# On the Relationship between Economic Growth and Environmental Sustainability*

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## <Abstract>

Traditional economic theory posits a trade-off between economic growth and environmental quality. Since the early 1990s, however, the rapidly expanding empirical and theoretical literature on the Environmental Kuznets Curve (EKC) has suggested that the relationship between economic growth and the environment could be positive. We have examined the effect of income on environmental sustainability, controlling for population density and civil-political liberty. The primary contribution of this paper is to address the different characteristics of eco-efficiency measures of environmental sustainability in comparison with the common measures of pollution.

Our examination has revealed that while income appears to have a beneficial effect on pollution measures, it has a detrimental effect on most eco-efficiency measures of environmental sustainability, *ceteris paribus*. This suggests that the Environmental Kuznets Curve needs to be renamed as the "Pollution" Kuznets Curve in order to give correct impression that not all environmental measures but only pollution measures may improve with income. This also suggests that while conventional policies focus more on pollution control, they need to be combined with policy options focusing on eco-efficiency aspects of environmental sustainability in the process of economic development. Otherwise, economic growth will continue to degrade environmental sustainability in most countries.

Keywords: growth, environment, pollution, sustainability
JEL Classification: O13, Q01, Q56, Q58

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## 1. Introduction

The relationship between economic growth and the environment is controversial.[1] Traditional economic theory posits a trade-off between economic growth and environmental quality. Since the early 1990s, however, the rapidly expanding empirical and theoretical literature on the Environmental Kuznets Curve (EKC) has suggested that the relationship between economic growth and the environment could be positive and hence growth is a prerequisite for environmental improvement.

The EKC depicts the empirical pattern that at relatively low levels of income per capita, pollution level (and intensity) initially increases with rising income, but then reaches a maximum and falls thereafter. For example, the air in London, Tokyo and New York was far more polluted in the 1960s than it is today. The same pattern has held in other major cities in many advanced countries. Thus, the EKC shows that the relationship between economic growth and pollution is an inverse U shape.[2]

Grossman and Krueger (1991, 1994) and the World Bank (1992) are the pioneering studies which brought the EKC to public attention. Grossman and Krueger's (1991) study explored the relationship between economic growth and pollution measures for air quality, and their (1994) study focused on water quality. Since its discovery, much statistical evidence on the EKC has accumulated for many other pollution measures.[3]

There have also been many attempts to derive the EKC theoretically.[4] The dominant theoretical explanation is that when GDP increases, the greater scale of production leads directly to more pollution, but, at a higher level of income per capita, the demand for health and environmental quality rises with income which can translate into environmental regulation, in which case there tend to be favorable shifts in the composition of output and in the techniques of production.

It is worth noting, however, that the EKC explains the relationship between "pollution" and income levels, while pollution represents only part of the environmental problem. Nonetheless, in part due to its name of "Environmental" Kuznets Curve, some authors seem to believe that the environment as a whole tends to improve ultimately as income rises. For example, referring to the EKC, Brock and Taylor (2004a) state that "there is a tendency for the environment to at first worsen at low levels of income but then improve at higher incomes. (p.3)"

However, the relationship between income and the environment as a whole remains in

[1] For a review, see Ekins (1999) and Xepapadeas (2003).
[2] This pattern is described as the EKC, following the original Kuznets curve, which was an inverted U-shaped relationship between average income and inequality.
[3] See, for example, Barbier (1997), Cole, *et al* (1997), Suri and Chapman (1998). Bradford, *et al* (2000), Harbaugh (2002), and Stern (2003), among others. See Brock and Taylor (2004b) and Yandel, *et al* (2004) for a review of the empirical studies on the EKCs.
[4] They include Selden and Song (1994), Stokey (1998), and Andreoni and Levinson (2001), among others. See Chapter 2 of Copeland and Taylor (2003) for a comprehensive review. For a more recent model, see also Brock and Taylor (2004).

question as there is much evidence that many measures related with the environment are worse in high income countries than in developing countries.

The purpose of this paper is to examine empirically the relationship between income and various measures of the environment (and environmental sustainability). For this purpose, we will use the 2005 Environmental Sustainability Index (ESI) produced by the Yale Center for Environmental Law and Policy at Yale University, in collaboration with the Center for International Earth Science Information Network at Columbia University.[5] The ESI is a composite profile of national environmental stewardship based on a compilation of 21 indicators for 146 countries. Among the 21 indicators, some are pollution measures for air and water quality, and others are more fundamental measures of environmental sustainability such as biodiversity and reducing ecosystem stresses.

Before we proceed, it should be worth clarifying the meaning of environmental sustainability and its fundamental measures. The term “environmental sustainability” refers to the continuity of the environmental carrying capacity more or less indefinitely into the future. The fundamental measures of environmental sustainability are those related with the endowed environmental carrying capacity and the eco-efficiency, which cannot be changed unless a society changes the way it produces and consumes. Therefore, for the environment to be sustainable, the society needs not only to limit the level of pollution but also to improve the eco-efficiency of a society as a whole.

Distinguishing pollution measures from more fundamental eco-efficiency measures of environmental sustainability is very important because while the conventional environmental approach has been focused mostly on regulating pollution and the discharge resulting mainly from production processes, the environment of most countries has been placed under increasing pressure, mainly due to the deterioration of most eco-efficiency measures of environmental sustainability.

As will be seen in the following, while income has a beneficial impact on reducing pollution level, it seems to have a “detrimental” impact on most of eco-efficiency measures of environmental sustainability.

The rest of the paper is organized as follows: a general picture of the relationship between income and these two distinct categories of environmental sustainability will be offered in Section 2, using the scatter plots of income per capita against the various indicators of environmental sustainability drawn from the 2005 ESI report. After discussing some important factors which seem to have an impact on environmental sustainability, Section 3 will present the findings obtained from formal regression analyses. Concluding remarks are offered in Section 4.

## 2. General Relationship between Income and the Environment

[5] Esty, D. C., M. A. Levy, T. Srebotnjak, and A. de Sherbinin (2005), *2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship,* New Haven, Connecticut, United States, Yale Center for Environmental Law and Policy.

The Environmental Sustainability Index

As noted above, the 2005 ESI represents an equally weighted average of the 21 indicator scores. Each indicator builds on between 2 and 12 data sets. For example, Air Quality (SYS_AIR) is a composite indicator that includes variables tracking the concentration of nitrogen oxides, sulfur dioxide and particulates in urban areas, and indoor air pollution from solid fuel use.

The world average of the ESI is 49.9, and Finland has the highest score with 75.1, while the Democratic People's Republic of Korea has the lowest with 11.7. The five highest-ranking countries are Finland, Norway, Uruguay, Sweden, and Iceland, while the five lowest countries are the Democratic People's Republic of Korea, Iraq, Taiwan, Turkmenistan, and Uzbekistan.

Because we are interested in examining how different pollution measures and eco-efficiency measures of environmental sustainability are related with income, we select among the 21 indicators only those indicators which fall into either of these two categories. We select 2 indicators for pollution measures and 9 indicators for more eco-efficiency related measures of environmental sustainability.[6] Thus, the overall measure of environmental sustainability (ESI) included in the 2005 ESI does not represent accurately the degree of environmental sustainability defined in this report, as it is not just the average value of the 11 indicators but that of the 21 indicators also including 10 indicators which are considered not relevant and hence excluded from this study.

