Reconciling the Environmental Kuznets Curve with the Free Rider Problem

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Abstract

The current paper studies the Environmental Kuznets Curve (EKC) hypothesis, which claims a parabolic relation exists between per capita GDP and environmental degradation. This would suggest a developing nation could expect to increase pollution significantly during the beginnings of industrialization and then, as the country began switching to a service-oriented economy, could expect pollution levels to begin to eventually drop with increasing per capita income. There has been much debate over said issue and the main goal of this paper is to study how the environmental free rider problem may play a role in plaguing the validity of the EKC model. Environmental free riding would allow nations to externalize some of the costs of their pollution such that it may never become economical to lower pollution levels despite rising income. My research focuses on an empirical study of carbon dioxide and sulfur dioxide emissions and ultimately supports the hypothesis that the effects of the free rider problem can be expected to spuriously affect the validity of the EKC model for certain pollutants.

Introduction

With explosive growth of the global population, it has become increasingly difficult to deny an environmental footprint left on the planet by humans. Many maintain that the economic development of humankind has a negative ecological impact. However, skeptical economists have recently made the argument that the correlation between environmental degradation and economic growth is better defined initially by a directly proportional relationship that gradually wanes until the two become inversely proportional. This inverted-U shape, known as the Environmental Kuznets Curve (EKC), suggests that a nation can deteriorate its environment during the beginning of industrialization, and eventually reaches a turning point at which further development only reduces environmental ruin.

The concept of the Kuznets Curve began with Simon Kuznets-who hypothesized that economic inequality increases over time as a country is developing and then eventually begins to decline once inequality reaches a peak. Economists Grossman and Krueger (1995) later hypothesized that this principle would also apply to the relation between the devastation of the environment and economic growth-thereby creating the EKC. Specifically, they stated that as a nation's per capita income increases, so does environmental damage. This is true until a turning point is reached where any further per capita income increase would lead to a fall in environmental degradation.

The underlying rationale behind the EKC is that as a country industrializes, it not only begins to produce pollution-abating technology, but it also moves away from pollution-intensive industries. As a nation is first industrializing, it is thought that the country's main priority is to rapidly develop by any means necessary. However, as the country reaches a certain level of development, the negative effects of pollution are no longer negligible and the nation begins to engage in pollution abatement. Likewise, as a nation's citizens become well-off it becomes economical for residents to substitute some of their wealth for the increased health benefits of living in a cleaner environment. In addition, upon industrialization developed nations historically have begun to move away from manufacturing and production industries towards more profitable service-based industries (which are far less pollutant-intensive). An obvious objection to this theory is that this concept can not be applied to all nations, since eventually this would mean all countries are providing services to one another while no nations are actually engaging in manufacturing. It is thus not surprising that since its initial publication, this forerunning paper has met with applause and skepticism alike from economists in the field.

Supporters of the EKC hypothesis maintain that there is evidence of the inverted-U shape between several environmental indicators ranging from air and water pollutants to deforestation levels. However, more pessimistic economists argue the trends displayed by the EKC raise unanswered questions. Some of the main critiques of the model are that it hides the effects of nations' legislation and other exogenous factors upon pollution levels and that the curve does not account for the possibility of economic outsourcing. Proponents of the theory raise the counterpoint that such legislation is an example of nations moving past the peak of the EKC such that pollution levels begin to fall. Even still, it is thought by some that as pollution emission legislation increases when a country is developing, polluting firms will outsource activity to "pollution havens" where little or no such legislation exists. These economists argue that as the "pollution haven" nations begin to pass their own legislation, EKC curves will begin to level out rather than drop as suggested by the hypothesis of Grossman and Krueger (1995). Still, other research by Dasgupta et al. (2002) indicates that the increased availability of pollution abating technology allows for faster development of nations such that EKC curves actually shift inward, causing the turning point predicted by the curve to appear at a much lower per capita income.

Despite the large controversy surrounding the EKC, current literature on the subject has yet to discuss the economic free rider problem. In economics, the free rider problem leads to a scenario in which certain individuals-in appeasing their self-interested motives-consume a resource in excess of their fair portion or reap the same benefits as others from its production while not bearing an equal cost. In the words of Gruber (2004), “when an investment has a personal cost but a common benefit, individuals will underinvest.” In the context of the EKC, this investment is pollution abatement and the problem can be likened to a form of market failure resulting from economically near-sighted individuals. The free rider problem (as it relates to environmental issues) was first brought to the large-scale attention of economists in the early 1960s. Demsetz (1964) discussed the pitfalls of communally-owned land and how the natural tendency of each individual will be to overhunt and overwork the land since he or she will not bear the full cost of these actions. Rather, those costs will be spread out evenly among other owners of the land while the benefit will go directly to that one individual. The result is the tragedy of the commons, in which entirely self-motivated agents lead to their own demise by squandering the resources vital to market efficiency as well as their own survival. Demsetz (1994) does suggest that agreements could form between individuals or laws could be set by government agents in order to solve this problem, but adds that both of these solutions lead to high negotiation and/or policing costs. This concept translates directly to the current dilemma being faced within environmental economics today.

Wind currents and atmospheric diffusion lead to the dispersion of air pollutants in the Earth's atmosphere as a country emits pollutants. Thus, as a country engages in pollution-intensive technology it will gain 100% of the benefits (usually energy) of such actions while not having to pay the full costs. Initially, many countries capitalize on this fact by carelessly engaging in technologies that produce heavy air pollution without many restrictions in place. Countries could potentially even go so far as to place pollution-causing manufacturing plants along their outlying borders to minimize the effect of the pollution on their own citizens and maximizing the effect of pollution-outsourcing. However, disputes would eventually arise with neighboring countries that would result in the formation of international treaties. If the free rider problem were severe enough, the U.N. might need to establish such treaties and act as a governing force over the policies. Since environmental free riding allows some countries to avoid the costs of their polluting technologies, it is possible that it may destroy the theorized inverted-U relation in EKC theory.

Opponents of EKC theory have criticized the concept for its seemingly spurious applicability to certain pollutants. For instance, carbon dioxide emissions as studied by Grossman and Krueger appear to better follow an S-shaped curve rather than the inverted-U shape previously discussed. This means that contrary to EKC theory, a country's carbon dioxide emissions ultimately continue climbing as per capita income rises. Carbon dioxide is an air pollutant which diffuses evenly across the Earth's upper atmosphere and thus may be morel likely to be associated with the environmental free rider problem. It is therefore interesting to compare data on the relationship between per capita income and carbon dioxide emissions with that of another air pollutant that does not disperse to the same degree within the atmosphere, such as sulfur dioxide.

