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Cowboy and Spaceman: The Driving Forces of Energy and theEconomic and Environmental Tradeoff

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An abstract of

a thesis submitted to the Faculty of Emory College of Arts and Sciences

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The environmental Kuznets curve (EKC) presents a framework that depicts the dynamic relationship between economic growth and environmental quality. As a society grows in income, it will be accompanied by environmental degradation, but after reaching an apex will begin to decrease monotonically as income continues to grow. In this project, renewable and nuclear energy productions are used as a proxy within this framework to analyze how such energy production relates to these EKC variables; Granger causality is used between the two sides, and both directionalities are compared. No significant causality is found from the EKC variables acting on energy production, but renewable energy production appears to have a causal link to GDP and carbon dioxide emissions.

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1 Abstract

The environmental Kuznets curve (EKC) presents a framework that depicts the dynamic relationship between economic growth and environmental quality. As a society grows in income, it will be accompanied by environmental degradation, but after reaching an apex will being to decrease monotonically as income continues to grow. In this project, renewable and nuclear energy productions are used as a proxy within this framework to analyze how such energy production relates to these EKC variables; Granger causality is used between the two sides, and both directionalities are compared. No significant causality is found from the EKC variables acting on energy production, but renewable energy production appears to have a causal link to GDP and carbon dioxide emissions.

2 Introduction

Economic development is broadly linked to its resource inputs. The way in which an economy manages its resources and the availability thereof are fundamental to how it progresses in terms of technology, manufacturing, and infrastructure. The historical progression of economic development, then, has resulted in the increasingly greater need for resource expenditure in order to advance, now to the point that the trade-off between the benefits of progress and the detriment of environmental destruction might be called into question. In the United States, for instance, the last century or so of policy-making has shaped the economy away from what could be thought of as a "cowboy economy" more towards the beginnings of a "spaceman economy" (Boulding, 1966): the former refers to a system wherein natural resources are considered practically infinite and their acquisition and waste byproducts are inconsequential, whereas the latter is a closed system that must base itself on as much renewable production as possible and as little nonrenewable and waste-producing consumption. These are somewhat vague descriptors and represent absolute ideals more so than actual economic periods, but they offer an interesting perspective by which to judge how our resources and environment are treated with respect to economics. The question that I want to address, then, is the driving force behind this trade-off: does continued growth spur change toward the "spaceman economy", or is the "spaceman economy" necessary to continue development?

The environmental Kuznets curve is a theoretical model that postulates the relationship between economic growth and environmental destruction that, when actualized, takes the shape of an inverted U-curve. This implies that at first, an economy's economic growth will come with a proportional increase in environmental degradation, but after a certain apex of degradation, that degradation will begin to decrease as income growth continues. With an economy that follows this U-curve, we can divide its mode of development into two distinct phases: the first is marked by an increase in profitable industry that takes an environmental toll proportional to its output, for instance agricultural farmland changing to industrial factories, then reaching a critical point and transitioning to a system wherein those high resource-cost processes are ceased or modulated into more sustainable ones such that environmental costs are diminished. While the fundamental causes of this shift are still only postulates, the U-curve phenomenon is widely observed for developed economies; an exact derivation of the inflection point is likely controlled by a great many factors, both exogenous and endogenous, but the respective increasing and decreasing relationships before and after the inflection point are indeed observable.

If this model were endogenously true, it would essentially mean that environmental policy is not required for environmental preservation, at least as far as economic resources are concerned; it implies that environmental destruction will decrease on its own so long as economic development continues. This claim is hard to verify and is understandably contentious, even intuitively; social factors controlling the need and demand for economic and environmental balance are broad and dynamic throughout levels of growth, so such a simple causal statement imposed on a complex scenario may be limiting. Indeed, if this model were not true and the environment went unregulated with the assumption that it did not need to be when it in fact should have been, the consequences would be disastrous. With this two-factor U-curve form alone, the model does not explicitly account for variables other than growth and degradation, and moreover lends only partial analysis to the topic at hand with no causal mechanism being implied. This paper will aim to use the model as the basis of analyzing such a mechanism by accounting for deeper underlying causal factors.

