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An Empirical Analysis Based on Per Capita GDP and Global Temperature Changes

Jijunfeng Yang

Faculty of Arts, McGill University, Montreal, Canada
jijunfeng.yang@mail.mcgill.ca

Abstract. This study examines the statistical relationship between global economic development measured by global GDP per capita, and global temperature change. The main goal for this paper is to determine whether the increasing global economic development is associated to annually global temperature increase. Three regression models are employed in this study: linear regression, multiple linear regression, and polynomial regression. The linear regression model is considered as the base model for whole analysis. The numerical and figure outcomes provide the direct linear relationship between GDP and temperature change. The multiple regression model extends the analysis by using three control variables, which are urbanization rate, CO_2 emissions from land use, and CO_2 emissions from industry. The polynomial regression model is applied to test for potential nonlinear dynamic relationship. The results show that the linear models suggest a positive association between economic growth and global temperature rise. In contrast, the polynomial models reveal nonlinear patterns resembling the environmental Kuznets curve. Overall, the findings highlight the importance of including demographic and emissions-related variables in climate–economy research and provide new evidence for ongoing debates on the complex interaction between economic development and climate change.

Keywords: Climate change, GDP per capita, Linear regression, Multiple regression, Polynomial regression.

1. Introduction

The main topic of this study is whether global GDP is statistically and positively associated with global temperature change. The chain reaction caused by global temperature rise has become one of the most serious challenges of the 21st century. To address this issue by data analysis, this study applies a range of econometric models to test both the direct GDP–climate link and the moderating effects of other variables. This analysis not only examines the basic statistical relationship but also identifies which control variables provide the greatest influence on global temperature dynamics. The global GDP data is obtained by basic processing of the GDP of different countries and the corresponding population in that year.

The Intergovernmental Panel on Climate Change (IPCC) reports that the global average temperature has been increased in recent decades, with widespread and accelerating impacts on natural and human systems [1]. At the same time, global economic development has advanced

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rapidly. It raises important questions about the interaction between growth and environmental outcomes. The Stern Review emphasizes that economic activity and climate change are deeply related and require coordinated responses [2].

The research problem of this study is defined as "An Empirical Analysis Based on Per Capita GDP and Global Temperature Changes." This analysis investigates whether national economic levels, measured by GDP per capita, are statistically associated with changes in global temperature. The study draws on long-term datasets covering GDP, global temperature change, CO_2 emissions, and national urbanization rates. These variables provide a comprehensive foundation for testing both direct economic–climate linkages and the potential influence of population and environmental factors. To address this research problem, the study applies three models. Similar regression models have been widely applied in climate–economy research, for example in Wooldridge's econometric framework [3] and York's empirical analysis of GDP and CO_2 emissions [4].

The significance of this study lies in its dual focus. First, it evaluates the direct relationship between GDP per capita and global temperature, providing evidence on whether economic growth alone can explain climate change. Second, based on the multiple regression framework, it evaluates how other economic and environmental variables condition the observed association. This perspective is consistent with recent arguments by Stern and Dietz & Stern [5, 6], who stress the importance of integrating economic and environmental dimensions in climate change analysis.

2. Regression models and data outputs

This study draws upon multiple international datasets to explore the relationship between GDP per capita and global temperature change. Global annual temperature data are obtained from Berkeley Earth [7]. GDP per capita data are sourced from the World Bank [8]. CO_2 emissions data are collected from Our World in Data, including fossil fuels and industry emissions [9] as well as land use change emissions [10]. Urbanization rates are also taken from Our World in Data [11]. Together, these datasets provide a comprehensive foundation for the regression analysis.

2.1. Linear regression results

To establish a baseline model, a simple linear regression was conducted to examine the direct association between per capita GDP and global temperature change. The regression equation can be expressed as:

$$Temp = \alpha + \beta \bullet logGDP + \epsilon \tag{1}$$

where Temp represents the global temperature change, log GDP denotes the logarithm of GDP per capita, and ϵ is the error term. The estimated regression coefficients are presented in Table 1.

Table 1. Linear regression results (dependent variable: global temperature change)

Variable	Coefficient (β)
Constant (α)	9.0813
Log GDP	0.5891

$R^2 = 0.8590$

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The results indicate a strong and positive relationship between GDP and global temperature change. The coefficient for log(GDP) is 0.5891, suggesting that economic development are statistically associated with an increase in global temperature. Importantly, the model achieves an R^2 of 0.8590, implying that approximately 86% of the variation in global temperature can be explained by GDP per capita alone. This highlights a substantial explanatory power of the baseline model. It also determines the need for further analysis using additional control variables and nonlinear specifications.

