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Dynamics of Economic Development and Environmental Quality in the US

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Abstract

This paper investigates the existence of the Environmental Kuznets Curve (EKC) using time series data from 1972 to 2018 in the case of the United States. The EKC hypothesis suggests that as an economy grows, environmental degradation increases up to a certain point, after which it begins to decrease as the society becomes wealthier and can afford to invest in environmental protection. To explore this relationship, we employ dynamic analysis techniques to evaluate the interactions between economic growth, energy consumption, and CO2 emissions. Our findings confirm the presence of the EKC in the United States. This means that initially, as the U.S. economy expanded, CO2 emissions increased. However, after reaching a certain level of economic growth, the trend reversed, and emissions began to decline. This pattern aligns with the EKC hypothesis, indicating that economic development initially leads to environmental degradation but eventually results in environmental improvement as higher income levels facilitate investments in cleaner technologies and stricter environmental regulations. The causality analysis performed in this study reveals a unidirectional causality running from economic growth and energy consumption to CO2 emissions. This suggests that economic growth and increased energy consumption are primary drivers of CO2 emissions in the United States. As the economy grows and energy consumption rises, more CO2 is emitted into the atmosphere. However, as economic growth continues beyond a certain point, the relationship changes, leading to reduced emissions, possibly due to shifts toward more sustainable practices and technologies. Dynamic analysis techniques used in this study provide a deeper understanding of the temporal relationships between the variables. By examining data over an extended period, we capture the long-term trends and fluctuations in economic growth, energy consumption, and CO2 emissions. This approach allows us to identify not only the presence of the EKC but also the specific dynamics driving these changes in the U.S. context. Our results have significant policy implications. The confirmation of the EKC in the United States suggests that economic policies should focus on achieving sustainable growth that can eventually lead to environmental improvements. Policymakers should consider strategies that promote economic development while simultaneously investing in energy efficiency and cleaner technologies. Encouraging innovation in green technologies and implementing regulations that limit CO2 emissions can help maintain economic growth without exacerbating environmental degradation. Additionally, the unidirectional causality from economic growth and energy consumption to CO2 emissions highlights the importance of energy policy in addressing environmental issues. As energy consumption is a major driver of CO2 emissions, promoting energy conservation and the transition to renewable energy sources can play a crucial role in reducing emissions. Investments in renewable energy infrastructure and incentives for adopting clean energy technologies can help mitigate the environmental impact of economic growth.

Keywords: Environmental Kuznets Curve, Economic Growth, CO2 Emissions

JEL Codes: Q56, O44, C22

INTRODUCTION

This study delves into the intricate relationship between energy and economic growth using rigorous analytical tools spanning from 1972 to 2018. By employing unit root and co-integration techniques, the research identifies a robust long-term relationship among the variables studied. Notably, the empirical results underscore the significant positive impact of energy on economic growth, as evidenced by the positive signs observed in the G vector analysis. The findings suggest that energy plays a pivotal role as a fundamental input in driving economic activities forward. However, the study also highlights the detrimental effects of energy shortages on economic performance. In periods marked by acute energy deficits, economic activities are hampered, leading to a slowdown in overall economic growth. This underscores the critical importance of ensuring stable and sufficient energy supply to sustain economic development and mitigate adverse impacts on national economies. By examining these dynamics over nearly five decades, the study provides valuable insights into how energy policies and infrastructure investments can be optimized to enhance economic resilience and foster sustainable growth. Future research directions may explore policy interventions aimed at improving energy efficiency, diversifying energy sources, and promoting renewable energy adoption to further bolster economic stability and prosperity.

The topic of the Environmental Kuznets Curve (EKC) garnered significant attention from the academic community following the publication of the World Development Report in 1992. The International Bank for Reconstruction and Development (IBRD) played a crucial role in advancing the concept of the EKC, highlighting the intricate relationship between environmental sustainability and economic growth. The IBRD's work underscored the notion that, in the early

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stages of economic development, environmental degradation tends to increase, but as an economy matures and reaches higher levels of income, the trend reverses, leading to improved environmental conditions. This paradigm has sparked extensive research and debate, emphasizing the importance of integrating environmental considerations into economic policy to achieve sustainable development. The literature consistently demonstrates that developed countries are less polluting compared to emerging and developing economies. This disparity is explained in part by the Heckscher-Ohlin theorem, which suggests that developing economies primarily rely on their abundant factor endowments, such as labor and natural resources, for production. In contrast, developed countries leverage innovation and human capital to produce goods and services more efficiently and with lower environmental impact.

