Does Economic Growth Lead to Environmental Improvement? An EKC Study of South Korea's Carbon Dioxide Emissions

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Introduction

The Environmental Kuznets Curve (EKC) proposes that pollution increases as an economy advances through early stages of industrialization, but later reaches a turning point, beyond which higher income levels correspond to declining environmental impacts (Grossman and Krueger 1995; Panayotou 1993). This idea, sometimes visualized as an inverted U-shape, has sparked significant debate over whether growth alone ensures eventual reductions in emissions or if additional policies are necessary (Dinda 2004; Yandle, Vijayaraghavan, and Bhattarai 2002). Numerous empirical studies have tested the EKC in various regions and for different pollutants, yet results often diverge because of differences in data sources, economic structures, and enforcement of regulations (Magnani 2000; Stern 2004).

This paper focuses on South Korea, chosen for its rapid industrial transformation, to investigate how gross domestic product per capita correlates to carbon dioxide emissions over a multi-decade period (Ha & Byrne, 2019). The analysis centers on determining whether a clear turning point emerges, suggesting that continued income growth might ultimately lead to improved environmental outcomes (Grossman and Krueger 1995; Panayotou 1993). It also addresses whether external factors, such as technological upgrades or changes in energy policy, play a crucial role in shaping the EKC pattern (Torras and Boyce 1998). The following sections first provide background and context by tracing key theoretical perspectives and critiques of the EKC. Next, a methodology and data collection discussion explains the selection of macroeconomic and emissions indicators, as well as the rationale for using a log-transformed regression approach. The subsequent analysis of findings compares the observed relationship with theoretical predictions, identifies whether a peak is present in the data, and explores policy implications. Finally, the conclusion considers how these results inform both South Korea's economic policy and the broader understanding of the EKC.

Background and Context

The Environmental Kuznets Curve (EKC) suggests that environmental degradation often rises in the early stages of economic development, but eventually declines once income surpasses a certain threshold (Grossman and Krueger 1995; Magnani 2000). This inverted U-shaped relationship implies that, at higher income levels, countries may have more resources to invest in cleaner technologies and better regulations (Stern 2004; Yandle, Vijayaraghavan, and Bhattarai 2002). Supporters of the EKC argue that liberalized trade can encourage environmental improvements (Radetzki 1992), while rising income has been linked to gains in air and water quality after a critical level is reached (Grossman and Krueger 1995).

However, critics warn that economic growth alone does not guarantee environmental recovery (Arrow et al. 1995). Magnani (2000) emphasizes that well defined property rights and democratic institutions enhance policy effectiveness, whereas Bimonte (2000) notes that increased education can shift public preferences toward stricter environmental protection. Furthermore, Torras and Boyce (1998) contend that a more equitable distribution of power helps communities harmed by pollution influence policy decisions, instead of leaving control to those who benefit from polluting activities.

South Korea provides a revealing case for examining the EKC, as the country experienced rapid industrial expansion and saw gross domestic product per capita multiply over the past decades (OECD 2024). While this growth fueled substantial improvements in infrastructure and technology, it also raised concerns about carbon dioxide emissions and other pollutants. Understanding whether South Korea has reached the EKC turning point is critical for informing policy interventions aimed at balancing economic growth with environmental sustainability.

Data & Methodology

All data for this study come from the World Bank's World Development Indicators (World Bank 2025). After downloading the full country dataset for South Korea, the relevant features, CO_2

emissions per capita (excluding LULUCF) and gross domestic product (GDP) per capita, were extracted into a Microsoft Excel spreadsheet for further analysis. To control for price inflation and enable more reliable comparisons across years, GDP per capita is measured in constant US dollars, rather than purchasing power parity (PPP) (Magnani 2000). Meanwhile, CO_2 emissions are expressed in metric tons per capita, providing a standardized gauge of environmental impact. Focusing on South Korea is justified by its rapid industrial expansion and transition to a high-tech, export-driven economy, making it a compelling context in which to assess whether economic growth eventually mitigates or amplifies pollution levels (OECD 2024).

The final dataset spans 54 observations, covering 1970 to 2023. This multi-decade window is long enough to capture potential shifts in the relationship between income and emissions, a core premise of the Environmental Kuznets Curve (EKC) hypothesis (Dinda 2004). Tracking both GDP per capita and CO_2 emissions over multiple decades increases the likelihood of detecting whether a turning point exists, aligning with the idea that early industrialization may raise pollution, while later stages of development could see environmental improvements (Grossman and Krueger 1995; Panayotou 1993; Dinda 2004.

