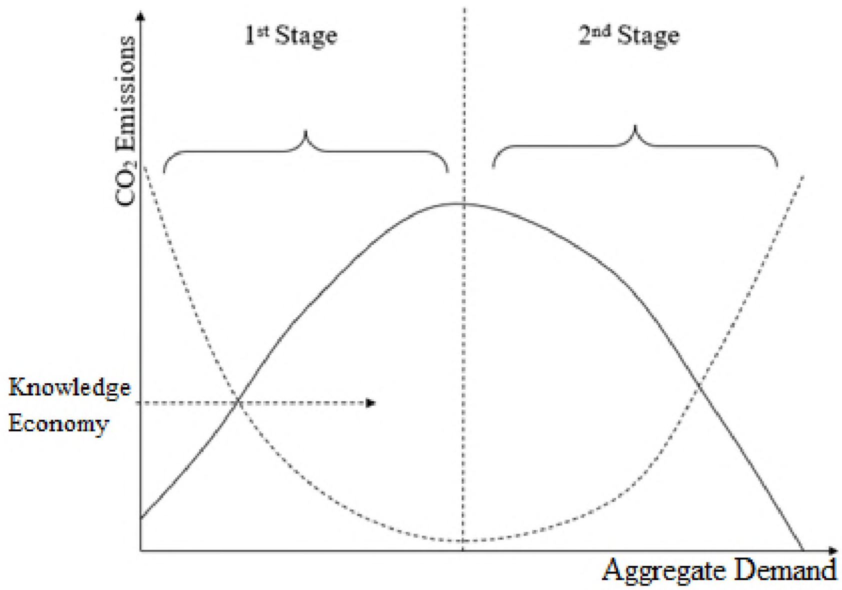
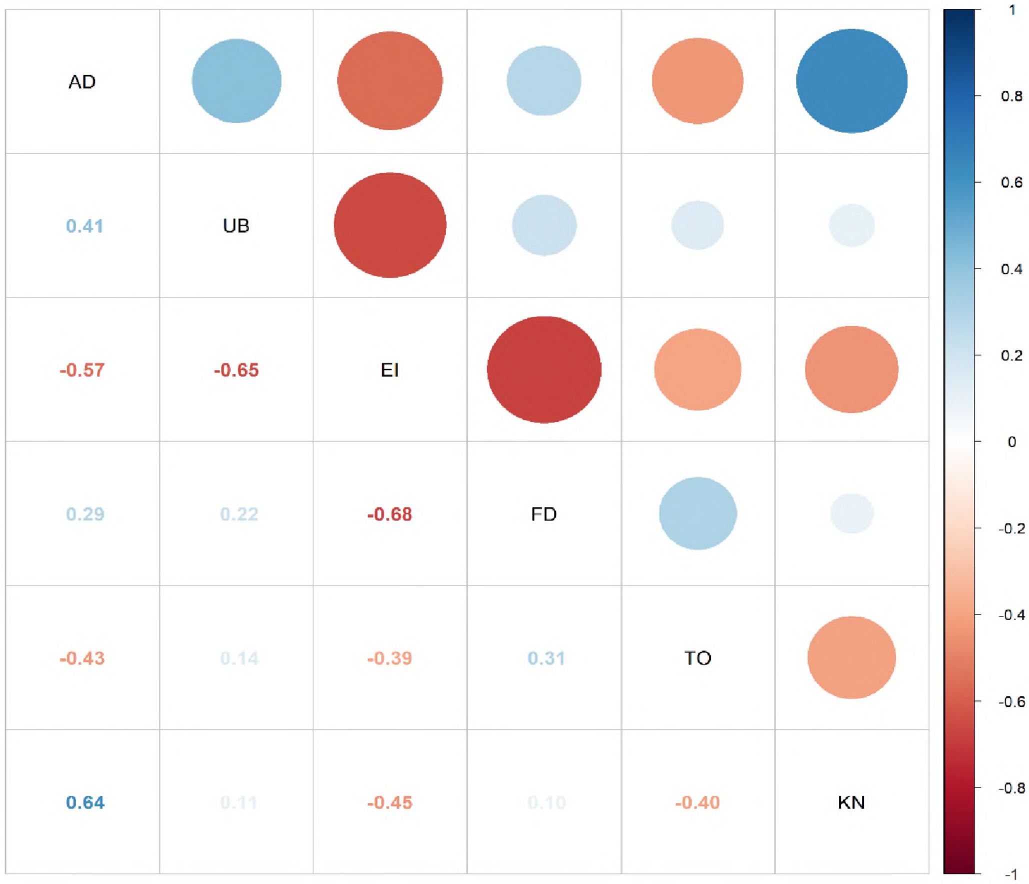
Figures