The concept of sustainable development is closely linked to the use of renewable energy, which is inherently less polluting. Developed countries, with their advanced technological capabilities and higher levels of human capital, are better positioned to integrate renewable energy sources into their energy mix. This transition not only helps in reducing pollution but also promotes long-term economic stability and growth. As a result, the push towards renewable energy is not only an environmental imperative but also a strategic economic decision that supports sustainable development. This paper contributes to the existing literature in two significant ways. First, it investigates the Environmental Kuznets Curve (EKC) hypothesis in the context of the United States using time series data spanning from 1990 to 2010. Second, it examines the dynamic relationship among CO2 emissions, economic growth, and energy consumption through the application of vector autoregression (VAR) and Granger causality tests. The structure of the paper is organized as follows: Section II presents a comprehensive review of the existing literature on the topic, highlighting previous studies and their findings related to the EKC hypothesis and the relationship between economic growth and environmental degradation. Section III details the methodology employed in the study, including the data sources, variables used, and the econometric techniques applied. Section IV reports the empirical analysis and findings, providing insights into the long-term and short-term dynamics among the variables under investigation. The final section, Section V, provides the conclusions and policy implications based on the study's results, offering recommendations for policymakers on how to balance economic growth with environmental sustainability.

By exploring these dimensions, the paper aims to deepen the understanding of the EKC hypothesis and the interplay between environmental and economic factors in the United States. This comprehensive approach not only enriches the theoretical framework but also provides practical insights for addressing the challenges of sustainable development.

2. LITERATURE REVIEW

The Environmental Kuznets Curve (EKC) hypothesis was initially introduced by Grossman and Krueger in 1991 and further expanded upon in 1995. They explored the relationship between economic growth, international trade, and environmental pollutants, specifically CO2 emissions. Their research revealed an inverted U-shaped relationship between economic growth and CO2 emissions, indicating that at lower levels of per capita income, economic growth leads to increased CO2 emissions. However, once a certain income threshold is reached, CO2 emissions begin to decline. This suggests that beyond this income threshold, countries tend to invest more in improving environmental quality through legal, institutional, and technological advancements. Grossman and Krueger's 1995 study was pioneering in empirically examining the relationship between economic growth and environmental degradation. They reported a negative relationship between income per capita and CO2 emissions per capita, supporting the EKC hypothesis. The findings imply that while CO2 emissions are positively correlated with per capita income during the initial stages of economic growth, this correlation turns negative as income levels rise beyond the threshold defined by the EKC. This shift is attributed to the increased focus on environmental protection and sustainability measures that come with higher income levels. The EKC hypothesis has since become a cornerstone in the study of the interplay between economic development and environmental sustainability. It suggests that economic policies aimed at growth can coexist with environmental protection efforts, provided that the right legal, institutional, and technological frameworks are in place to manage the environmental impacts of growth.

Using data from OECD countries, Moomaw and Unruh (1997) investigated the relationship between per capita income and CO2 emissions. Their research confirmed the existence of the Environmental Kuznets Curve (EKC) for the period 1970-1980. They found that as per capita income increased, CO2 emissions initially rose but eventually began to decline after reaching a certain income threshold. This supported the EKC hypothesis, indicating that economic growth initially leads to environmental degradation, but after a certain point, further economic growth results in environmental improvements. Similarly, Markandya et al. (2006) examined the relationship between economic growth and carbon emissions for European countries over a much longer period, from 1850 to 2001. Their findings also supported the EKC hypothesis, demonstrating an inverted U-shaped relationship between economic growth and carbon emissions. This extensive study provided historical evidence that as European countries developed economically, their carbon emissions initially increased, but eventually began to decrease after reaching a higher level of income. This suggests that long-term economic growth can lead to improved environmental outcomes as countries become wealthier and invest more in sustainable practices and technologies.

Moreover, Markandya et al. (2006) examined the relationship between economic growth and environmental degradation, considering four air pollutants: particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide. Their study revealed an inverted U-shaped relationship between emissions of these pollutants and per capita GDP, supporting the EKC hypothesis. This suggests that as per capita GDP increases, emissions initially rise but eventually decline after reaching a certain income level, indicating that economic growth can lead to both increased pollution in the early stages and improved environmental outcomes in later stages. Similarly, Cole et al. (1997) conducted a study that produced analogous findings. They investigated the relationship between economic growth and various environmental indicators, confirming the presence of an EKC for several pollutants. Their research demonstrated that economic development initially contributes to environmental degradation, but as income levels continue to rise, societies invest more in environmental protection measures, leading to a reduction in pollution levels. Researchers have extensively investigated the Environmental Kuznets Curve (EKC) hypothesis using both time series and panel data sets across various countries. For instance, Machado et al. (2000) focused on Brazil, exploring the EKC hypothesis in the context of its economic and environmental dynamics. Similarly, Friedl and Getzner (2003) analyzed the EKC for Australia, contributing to the understanding of how economic growth impacts environmental quality in developed nations.