The main driver of environmental degradation, especially in the sense of resource exhaustion, is energy consumption. The significance is twofold in that energy is the most basic requirement for economic development of any kind, and indeed underlies all other processes that might be detrimental to the environment. Therefore it is a fair representation of the sum of humanity's resource use behaviors, in both its acquisition and waste production. A cowboy economy is based on using the most readily available and usable energy sources regardless of their pollutant emissions or environmental harvesting hazard, namely fossil fuels or coal. Both of these are significant sources of various damaging pollutants. Their use may in part be attributed to the attitude towards but also the imminence of these resources; when these sources can be found widely and require little innovation to use, they can provide the foundation for societies that lack the income for such innovation until their growth otherwise might incentivize it. As such, a spaceman economy would be defined by the use of clean or renewable energy sources, like wind, solar, or nuclear, among others. Many countries, especially higher income countries in the OECD, have come to acquire a majority of their power from these sources, but many developing countries, albeit lower income, still represent a sizable output of fossil fuel pollution. Large countries like China and India produce a good deal of renewable energy as well, but still use a large proportion of fossil fuels in spite of their income and innovation potential, adding to the complexity of the energy-income-environmental nexus.

Renewable energy is undoubtedly one of the hallmarks of the ideal of the spaceman economy and a greater reliance on it would almost certainly be the most significant step humanity could make towards a sustainable economy. Renewable sources generally include energy produced by wind, solar, hydroelectric, or biomass sources like compost or wood. Nuclear energy, which technically is non-renewable due to the finite supply of radioactive material on earth, will be included since it is far more sustainable than fossil fuel sources. The waste produced is far less consequential to the global environment, especially relative to the amount of energy produced per waste produced. Particularly with the growing possibility of nuclear fusion power in the coming decades, allowing nuclear power to become far more efficient with even less volatile waste, nuclear energy will certainly have a place in the sustainable spaceman paradigm.

With this project, I aim to investigate the causal relationship between the EKC factors, namely income level and environmental quality, and sustainable energy production, namely renewable and nuclear. By applying countries' energy production behavior against their environmental Kuznets curve outputs, the relationship between renewable energy use and slope stage of the curve can be evaluated. Granger causality tests, which infer causality between time series datasets by lagging terms within a regression, will be used to test causality between income, carbon dioxide emissions, and the renewable energy source usages. For instance, within the spaceman economy framework, we might expect renewable energy use to be a causal factor of economic growth and an inverse causal factor of CO2 emissions, or, just as likely, the reverse: that economic growth is a causal factor of renewable energy use. Taken together with the phase results of the EKC charts, regression analysis will be done to investigate whether these causalities are indicative of which phase a country's economy is in. In other words, it will suggest whether transitioning into a spaceman economy from a cowboy economy is necessary for continued economic growth or whether economic growth itself necessitates that transition.

3 Literature Review

3.1 Environmental Kuznets Curve

The Kuznets curve (Kuznets, 1955) was initially proposed as a measure of the relationship between income inequality and income per capita. The same inverted-U shape holds, implying that inequality will initially rise as income per capita does, but will then decrease after a certain maximal inflection point. This relationship was later extrapolated to environmental quality and income (Grossman and Krueger, 1995), with the inverted-U shaped relationship being observed with some environmental factors such as air and river pollution. However, even since the early days of this theory has its implications been questioned; an early meta-analysis by Stern (1995) points out that while the U-curve is observed in many studies, any attempt therein to identify the causes underlying it have been limited by poor econometric techniques. Since then, more modern reviews have been done with similarly ambiguous verdicts (Dinda, 2004; Kaika and Zervas, 2013). Some of this uncertainty arises from the basic parameters of the model, such as the measure of environmental quality. Some data indicate that environmental output is sensitive to other exogenous factors such that a straightforward relationship according to income is not necessarily implied (Harbaugh, 2002), or that the relationship changes among different pollutant measures (Effiong and Oisaozoje, 2016). However, although these studies indeed challenge some of the assumptions of the parametric model, the significance of this relationship is somewhat spurious with regard to the curve itself—when non-stationarity is taken into account, we cannot even treat the curve as a reliable indicator of an absolute trend on its own (Barra and Zotti, 2018).