Figure 1 – Theoretical Model



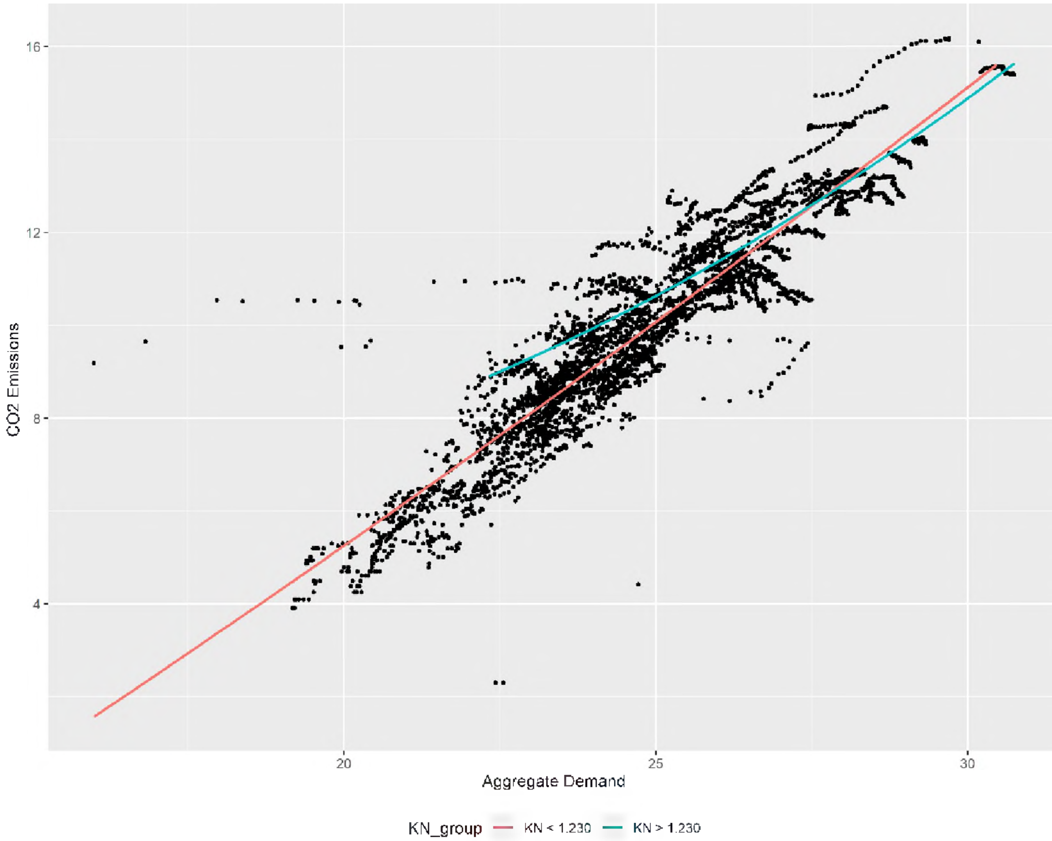
Source: Authors' own work

Figure 2 – Correlation Matrix



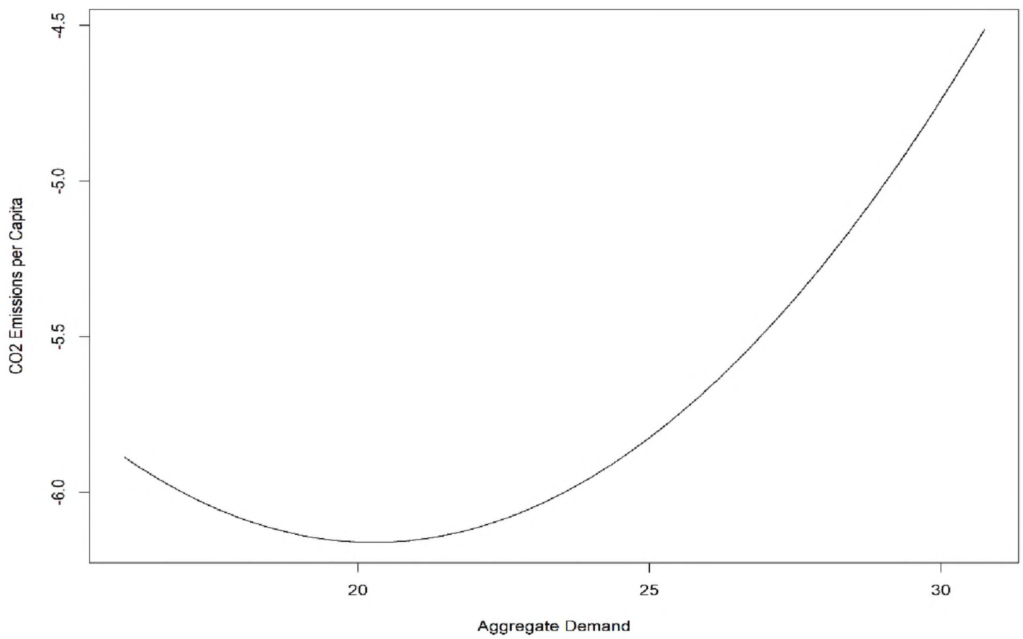
Source: Authors' own work