2.2. Multiple linear regression results

To extend the analysis, a multiple linear regression model was employed with additional control variables to account for environmental influences. The general specification of the model is given as:

$$Temp = \alpha + \beta_1 * logGDP + \beta_2 * Control + \epsilon \quad (2)$$

Where Temp represents global temperature change, log GDP denotes the logarithm of GDP per capita, and Control stands for one of the additional explanatory variables, including fossil fuel and industrial CO_2 emissions, CO_2 emissions from land use change, and the urbanization rate. The following subsections present the results for each specification separately.

2.2.1. Industrial CO2 emissions as a control variable

The first specification introduces fossil fuel and industrial CO_2 emissions as a control variable alongside per capita GDP. The regression results are reported in Table 2.

Table 2. Multiple linear regression results with industrial CO_2 emissions

Variable	Coefficient (β)
log GDP	0.1519
Industrial CO_2 Emissions	0.2175
Constant (α)	14.0104

R^2=0.8763

The findings indicate that both per capita GDP and fossil fuel/industrial CO_2 emissions are positively associated with global temperature change. Compared with the baseline linear regression, the coefficient for log(GDP) decreases substantially to 0.1519, suggesting that once industrial CO_2 emissions are included, the independent explanatory power of GDP becomes smaller. Meanwhile, the coefficient for CO_2 emissions is 0.2175, reinforcing the strong contribution of industrial activity to global warming. The intercept is 14.0104, and the model achieves an R-squared of 0.8763, which is higher than in the simple regression model. This improvement in explanatory power demonstrates that industrial CO_2 emissions are a key driver of climate variation and should be considered in assessing the link between economic growth and temperature change.

2.2.2. Land Use CO2 emissions as a control variable

The second specification incorporates CO_2 emissions from land use change as a control variable. The results are presented in Table 3.

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Table 3. Multiple linear regression results with land Use CO_2 emissions

Variable	Coefficient (β)
log GDP	0.3794
CO_2 (land use change)	-0.0363
Constant (α)	14.0104

R^2=0.8659

The findings indicate that GDP per capita remains positively associated with global temperature change, with a coefficient of 0.3794, which is stronger than in the industrial CO_2 specification. Interestingly, the coefficient of land use CO_2 emissions is negative. It suggests that within this model, land use–related CO_2 emissions are not a strong explanatory factor for rising temperatures, and may even be inversely correlated. The intercept is 14.0104, and the model achieves an R-squared of 0.8659, which is close to the explanatory power of the industrial CO_2 model. These results indicates the complexity of environmental drivers, implying that the role of land use CO_2 emissions in explaining global temperature variation may be more nuanced and potentially overshadowed by other factors such as fossil fuel–based emissions.

2.2.3. Urbanization rate as a control variable

The third specification adds the urbanization rate as a control variable. The estimated results are presented in Table 4.

Table 4. A: multiple linear regression results with urbanization rate

Variable	Coefficient (β)
log GDP	-0.0771
Urbanization rate	0.4060
Constant (α)	14.408

R^2=0.9205

The results suggest a obvious shift in the estimated effect of GDP per capita when urbanization is included in the model. The coefficient of log(GDP) becomes negative, indicating that once urbanization is controlled for, GDP itself no longer shows a direct positive association with global temperature. In contrast, the coefficient for urbanization rate is 0.4060, highlighting the strong and positive impact of urbanization on temperature change. The model achieves an R-squared of 0.9265, the highest among all specifications tested in this study. These findings imply that urbanization plays a dominant role in shaping the climate–economy relationship, potentially mediating the direct effect of GDP.

2.3. Polynomial regression results

To further explore potential non-linear relationship between economic development and global temperature change, polynomial regression models are applied. By introducing a squared term of per capita GDP, these models test whether the link between GDP and temperature follows a nonlinear

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curve, such as the pattern hypothesized in the Environmental Kuznets Curve (EKC). The general specification of the polynomial model is given as:

$$Temp = \alpha + \beta_1 * logGDP + \beta_2 * (logGDP)^2 + \beta_3 * Control + \epsilon \quad (3)$$

where Temp denotes global temperature change, log GDP is the logarithm of per capita GDP, $(\log GDP)^2$ captures the nonlinear effect of economic development,and Control represents additional explanatory variables, including industrial CO_2 emissions, land use CO_2 emissions, and the urbanization rate.

2.3.1. Non-standardized polynomial regression results

The first set of results reports the non-standardized coefficients, which are presented in Table 5.