It is helpful to view the relation between pollutant emissions and per capita GDP graphically to exemplify these points. Figures 1 and 2 below display annual CO_2 emissions in millions of metric tons plotted against per capita GDP and annual SO_2 emissions in millions of metric tons plotted against per capita GDP, respectively.

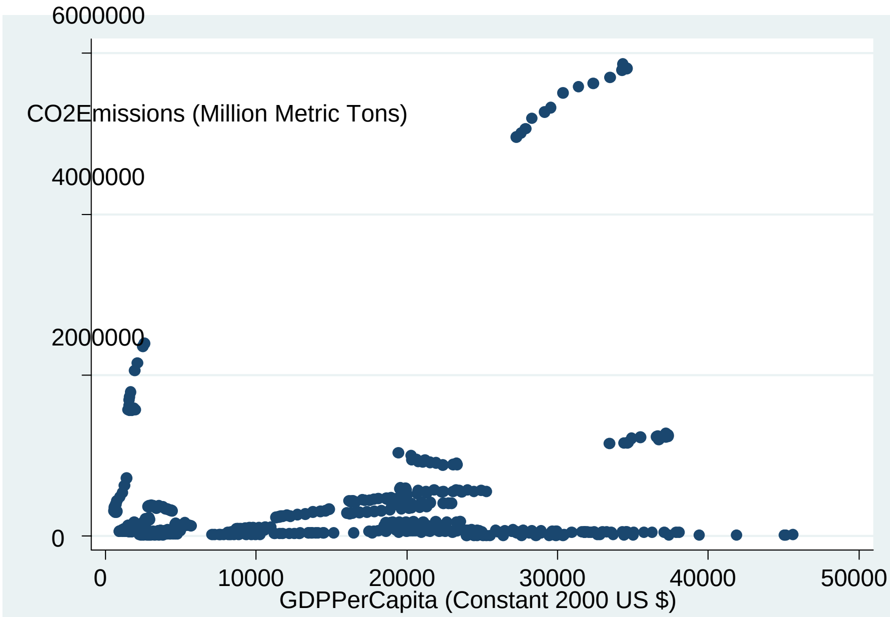

Fig.1-CO2 Emission Relation to Per Capita GDP

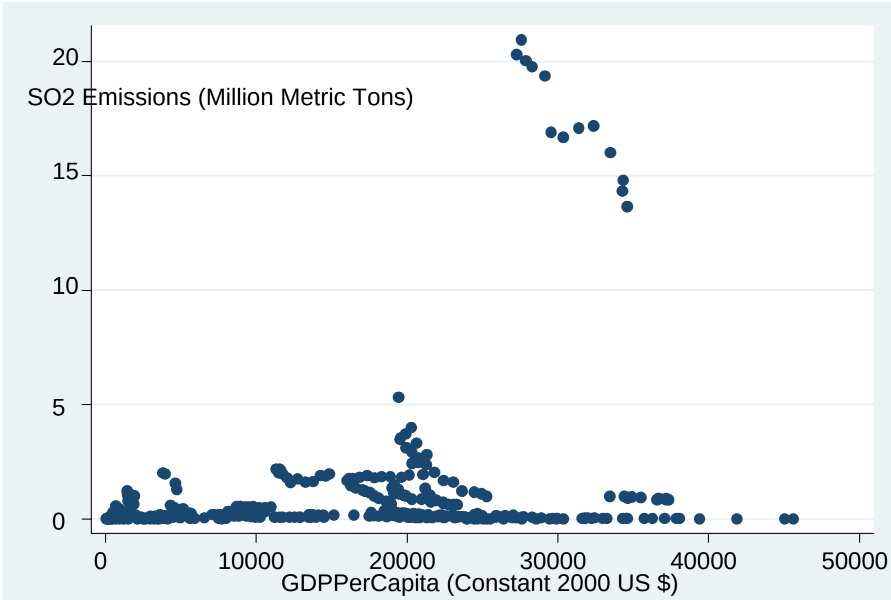

Fig.2-SO2 Emission Relation to Per Capita GDP

Given the aggregate nature of the graphs and the wide-ranging emission levels between different countries during different times, the relation between per capita GDP and pollution is difficult to determine. There does seem to be an overall upward trend in CO_2 emissions and a downward trend for SO_2 emissions, but this may not necessarily be the case. By taking a look at the data on a logarithmic scale however, the raw data seems to much more clearly support the notion that environmental free riding is causing carbon dioxide to continue rising unbounded while sulfur dioxide seems bound by the EKC.