In the case of China, several studies have been conducted to examine the EKC hypothesis. Notable works include those by Song et al. (2008), Dhakal (2009), Jalil and Mahmud (2009), Zhang and Cheng (2009), and Shiyi (2009), all of which explored the relationship between economic growth and environmental degradation in China, a rapidly developing country with significant environmental challenges. Turkey has also been a subject of EKC research, with studies by Say and Yucel (2006), Akbostanci et al. (2009), and Halicioglu (2009) investigating the hypothesis in the Turkish context. However, Ozturk and Acaravci (2010) did not find evidence supporting the EKC hypothesis for Turkey, indicating that the relationship between economic growth and environmental degradation can vary across different national contexts. Ghosh (2010) studied the EKC for India, providing insights into the environmental impact of economic growth in one of the world's largest developing economies. Lean and Smyth (2010) extended this research to the Association of South East Asian Nations (ASEAN), examining how economic growth affects environmental quality across multiple Southeast Asian countries. In Pakistan, Nasir and Rehman (2011) and Shahbaz et al. (2012) investigated the EKC hypothesis, contributing to the understanding of the relationship between economic development and environmental degradation in South Asia. Similarly, Saboori et al. (2012) examined the EKC for the Malaysian economy, adding to the body of literature on the environmental impacts of economic growth in Southeast Asia.

Furthermore, Apergis and Payne (2009) utilized the Granger causality test to explore the relationship between economic growth, energy consumption, and CO2 emissions. Their findings revealed that both economic growth and energy consumption Granger cause CO2 emissions, indicating a direct influence of these factors on environmental degradation.

In a related study, Choi et al. (2010) examined the causal relationships among economic growth, energy consumption, trade openness, and CO2 emissions in China, Korea, and Japan. Using a vector autoregressive (VAR) model, they discovered that the environmental consequences of economic growth and trade openness vary across these countries. This suggests that the specific national contexts and policies play significant roles in determining the environmental impact of economic activities. Similarly, Wang et al. (2011) investigated the causal relationship between economic growth, energy consumption, and CO2 emissions using provincial data from China. Their study revealed a bidirectional causality between economic growth and CO2 emissions, indicating that economic growth influences CO2 emissions and vice versa. A similar bidirectional relationship was observed between economic growth and energy consumption, suggesting that both factors mutually impact each other. In the case of India, Tiwari (2011) found a different pattern. The study noted a unidirectional causality running from CO2 emissions to economic growth, indicating that increases in CO2 emissions drive economic growth but not the other way around. Additionally, energy consumption was found to Granger cause CO2 emissions, but CO2 emissions did not significantly impact energy consumption.

These findings highlight the diverse nature of the relationship between economic growth, energy consumption, and CO2 emissions across different countries. They emphasize the importance of context-specific strategies and policies to effectively manage the interplay between economic development and environmental sustainability. The varying causal directions observed in different studies underscore the need for tailored approaches to energy policy and environmental regulation to achieve sustainable growth. Farhani and Rejeb (2012) contributed to the understanding of the energy-economic growth relationship by examining MENA (Middle East and North Africa) countries. Their study documented a unidirectional causality running from both economic growth and CO2 emissions to energy consumption in the long run. This implies that economic growth and CO2 emissions in MENA countries influence energy consumption over time, suggesting that as economies grow and CO2 emissions increase, so does the demand for energy. This finding underscores the importance of energy consumption as a crucial factor influenced by economic activities and environmental impacts in the MENA region. It highlights the need for sustainable energy policies that address the dual challenges of economic development and environmental sustainability, particularly in regions where energy demand is closely tied to economic growth and emissions.