Figure 3 – Scatter Plot of EKC



Source: Authors' own work

Figure 4 – EKC Fit Plot



Source: Authors' own work

Figure 5 – EKC with Moderator

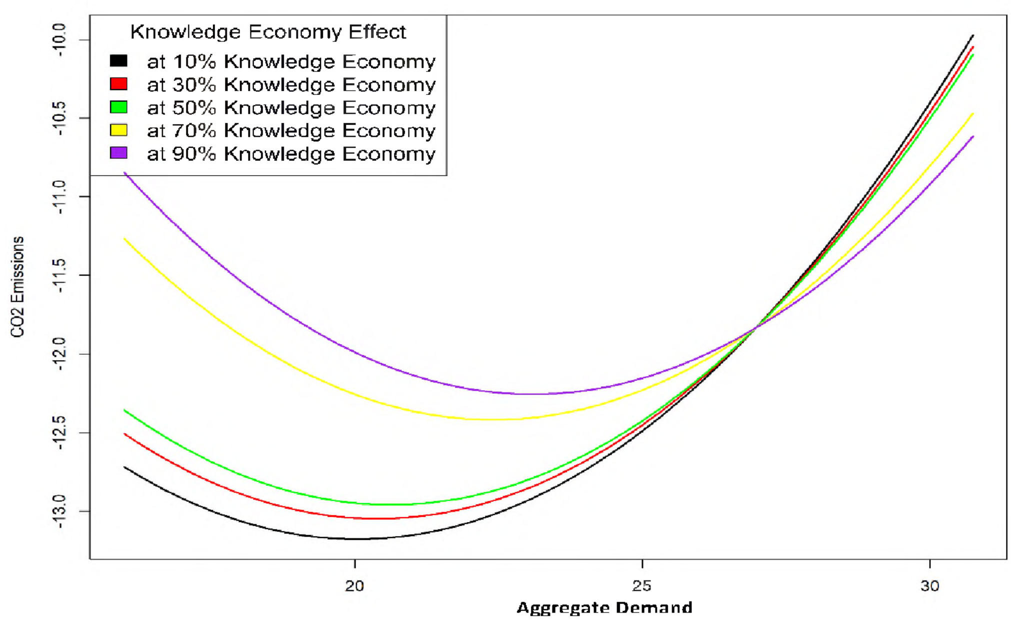