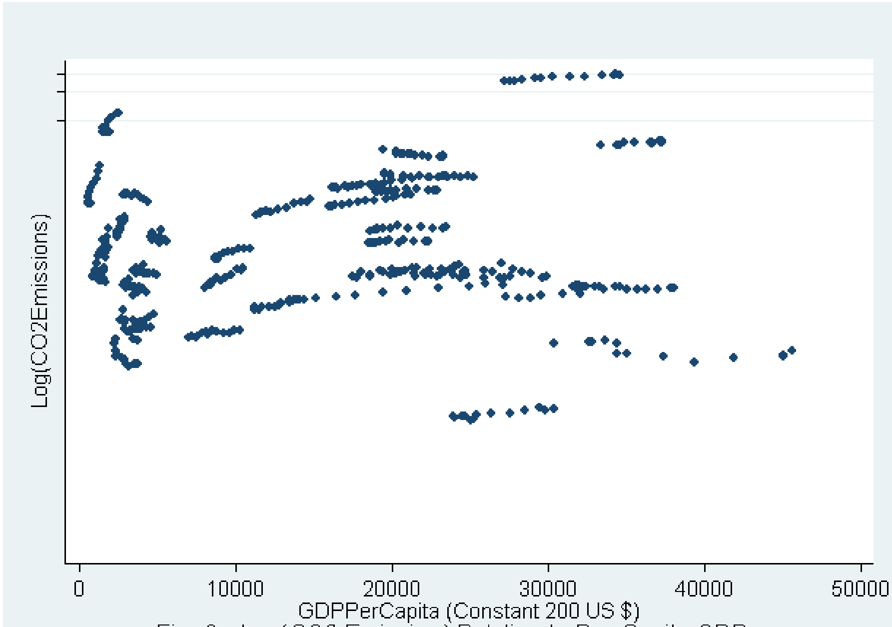

Fig. 3 - Log(CO2 Emission) Relation to Per Capita GDP

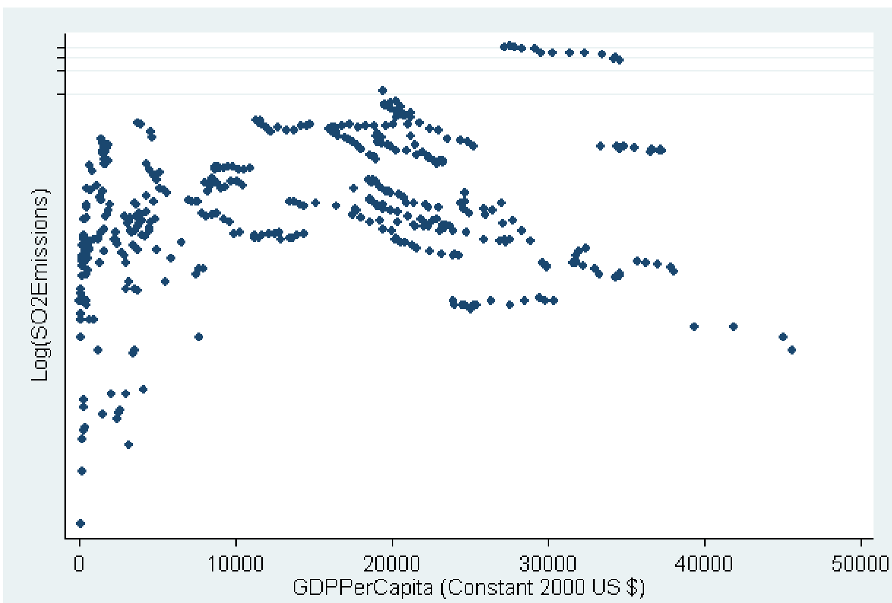

Fig.4 - Log(SO2 Emission) Relation to Per Capita GDP

Considering the possibility of population growth leading to pollution levels surpassing the Earth's carrying capacity, whether or not we can expect a reduction in environmental devastation from increased per capita income has enormous policy implications. If a statistically and economically reliable model could be formulated based on EKC theory, nations could better estimate cost-benefit analyses of their current growth to determine the sustainability of development. Two common products of developing nations' growth that could be studied are the increase in carbon dioxide and sulfur dioxide emissions. Due to their direct link to global warming and acid rain, respectively, a sustainable course of carbon dioxide and sulfur dioxide emission is absolutely imperative to ecological preservation. Unfortunately as previously mentioned, studies to date on the EKC have left many economists uncertain of its capability to accurately relate pollutant emissions to economic growth-due in part to the economic free rider problem.

It is therefore the purpose of this paper to first examine the reliability of the EKC as it pertains to carbon dioxide emissions and sulfur dioxide emissions specifically. In particular, I seek to determine whether an inverted-U relationship holds for both sulfur dioxide and carbon dioxide emissions. If they exhibit different shapes, I will seek to determine to what degree the environmental free rider problem plays in such results. While current EKC research focuses either only on the reliability of the EKC or on the empirical turning points determined by the model, this paper aims to employ such data to explain discrepancies from the EKC model in terms of the environmental free rider problem.

The next section reviews the relevant literature on the EKC and the free rider problem in order to further convince the reader of the need for the extension of research in the field. Papers outlining the strengths and weaknesses of EKC theory and the assumptions upon which it is based are also noted to stress the call for extending empirical analyses that either refute or support the model. The section also expounds upon the economic framework of EKC theory and how it naturally lends itself to empirical analysis such as that carried out within this paper. The third section then explores data sources available on the topic and the drawbacks or advantages of such records. The Empirical Specification section clarifies the mathematical model and empirical hypotheses to be implemented within the paper. This section additionally lists the study's findings and how they relate to those of other economists' research. Finally, the last section summarizes the results and implications of the paper as well as discusses possible routes for further exploration on the topic.

Theoretical Framework and Literature Review

One of the first papers to discuss the EKC, which has since become a precursor to most research on the subject, was "Economic Growth and the Environment," written by economists Grossman and Krueger (1995). In studying the EKC, Grossman and Krueger (1995) test the idea that "the forces leading to change in the composition and techniques of production may be sufficiently strong to more than offset the adverse effects of increased economic activity on the environment." The economists went about researching this empirical topic using panel data on ambient pollution levels in several countries. Forming the basis of their research was the Global Environmental Monitoring System (GEMS), "a joint project of the World Health Organization and the United Nations Environmental Programme." Using indicator variables relating to urban air pollution and contamination in river basins, Grossman and Krueger (1995) concluded that "while increases in GDP may be associated with worsening environmental conditions in very poor countries, air and water quality appear to benefit from economic growth once some critical level of income has been reached." Despite these findings, Grossman and Krueger (1995) do admit to a few shortcomings to their research. The first major weakness is that, while their study was the most comprehensive possible given the availability of comparable data from different countries, their measures covered relatively few dimensions of environmental quality. Additionally, the authors bring up the possibility that, while a drop in pollution emissions is correlated with an increase in GDP, it is not necessarily caused by such changes. For instance, the drop could have to do more with increased legal liability and litigation arising due to industrialization which then causes pollutant-heavy firms to outsource business offshores where legal restrictions are less demanding. This would then eventually mean that, as all countries establish environmental laws, the EKC theory trends would cease to continue.

The conventional EKC was first described by the following equation from Grossman and Krueger (1995):

$$Y_{it} = G_{it}\mathrm{B}_1 + G_{it}^2\mathrm{B}_2 + G_{it}^3\mathrm{B}_3 + \overline{G}_{it-}\mathrm{B}_4 + \overline{G}_{it-}^2\mathrm{B}_5 + \overline{G}_{it-}^3\mathrm{B}_6 + X'_{it}\mathrm{B}_7 + \varepsilon_{it} \qquad (1)$$

Y_{it} is a measure of water or air pollution in an environmental testing station i in year t, G_{it} is the per capita GDP for year t in the country where station i is located, and the $\overline{G}_{it}$ terms are the averages of GDP per capita over the prior three years. Finally, X'_{it} is a vector of other covariates while ε_{it} represents an error term. The major drawback to Equation 1 and the EKC theory itself is that research shows neither seem to be applicable to all pollutants equally, which led to the interest in testing the model's applicability to carbon dioxide versus sulfur dioxide emissions and in testing its relation to the free rider problem within this paper.