Table 1 shows in summary the nesting of indicators within categories and variables within indicators. The pollution category includes 2 indicators: Air Quality (SYS_AIR) and Water Quality (SYS_WQL). The category for eco-efficiency related measures includes 9 indicators: Biodiversity (SYS_BIO), Land (SYS_LAN), Reducing Air Pollution (STR_AIR), Reducing Ecosystem Stress (STR_ECO), Reducing Waste and Consumption Pressures (STR_WAS), Reducing Water Stress (STR_WAT) Natural resource Management (STR_NRM), Energy Efficiency (CAP_EFF),[7] and Greenhouse Gas Emissions (GLO_GHG). In spite of a certain overlap between pollution measures and eco-efficiency related measures of environmental sustainability, there seems to be no direct relationship between the two. Therefore, the relationship between economic growth

[6] Thus, 10 indicators in the 2005 ESI report are excluded from this study. They are excluded because they are social-issue related (VUL_HEA, STR_POP, VUL_SUS), uncontrollable natural disaster related (VUL_DIS), too broad a measure of political and governance system (CAP_GOV), or too broad a measure of technology (CAP_ST). The instrumental capacity variables such as CAP_GOV and CAP_ST are important to fix problems of and improve environmental sustainability over time, and hence are determining factors, not the environmental sustainability itself. Some variables (CAP_PRI, GLO-COL, GLO_TBP, SYS_WQN) are excluded because they do not fall into either category of pollution or eco-efficiency measures of sustainable environment.

[7] The 2005 ESI report names CAP_EFF as "Eco-Efficiency", which in fact refers to energy efficiency, while eco-efficiency used here is a broader concept involving most fundamental measures of environmental sustainability. Therefore, it is replaced with the name "Energy Efficiency".

and environmental sustainability is best understood by examining the results with respect to these two distinct categories of environmental sustainability.

General pictures

Figure 1 shows the regression results of the ESI on per capita GDP and simple scatter plots of original data. The names of 32 Asia-Pacific countries are also shown in the figure. The result seems to suggest that higher income countries are better positioned in general to maintain favorable environmental conditions into the future. However, it should be noted that only 22% of the variance in the ESI is accounted for by per capita GDP, implying that many countries fall apart quite a lot from the regression line. For example, South Korea falls well below the regression line, indicating sub-par level of environmental sustainability given its level of income.

Figures 2-3 show the regression results of pollution measures for Air Quality (SYS_AIR) and Water Quality (SYS_WQL), respectively, on per capita GDP expressed in natural logarithms. Scatter plots of original data and the names of 32 Asia-Pacific countries are also shown in the figures. Both figures show that there is a positive relationship between the pollution measures and income level. This seems to suggest that high-income countries tend to have lower degree of air and water pollution problems.

Figures 4-12 show the regression results of eco-efficiency related measures of environmental sustainability on per capita GDP. The picture is quite different. None of these measures show a positive relationship with per capita GDP. In fact, Reducing Air Pollution (STR_AIR), Reducing Water Stress (STR_WAT), Natural Resource Management (STR_NRM), and Greenhouse Gas Emissions (GLO_GHG) seem to have a relatively strong "negative" relationship with per capita GDP.

The results seem very alarming because the Figures show that the higher income countries tend to have lower values of eco-efficiency of environmental sustainability. Therefore what follows in the next section is a more formal analysis of the relationship between the two categories of environmental sustainability and income.

## 3. Estimation of the Determinants of Environmental Sustainability

Data and Model Specification

We will use as dependent variable each of the 2 pollution measures and the 9 eco-efficiency measures of environmental sustainability drawn from the 2005 ESI report to estimate the relationship of income with environmental sustainability.

Income per capita (PCGDP) is our main explanatory variable of interest. Because we are not interested in measuring the precise shape of the EKC but in the general relationship between income and various measures of environmental sustainability, we will use the natural logarithm of per capita GDP as a key explanatory variable but does not include the squared value of the log of per capita GDP. Among the 146 countries in the 2005 ESI report, we were able to obtain per capita GDP of 2003 for 140 countries.[8]

In addition, we include two control variables. The first variable is the log of land area per capita (PCLAN). This is included because higher population tends to lead to environmental degradation (for a given level of per capita income).[9]

An improved environmental regulation resulting from appropriate political institutions is also likely to improve environmental sustainability. Many studies (for example, Barrett and Graddy, 2000) find that an increase in civil and political freedoms significantly reduces some measures of pollution and hence improves the quality of the environment. Thus, we include a measure of civil and political freedom in the right hand side of the equation. For this measure, a variable called Civil and Political Liberties (CIVLIB) is drawn from the 2005 ESI report.[10] This variable is one of the 12 variables nested within the indicator of Environmental Governance (CAP_GOV). The original CIVLIB ranges from 1 (strongly democratic) to 7 (strongly autocratic). This measure is inverted to hypothesize that CIVLIB has a positive relationship with environmental sustainability.

It should be noted that per capita income and civil-political liberty are highly correlated: *i.e.*, in general the higher per capita GDP of a country, the higher the degree of civil and political liberty of the country. The simple correlation coefficient for the variables is 0.78 in our sample. Therefore, to control the collinearity between income and the civil-political liberty index, we use an income adjusted civil-political liberty index defined as the residual from a regression of the original civil-liberty index on log of per capita income and constant. In doing so, we loose one observation, so the total observation number in our regression analysis is 139.

Lastly, we include a dummy variable called ASIA-PACIFIC which takes 1 for the 32 countries in the Asian and Pacific region and 0 otherwise.[11] We include this variable to investigate how the countries in the Asian and Pacific region perform in comparison with countries in other regions.

To summarize, we estimate the following cross-country equation:

(1) ESI = f(PCGDP, PCLAN, CIVLIB, ASIA-PACIFIC)

where

· ESI represents the two pollution measures and 9 eco-efficiency measures of

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[8] The data are drawn from the World Bank's World Bank Development Indicators (WDI) database (http://www.worldbank.org/data), except for Iraq, Kuwait, Syria, Saudi Arabia, and United Arab Emirates, for which data are drawn from the OPEC Secretariat website (http://www.opec.org).

[9] Land area (in sq km) is taken from the CIA's website (http://www.cia.org).

[10] The original source is Freedom House (http://www.freedomhouse.org).

[11] The 32 Asian-Pacific countries included in this study are Armenia, Australia, Azerbaijan, Bangladesh, Bhutan, Cambodia, China, Georgia, India, Indonesia, Iran, Japan, Kazakhstan, Kyrgyzstan, Laos, Malaysia, Mongolia, Nepal, New Zealand, North Korea, P. N. Guinea, Pakistan, the Philippines, Russia, South Korea, Sri Lanka, Tajikistan, Thailand, Turkey, Turkmenistan, Uzbekistan, and Vietnam.

environmental sustainability, respectively
· PCGDP is the natural logarithm of 2003 GDP per capita
· PCLAN is the natural logarithm of per capita land area
· CIVLIB is the residual from a regression of the civil and political liberty index on PCGDP
· ASIA-PACIFIC is a binary variable for the countries in the Asian and Pacific region

Results

Before the regression results are reported, the simple correlation coefficients between the variables are presented in Table 2. Note that the greater value of our measures of pollution and other measures of environmental sustainability means a better quality of the environment. As seen in the table, per capita GDP has a positive relationship with the overall index of environmental sustainability and with the two pollution measures. In contrast, all of the correlation coefficients for per capita GDP and the 9 measures have negative signs. This confirms the observations we made in the previous section.

Per capita land has a positive relationship with the overall index of environmental sustainability and with most of the indicators. This implies that the greater the land area per capita of a country, the higher the degree of environmental sustainability the country tends to enjoy. However, greater land area per capita does not always results in higher degree of environmental sustainability, as exceptions exist: land area per capital has a negative relationship with Reducing Waste and Consumption Pressures (STR_WAS).