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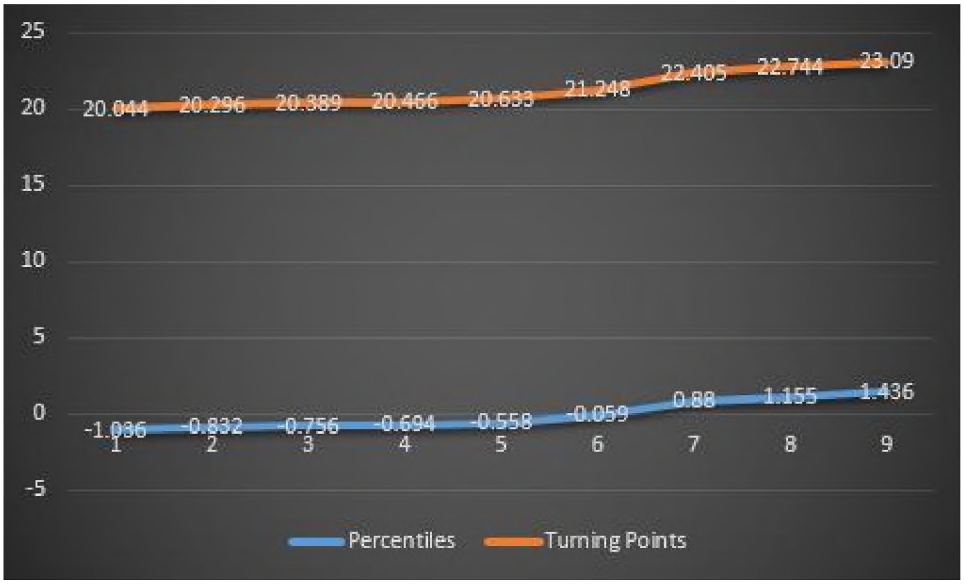
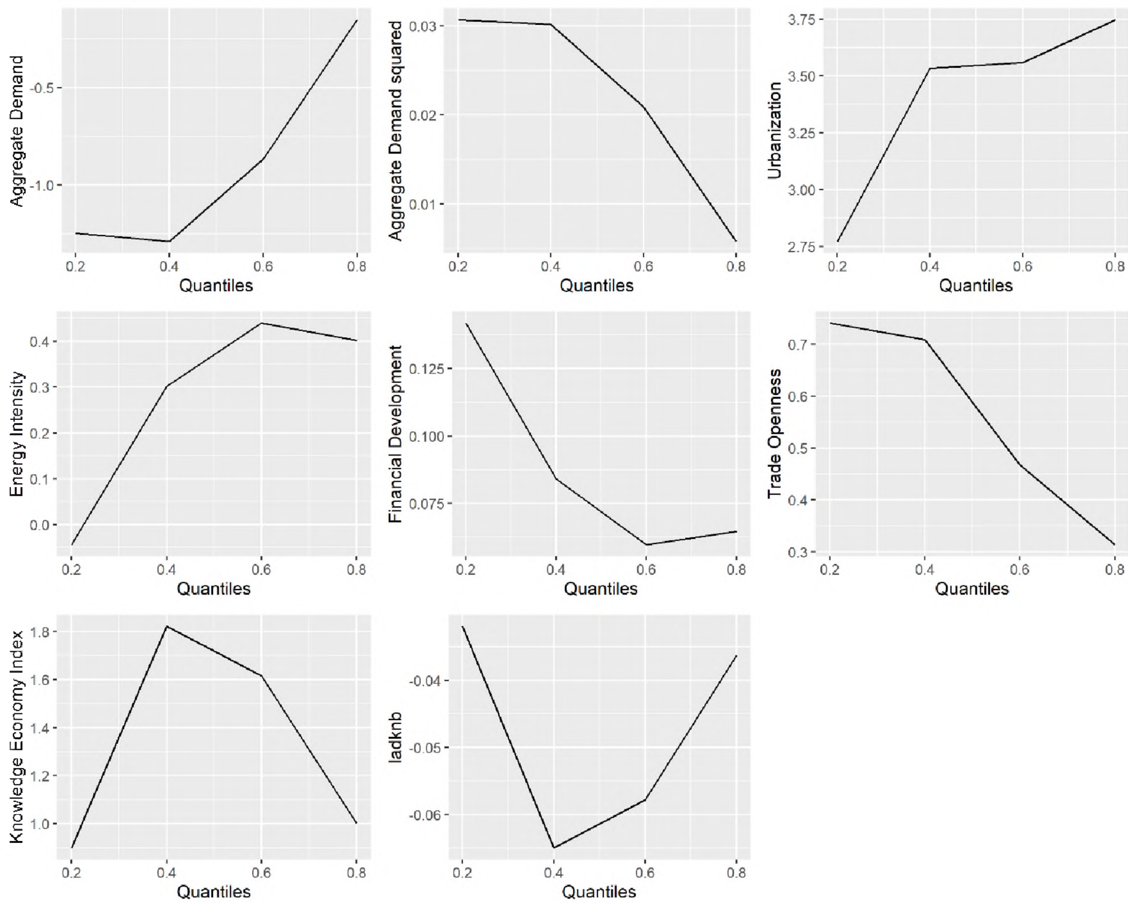
Figure 6 – Percentile-wise Turning Points