To investigate whether South Korea's carbon dioxide (CO_2) emissions follow an Environmental Kuznets Curve (EKC) pattern, this study employs a log-quadratic regression model. Such models are widely used in EKC literature (Grossman and Krueger 1995; Panayotou 1993; Stern 2004) because they capture the possibility of an inverted U-shaped relationship between emissions and income. Formally, the model can be expressed as:

$$\ln(E_t) = \beta_0 + \beta_1 * \ln(G_t) + \beta_2 * [\ln(G_t)]^2 + \varepsilon_t \tag{1}$$

where E_t denotes CO_2 emissions per capita in year t, G_t stands for real GDP per capita in year t, and ε_t is the error term. A positive β_1 combined with a negative β_2 would indicate the classic EKC pattern, meaning emissions initially rise with income but eventually decline. The point at which emissions reach their maximum is the turning point, given by:

$$Turning\ Point = \exp\left(-\frac{\beta_1}{2*\beta_2}\right) \tag{2}$$

which shows the income per capita level at which the slope changes from positive to negative.

Both a linear ($\ln(E_t)$ on $\ln(G_t)$) and quadratic (Equation (1)) model were considered to see if emissions follow a strictly monotonic trend or if they peak at higher income levels (Yandle, Vijayaraghavan, and Bhattarai 2002). The data was log-transformed to linearize potential exponential growth patterns. An Ordinary Least Squares (OLS) regression was performed using Excel's Data Analysis ToolPak, generating coefficients, t-statistics, p-values, and measures of fit (e.g., R square, F-statistic). While the linear approach revealed a strong correlation, the quadratic specification achieved a higher R square, suggesting that allowing for a turning point better reflects how CO_2 emissions relate to GDP in this dataset.

Log transformations of both the dependent and independent variables help stabilize variance and interpret coefficients in terms of percentages (Panayotou 1993). Including a squared income term distinguishes a possible EKC from a single-direction rise in emissions. This approach ensures a robust test of whether South Korea's economic growth might ultimately lead to environmental relief. By combining an extended historical dataset, relevant macroeconomic indicators, and a log-quadratic model, the study aims to provide a rigorous basis for determining whether the EKC framework applies to South Korea's development trajectory.

Results

A key component of this study is determining whether South Korea's economic growth aligns with the Environmental Kuznets Curve (EKC) hypothesis, which predicates that pollution first rises alongside income but eventually declines once a turning point is reached (Grossman and Krueger 1995; Panayotou 1993). To assess this, a log-quadratic regression was performed, linking the natural log of carbon dioxide (CO_2) emissions per capita to the natural log of real GDP per capita and its square. The data, spanning 54 annual observations from 1970 to 2023, show a remarkably tight statistical relationship between economic indicators and emissions .

The regression displays a Multiple R of 0.9955 and an R^2 of approximately 0.991, indicating that 99.1% of the variation in $\ln(CO_2)$ is captured by the income variables. With 54 observations, the F-statistic of 2797.64 and a Significance F near 7.47×10^{-53} further emphasize the significance of the explanatory variables. Such a high degree of explanatory power, while not unheard of in some EKC-based studies (Stern 2004), suggests a very close fit between rising incomes and CO_2 emissions over the examined time frame.

Turning to specific coefficients, each is statistically significant at better than the 1% level. The Intercept of about -13.8555 ($p \approx 8.39 \times 10^{-18}$) indicates that in log form, projected emissions would be quite low if income were minimal. The coefficient on ln(GDP per capita) stands at +2.7699 ($p\approx3.82\times10^{-16}$), implying a steep increase in emissions as per capita income moves from lower to middle levels. Meanwhile, the squared term $[\ln(\text{GDP per capita})]^2$ is -0.1146 ($p\approx6.08\times10^{-12}$), consistent with an inverted U shape where pollution eventually decreases at sufficiently high income (Panayotou 1993; Yandle, Vijayaraghavan, and Bhattarai 2002).

Using the standard formula for an EKC turning point (Equation (2)), the critical GDP per capita emerges at about $177,333. Because South Korea's current GDP per capita remains well below this threshold (OECD 2024; World Bank 2025), the country appears to be on the upward portion of the curve, where emissions continue to climb as the economy expands (Koc & Bulus, 2020). This raises questions about whether growth alone can rapidly reduce pollution in the near term (Magnani 2000). Although some observers might anticipate an advanced industrial economy to have already slowed its carbon output, global pollutants like CO_2 often exhibit delayed inflection points, particularly in export-oriented nations that rely on fossil fuels (Arrow et al. 1995; OECD 2024). Studies also suggest that targeted investments in clean energy and stricter environmental regulations could bridge the gap well before incomes naturally reach this theoretical peak (Ha & Byrne, 2019). As such, while the EKC framework points to an eventual downturn in emissions, the data implies that South Korea's downward phase may not materialize soon unless policy measures actively accelerate the transition.