Civil and political liberty also has a positive relationship with the overall measure of environmental sustainability, but the results are somewhat mixed for the 2 pollution measures and the 9 eco-efficiency measures of environmental sustainability.

It is also noted that the correlation coefficients between the explanatory variables are very low and hence we do not need to worry about the multicollinearity problem in the regression analysis.

Table 3 reports the regression results for the overall measure of environmental sustainability. The estimated effect of per capita GDP on the ESI is positive and statistically significant at the one percent level. The same is true of land area per capita and civil-political liberty index. The estimated coefficient for the Asia-Pacific dummy has a negative sign, but is not statistically significant. Thus, one may conclude that a country's environmental sustainability improves as the country's income per capita improves, population density declines and/or the country enjoys greater degree of civil and political liberty.

It should be noted, however, that the ESI is a composite index which includes not only the 11 indicators which we consider relate closely with environmental sustainability, but also the 10 indicators which we consider do not relate directly with environmental sustainability and hence are excluded from this study. Therefore, it is cautioned that the result for the ESI does not adequately represent the result for our definition of environmental sustainability.

Table 4 reports the estimation results, where the dependent variable is represented in turn by the two measures of pollution. The estimated effect of per capita GDP on both measures of pollution is positive and significant at the one percent level, suggesting that increased income per capita has a beneficial effect on reducing pollution levels.

On the other hand, the two control variables do not have such consistent relations with the pollution measures. Land area per capita does not have a statistically significant effect on Air Quality (SYS_AIR), but has a positive effect on Water Quality (SYS_WQL). The variable for civil-political liberty has a statistically significant positive effect only on Water Quality, among the two pollution measures.

The estimated coefficients for the dummy variable for the Asian-Pacific countries in both equations do not show any statistical significance, suggesting that countries in the Asian-Pacific region are not distinct from countries in other regions of the world in terms of performance in controlling pollution levels.

Let us now turn to the estimation results for the nine eco-efficiency related indicators of environmental sustainability, which are reported in Table 5. As for the effects of income per capita, our regression results confirm the previous findings we reported with the scatter plots and correlation coefficients. The estimated effect of income per capita on the eight eco-efficiency measures (among the nine measures) of environmental sustainability is negative and significant at the one percent level. The only exception is the result for Reducing Ecosystem Stress (STR_ECO), which has no statistically significant coefficient.

Thus, our results reveal that while there is a statistically significant positive relationship between per capita income and pollution-related indicators, there is a statistically significant negative relationship between per capita income and eco-efficiency indicators of environmental sustainability. This finding should be interpreted to mean that environmental sustainability in general does not improve, and may in fact deteriorate, as income rises, while environmental performance of reducing pollution level may improve with income.

On the other hand, the estimated effect of land area per capita is consistently positive and statistically significant for six eco-efficiency related indicators. Only one indicator, Reducing Waste and Consumption Pressures (STR_WAS), has a statistically meaningful negative relation with land area per capita. This suggests that more populated countries tend to have a lower degree of environmental sustainability, *ceteris paribus*.

Civil and political liberties do not always seem to improve eco-efficiency, as in two equations estimated coefficients are negative and statistically significant, while only in three equations they are positive and statistically significant.

Our regression results also reveal that given their level of income per capita, land per capita and civil-political liberties, eco-efficiency of Asian-Pacific countries seem to be sub-par in general, as five equations have negative and significant coefficients for the Asia-Pacific dummy, while only two equations have positive and significant coefficients.

## 4. Concluding Remarks

Environmental sustainability is ensuring the needs of the present generation without compromising environmental carrying capacity for the future generation. Maintaining environmental sustainability needs not only to limit pollution but also to ensure eco-efficiency in meeting the needs of the present generation.

We have examined the effect of income on environmental sustainability, controlling for population density and civil-political liberty. The primary contribution of this paper is to address the different characteristics of eco-efficiency measures of environmental sustainability in comparison with the common measures of pollution.

Our examination has revealed that while income appears to have a beneficial effect on pollution measures, it has a detrimental effect on most eco-efficiency measures of environmental sustainability, *ceteris paribus*. This suggests that the Environmental Kuznets Curve needs to be renamed as the “Pollution” Kuznets Curve in order to give correct impression that not all environmental measures but only pollution measures may improve with income. This also suggests that while conventional policies focus more on pollution control, they need to be combined with policy options focusing on eco-efficiency aspects of environmental sustainability in the process of economic development. Otherwise, economic growth will continue to degrade environmental sustainability in most countries.

It has also been found that low population density and civil-political liberty have been identified as important in their effects on environmental sustainability, but the signs for the estimated coefficients are not always positive. This is especially apparent for civil and political liberty. Thus, we have evidence that civil and political liberty does not automatically improve environmental sustainability.

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## Table 1. Two Categories of Environmental Sustainability Indicators

| | Indicator | Variable code | Variable |
|---|---|---|---|
| Pollution Measures | Air Quality (SYS_AIR) | NO2<br>SO2<br>TSP<br>INDOOR | ▪ Urban population weighted NO2 concentration<br>▪ Urban population weighted SO2 concentration<br>▪ Urban population weighted TSP concentration<br>▪ Indoor air pollution from solid fuel use |
| | Water Quality (SYS_WQL) | WQ_DO<br>WQ_EC<br>WQ_PH<br>WQ_SS | ▪ Dissolved oxygen concentration<br>▪ Electrical conductivity<br>▪ Phosphorus concentration<br>▪ Suspended solids |
| Eco-efficiency Related Measures | Biodiversity (SYS_BIO) | ECORISK<br>PRTBRD<br>PRTMAM<br>PRTAMPH<br>NBI | ▪ Percentage of country's territory in threatened ecoregions<br>▪ Threatened bird species as percentage of known breeding bird species in each country<br>▪ Threatened mammal species as percentage of known mammal species in each country<br>▪ Threatened amphibian species as percentage of known amphibian species in each country<br>▪ National Biodiversity Index |
| | Land (SYS_LAN) | ANTH10<br>ANTH40 | ▪ Percentage of total land area (including inland waters) having very low anthropogenic impact<br>▪ Percentage of total land area (including inland waters) having very high anthropogenic impact |
| | Reducing Air Pollution (STR_AIR) | COALKM<br>NOXKM<br>SO2KM<br>VOCKM<br>CARSKM | ▪ Coal consumption per populated land area<br>▪ Anthropogenic $NO_x$ emissions per populated land area<br>▪ Anthropogenic $SO_2$ emissions per populated land area<br>▪ Anthropogenic VOC emissions per populated land area<br>▪ Vehicles in use per populated land area |
| | Reducing Ecosystem Stress (STR_ECO) | FOREST<br>ACEXC | ▪ Annual average forest cover change rate from 1990 to 2000<br>▪ Acidification exceedance from anthropogenic sulphur deposition |

| | | | |
|---|---|---|---|
| | Reducing Waste & Consumption Pressures (STR_WAS) | EFPC<br>RECYCLE<br>HAZWST | ▪ Ecological Footprint per capita<br>▪ Waste recycling rates<br>▪ Generation of hazardous waste |
| | Reducing Water Stress (STR_WAT) | BODWAT<br><br>FERTHA<br>PESTHA<br>WATSTR | ▪ Industrial organic water pollutant (BOD) emissions per available freshwater<br>▪ Fertilizer consumption per hectare of arable land<br>▪ Pesticide consumption per hectare of arable land<br>▪ Percentage of country under severe water stress |
| | Natural Resource Management (STR_NRM) | OVRFSH<br>FORCERT<br><br>WEFSUB<br>IRRSAL<br><br>AGSUB | ▪ Productivity over fishing<br>▪ Percentage of total forest area that is certified for sustainable management<br>▪ World Economic Forum Survey on subsidies<br>▪ Salinized area due to irrigation as percentage of total arable land<br>▪ Agricultural subsidies |
| | Energy Efficiency (CAP-EFF) | ENEFF<br>RENPC | ▪ Energy efficiency<br>▪ Hydropower and renewable energy production as a percentage of total energy consumption |
| | Greenhouse Gas Emissions (GLO_GHG) | SO2EXP<br>POLEXP | ▪ Carbon emissions per million US dollars GDP<br>▪ Carbon emissions per capita |