Carbon dioxide emissions are generally used as the favored measure of environmental quality, and are especially applicable for this project due to its broadly indicative power of localized policy or industrial investment; early research in this field found that investment was classically linked with carbon emissions, which consequently responded best to alternative energy incentives (Nemat and Bandyopadhyay, 1992). Support for the EKC hypothesis according to CO2 emissions has widely been shown (Holtz-Eakin and Selden, 1995; Heil and Selden, 2001; Parajuli et al., 2019; Le et al., 2019), sometimes so extremely to the point that it is concluded that no environmental policy is even necessary (Bozokulu et al., 2019). This interpretation seems almost too radically positive even with data to support the model, which has also been met with varying dissenting interpretations of its underlying causes. York et al. (2003), Nutakor et al. (2020), and Nasr et al. (2015) use more advanced econometric techniques to deny the EKC hypothesis in favor of alternative hypotheses based on other exogenous factors as the driving forces. However, significantly to this project, none of these studies necessarily denies the existence of the inverted U-curve relationship between GDP and CO2, only its interpretation; as such, the EKC's importance to this project lies namely in the assumption that such curvature exists, as has been thoroughly confirmed.

3.2 Energy-Environmental-Income Growth Nexus

Energy production is closely tied to the environmental degradation measured by the EKC, and much research has been done on the relationship between different types of energy and economic growth. Energy consumption in general has been observed to have a long-term positive association with economic development across all income strata (Liddle, 2013; Adhikari and Chen, 2013; Lee and Lee, 2010). As far as nonrenewable energy sources, positive correlations have been observed between CO2 emissions and coal (Chandran and Tang, 2013), oil (Alam and Paramati, 2015), and gas (Solarin and Lean, 2016) usage. Furthermore, Bimanatya and Widodo (2018) found bidirectional Granger causality between all three forms of fossil fuels together with income and CO2 emissions, and Farhani and Balsalobre-Lorente (2020) applied fossil fuel consumption as a proxy to the EKC, implying that energy use is closely tied with income growth and environmental degradation.

In terms of renewable and sustainable energy sources, namely wind, solar, hydroelectric, and nuclear, intuitively will reduce CO2 emissions as they are used in substitute of carbon-emitting fossil fuels (Shafiei and Salim, 2012). There has been considerably less research on their connection to economic development as opposed to non-renewable sources, at least those that differentiate the effects of the two. Le et al. (2020) provide the most comprehensive existing analysis, finding that renewable energy use exerts the same positive forces on output as total energy use but at greatly reduced environmental cost.

4 Methodology

4.1 Environmental Kuznets Curve Specification

This environmental Kuznets curve definition is largely modeled after Farhani et al. (2020). The general form of the Kuznets curve derives the output environmental quality as a product of input income. This formulation arises from the more general environmental Engel curve, which is a simple form applied to the Kuznets hypothesis (Coondoo and Dinda, 2009). Using CO2 emissions as an indicator of environmental quality and GDP as income, the equation takes the form of

$$CO2 = f(GDP)$$

According to the theoretical basis of the Kuznets curve, f(GDP) will increase monotonically with GDP before reaching an inflection point, after which it will decrease monotonically. In practical terms the curve is created simply by graphing GDP on the x-axis against CO2 emissions on the y-axis. Both measures are significantly used on a per-capita basis. As referenced, many studies on the EKC have presented differing parametric forms of the curve, often using more sophisticated plotting measures than the unitary form listed above. However, such modulations were done in response to questionable causality implications, but in this project those issues will be addressed separately; as such, the curve itself will only be used to categorize economies by phase. In this case, phase refers to the two stages that may be seen in the curve, namely the monotonic increase of CO2 with GDP, phase 1, and the subsequent decrease after an inflection point, phase 2. This simple formulation of the EKC naturally follows as it only portrays that relationship of interest. Curves will be graphed for each respective country and categorized among the two phases.