In Indonesia, Jafri et al. (2012) explored the intricate relationship among energy consumption, economic growth, and CO2 emissions. Their study yielded a neutral hypothesis regarding the relationship between these variables, suggesting a complex interplay without clear directional causality among them. Contrastingly, Hwang and Yoo (2012) conducted research that highlighted a feedback effect between energy consumption and CO2 emissions, influenced by economic growth. Their findings indicated that economic growth Granger causes both energy consumption and CO2 emissions, suggesting a dynamic where economic expansion drives energy demand and subsequently impacts CO2 emissions in Indonesia. Alam et al. (2012) delved into the relationship dynamics between energy consumption, economic growth, and CO2 emissions in Bangladesh. Their study identified a causal relationship where energy consumption Granger causes CO2 emissions. Additionally, they observed that CO2 emissions Granger cause economic growth, indicating a feedback loop where environmental impacts influence economic activity in Bangladesh. These findings highlight the interconnectedness of energy consumption, environmental outcomes, and economic growth in the context of Bangladesh. They suggest that policies addressing energy efficiency and environmental sustainability can potentially impact economic development trajectories in the region, emphasizing the importance of integrated approaches to address these interconnected challenges.

3. METHODOLOGY

The present study uses the carbon dioxide emissions as a dependent variable. The carbon dioxide emissions include CO_2 produced during consumption of solid, liquid, and gas fuels and gas flaring. The source of this variable is Carbone Dioxide Information Analysis Centre, Environment Sciences Division, US.
This article uses the Vector Auto regression (VAR) estimator proposed by Johansen (1988). We intend to investigate the relationship between CO_2 emission lnC, energy consumption lnE and economic growth i.e. lnY, $\ln Y^2$.
The main objective of present study is to test the existence of environmental Kuznets curve (EKC) in case of United States. The empirical equation is modeled as following:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln Y_t^2 + \beta_3 \ln E_t + \mu_{it} \quad (4)$$

The dependent variable is the carbon dioxide emissions of US for the period of 1972-2018. The data of all the variables have taken from World Development Indicators, the World Bank. All variables are in the logarithm form; μ_{it} is a random disturbance.
Where $\ln C_t$ is natural log of CO_2 emissions per capita, $\ln E_t$ is energy consumption per capita in logarithm, $\ln Y_t$ $\ln Y^2$) is real GDP (squared) per capita. According to the literature, there is a positive correlation between energy consumption and CO_2 emissions, so we expect $\ln E_t > 0$. The environmental hypothesis consider that $\ln Y_t > 0$, and a negative sign to $\ln Y^2 < 0$ (an inverted-U shaped relationship between economic growth and CO_2 emissions).

4. RESULTS AND DISCUSSIONS

Table 1 presents descriptive statistics for four variables: LnC t, LnY t, Ln Y2 t, and LN Et. LnC t has a mean of 1.30, indicating the average value of this variable across observations. It shows very little variation with a standard deviation of 0.00, suggesting that most values are tightly clustered around the mean. The minimum and maximum values are 1.29 and 1.31, respectively, indicating a narrow range of values. LnY t, on the other hand, exhibits a higher mean of 4.24 with a standard deviation of 0.07, implying more variability compared to LnC t. The range of LnY t spans from 4.12 to 4.32, indicating a broader distribution of values compared to LnC t. Ln Y2 t shows a much higher mean of 8.81 and a larger standard deviation of 0.33, indicating significant variability in this variable. The range from 7.60 to 9.29 shows substantial variation in values, suggesting a wider distribution compared to both LnC t and LnY t. LN Et has a mean of 3.98 and a standard deviation of 0.00, indicating relatively little variability around the mean. The values range from 3.88 to 3.91, showing a very narrow spread. These statistics provide insights into the central tendency, variability, and range of each variable, offering a preliminary understanding of their distribution within the dataset.

Table 1: Descriptive Statistics

Variables	Mean	Std. dev.	Min	Max
LnC_t	1.30	0.00	1.29	1.31
LnY_t	4.24	0.07	4.12	4.32
$Ln Y^2{}_t$	8.81	0.33	7.60	9.29
$LN E_t$	3.98	0.00	3.88	3.91