Table 5. Non-standardized polynomial regression results

Model	Log(GDP) Coefficient(β)	$(\text{Log(GDP)})^2$ Coefficient(β)	Control Variable	Control Variable Coefficient(β)	Constant (α)	R^2
A	-2.9603	0.2118	None	----	23.7961	0.9008
B	-3.0074	0.2083	Industrial CO_2	0.00	24.4008	0.9009
C	0.3889	-0.0355	Urbanization Rate	6.1893	11.084	0.9266
D	-3.2641	0.2309	Land Use CO_2	0.00	24.7804	0.9052

The results highlight several important findings. Model A shows that the coefficient of log(GDP) is negative, but the squared term is positive. It suggests a nonlinear U-shaped relationship between GDP per capita and temperature change. Model B, which incorporates industrial CO_2 emissions, produces coefficients very similar to Model A, indicating that industrial emissions add little explanatory power once the nonlinear GDP terms are included. Model C introduces urbanization and produces the highest explanatory power. The coefficient for urbanization is strongly positive, while the squared GDP term turns negative (-0.0355), suggesting that urbanization substantially reshapes the GDP–temperature relationship. Finally, Model D, which adds land use CO_2 emissions, suggesting that land use variable contributing little explanatory effect.

While the non-standardized regression results provide useful insights into the direction and magnitude of coefficients, they are influenced by differences in measurement units across variables. For instance, GDP is measured in logarithmic terms, CO_2 emissions are measured in tons, and urbanization is expressed as a percentage. This makes it difficult to compare the relative importance of variables directly. The results cannot clearly highlight the differences across models or the distinct role of each control variable. Therefore, to obtain a clearer and more convincing understanding of variable importance, the next subsection presents standardized regression results.

2.3.2. Standardized regression results

To allow direct comparison of variable importance, the models were re-estimated with standardized variables. The results are shown in Table 6.

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Table 6. Standardized polynomial regression results

Model	Log(GDP) Coefficient(β)	$(Log(GDP))^2$ Coefficient(β)	Control Variable	Control Variable Coefficient(β)	Constant (α)	R^2
A	-1.0731	1.3974	None	----	14.408	0.9008
B	-1.0901	1.3742	Industrial CO_2	0.0404	14.408	0.9009
C	0.1410	-0.2345	Urbanization Rate	0.4225	14.408	0.9266
D	-1.1832	1.5232	Land Use CO_2	0.0278	14.408	0.9052

The standardized results highlight two key findings. First, the relationship between GDP and temperature is nonlinear and U-shaped, based on the negative coefficient log(GDP) with positive coefficient of log(GDP)², which diverges from the inverted-U shape predicted by the Environmental Kuznets Curve (EKC). Second, urbanization emerges as the most influential factor, with a standardized coefficient of 0.4225 and the highest explanatory power (R^2 = 0.9266). In contrast, both industrial CO_2 and land use CO_2 emissions show negligible effects once GDP and urbanization are included.

3. Graphical results and visualization

While Section 2 presented the statistical outputs of linear, multiple, and polynomial regression models, this section provides a graphical representation of the findings. Visualizations are employed to illustrate the historical trends, scatter plot relationships, and fitted regression lines, in order to complement the numerical results with more intuitive insights.

3.1. Linear regression visual results

The graphical outputs of the linear regression model are presented to complement the numerical results discussed in Section 2.1. These visualizations provide an intuitive understanding of the relationship between GDP per capita and global temperature change.

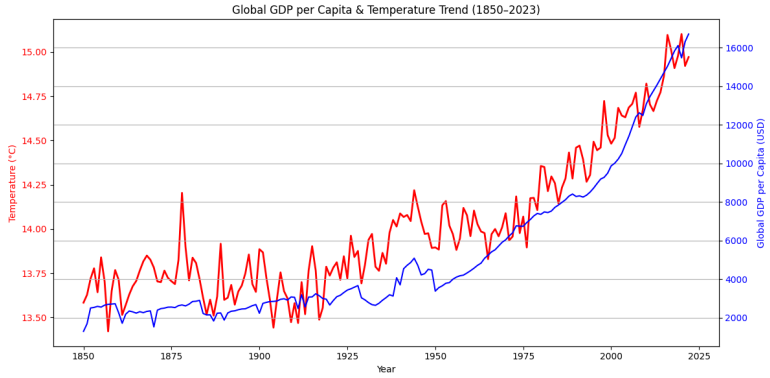


Figure 1. Global GDP per capita and temperature trend (1850–2023)

Figure 1 illustrates the long-term evolution of global GDP per capita (blue line) and global average temperature (red line). Prior to 1950, GDP per capita remained relatively low and stable, while temperature fluctuated within a narrow range. After 1950, economic growth accelerating sharply and global temperatures rising at an unprecedented pace. The simultaneous increase in both

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variables after the mid-twentieth century suggests a strong correlation between economic development and climate change.