4.2 Granger Causality

Granger causality will be used to investigate both directions of the causal relationship between the EKC variables, namely economic output and environmental quality, and the modes of energy production of interest. GDP per capita and carbon dioxide emissions per capita will be used for the former, just as in the EKC specification, and the latter will be represented by both renewable energy production and nuclear energy production per country. Granger causality will be employed with eight tests per country: GDP to nuclear, GDP to renewable, CO2 to nuclear, and CO2 to renewable, and all the respective inverses will be used with a third-order causality test. The two directionalities, EKC to energy and energy to EKC, will be categorized separately and analyzed with separate regressions so as to avoid dilution of significance levels by forcing the necessity of a Bonferroni correction. As such, a significance level of .05 will be used throughout for identifying causality.

4.3 Empirical Regression Analysis of Phase and Causality

With the EKC phase and Granger causality results in hand, a novel regression analysis will be performed between the two to evaluate the relationship between driving forces and EKC slope. As mentioned, two regressions will be used, with one patterning the causality from EKC to energy production and the other from energy to EKC. Therefore, the regressions will take the form of:

$$PHASE = \beta_0 + \beta_1 GDP - REN + \beta_2 GDP - NUC + \beta_3 CO2 - REN + \beta_4 CO2 - NUC + u$$

$$PHASE = \beta_0 + \beta_1 REN - GDP + \beta_2 NUC - GDP + \beta_3 REN - CO2 + \beta_4 NUC - CO2 + u$$

PHASE represents a country's EKC phase, which takes the value of either 1 or 2 as previously described. The paired terms represent dummy variables for the Granger causality results, for instance with GDP-REN representing the result of testing causality from income to renewable energy. These terms, as dummy variables, take the value of either 0, not significant, or 1, significant, according to the result of their respective test. The values of the corresponding coefficients will indicate whether the significance, or lack thereof, of the causality tests is correlated with one phase of the EKC or another. This, in addition to the separation of the two directionalities, is designed to test the original question of whether the EKC inflection point is driven by energy production or vice versa.

5 Data

5.1 Kuznets Curve Categorization

Data for every country that produces energy from renewable and nuclear sources was gathered from the U.S. Energy Information Administration database, totalling thirty countries. Total production of these sources was measured from 1980 to 2016 in BTU. Gross domestic product and carbon dioxide emissions per capita data were gathered for these same countries for the same time period from the World Bank database.

Of the 30 EKC graphs produced, 14 showed a phase 2 downward trend and 16 showed phase 1. Some graphs were more ambiguous and showed less obvious trends, but were only categorized as phase 2 given a unquestionable downward trend since phase 2 may only follow phase 1.

5.2 Granger Causality and Regression

Table 1 shows the results of the Granger causality tests of the EKC to energy variables by country, with 0 representing an insignificant result and 1 representing a significant one. In general, most results were not significant for all relationships, the most common being carbon dioxide to renewable energy with 7 out of 30 significant tests, and the least common being income to nuclear energy with no significant results whatsoever. Table 2 shows the regression analysis of the EKC to energy Granger causality results against phase. The regressed variables are dummy values defined either as 0 (not significant) or as 1 (significant), just as in Table 1, and phase has a value of either 1 or 2 according to the aforementioned phase definitions. In this regression, none of the variables' coefficients are significant or particularly large at all, including zero significance for GDP's effect on nuclear energy production. This corresponds with the relative lack of significant test values for this causal direction, and indeed the R-squared value is exceedingly low, implying that any such causation is practically nonexistent.