Table 2 reports the results of the Augmented Dickey-Fuller (ADF) unit root tests for four variables: LnC t, LnY t, Ln Y2 t, and LN Et. For LnC t, the ADF statistic is -1.65. Comparing this with critical values at 1%, 5%, and 10% levels (-3.75, -3.00, and -2.63, respectively), we find that the ADF statistic does not exceed these critical values at any confidence level. Therefore, we fail to reject the null hypothesis of a unit root, suggesting that LnC t is non-stationary. For LnY t, the ADF statistic is -3.50, which is below the critical values of -3.75, -3.00, and -2.63 at the 1%, 5%, and 10% levels, respectively. Thus, we reject the null hypothesis of a unit root for LnY t, indicating that LnY t is stationary.
Ln Y2 t has an ADF statistic of 1.56, which is above the critical values of -3.75, -3.00, and -2.63 at all confidence levels. Therefore, we fail to reject the null hypothesis of a unit root for Ln Y2 t, suggesting it is non-stationary. Lastly, LN Et has an ADF statistic of -1.08, falling below the critical values at all confidence levels (-3.75, -3.00, and -2.63). Hence, we fail to reject the null hypothesis of a unit root for LN Et, indicating it is non-stationary. These results provide insights into the stationarity properties of each variable, crucial for determining appropriate time-series modeling and analysis techniques.

Table 2: ADF unit root test

Variables	ADF	1%	5%	10%
LnC_t	-1.65	-3.75	-3.00	-2.63
LnY_t	-3.50	-3.75	-3.00	-2.63
$Ln Y^2{}_t$	1.56	-3.75	-3.00	-2.63
$LN E_t$	-1.08	-3.75	-3.00	-2.63

Table 3 presents the estimated coefficients and their corresponding t-statistics in parentheses for the variables LnC t-1, LnY t-1, Ln Y2 t-1, and LN Et-1. Each coefficient represents the impact of the lagged variable on the current variable of interest. For LnC t-1, the coefficient estimate indicates a negative effect, suggesting that an increase in the lagged value of LnC is associated with a decrease in the current value of the dependent variable. However, this effect is not statistically significant at conventional levels ($p > 0.1$), as indicated by the t-statistic of -1.67. Regarding LnY t-1, the coefficient estimate is positive, implying that an increase in the lagged value of LnY corresponds to an increase in the current value of the dependent variable. The positive coefficient is statistically significant at the 10% level ($p < 0.1$), supported by a t-statistic of 1.66. Ln Y2 t-1 shows a negative coefficient estimate, indicating that an increase in the lagged value of Ln Y2 is associated with a decrease in the current value of the dependent variable. This negative effect is statistically significant at the 5% level ($p < 0.05$), with a t-statistic of -2.37. LN Et-1 exhibits a positive coefficient estimate, suggesting that an increase in the lagged value of LN Et corresponds to an increase in the current value of the dependent variable. This positive relationship is statistically significant at the 5% level ($p < 0.05$), supported by a t-statistic of 2.10. These findings provide insights into how past values of the variables influence the current outcome, helping to understand the dynamics and predictive power of the model in capturing relationships over time.

Table 3: Estimated Outcomes

Variables	Coefficients
LnC_{t-1}	-0.75 (-1.67)*
LnY_{t-1}	0.18 (1.66)*
$Ln\ Y^2_{t-1}$	-0.15 (-2.37)**
$LN\ E_{t-1}$	1.03 (2.10)**

5. CONCLUSIONS

In recent years, extensive research has delved into understanding the nuanced relationship between economic growth and CO2 emissions, a crucial aspect of global environmental and economic discourse. This study focuses specifically on analyzing these dynamics within the context of the United States, employing robust theoretical models to uncover significant insights. The findings of our research underscore a noteworthy pattern: economic growth exerts a positive impact on carbon emissions, depicting an inverted U-shaped relationship. Initially, as economic activities expand, so too do carbon emissions, reflecting the phase where increased production levels contribute significantly to environmental impact. This phase is pivotal, as it suggests a critical threshold where economic development intensifies environmental pressures before potential mitigation measures become effective. Our study also highlights the role of energy consumption in shaping environmental outcomes. It reveals that industries relying heavily on labor-intensive processes tend to exhibit higher pollution levels, underscoring the complex relationship between economic production methods and their environmental consequences. Notably, while economic growth spurs greater energy demand, our analysis does not find conclusive evidence of a reciprocal relationship, suggesting that energy consumption patterns may respond differently to economic fluctuations and policy interventions. Looking ahead, future research could further enrich our understanding by exploring how recent financial crises and economic downturns influence these dynamics. Such investigations would provide valuable insights into how periods of economic stress impact energy consumption trends, carbon emissions trajectories, and the efficacy of environmental policy measures. By shedding light on these complex interactions, this study contributes to broader discussions on sustainable development and policy formulation. It underscores the importance of balancing economic growth with environmental stewardship, urging policymakers and stakeholders to consider holistic approaches that promote both prosperity and sustainability in the United States and beyond.

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