## Table 2. Correlation Matrix

| | PCGDP | PCLAN | CIVLIB |
|---|---|---|---|
| PCGDP | 1.0000 | | |
| PCLAN | -0.0265 | 1.0000 | |
| CIVLIB | 0.0000 | -0.0307 | 1.0000 |
| ESI | 0.4678 | 0.3297 | 0.3901 |
| SYS_AIR | 0.4326 | 0.0362 | -0.0572 |
| SYS_WQL | 0.4975 | 0.3242 | 0.2589 |
| SYS_BIO | -0.2294 | 0.3885 | 0.0001 |
| SYS_LAN | -0.3472 | 0.7978 | -0.1027 |
| STR_AIR | -0.7396 | 0.3016 | -0.0338 |
| STR_ECO | -0.0557 | 0.3360 | -0.2679 |
| STR_WAS | -0.4223 | -0.2295 | 0.0115 |
| STR_WAT | -0.6063 | 0.4007 | 0.2355 |
| STR_NRM | -0.4911 | 0.2156 | -0.0845 |
| CAP_EFF | -0.2145 | 0.0744 | 0.3950 |
| GLO_GHG | -0.4025 | 0.0165 | 0.3643 |

Note: CIVLIB is the residual from a regression of the civil and political liberty index on PCGDP. For the descriptions of other variables, see the main text.

## Table 3. Determinants of the ESI

| | Constant | PCGDP | PCLAN | CIVLIB | ASIA-PACIFIC | obs | R-squared |
|---|---|---|---|---|---|---|---|
| ESI | 40.15***<br>(14.01) | 2.49***<br>(7.81) | 2.78***<br>(5.80) | 18.67***<br>(6.56) | | 139 | 0.497 |
| | 28.30***<br>(5.15) | 2.47***<br>(7.63) | 2.27***<br>(5.71) | 18.53***<br>(6.41) | -0.39<br>(0.31) | 139 | 0.497 |

Notes: 1. Cross-country estimation with ordinary least squares. 2. PCGDP is the log of GDP per capita, PCLAN is the log of land size per capita, CIVLIB is civil and political liberties index, and ASIA-PACIFIC is a dummy variable for the countries in the Asian and Pacific region. 3. t-statistics are shown in parentheses. 4. ***, **, and * denote one, five, and ten percent level of significance, respectively, for a two tailed test.

## Table 4. Determinants of Pollution Measures

| | Constant | PCGDP | PCLAN | CIVLIB | ASIA-PACIFIC | obs | R-squared |
|---|---|---|---|---|---|---|---|
| SYS_AIR | -1.18***<br>(4.40) | 0.17***<br>(5.61) | 0.02<br>(0.59) | -0.19<br>(0.72) | | 139 | 0.193 |
| | -1.17***<br>(4.25) | 0.17***<br>(5.46) | 0.02<br>(0.55) | -0.21<br>(0.76) | -0.04<br>(0.32) | 139 | 0.193 |
| SYS_WQL | -0.86***<br>(3.70) | 0.20***<br>(7.82) | 0.17***<br>(5.34) | 0.96***<br>(4.16) | | 139 | 0.434 |
| | -0.88***<br>(3.75) | 0.20***<br>(7.80) | 0.17***<br>(5.36) | 0.98***<br>(4.20) | 0.06<br>(0.61) | 139 | 0.434 |

Notes: 1. Cross-country estimation with ordinary least squares. 2. PCGDP is the log of GDP per capita, PCLAN is the log of land size per capita, CIVLIB is civil and political liberties index, and ASIA-PACIFIC is a dummy variable for the countries in the Asian and Pacific region. 3. t-statistics are shown in parentheses. 4. ***, **, and * denote one, five, and ten percent level of significance, respectively, for a two tailed test.

**Table 5. Determinants of Eco-efficiency Measures of Environmental Sustainability**

| | Constant | PCGDP | PCLAN | CIVLIB | ASIA-PACIFIC | obs | R-squared |
|---|---|---|---|---|---|---|---|
| SYS_BIO | 1.04*** (5.05) | -0.07*** (2.85) | 0.14*** (4.97) | 0.03 (0.15) | | 139 | 0.199 |
| | 1.21*** (6.26) | 0.08*** (3.84) | 0.13*** (4.81) | 0.13 (0.61) | -0.42*** (4.96) | 139 | 0.323 |
| SYS_LAN | 3.17*** (16.20) | -0.16*** (7.57) | 0.49*** (18.23) | -0.35* (1.82) | | 139 | 0.749 |
| | 3.10*** (15.76) | -0.16** (7.23) | 0.50*** (18.53) | -0.29 (1.51) | 0.17* (1.98) | 139 | 0.756 |
| STR_AIR | 3.23*** (14.56) | -0.34*** (13.93) | 0.16*** (5.35) | -0.11 (0.48) | | 139 | 0.627 |
| | 3.31*** (14.80 | -0.35*** (14.19 | 0.16*** (5.16) | -0.17 (0.77) | -0.18* (1.90) | 139 | 0.637 |
| STR_ECO | 0.70** (2.62) | -0.02 (0.06) | 0.15*** (4.19) | -0.88*** (3.31) | | 139 | 0.182 |
| | 0.61** (2.26) | 0.01 (0.29) | 0.16*** (4.43) | -0.80*** (3.00) | 0.23* (1.95) | 139 | 0.204 |
| STR_WAS | 0.70*** (3.36) | -0.13*** (5.70) | -0.09*** (3.20) | 0.01 (0.06) | | 139 | 0.236 |
| | 0.75*** (3.55) | -0.14*** (5.85) | -0.10*** (3.33) | 0.03 (0.15) | -0.12 (1.33) | 139 | 0.246 |

Notes: 1. Cross-country estimation with ordinary least squares. 2. PCGDP is the log of GDP per capita, PCLAN is the log of land size per capita, CIVLIB is civil and political liberties index, and ASIA-PACIFIC is a dummy variable for the countries in the Asian and Pacific region. 3. t-statistics are shown in parentheses. 4. ***, **, and * denote one, five, and ten percent level of significance, respectively, for a two tailed test.