The reduced-form approach that Grossman and Krueger (1995) take in describing mathematically the relationship between pollution and growth was done for two main reasons-first, the reduced-form estimate gave the authors the net effect of a nation's income on pollution. If structural equations had been estimated, then it would be necessary to solve back to find the net effect of income changes on pollution, and confidence in the implied estimates would depend upon the precision and bias of the estimates at each stage. Additionally, the reduced-form approach spared the authors from collecting data on pollution regulations and technology, data not readily available for researchers and whose estimation would lead to results with questionable validity. Admittedly, the major disadvantage to this approach though is that it is still unclear why the estimated relationship between pollution and income actually exists. This paper aims to explain in terms of the environmental free rider problem.

According to Dasgupta et al. (2002), the economic theory underlying the EKC depends on four main assumptions. The first is that the marginal utility of consumption must be non-increasing. That is, as consumption of environmental resources continues, the law of diminishing marginal utility takes effect in addition to an increased realization among consumers of the ecological cost of the process. The next assumption is that the disutility of pollution is rising, meaning that a marginal increase in pollution when pollution levels are low does not produce as much disutility as does a similar increase when they are already quite high. Likewise, the EKC assumes that the marginal damage of pollution is rising, meaning more marginal environmental degradation occurs for increasing pollution when pollution levels are already high. Finally, the last assumption of the EKC is that the marginal cost of abating pollution is rising. This assumption is intuitive since, if the marginal cost of abating pollution were decreasing, it would be possible to produce complete pollution abating technologies in an economically feasible manner. In order to better convey the different points of view on the EKC, the figure below outlines four EKC scenarios.

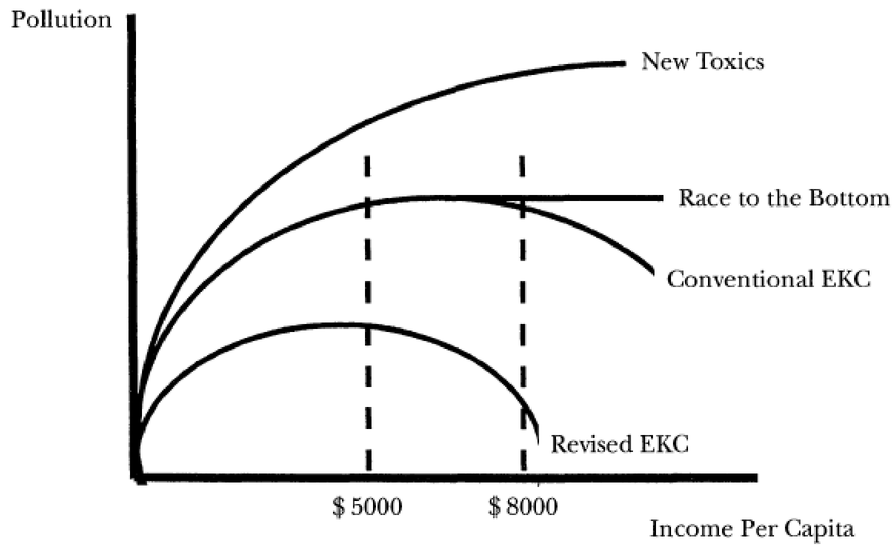

Figure 5: Different EKC Scenarios from Dasgupta et al. (2002)

The conventional EKC shown in Figure 5 displays the idea outlined originally by Grossman and Krueger (1995) in their first publication. The "race to the bottom" curve represents the "pollution haven" counterpoint to the EKC, outlined by the flattening EKC curve in the figure. Another point of debate on the topic is the possibility of non-conventional polluting toxins that are produced from new technologies that are not accounted for within the EKC. Thus, the above figure shows that these pollutants do not follow the typical EKC shape as they continue to rise for increasing income per capita. Finally, the revised EKC theory is outlined by the inward-shifted curve, conveying the concept that since many pollution-abating technologies already exist for developing countries to implement, they are able to reach their EKC turning points at lower levels of income per capita than currently developed countries once did.

Shortly after the publication of Grossman and Krueger's (1995) famous paper, economists Stern, Common, and Barbier (1996) critically examined the EKC concept stating that the theory is inherently flawed as it "is dependent on a model of the economy in which there is no feedback from the quality of the environment to production possibilities, and in which trade has a neutral effect on environmental degradation." The authors also argue that while the EKC estimates depend on the assumption of world per capita income being a normally distributed variable, the median income is in reality much lower than the mean income. The paper then goes on to outline major flaws in the data used by several economists to support EKC theory. Stern et al. (1996) argue that data for such environmental issues is "notoriously patchy in coverage and/or poor in quality." Specifically relating to the study by Grossman and Krueger (1995), the authors argue that their ambient pollution data from urban areas is only appropriate for drawing conclusions on these specific regions, and the results should not be extrapolated to include more agricultural regions. In their conclusion, the authors finally declare that "the problems associated with both the concept and empirical implementation of the EKC are such that its usefulness is limited to the role of a descriptive statistic." The criticism of the pollution data utilized by Grossman and Krueger motivates the use of a more global database that would be equally applicable to all areas of all nations-such as the one used in this study.

Similar to Stern et al. (1996), economists Bruyn, van den Bergh, and Opschoor (1998) refuted conclusions drawn from EKC theory, claiming that "emissions correlate positively with economic growth." Bruyn (1998) and his colleagues argue the previously mentioned point that the EKC inaccurately depicts the inverted-U relation between economic growth and environmental degradation, claiming that the model does not isolate economic growth from other confounding variables such as technological development and government legislation and regulation. The authors eventually conclude that "estimating a dynamic model shows that economic growth has a direct positive effect on the levels of emissions" and therefore refute EKC theory in general.

However, for each paper that is published opposing EKC theory, there seems to be at least one published supporting the model. Due to the widespread disagreement on the theory itself, economists Dasgupta, Laplante, Wang, and Wheeler (2002) summarized EKC theory research and provided further insight into the model's statistical reliability. Claiming that "empirical researchers are far from agreement that the environmental Kuznets curve provides a good fit to the available data, even for conventional pollutants," Dasgupta (2002) and his fellow economists set out to solve this issue. The authors begin their analysis by discussing the importance of recent efforts to improve the data sources available for study. This is one major motivating factor for my paper, as data availability has improved significantly since empirical studies on the EKC model first began. Significant strides can thus be made within the topic. Dasgupta et al. (2002) show that there does in fact seem to be a high correlation between income per capita and air pollution regulation, therefore supporting the idea of "pollution havens" in which firms outsource pollutant-intensive labor which falsely creates an EKC. However, the authors also discuss the fact that increasing availability of technology for developing countries has caused the average EKC to shift inward so that pollution reduction turning points are reached at lower income per capita levels. Dasgupta et al. (2002) also point out the alarming fact that the stability of EKC theory is a little-researched topic. Thus, while the inverted-U shape may apply within certain ranges of income per capita, the true relation of pollutant emissions to income per capita could be more of an S shape. In general, the authors agree that the EKC can be used as a starting point for formulating economic theories on the topic of sustainable development, but that the theory is far from perfect.