Table 3 shows the Granger causality results for the energy to EKC variable tests with the same parameters as Table 1. This causal direction clearly shows more significant results than the EKC to energy directionality, with 22 total significant tests as opposed to 12. This is seen in the regression results in Table 4, which has the same parameters as

Table 1: EKC to Energy Granger Causality Results

country	GDP-NUC	GDP-REN	CO-NUC	CO-REN
Argentina	0	0	0	1
Armenia	0	0	0	0
Belgium	0	0	0	1
Russia	0	0	1	0
South Korea	0	0	0	0
USA	0	0	0	0
Bulgaria	0	0	0	0
Czech Rep.	0	0	0	0
Finland	0	0	0	1
France	0	0	0	0
Germany	0	0	0	0
Hungary	0	0	1	0
Netherlands	0	0	0	0
Romania	0	0	0	0
Slovakia	0	0	0	0
Slovenia	0	0	0	0
Sweden	0	0	0	0
Brazil	0	1	0	1
China	0	0	0	0
India	0	0	0	1
Iran	0	0	0	0
Pakistan	0	1	0	1
South Africa	0	0	0	0
Ukraine	0	0	0	0
Canada	0	0	0	0
Japan	0	0	0	0
Mexico	0	0	0	0
United Kingdom	0	0	0	1
Italy	0	1	0	0
Lithuania	0	0	0	0
Totals	0	3	2	7

Table 2: EKC to Energy Regression Results

	Dependent variable:
	phase
GDP-NUC	
GDP-REN	-0.140
	(0.346)
CO-NUC	0.017
	(0.395)
CO-REN	-0.014
	(0.247)
Constant	1.483^{***}
	(0.118)
Observations	30
R^2	0.008
Adjusted R^2	-0.106
Residual Std. Error	0.534 (df = 26)
F Statistic	0.071 (df = 3; 26)
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 3: Energy to EKC Granger Causality Results

country	NUC-GDP	REN-GDP	NUC-CO	REN-CO
Argentina	0	0	0	0
Armenia	0	1	0	0
Belgium	1	1	0	0
Russia	0	0	0	0
South Korea	0	0	0	0
USA	0	0	0	0
Bulgaria	0	1	0	0
Czech Rep.	0	1	0	0
Finland	0	0	0	0
France	0	0	0	1
Germany	1	1	0	0
Hungary	0	1	0	0
Netherlands	0	1	0	0
Romania	0	0	0	1
Slovakia	0	1	0	1
Slovenia	1	0	0	0
Sweden	0	0	0	0
Brazil	0	0	0	0
China	0	1	0	0
India	0	0	1	1
Iran	1	0	0	0
Pakistan	1	0	0	0
South Africa	0	0	0	0
Ukraine	0	0	0	0
Canada	0	0	0	0
Japan	0	0	0	0
Mexico	0	0	0	0
United Kingdom	0	0	0	1
Italy	0	0	0	0
Lithuania	1	1	0	0
Totals	6	10	1	5

Table 4: Energy to EKC Regression Results

	Dependent variable:
	phase
NUC-GDP	-0.159
	(0.212)
REN-GDP	0.389^{**}
	(0.177)
NUC-CO	-0.903^{*}
	(0.502)
REN-CO	0.605^{**}
	(0.246)
Constant	1.298^{***}
	(0.117)
Observations	30
R^2	0.330
Adjusted R^2	0.223
Residual Std. Error	0.447 (df = 25)
F Statistic	3.079^{**} (df = 4; 25)
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

the regression in Table 2 but now three of the coefficients are at least weakly significant, with two being significant at the previously established .05 level. This coefficient, representing the causality of nuclear energy production causing carbon dioxide emissions, is negative with regard to phase, suggesting that use of nuclear energy affecting carbon dioxide emissions is more likely to be associated with a phase 1 economy. On the other hand, the coefficients for renewable energy driving both GDP and CO2 are both slightly positive, suggesting that countries that have this causal relationship are more likely to be a phase 2 economy. The R-squared value is moderate at 0.330, suggesting a fair amount of the variations in phase might be accounted for by these causalities.