Source: Authors' own work

Figure 7 – Quantile Coefficients Slopes of Knowledge Economy Model



Source: Authors' own work

Tables

Table 1 – Literature of EKC

U-Shaped EKC		Inverted U-Shaped EKC	
Citation	**Targeted Sample**	**Citation**	**Targeted Sample**
Destek *et al*. (2018)	For European Union countries	Alsamara *et al*., (2018)	For the Gulf Cooperation Council region
Hove and Tursoy (2019)	For 24 emerging economies	Akadiri *et al*. (2019)	For 15 selected tourism destination states
Gormus and Mucahit (2020)	For the panel of 10 innovative economies	Churchill *et al*. (2020)	For a panel of eight Australian states
Arshed *et al*. (2021)	For a panel of 80 countries	Ahmad *et al*. (2021)	For 11 developing countries
Ongan *et al*. (2022)	For NAFTA	Bilgili *et al*. (2022)	for 36 Asian countries
Kilinc-Ata and Likhachev (2022)	For Russia and Karahasan	Wang *et al*. (2022)	For a panel of 134 countries
Karahasan and Pinar (2022)	For Turkish provinces	Zhenbo and Yan (2022)	For a panel of 274 cities in China

Source: Authors' own work

Table 2 – Literature on Knowledge Indicators

Knowledge Indicator	Role in Environmental Quality	Citations
Technology	Efficient allocation of resources in the production process	Mensah *et al*. (2018), Khan *et al*. (2020) Erdoğan (2021), and Arshed *et al*. (2021)
Innovation	Advancements in cleaner living and methods of production	Mensah *et al*. (2019), Wang and Zhu (2020), Sinha *et al*. (2020), and Ullah *et al*. (2021)
Education	Awareness among the economic agents of society	Cai *et al*. (2018), Omri and Afi (2020), Zaman *et al*. (2021), and Mehmood (2022)
Institutions	Rules and regulations for the attainment of clean environment quality	Danish *et al*. (2019), Haldar and Sethi (2021), Khan *et al*. (2021), Yuan *et al*. (2022), and Kim *et al*. (2022)