Relating EKC theory back to the free rider problem, it should be clear that the inverted-U relation between per capita income and pollution is disrupted by the free rider problem, since a country won't feel the full effects of its own polluting activity, and therefore would feel less obligation to engage in costly pollution-abating activities. This hypothesis can be tested by isolating variables that might signal the presence of the free rider problem and observing how such factors affect the relation between a nation's per capita income and pollution emissions.

As stated previously, the free rider problem as it relates to environmental economics was first widely publicized by Demsetz (1964). Demsetz's (1964) paper concludes that users of communally owned resources (such as the atmosphere) will fail to reach an agreement on proper resource management despite this being in the best-interest of all users. This argument is supported by the underlying principles of game theory. Assuming an agreement was reached by all users, the benefits that could potentially arise from breaching such a pact would significantly increase for each individual and this, states Demsetz (1964), would lead to the unraveling of the said agreement entirely.

The theoretical underpinnings of the free rider problem are best explained by Gruber (2004) in the form of private provision of public goods. In general, the private sector will underprovide public goods as a result of the free rider problem-a truth that many economists say calls for government intervention. This can be clarified by simply defining a public good. According to Gruber (2004), pure public goods are those "that are perfectly non-rival in consumption and are non-excludable." A good is deemed non-excludable if "individuals cannot deny each other the opportunity to consume" and is considered non-rival in consumption if "one individual's consumption…does not affect another's opportunity to consume." Thus, since a public good brings benefit to all agents within a community regardless of whether or not those same agents endured the associated costs, underprovision occurs as presumably all agents will attempt to free ride off those willing to pay for the good. This concept can also be easily described in the context of environmental economics. The profits a nation attains that are associated with pollution-causing technologies could be used to produce, at least in part, pollution-abating technologies that benefit the entire world. Many countries would shy away from this policy though, considering that their contribution is evenly spread out among all nations while the costs they bear are shouldered solely by the specific country. Unfortunately, although government regulation is one of the more popular solutions to the free rider problem, there is no entity that has total control over the nations of the world. As mentioned before, any member of the United Nations Environment Programme can elect to veto a majority decision by the committee, thereby making any legislation futile. Moreover, nations are forced to share the planet's resources, for better or for worse, and thus there is no way to avoid the free rider problem within environmental economics.

Demsetz (1964) states that the only true solution to the free rider problem is government intervention and/or regulation. Unfortunately, as pointed out by economist Barrett (1990) there is no true world government that oversees and regulates environmental legislature. The closest thing to such an entity is the United Nations Environment Programme-but this is far from an all-powerful government agency as any voting member can object to a majority decision, rendering the vote meaningless. This was exemplified in 1954 when a proposal to prohibit the taking of blue whales in the North Pacific Ocean was rejected by Canada, Japan, the US, and the USSR (which just happen to be the only countries engaging in said activity). Again, in 1981 the proposal to ban the use of explosive harpoons for killing minke whales was rejected by the only countries that hunted this species (i.e., Brazil, Iceland, Japan, Norway, and the USSR), making the ban futile.

Despite the bleak outlook Demsetz (1964) and Barrett (1990) convey on the free rider problem in environmental resources, Folmer et al. (1993) attempt to solve this issue using interconnected games that offer an alternative solution to using financial payments to induce countries to cooperate with international agreements--an idea which Barrett (1990) supported. Folmer et al. (1993) show that there are substantial gains to be realized under efficient international coordination, which can be achieved using bartering techniques with pollution emissions. For example, one country might offer another nation fewer restrictions on imports of their goods in exchange for pollution emission reductions. In this scenario, pollution emissions are viewed as “bads” that are to be treated as any other similar resource in economics.

Two suggested solutions to the paradox of environmental free rider theory outside that of government regulation are trade and bartering for the reduction of pollution emissions and financial subsidy agreements, which are really a subset of the former. Nations can trade goods and services or financial equity or otherwise make negotiations with polluting countries to reduce emissions. Unfortunately, these solutions clearly increase dead-weight loss as negotiation costs and trading costs can get quite high.

Within current research there are high levels of dispute on both the topic of the EKC and the environmental free rider problem, thereby justifying the study of this paper. Additionally, it has been noted that very little EKC research has gone beyond determining the reliability of EKC theory, another key difference between this study and past research. The next section depicts how empirical data available for a wide range of countries will be used to test the predictions of the effects of the free rider problem on EKC theory for carbon dioxide emissions versus sulfur dioxide emissions and then how those results could be extrapolated for further research and analysis.

Data

Numerous environmental databases containing information relevant to EKC theory were compared for the current study since the quality of any database chosen would play a vital role in the overall reliability of the paper's conclusions. I considered using research from the World Resource Institute (WRI) within the EarthTrends database. This database has grown dramatically in recent years--an indication of the increased attention given to environmental economics as of late. However, concerns of potential bias and data deficiencies led to the decision to obtain data for the current study from the GEO Data Portal, which is provided by the United Nations Environment Programme. Since WRI is an environmental think tank based in the United States I feared that skeptics may view the EarthTrends data as having an ethnocentric bias towards Western culture. However, this notion was later deemed erroneous given the high level of collaboration between the United Nations Environment Programme and WRI. Even still, the GEO Data Portal was ultimately chosen for this study due to its depth of datasets and vast number of options available for data sorting and organization. A final advantage to using the GEO Data Portal arose as development of the regression analysis equation testing the effect of the free rider problem upon EKC theory progressed; as new regressors were investigated, corresponding statistics were easily attained from the numerous other datasets located in the database.

The GEO Data Portal compiles smaller datasets from other environmental agencies, which improves the researchers' ability to make cross-country analyses. Unfortunately, this does introduce data comparability issues since some of these smaller, synthesized data sets could employ different data-gathering methodologies. Overall, this issue was deemed too inconsequential to significantly alter or otherwise bias the study's results. The major weakness associated with the pollutant datasets provided by the GEO Data Portal is that their emission statistics disregard contributions arising from biomass burning, removals from the land-use change and forestry sector, and the oxidation of non-fuel hydrocarbon products such as asphalt. Reported emission levels within these datasets also consist only of those arising from human activity, making it more difficult to compare the study's results with those of Grossman and Krueger (1995), whose data included natural emissions. Despite these pitfalls, the United Nations Environment Programme stood out as the preeminent source for data to test the EKC hypothesis.