6 Discussion

The results of the EKC graphs showed a fairly even distribution of phase 1 and phase 2 patterning among the countries sampled. Since the sample was only countries that produce nuclear and renewable energy, there is a possibility of bias for one phase over another since nuclear energy is produced mostly by higher-income countries; this bias will be discussed more in terms of the causality tests, but as far as the EKC graphs went, there was no bias for one phase over another. As previously mentioned, the relevance of EKC trends with regard to informing economic policy or forecasting is a topic of some dispute, but the graphs gave robust evidence that an inflection point in many countries' economies for this relationship is observable, and that carbon dioxide emissions do decrease monotonically after that point. This alone is enough to give credence to an analysis based on that relationship as it is observed within this framework.

The first striking result in the causal analysis is that there is almost no significant Granger causality from the EKC variables to the energy production at all, but the causality of the reverse relationships are quite significant. As far as economic and environmental conditions drive energy production, it appears that there is little reason to believe in a strong connection. This somewhat dissuades the previously mentioned potential bias of lower income countries being excluded from the analysis, since increased income does not seem to be a driving force of increased nuclear energy production. This does not necessarily contradict the idea that countries of higher income will incentivize non-polluting energy sources like nuclear, just that doing so does not seem to have any effect on the relationship of income and environmental quality. This raises an interesting question, though, regarding the negative magnitude of the NUC-CO coefficient; both REN-GDP and REN-CO are positive, implying that countries whose renewable energy use is correlated with their income and carbon dioxide emissions are more likely to have a monotonic decreasing trend of carbon dioxide as income increases. Granger causality implies only a temporal causation, such that a significant test could imply a positive or negative relationship, so it makes sense that a positive coefficient can be associated with a positive GDP trend and negative CO2 trend at the same time. Having a negative coefficient for NUC-CO, though, implies that countries whose nuclear energy use is associated with their carbon dioxide emissions are more likely to have monotonically increasing carbon dioxide; this suggests a potentially complex policy issue, but is reduced somewhat when considering that the only country to register a positive NUC-CO causality result is India, a phase 1 country. Without this one result, the coefficient would otherwise have been 0, so it is hard to identify this as being indicative of a broader trend. Regardless, the positivity of the other two coefficients, REN-GDP and REN-CO, reinforces the intuitive basis of the EKC in the sense that increased renewable energy use is indeed associated with higher income and improved environmental quality.

Interestingly, though, the significance of the renewable energy causalities seems to come with a lack of significance for nuclear energy, as even the few significant recorded tests show very little correlation with phase at all. This does not necessarily exclude nuclear energy from being considered an environmentally beneficial alternative energy source, just that as production stands currently has not yet had a significant impact on improving environmental quality over other sources on a global level. This is duly significant when considering how few countries in the world, only 30, have access to nuclear energy production. Global income will likely have to increase in order for nuclear energy to cross the threshold for it to become a more beneficial alternative, a threshold which may be more easily crossed with the advent of nuclear fusion energy in the coming decades.

The same bias that comes with nuclear energy's relative exclusivity worldwide, though, applies somewhat to renewable energy as well within this project. As opposed to nuclear, almost every country in the world produces energy by some renewable sources, but as mentioned, many were not included in this study if they did not also produce nuclear energy. While the found significance of renewable energy was encouraging, a wider scope may have to be used in order to better establish more universal significance and possibly inform energy policy. Renewable sources might be further stratified in this way as well, perhaps testing causality for wind, solar, etc. to get a more specific idea of the exact causal mechanism.

As far as the cowboy and spaceman paradigm goes, this investigation on the implications of the EKC gives moderate support. We have found that the inflection point of increasing to decreasing carbon dioxide emissions as income grows is positively correlated with renewable energy use being causally associated with both income and CO2 emissions, which essentially implies that such renewable energy use may be a driving force for income growth beyond that inflection point. As for whether renewable energy is a necessary or even a sufficient condition for this growth is not clear by this analysis alone, and would need to be researched further with non-nuclear producing countries to establish a more robust image of the relationship. However, the fact that the EKC to energy tests showed no causality at all but the energy to EKC did is certainly the most salient discovery of this project, and suggests a good groundwork for further study on this causal direction.

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