Source: Authors' own work

Table 3 – Descriptive Statistics

	CO_2	AD	UB	EI	FD	TO	KN
Mean	0.663	24.727	5.134	1.530	3.095	4.221	0.206
Median	0.959	24.579	5.032	1.488	3.434	4.304	0.346
Maximum	4.423	30.748	15.556	3.339	5.718	6.080	2.705
Minimum	-3.893	15.992	2.195	0.239	-1.681	-0.242	-1.235
Std. Dev.	1.533	2.159	1.508	0.490	1.442	0.782	1.050
JB Test	224.661	9.898	58182.73	95.290	482.946	29553.14	348.325
Prob.	0.000	0.007	0.000	0.000	0.000	0.000	0.000

Source: Authors' own work

Table 4 – LLC and PP-Fisher Unit Root Test

	LLC		PP-Fisher	
	At Level		**At Level**	
Variables	**Statistic**	**Prob.**	**Statistic**	**Prob.**
CO_2	-3.856	0.000	426.439	0.000
AD	-9.959	0.000	470.474	0.000
UB	-1.461	0.072	746.201	0.000
EI	-7.861	0.000	473.841	0.000
FD	-10.006	0.000	358.340	0.014
TO	-1.911	0.028	403.577	0.000
KN	-4.570	0.000	355.859	0.037

Source: Authors' own work

Table 5 – Estimated Models using Panel Quantile Regression

	Baseline Model		**Before Turning Point**		**After Turning Point**		**Knowledge Economy Model**	
Variables	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
AD	-0.608	0.000	-1.341	0.000	0.274	0.000	-1.194	0.000
AD^2	0.015	0.000	-	-	-	-	0.028	0.000
UB	0.718	0.000	0.607	0.000	0.652	0.000	0.583	0.000
EI	0.347	0.000	0.308	0.000	0.358	0.000	0.336	0.000
FD	0.184	0.000	0.448	0.000	0.118	0.000	0.058	0.000
TO	0.557	0.000	0 .111	0.000	0.399	0.000	0.737	0.000
KN	-	-	-	-	-	-	1.861	0.000
AD*KN	-	-	-	-	-	-	-0.069	0.000

Source: Authors' own work

Supplementary File

Technology helps to efficiently utilize the resources in the production process and helps to increase flexibility and efficiency (Arshed *et al*., 2021). At the same time, innovations help to improve existing technologies (Ullah *et al*., 2021). With its help, advancement in cleaner lifestyles as well as methods of production can be encouraged for better environmental quality. Moreover, education can spread awareness among people (Mehmood, 2022) which could, in turn, improve the way people spend money. Stability in the economy's institutions is indispensable for environmental betterment (Kim *et al*., 2022). In addition, only the efficient performance of institutions can smooth the functioning of other knowledge economy pillars.

Table 6 has been created to showcase the role of the knowledge economy in achieving environmental sustainability on a country-by-country basis through an index. It contains the average aggregate demand for every country. Therefore, the average value is greater than the turning point for 152 countries. It implies that these countries have already crossed the turning point and are suffering from environmental deterioration. Downward moderation is already confirmed using Figure 4. However, turning points using the knowledge economy's average have also increased compared to the baseline turning point, indicating that the knowledge economy helps keep carbon emissions low for a longer time for each country.

Table 6 – Country-wise Turning Points Comparison

Countries	AVG AD	Turning Point	AVG KN	Turning Point With KN
Albania	23.017	20.026	-0.241	21.024
Algeria	25.717	20.026	0.008	21.331
Angola	25.026	20.026	-0.655	20.514
Argentina	27.001	20.026	0.826	22.339
Armenia	22.75	20.026	0.455	21.882
Australia	27.889	20.026	0.93	22.467
Austria	26.75	20.026	0.369	21.776
Bahamas, The	23.226	20.026	-0.46	20.754
Bahrain	23.062	20.026	0.175	21.537
Bangladesh	25.668	20.026	0.461	21.889
Belarus	24.512	20.026	0.164	21.523
Belgium	26.961	20.026	-0.721	20.433
Belize	21.199	20.026	-0.638	20.535
Benin	22.963	20.026	-0.807	20.327
Bhutan	21.042	20.026	-0.099	21.199
Bolivia	24.051	20.026	0.192	21.558
Bosnia and Herzegovina	23.643	20.026	1.192	22.790
Botswana	23.254	20.026	-0.397	20.832
Brazil	28.201	20.026	0.968	22.514
Brunei Darussalam	23.423	20.026	-0.491	20.716
Bulgaria	24.535	20.026	0.598	22.058
Burkina Faso	22.921	20.026	-0.996	20.094
Burundi	21.791	20.026	-0.534	20.663