**Table 5. Determinants of Eco-efficiency Measures of Environmental Sustainability (Continued)**

| | Constant | PCGDP | PCLAN | CIVLIB | ASIA-PACIFIC | obs | R-squared |
|---|---|---|---|---|---|---|---|
| STR_WAT | 2.68***<br>(12.79) | -0.25***<br>(10.64) | 0.20***<br>(7.00) | 0.92***<br>(4.42) | | 139 | 0.577 |
| | 2.76***<br>(13.15) | -0.26***<br>(11.00) | 0.19***<br>(6.82) | 0.85***<br>(4.09) | -0.20**<br>(2.18) | 139 | 0.591 |
| STR_NRM | 1.36***<br>(7.13) | -0.14***<br>(6.69) | 0.07**<br>(2.76) | -0.20<br>(1.08) | | 139 | 0.288 |
| | 1.44***<br>(7.58) | -0.15***<br>(7.12) | 0.07**<br>(2.52) | -0.28<br>(1.47) | -0.20**<br>(2.46) | 139 | 0.319 |
| CAP-EFF | 0.89***<br>(2.86) | -0.10***<br>(2.77) | 0.05<br>(1.06) | 1.61***<br>(5.19) | | 139 | 0.209 |
| | 0.97***<br>(3.07) | -0.10***<br>(2.96) | 0.04<br>(0.91) | 1.54***<br>(4.93) | -0.18<br>(1.35) | 139 | 0.219 |
| GLO_GHG | 1.56***<br>(4.77) | -0.20***<br>(5.56) | 0.01<br>(0.24) | 1.63***<br>(5.05) | | 139 | 0.295 |
| | 1.70***<br>(5.22) | -0.22***<br>(5.99) | -0.001<br>(0.03) | 1.51***<br>(4.69) | -0.35**<br>(2.47) | 139 | 0.326 |

Notes: 1. Cross-country estimation with ordinary least squares. 2. PCGDP is the log of GDP per capita, PCLAN is the log of land size per capita, CIVLIB is civil and political liberties index, and ASIA-PACIFIC is a dummy variable for the countries in the Asian and Pacific region. 3. t-statistics are shown in parentheses. 4. ***, **, and * denote one, five, and ten percent level of significance, respectively, for a two tailed test.