The specific data used were the trends in several nations' GDP per capita in constant 2000 US dollars, CO_2 and SO_2 annual emissions in millions of metric tons, and the population density of these nations over time. The first three variables were used to plot the relation between per capita income and air pollutant emission for each country during each year being studied. The final variables described trends for two hundred and fifty-two countries during the timeframe of 1990 through 2002. Each of the previously mentioned datasets are available online at http://geodata.grid.unep.ch/ for public use. Country dummy variables were also constructed in order to account for potential time-invariant, country-specific characteristics such as natural resources, local wind patterns, climate, and coastline traits that might spuriously affect the EKC. Similarly, year dummy variables were used to control for the different social pressures countries might have faced as a result of industrializing over different time periods.

Due to different government policies, natural resources, and industrialization timelines among countries there will clearly be some nations that show data supporting the hypotheses and some that refute it. Similarly, these same factors can cause certain countries to behave as statistical outliers, displaying emission levels vastly different from those of other nations. Both Figures 1 and 2 seem to suggest the data may be victim to such outliers given the deviating cluster of data points appearing within each plot. By consulting the raw data values, it appears that these clusters in both figures represent the emission levels of the United States. This display of one country resulting in such a large percentage of global pollution emissions also supports the theory that the free rider problem plagues modern environmental policy.

Downward trends seen in sulfur dioxide emissions from Figures 2 and 4 do imply the inverted-U relation between income per capita and pollution emissions. Although the entirety of the U-shape is not seen for all countries, it is intuitive that pollution at one point in time must have been increasing with rising income per capita since overall emissions have clearly increased with human industrialization patterns. Thus, showing falling pollution levels displays a snapshot in time of the tail end of the EKC, where the turning point has already been reached and pollution is on the decline.

Alternatively, the carbon dioxide emissions seem to be increasing-which can lead to two possible conclusions. The first is that the figure is displaying a snapshot of the beginning of the inverted-U EKC model and the turning point has not yet been reached so emissions are continuing to increase with rising per capita GDP. However, the more likely conclusion given that many countries in the dataset are fully developed, is that the EKC model fails entirely for carbon dioxide, as there seems to be no inverse relation between emissions and per capita income.

Shown below are summary statistics describing the data collected and analyzed in the regression model outlined in the next section. As can be seen, twenty-four countries (outlined in the graphs) will be studied over a time period of twelve years.

Table 1
Data Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
GDP Per Capita	2313	5418.467	8189.189	57	45615
CO2 Emissions	499	371354.5	909256.6	105	5864465
SO2 Emissions	459	0.952483	2.940348	1.00E-05	20.936
Population Density	2824	163.485	437.0105	0.1	6214.6

As shown by Table 1, a large standard deviation was seen for each of the four listed variables, this can be explained by the vastly different socioeconomic and political states of the countries studied. The variables summarized within Table 1 are clearly those most applicable to my research as they specifically outline the information necessary for formulating the EKC relation and for testing the hypothesis that the free rider problem has a strong influence on the EKC-both of which are done within the following section.

Empirical Specification

In order to implement the current study, the aforementioned data sets acquired from GEO Data Portal, the authoritative data source formed by the United Nations Environment Programme, were used to estimate the functions relating per capita income to pollution for both carbon dioxide and sulfur dioxide. The hypothesis of the study was two-fold: it was first hypothesized that sulfur dioxide will match the inverted-U shape common to EKC theory while carbon dioxide will exhibit an S-shaped curve.

This was done by modifying Equation 1, the traditional regression equation used by Grossman and Krueger, by dropping those regressors irrelevant to this study's dataset while including additional regressors such as population density and dummy variables for the year (ranging from 1990-2002) and for each country. The final mathematical model that was followed can be seen in Equation 2 below.

$$Y_{it} = G_{it}\mathrm{B}_1 + G_{it}^2\mathrm{B}_2 + G_{it}^3\mathrm{B}_3 + PopDens\mathrm{B}_4 + Country + Year + \varepsilon_{it} \qquad (2)$$

This paper's model did not include lagged GDP terms due to high collinearity issues arising between the non-lagged GDP terms, which biased results. This seemed a minor change to the equation of Grossman and Krueger (1995) who admit "lagged and current GDP per capita are highly correlated, so including just current (or just lagged) GDP per capita does not qualitatively change the results." The addition of the dummy variables was done to hopefully capture any effects constant across time for each individual country as well as any effects constant across all countries for a given time. Assuming the free rider problem were indeed present within the emission of carbon dioxide but not within the emission of sulfur dioxide, the results of the study should display a positive, statistically significant correlation between the cubic per capita GDP term and pollution emissions in the case of carbon dioxide while alternatively showing a traditional inverted-U relation between per capita income and pollution emissions for sulfur dioxide.

In summary, two hundred and seventy-one variables were included in the analysis. The first two being the separate dependent variables-per capita sulfur dioxide or carbon dioxide emissions, measured annually in millions of metric tons. The first three independent regressors were per capita GDP, then per capita GDP squared, and finally per capita GDP cubed. These were to account for the linking and decoupling between pollution and income. The next regressors analyzed were population density followed by the two hundred and fifty-two country dummy variables and the thirteen year dummy variables. Assuming the EKC model were to hold for a pollutant, the expectation for the aforementioned coefficients would be a positive sign for that in front of the GDP per capita term and a negative sign for that in front of the squared GDP per capita term. Finally, a positive, statistically significant coefficient for the cubic GDP per capita term would imply an S-shaped curve rather than the EKC. Regressions were run using OLS with one suppressed country dummy variable (United States) and one suppressed year dummy variable (1990). Table 2 below displays the results for CO_2 when the cubic GDP per capita term is included in the regression.

Table 2
CO_2 Emissions Statistical Results

Adjusted $R^2 = 0.99403$

CO2Emissions	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
GDPPerCapita**	116.0749	31.40345	3.7	0	54.34701	177.8029
SquaredGDPPerCapita**	-0.00456	0.001212	-3.76	0	-0.00695	-0.00218
CubedGDPPerCapita**	6.91E-08	1.78E-08	3.89	0	3.42E-08	1.04E-07
PopulationDensity**	2499.83	934.058	2.68	0.008	663.8062	4335.853
_cons**	4121538	328366.3	12.55	0	3476088	4766989
Country Dummy Variables	Yes					
Year Dummy Variables	Yes					

*=Statistically Significant at the 5% level

**=Statistically Significant at the 1% level

As expected, the coefficient of the GDP per capita and the cubed GDP per capita regressors were positive while the coefficient of the squared GDP per capita variable was negative-thus forming the hypothesized S-shape. The results found using the same regression techniques for SO_2 are shown below.