To illustrate the data fit, Figure 1 presents a scatter plot of $\ln(CO_2)$ on the vertical axis versus ln(GDP per capita) on the horizontal axis, with the best-fit quadratic curve superimposed.

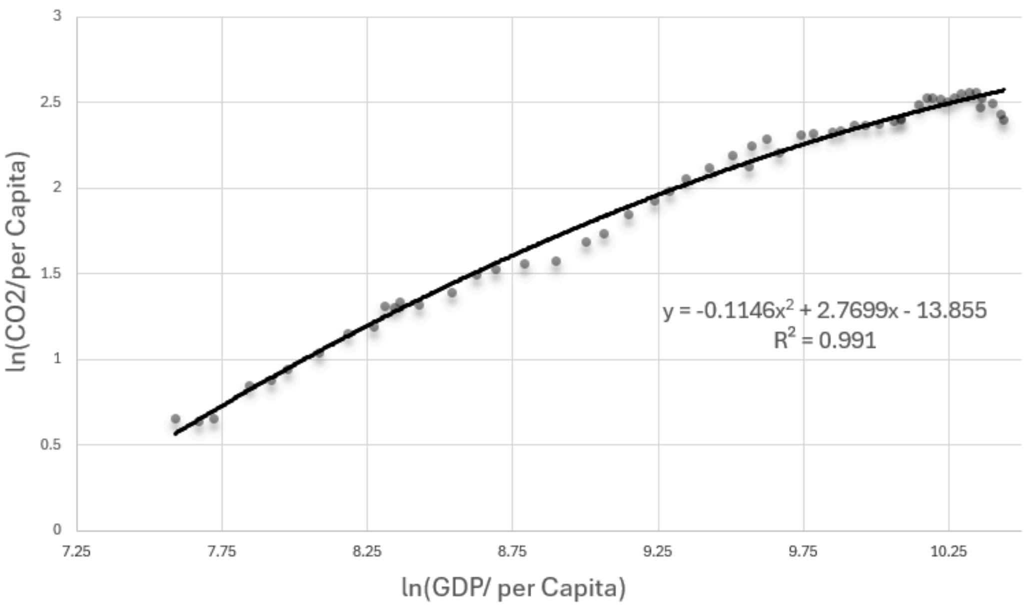

Figure 1. Visualizing the EKC: CO_2 Emissions vs. GDP per Capita in South Korea (1970–2023).

Observing the plot, emissions rise sharply with income, showing only a slight plateau at the higher end of the observed range. No definitive peak appears within the data, reinforcing the notion that South Korea's emissions likely will not decline spontaneously unless income surpasses the model's projected turning point, or targeted environmental policies shift the curve downward.

Conclusions and Discussion

The results indicate that while South Korea's economic expansion is strongly correlated with rising carbon dioxide (CO_2) emissions, the estimated turning point of approximately $177,333 GDP per capita remains beyond the country's present income level. This finding implies that, under current trajectories, emissions may continue to climb rather than taper off on their own. Although the log-quadratic specification supports the Environmental Kuznets Curve this high threshold calls into question whether natural growth alone can deliver meaningful environmental relief in the near term (Magnani 2000; Stern 2004).

From a sustainability standpoint, the evidence highlights the possibility that policy interventions are needed to bend the emissions curve downward before incomes reach such lofty levels (Grossman and Krueger 1995; Ha & Byrne, 2019). In particular, expanding renewable energy infrastructure, introducing stronger regulatory frameworks, and fostering public awareness could hasten progress toward lower emissions (Arrow et al. 1995). Moreover, the heavy reliance on export-oriented manufacturing and fossil fuels may prolong the upward slope, suggesting a mismatch between short-term economic objectives and longer-term environmental goals (Yandle, Vijayaraghavan, and Bhattarai 2002).

Although the model's high R^2 underscores its explanatory power, several limitations warrant caution. First, focusing solely on CO_2 neglects other pollutants and broader ecosystem impacts. Second, structural variables such as energy mix, technological capacity, and policy regime are not explicitly modeled, potentially masking significant drivers of emissions. Nevertheless, these findings provide a valuable lens for understanding South Korea's emissions trajectory and underscore the EKC's relevance while pointing to the crucial role of proactive environmental policies.

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