**Figure 1. Regression of the ESI on per capita GDP (R-squared = 0.222)**

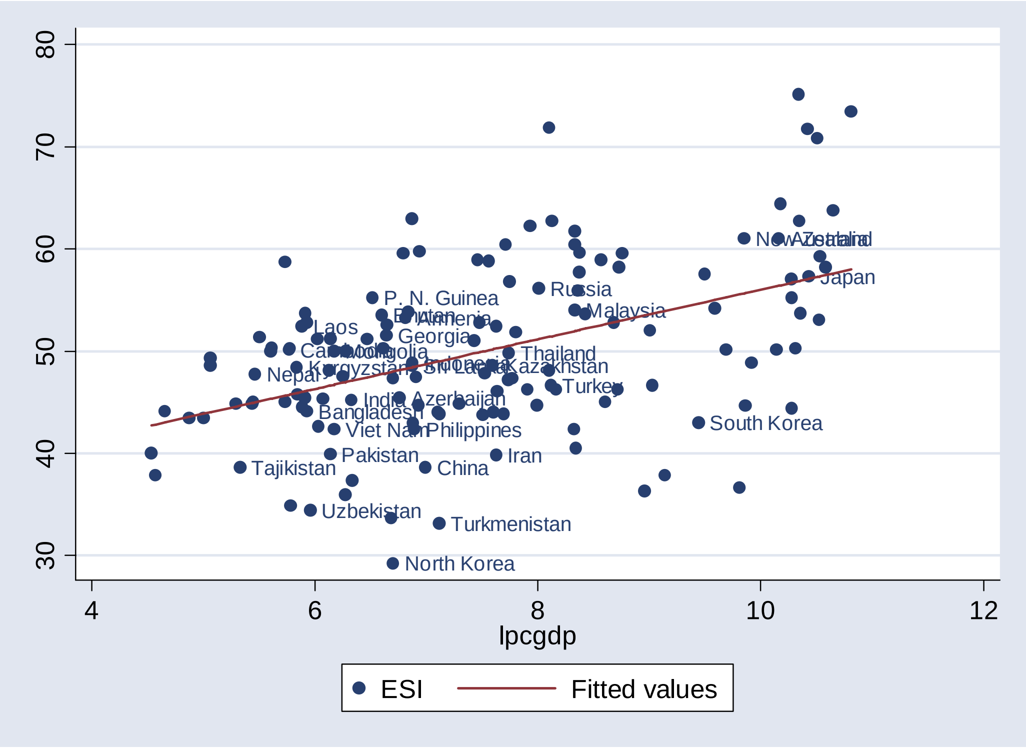

**Figure 2. Regression of SYS_AIR on per capita GDP (R-squared = 0.191)**

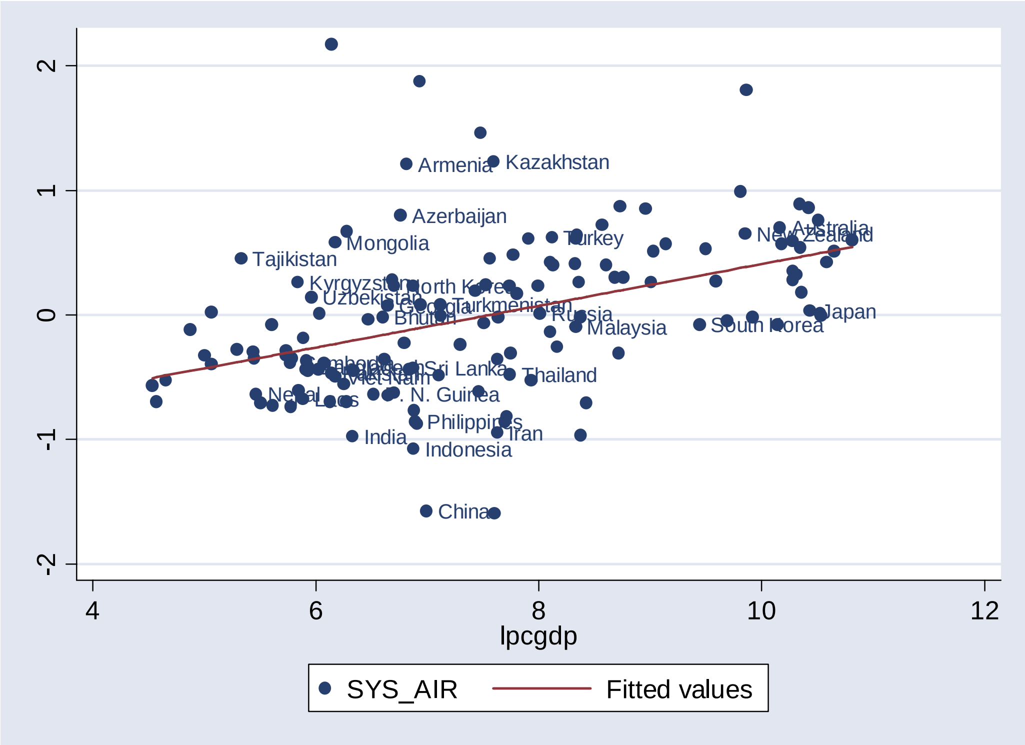


**Figure 3. Regression of SYS_WQL on per capita GDP (R-squared = 0.243)**

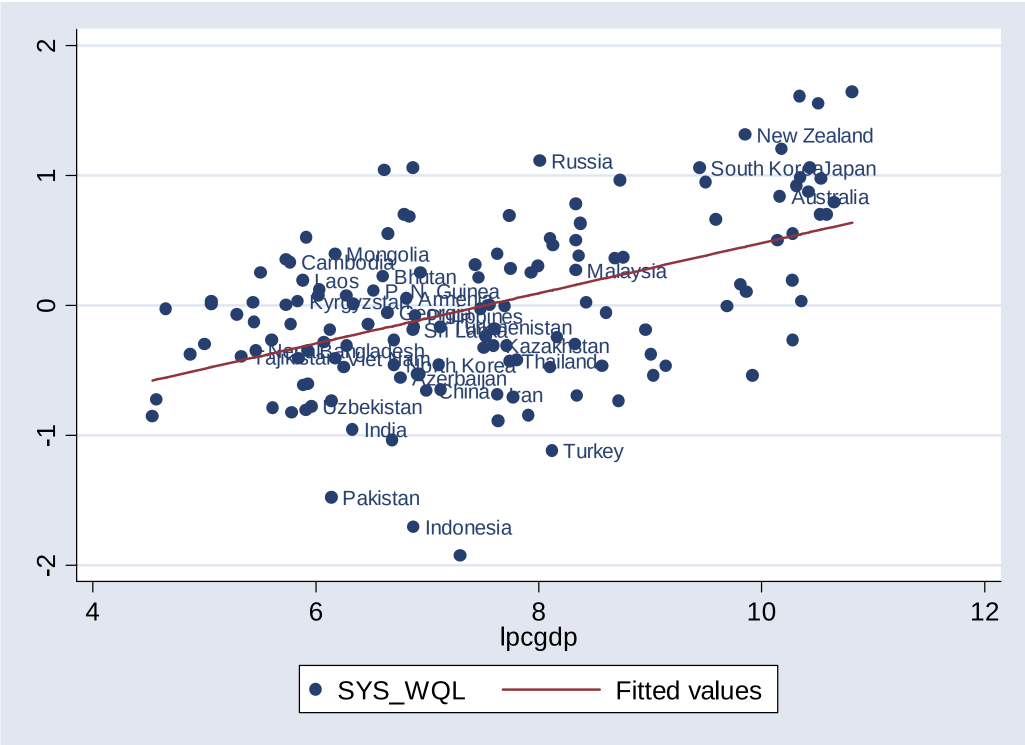

**Figure 4. Regression of SYS_BIO on per capita GDP (R-squared = 0.058)**

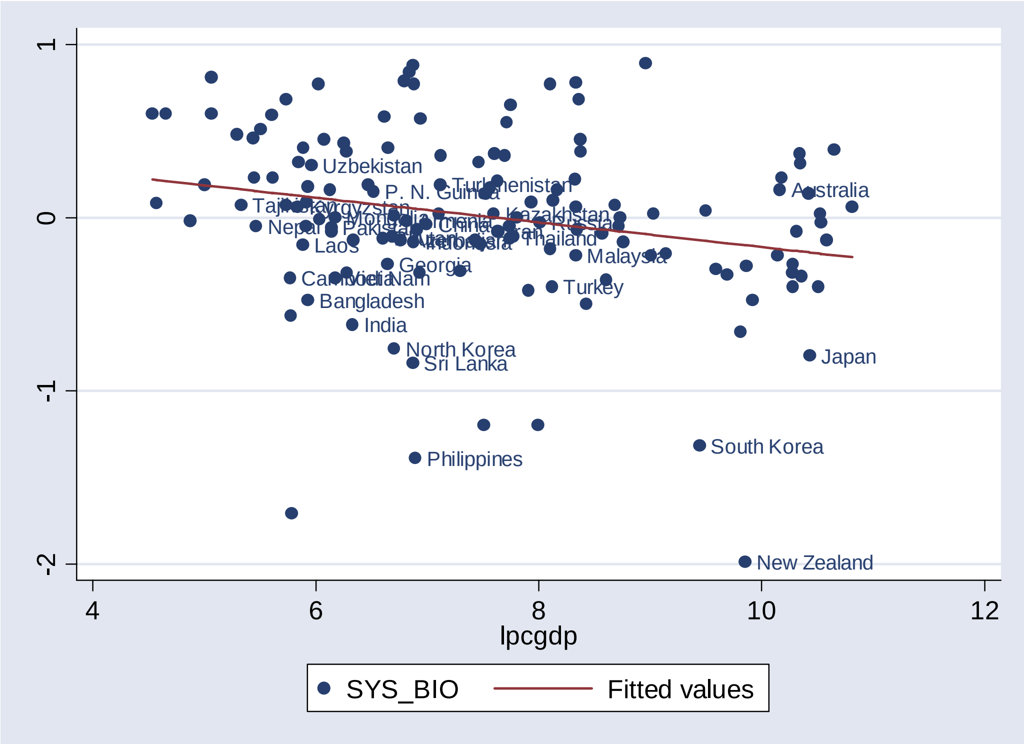