Cabo Verde	20.964	20.026	-0.506	20.697
Cambodia	23.131	20.026	0.438	21.861
Cameroon	23.98	20.026	-1.046	20.032
Canada	28.119	20.026	0.498	21.935
Central African Republic	21.604	20.026	-0.734	20.417
Chad	23.031	20.026	-0.776	20.365
Chile	26.006	20.026	0.533	21.978
China	28.788	20.026	1.4	23.046
Colombia	26.237	20.026	0.695	22.177
Comoros	20.587	20.026	-0.729	20.423
Congo, Dem. Rep.	24.019	20.026	-0.767	20.376
Congo, Rep.	22.921	20.026	-1.024	20.059
Costa Rica	24.631	20.026	0.33	21.728
Cote d'Ivoire	24.397	20.026	-1.026	20.057
Croatia	24.749	20.026	0.574	22.028
Cuba	25.188	20.026	-0.018	21.299
Cyprus	23.801	20.026	0.031	21.359
Czechia	25.982	20.026	0.697	22.180
Denmark	26.577	20.026	0.542	21.989
Djibouti	22.01	20.026	-0.73	20.421
Dominican Republic	24.726	20.026	0.396	21.8096
Ecuador	25.125	20.026	0.56	22.011
Egypt, Arab Rep.	26.348	20.026	0.606	22.068
El Salvador	23.875	20.026	-0.448	20.769
Equatorial Guinea	23.378	20.026	-0.729	20.423

Estonia	23.811	20.026	0.452	21.878
Eswatini	22.118	20.026	-0.789	20.349
Ethiopia	25.141	20.026	-0.114	21.180
Finland	26.325	20.026	0.478	21.910
France	28.648	20.026	0.221	21.593
Gabon	23.317	20.026	-1.013	20.073
Gambia, The	21.05	20.026	-0.088	21.213
Georgia	23.553	20.026	0.67	22.146
Germany	28.922	20.026	1.05	22.615
Ghana	24.624	20.026	-0.585	20.600
Greece	26.229	20.026	-0.427	20.795
Guatemala	24.697	20.026	-0.406	20.821
Guinea	23.016	20.026	-0.564	20.626
Guinea-Bissau	20.726	20.026	-0.818	20.313
Haiti	23.263	20.026	0.06	21.395
Honduras	23.631	20.026	0.294	21.683
Hungary	25.577	20.026	0.576	22.031
Iceland	23.639	20.026	0.404	21.819
India	27.977	20.026	1.033	22.594
Indonesia	27.212	20.026	0.122	21.471
Iran, Islamic Rep.	26.588	20.026	-0.067	21.238
Iraq	25.81	20.026	-0.636	20.537
Ireland	26.175	20.026	-1.047	20.031
Israel	26.392	20.026	0.655	22.128
Italy	28.418	20.026	0.172	21.533