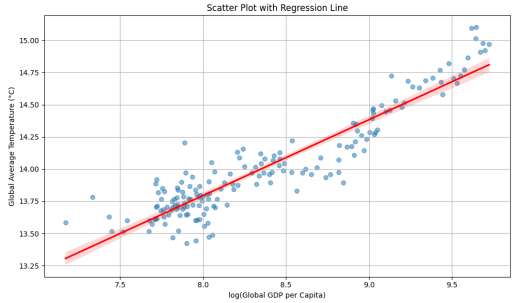


Figure 2. Scatter plot of log(GDP) and global temperature with regression line

Figure 2 presents the scatter plot of log(GDP) against global average temperature, with a fitted regression line shown in red. The upward slope of the line clearly indicates a positive association between GDP per capita and global temperature, consistent with the baseline regression results in Section 2.1. The data points are closely clustered around the fitted line. It suggests a relatively tight relationship with limited dispersion. The inclusion of the regression line also highlights the statistical robustness of the relationship that as log(GDP) increases, global temperature consistently rises. The narrow confidence interval further reinforces the reliability of the estimated slope. Together, these visual results support the conclusion that economic growth and rising global temperatures are strongly correlated, aligning with the numerical findings reported in Table 1.

3.2. Polynomial regression visualization

The graphical outputs of the polynomial regression models are presented in Figure 3. This figure compares the actual global temperature trend (blue line) with the predicted values from four polynomial regression specifications: Model A (log(GDP) + log(GDP)²), Model B (adding industrial CO_2), Model C (adding urbanization rate), and Model D (adding land use CO_2).

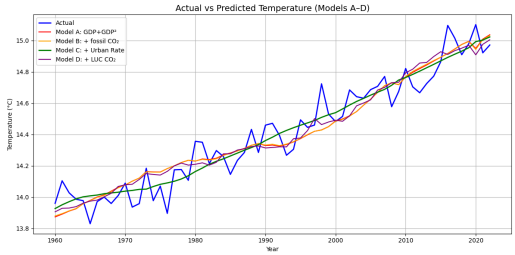


Figure 3. Actual vs. predicted global temperature (polynomial regression models A–D)

As shown in Figure 3, all polynomial models track the actual temperature trend reasonably well, with predicted lines closely following the observed data. Model A captures the broad upward trajectory of temperature using only GDP terms, but Models B–D demonstrate how control variables alter the model's fit. Notably, Model C, which incorporates urbanization rate, aligns most closely with the actual temperature trend, particularly after 1980, reflecting its stronger explanatory power as also indicated by the regression results in Section 2.3. By contrast, Models B and D, which include industrial CO_2 and land use CO_2 respectively, show minimal deviation from the baseline, suggesting limited additional explanatory value.

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Overall, Figure 3 emphasizes the conclusion that while GDP and its nonlinear terms explain much of the variation in global temperature, urbanization emerges as the most influential control variable in the polynomial framework.

4. Discussion

This study finds that urbanization is the most influential control variable in explaining global temperature change, surpassing CO_2 emissions. While GDP remains positively linked to temperature, the marginal effect of CO_2 is limited, whereas urbanization substantially improves model fit.

The polynomial regression reveals a U-shaped relationship between GDP and temperature, contrasting with the inverted-U of the Environmental Kuznets Curve (EKC). This indicates that EKC dynamics may not extend to global climate change, where long-term warming is more closely tied to cumulative emissions and urbanization. The findings carry clear policy implications: sustainable growth must decouple GDP from emissions, and urban-focused mitigation strategies are essential, as cities amplify climate impacts.

Finally, some limitations remain. The use of global-level data may obscure regional variation, and the reliance on linear and polynomial models restricts methodological scope. Expanding control variables (e.g., renewable energy, energy intensity, institutional quality) could offer deeper insights in future research.

5. Conclusion

This study investigated the relationship between GDP per capita and global temperature change using linear, multiple, and polynomial regression models. By incorporating control variables such as industrial CO_2 emissions, land use CO_2 emissions, and urbanization rate, the analysis provided a comprehensive assessment of the climate–economy nexus. The results confirm a strong and positive statistical association between economic development and rising global temperatures, with regression models explaining a substantial share of observed variation.

In conclusion, the study contributes by empirically showing that urbanization plays the most significant role in shaping the link between GDP and global temperature, rather than CO_2 emissions. This finding diverges from common expectations and underscores the complexity of climate–economy dynamics. Future research should expand the range of explanatory variables and apply more advanced econometric models to deepen understanding of these relationships and to inform more effective climate and development policies.

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