**Figure 5. Regression of SYS_LAN on per capita GDP (R-squared = 0.122)**

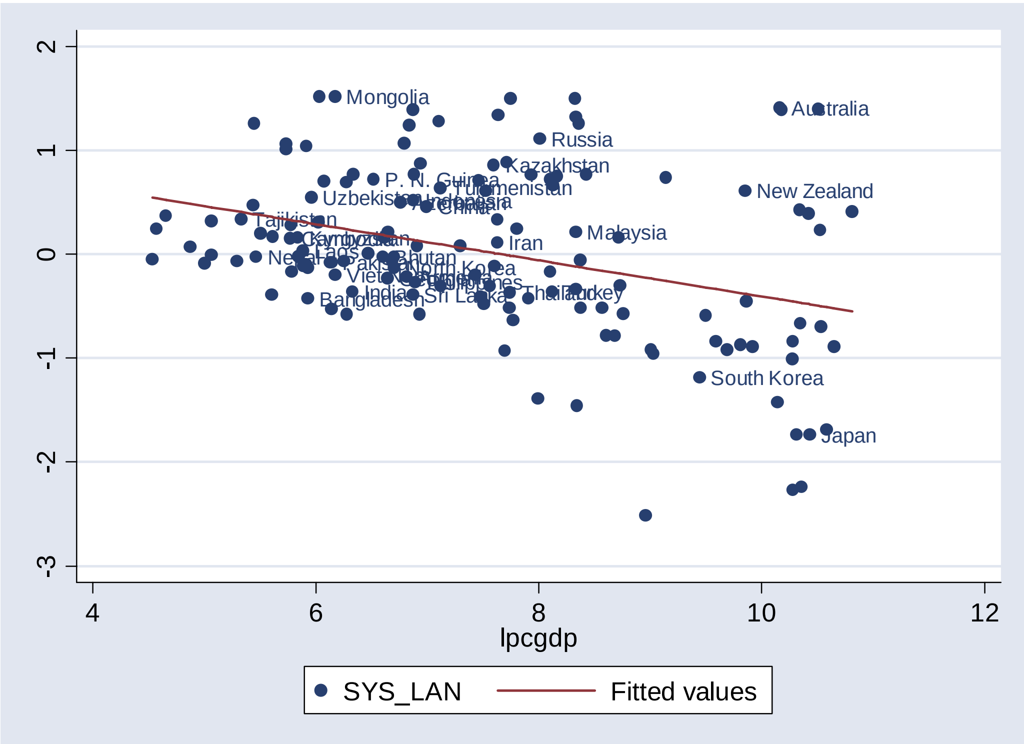

**Figure 6. Regression of STR_AIR on per capita GDP (R-squared = 0.557)**

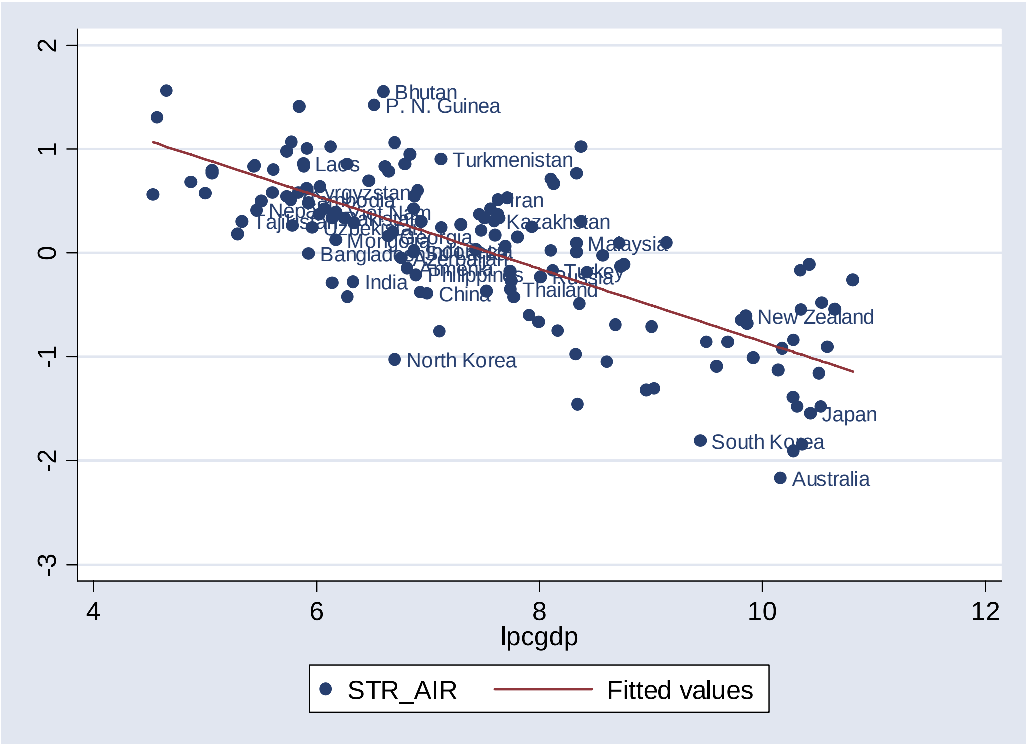


**Figure 7. Regression of STR_ECO on per capita GDP (R-squared = 0.004)**

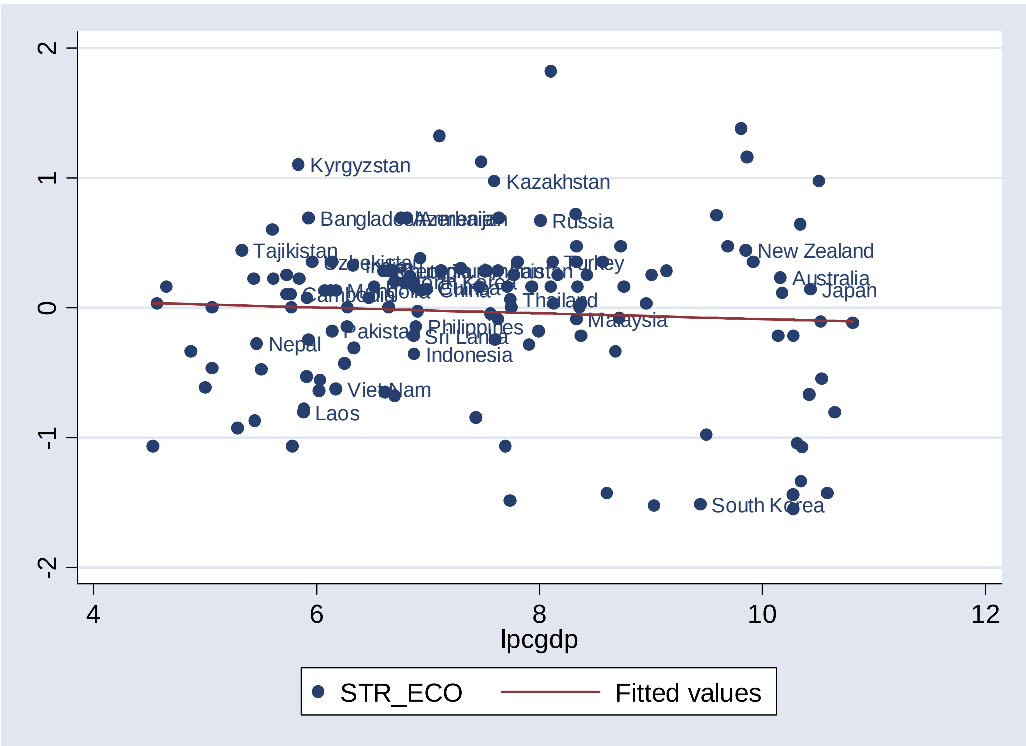

**Figure 8. Regression of STR_WAS on per capita GDP (R-squared = 0.178)**

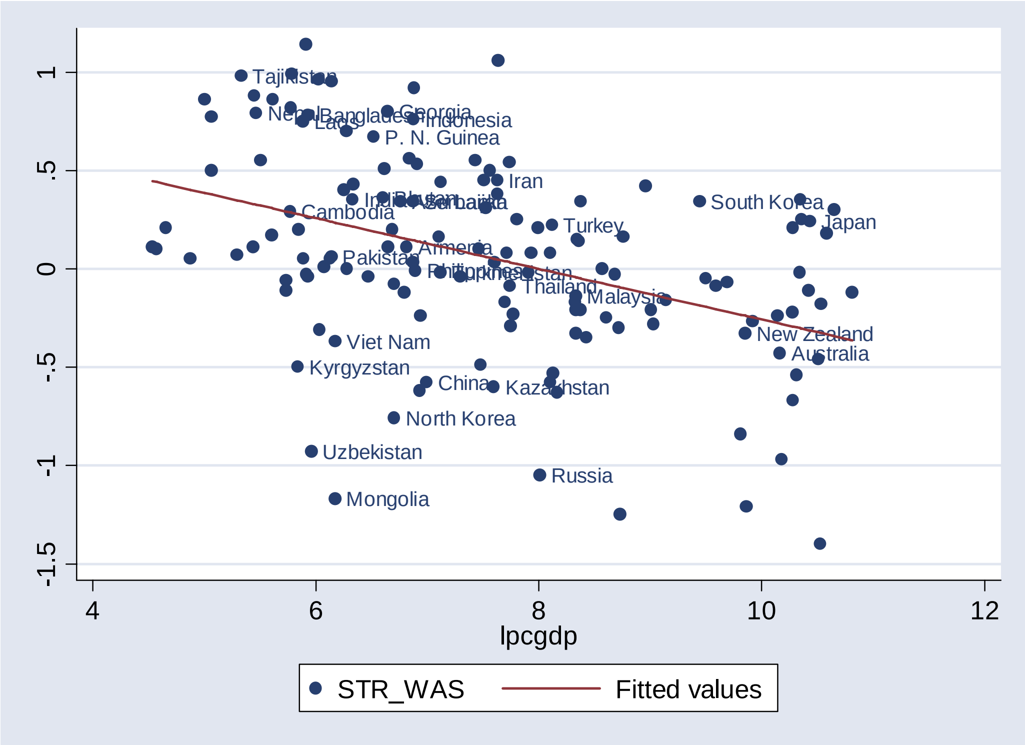