Jamaica	23.509	20.026	-0.102	21.195
Japan	29.24	20.026	0.42	21.838
Jordan	24.191	20.026	0.222	21.594
Kazakhstan	25.523	20.026	0.097	21.440
Kenya	24.777	20.026	-0.376	20.858
Kiribati	19.389	20.026	-0.715	20.440
Korea, Rep.	27.872	20.026	1.137	22.722
Kuwait	25.438	20.026	-0.8	20.335
Kyrgyz Republic	22.5	20.026	0.397	21.810
Lao PDR	23.092	20.026	0.376	21.784
Latvia	23.977	20.026	0.456	21.883
Lebanon	24.399	20.026	-0.444	20.774
Lesotho	21.423	20.026	-0.569	20.620
Libya	23.066	20.026	-0.879	20.238
Lithuania	24.402	20.026	0.448	21.873
Luxembourg	24.463	20.026	-0.787	20.351
Madagascar	23.159	20.026	0.243	21.620
Malaysia	26.185	20.026	0.746	22.240
Maldives	22.383	20.026	-0.771	20.371
Mali	23.136	20.026	-1.009	20.078
Malta	23.101	20.026	0.042	21.373
Marshall Islands	19.491	20.026	-0.728	20.424
Mauritania	22.426	20.026	-0.785	20.354
Mauritius	23.059	20.026	-0.091	21.209
Mexico	27.711	20.026	0.917	22.451

Moldova	22.653	20.026	0.584	22.041
Mongolia	23.223	20.026	0.166	21.525
Montenegro	22.276	20.026	0.169	21.529
Morocco	25.197	20.026	0.032	21.360
Mozambique	22.955	20.026	0.201	21.569
Myanmar	24.521	20.026	-0.924	20.182
Namibia	23.038	20.026	-0.42	20.803
Nepal	23.827	20.026	0.132	21.484
Netherlands	27.493	20.026	-0.657	20.511
New Zealand	25.879	20.026	0.779	22.281
Nicaragua	23.061	20.026	-0.522	20.678
Niger	23.796	20.026	-0.982	20.111
Nigeria	26.445	20.026	-0.344	20.897
North Macedonia	22.934	20.026	-0.544	20.651
Northern Mariana Islands	19.458	20.026	-0.223	21.046
Oman	24.988	20.026	-0.543	20.652
Pakistan	26.12	20.026	0.55	21.999
Panama	24.302	20.026	0.301	21.692
Paraguay	24.133	20.026	-0.066	21.240
Peru	25.71	20.026	0.155	21.512
Philippines	26.17	20.026	0.32	21.715
Poland	26.804	20.026	0.772	22.272
Portugal	26.168	20.026	0.574	22.028
Romania	25.82	20.026	0.686	22.166
Russian Federation	27.871	20.026	1.034	22.595

Rwanda	22.444	20.026	-0.1	21.198
Saudi Arabia	27.161	20.026	-0.282	20.973
Senegal	23.462	20.026	-1.039	20.041
Serbia	24.386	20.026	0.435	21.857
Sierra Leone	21.942	20.026	-0.473	20.738
Singapore	25.54	20.026	0.544	21.991
Slovak Republic	25.126	20.026	0.742	22.235
Slovenia	24.549	20.026	0.401	21.815
Solomon Islands	20.846	20.026	-0.761	20.383
South Africa	26.535	20.026	0.743	22.236
Spain	27.885	20.026	0.78	22.282
Sri Lanka	24.771	20.026	0.252	21.631
Sudan	26.302	20.026	0.263	21.645
Sweden	27.03	20.026	0.351	21.753
Switzerland	27.243	20.026	0.751	22.246
Syria	23.977	20.026	-0.4	20.828
Tanzania	24.244	20.026	-0.641	20.531
Thailand	25.786	20.026	0.793	22.298
Timor-Leste	21.463	20.026	-0.655	20.514
Togo	21.951	20.026	-0.992	20.099
Tonga	20.089	20.026	-0.456	20.759
Tunisia	24.289	20.026	-0.73	20.421
Türkiye	27.037	20.026	0.582	22.038
Uganda	23.842	20.026	-0.148	21.139
Ukraine	25.452	20.026	0.818	22.329

UAE	26.567	20.026	0.503	21.941
United Kingdom	28.786	20.026	0.842	22.358
United States	30.533	20.026	1.21	22.812
Uruguay	24.423	20.026	0.141	21.496
Uzbekistan	24.717	20.026	0.708	22.193
Vanuatu	20.418	20.026	-0.739	20.410
Zimbabwe	22.469	20.026	-0.376	20.858

Source: Authors' own work