Table 3
SO_2 Emissions Statistical Results

Adjusted $R^2 = 0.97120$

SO2Emissions	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
GDPPerCapita	0.00017	0.000134	1.26	0.207	-9.5E-05	0.000434
SquaredGDPPerCapita	-2.60E-09	7.54E-09	-0.34	0.731	-1.74E-08	1.22E-08
CubedGDPPerCapita	-6.63E-14	1.49E-13	-0.44	0.657	-3.60E-13	2.27E-13
PopulationDensity	-0.00513	0.010244	-0.5	0.617	-0.02528	0.015016
_cons**	17.06551	1.43922	11.86	0	14.2349	19.89612
Country Dummy Variables	Yes					
Year Dummy Variables	Yes					

*=Statistically Significant at the 5% level

**=Statistically Significant at the 1% level

Table 3 shows each of the proposed regressors as being statistically insignificant as can be seen by the corresponding t-statistics. However, assuming the hypothesis that sulfur dioxide follows the EKC were correct then these results may be logical since including the highly collinear cubic GDP per capita regressor may make it difficult to estimate the other parameters. Similar reasoning would also imply that removing this term for carbon dioxide emissions would invalidate the model as its emissions were thought to better fit an S-shape rather than the EKC. Table 4 below displays the results of the same regression for CO_2 without the cubic GDP per capita term.

Table 4
CO_2 Emissions Statistical Results
Adjusted R^2 = 0.99343

CO2Emissions	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
GDPPerCapita	14.80824	15.20688	0.97	0.331	-15.0828	44.69931
SquaredGDPPerCapita	0.000172	0.000297	0.58	0.564	-0.00041	0.000757
PopulationDensity	1804.251	995.3251	1.81	0.071	-152.188	3760.69
_cons**	4804703	241443.7	19.9	0	4330114	5279291
Country Dummy Variables	Yes					
Year Dummy Variables	Yes					

*=Statistically Significant at the 5% level

**=Statistically Significant at the 1% level

These results show exactly what was expected-removing the cubic GDP per capita term invalidates the proposed model entirely and a drop in the adjusted r-squared value. Table 5 below shows the results for SO_2, also excluding a cubic GDP per capita regressor.

Table 5

SO_2 Emissions Statistical Results

Adjusted $R^2 = 0.97123$

SO2Emissions	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
GDPPerCapita*	0.000265	0.000114	2.33	0.021	0.000041	0.00049
SquaredGDPPerCapita*	-7.09E-09	3.05E-09	-2.33	0.021	-1.31E-08	-1.10E-09
PopulationDensity	-0.00463	0.010743	-0.43	0.667	-0.025757	0.016501
_cons**	16.41862	1.291678	12.71	0	13.87822	18.95902
Country Dummy Variables	Yes					
Year Dummy Variables	Yes					

*=Statistically Significant at the 5% level

**=Statistically Significant at the 1% level

Just as predicted, removing the cubic GDP per capita regressor resulted in a valid model with only population density proving to be statistically insignificant and an increase in the adjusted r-squared value. The inverted-U EKC is supported for sulfur dioxide emissions as the coefficient for GDP per capita is positive while a negative coefficient precedes the squared GDP per capita term. These results support the initial hypothesis stating that carbon dioxide emissions would fit an S-shaped curve while sulfur dioxide emissions would fit the EKC. Furthermore, Tables 2 and 5 support the hypothesis that the free rider problem plagues EKC theory, explaining why carbon dioxide emissions cannot be predicted using the inverted-U model.

The current findings seem to validate results previously found by Grossman and Krueger (1995) in their initial research of the EKC and its implications within environmental economics. Although this is not a popular belief among skeptics of the EKC, it seems unlikely that the displayed results, along with those of Grossman and

Krueger (1995), could be obtained if EKC theory were completely invalid. It is still thought however that there may be omitted variable bias affecting the study's results. Evidence that this pitfall may be occurring can be seen by noting the large differences between corresponding coefficient magnitudes when the cubic GDP per capita regressor is omitted.

Predicted emissions of carbon dioxide and sulfur dioxide were also plotted using variable coefficients and standard errors obtained for the per capita GDP terms from Tables 2 and 5. Next to these curves were plotted the upper and lower EKC bounds of the 95% confidence interval. These were obtained by constructing thousands of curves arising from randomly sampling from a normal distribution of coefficients given the aforementioned STATA coefficients and standard errors as mean and standard deviation values, respectively. After taking the appropriate percentiles from each EKC, the upper and lower bound curves were then constructed for comparison.