**Figure 9. Regression of SYS_WAT on per capita GDP (R-squared = 0.375)**

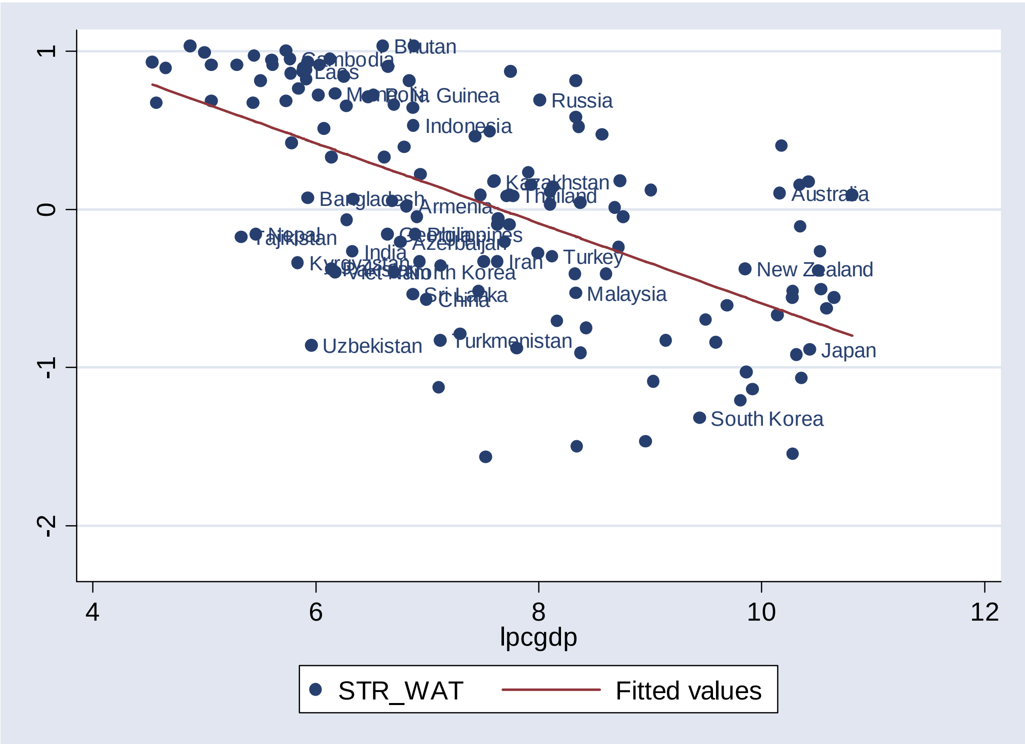

**Figure 10. Regression of ST4_NRM on per capita GDP (R-squared = 0.239)**

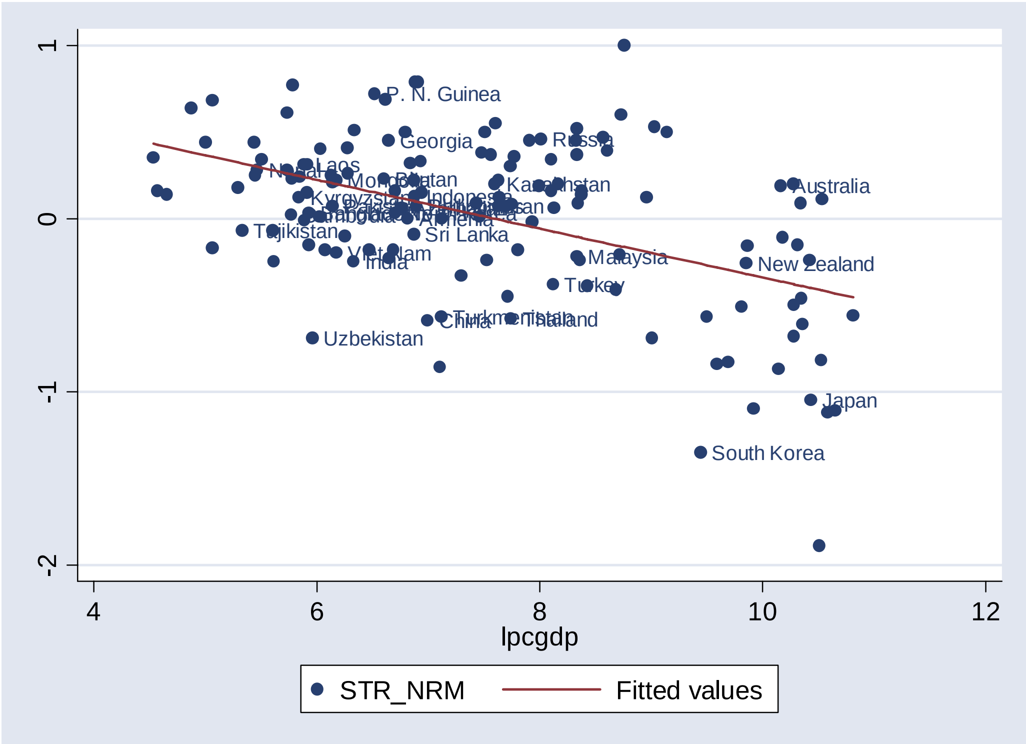


**Figure 11. Regression of CAP_EFF on per capita GDP (R-squared = 0.057)**

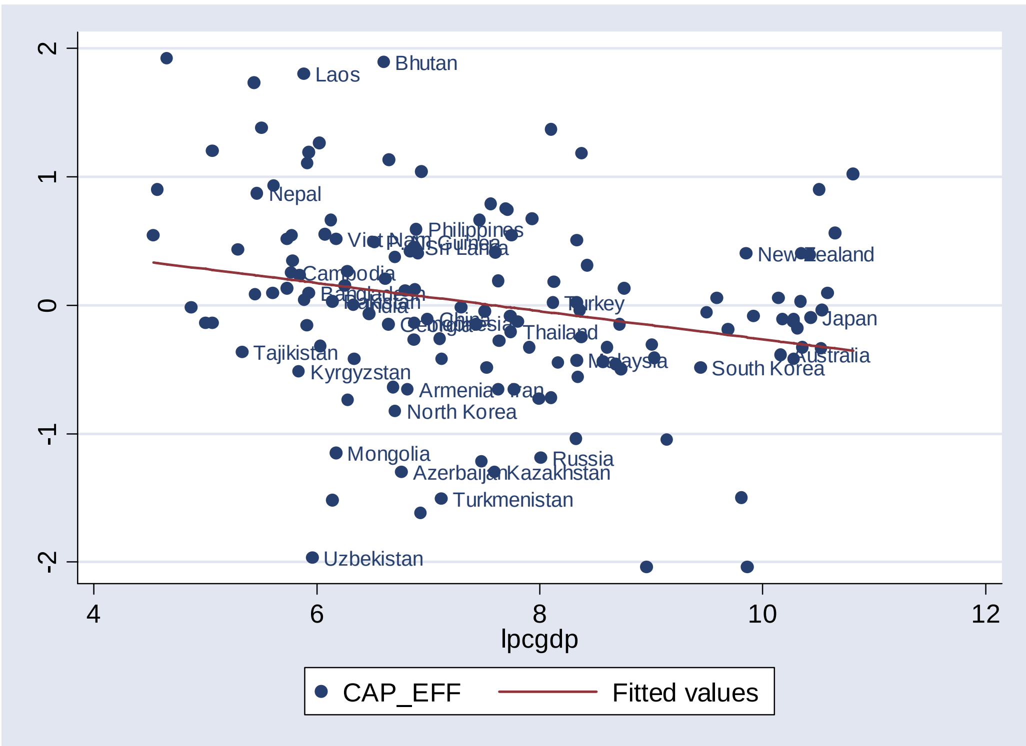

**Figure 12. Regression of GLO_GHG on per capita GDP (R-squared = 0.171)**