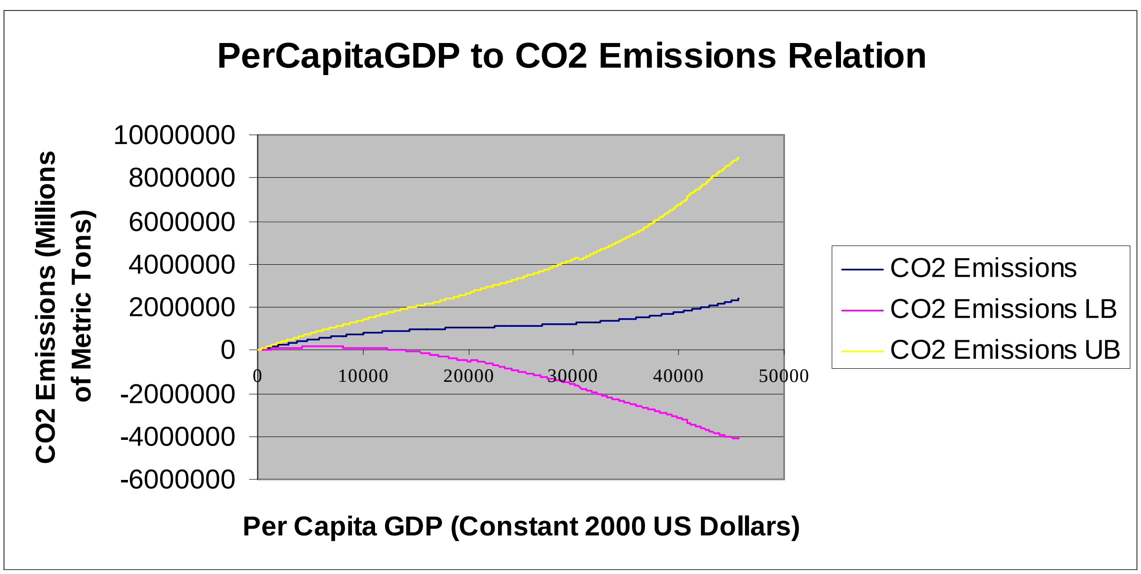

Figure 6: PerCapitaGDP to CO2 Emissions Relation

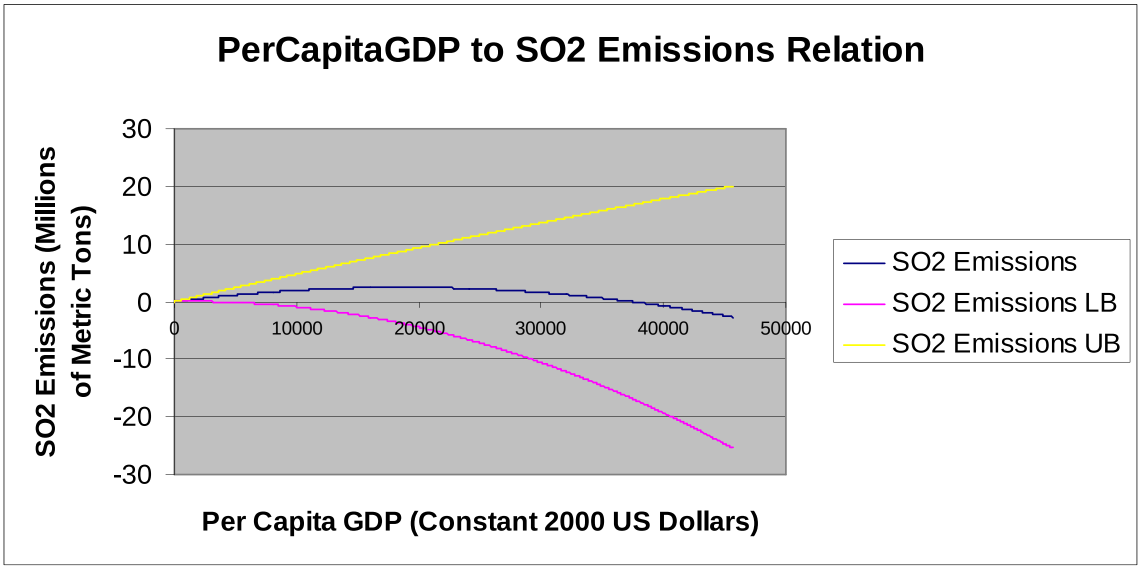

Figure 7: PerCapitaGDP to SO2 Emissions Relation

While omitting the other regressors from these plots results in the magnitude of these predicted emissions losing economical significance, their most important features are their curvature and shape. Carbon dioxide emissions and sulfur dioxide emissions in relation to per capita GDP clearly resemble cubic and quadratic functions, respectively. These figures provide further evidence that the free rider problem is to blame for the invalidation of the EKC for CO2. Figure 6 and 7 both show the hypothesized shapes for each corresponding pollutant, although the lower bound of Figure 6 appears to resemble an inverted U while the upper bound of Figure 7 seems to imply a linear relation. However, given the statistically significant cubic parameter in the case of carbon dioxide and the statistically significant quadratic parameter in the case of sulfur dioxide it is clear that if the plots were extended the curves would take the hypothesized shape.

Another fact in support of EKC theory is that the results of this paper and those of the study conducted by Grossman and Krueger (1995) are similar despite vastly different methods of data acquisition. Data analyzed by Grossman and Krueger (1995) was obtained from an individual, Robert Bisson of the Canada Centre for Inland Waters, which is the WHO Collaborating Centre for Surface and Groundwater Quality. As mentioned previously all data analyzed within the current study were obtained from the United Nations Environment Programme database, specifically from GEO Data Portal. It is possible that this key difference between data acquisition methods may have led to different results, but this was clearly not the case. Additionally, the data acquired by Grossman and Krueger (1995), unlike those of GEO Data Portal, included natural emissions of air pollutants. Next, the data obtained by GEO Data Portal also did not include emissions arising from land use change and agriculture, such as deforestation. This is a crippling feature of the dataset, which could have caused the results to deviate from those of Grossman and Krueger (1995). Furthermore, given the specific and detailed knowledge that Grossman and Krueger (1995) had of their own sample dataset, the authors were able to include a covariate vector containing more specific variables differentiating between air quality testing centers used within their study. Given the more aggregate level of study included within this paper, that precise level of detail was not possible. The fact that similar results were obtained from such fundamentally different data sets is strong evidence in support of EKC theory.

The next steps that could be taken are first and foremost the analysis of what additional regressors would be appropriate to include in the regression equation used to test for the presence of the EKC model as well as to test the effects of the free rider problem on EKC theory. Given the wealth of information in the GEO Data Portal database, a large amount of data could be sorted through before a decision could made on this. Furthermore, an ever-present burden on the study was the evaluation of an accurate and justifiable (both logically and mathematically) method to properly pinpoint and define the presence of the free rider problem within the study's results. The method being employed analyzed the cubic per capita GDP regressor for statistical significance. Unfortunately, this can only be assumed to be the best method of analysis for this issue and no true *a priori* justification has been formulated for support.

Conclusion

In summary, the findings of the paper suggest the lack of an EKC model for CO_2 emissions while supporting EKC theory for SO_2 emissions, just as was hypothesized. This matches the results obtained from the study conducted by Grossman and Krueger (1995). This is strong evidence supporting the claim that the free rider problem is a leading contributor to the invalidation of EKC theory in the context of carbon dioxide emissions. It seems likely that further studies will continue to support these preliminary results, although these projects might also prove additional regressors should be used to better predict accurate pollutant emission levels.

The topic of environmental sustainability is one of increasing importance given human dependence on the planet's ecological systems. Given the difficulty in quantifying sustainable development, the Environmental Kuznets Curve is an important tool in this field of study. Given its novelty, the theory has met with much debate and deserves further study beyond that done within this paper. This paper is unique given its empirical focus on the role of the free rider problem in EKC theory rather than solely its theoretical validity. The paper ultimately supports the EKC theory and implies that discrepancies might be explained as a direct result of the free rider problem. That being said, and given that one of the few solutions to the free rider problem is government regulation, this paper will hopefully add to the voices calling for the United Nations to draft more serious legislation on the matter of greenhouse gas emission. Continued areas of exploration could improve upon this paper's findings by studying the effects of economic growth upon environmental degradation after isolating these variables from governmental regulation and other exogenous compounding variables.

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