Examining the Rationality of Carbon-Driven Economic Policies: Global Evidence and Implications for Decision-Making

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Abstract

Economically rational behavior is likely to be more important than social change in terms of determining the quality of the human response to climate change. The main drawback of previous methods of calculating the environmental Kuznets hypothesis (EKH) curve has been the absence of a time component, which not only precludes forecasting but also impedes the identification of when, if at all, a country might have transitioned to the downslope of the EKH. In this paper, a log-transformed, time-series ratio approach is utilized as a means of overcoming these limitations and generating the practical recommendations. The relationship between carbon emissions and economic developments in the context of the United States, China, and the world are examined.

Examining the Rationality of Carbon-Driven Economic Policies:

Global Evidence and Implications for Decision-Making

Perhaps the most important question that can be asked of policies that favor a carbon-driven approach to economic development is whether—and for whom—such policies are rational. In the context of numerous countries in the developing world, carbon has been overtly or tacitly described as a driver of economic growth, a necessary evil whose existence is accepted in order to grow the global middle class (Müller et al., 2013; Wiedenhofer et al., 2017). Such claims make conceptual sense in the context of economies heavily dependent on manufacturing and industry as well as on the mass purchase of automobiles and other sources of emissions (Wang & Chen, 2015). Even in the United States, which is both a service economy and a country in which middle-class consumption is highly advanced, there are numerous voices in government that support more emissions-friendly policies. In 2017, under the direct of President Donald Trump, the United States abandoned (Butler, 2017) the Paris Treaty, placing it, for the moment, on the side of those countries that embrace carbon emissions as a source of economic growth.

The main question asked, and answered, in this paper is whether a carbon-driven approach to economic development is rational. One plausible rationale for emissions-friendly practices would be if such practices exerted a causal impact on economic growth. If such a causal relationship either does not exist—for a set of countries, a specific country, or the globe as a whole—or if the relationship is weak, then the argument for embracing emissions is weakened. Accordingly, the first objective of this paper is to test the relationship between carbon emissions and economic developments in the context of the United States, China, and the world. The second objective of the paper is to apply the results of the empirical analysis to the formulation of global emissions policies.

In order to achieve these objectives, the paper has been divided into two main parts. First, the relationship between carbon emissions and economic growth has been empirically tested through the use of an autoregressive distributed lag (ARDL) model, Granger-causality testing, Chow breakpoint testing, and other statistical means. Second, American emissions policies are examined in greater depth, and the findings of the empirical analysis are applied to an evaluation of the rationality of such policies.

Examining the Emissions-Growth Relationship

Carbon emissions are conceptually related to economic growth in numerous ways. First, carbon emissions result from the operation of the industrial and manufacturing infrastructure; nations that are rich in factories and other sites of physical production are therefore likely to emit (on a per capita basis) high amounts of carbon (Lin & Wang, 2015). To the extent that industry and manufacturing are drivers of economic growth, then, there is a positive correlation between emissions and economic growth. This correlation can be weakened by newer approaches to production, but, as of yet, the applicability of renewable energy—which reduces overall emissions—to physical production is still limited (Karakosta, Pappas, Marinakis, & Psarras, 2013).

Second, in addition to being a byproduct of the kind of industrial and manufacturing activity that drives growth in many countries, carbon emissions reflect the kind of consumption likely to drive further growth. In countries such as China and India, an expanding middle class has taken to the mass purchase of automobiles and the consumption of natural gas for heating and powering dwellings, thus increasing emissions further (Huaman & Jun, 2014; Sanwal & Wang, 2015; Shirgaokar, 2014). Thus, in terms of both consumption and production, carbon emissions appear to be positively correlated with economic growth.

However, it is not universally accepted that carbon emissions are positively correlated with economic growth in an open-ended manner. The environmental Kuznets hypothesis (EKH) is that, after a certain threshold of development, the environmental damage wrought by economic activity declines (Al-Mulali, Saboori, & Ozturk, 2015; Apergis & Ozturk, 2015; de Vita, Katircioglu, Altinay, Fethi, & Mercan, 2015; Jebli, Youssef, & Ozturk, 2016; Lau, Choong, & Eng, 2014; López-Menéndez, Pérez, & Moreno, 2014). Thus, according to the EKH, income first increases as environmental quality declines; afterwards, income increases as environmental quality also increases.

If the EKH is correct, there are several important implications for policy and practice. First, emissions-friendly policies are likely to be rational for countries in the first stage of the EKH, because the relationship between environmental degradation and economic growth is self-correcting. At the first stage of development, a country will incur environmental damage, but this damage will decline once a certain threshold of development is reached. There has been evidence for this claim long before the advent of statistical testing; for example, developed countries such as the United States and the United Kingdom have been noted to experience periods of high emissions during their early stages of industrial and manufacturing growth, with such emissions declining steadily as both countries became more mature industrial powers and continuing to decline as the U.K. and U.S. moved to services-based economies (Marsiglio, Ansuategi,

& Gallastegui, 2016). More recently, there is panel-based and other kinds of statistical evidence for the viability of the EKH as tested for specific countries (Al-Mulali et al., 2015; Apergis & Ozturk, 2015; de Vita et al., 2015; Jebli et al., 2016; Lau et al., 2014; López-Menéndez et al., 2014).

Second, if the EKH is correct, countries who are in the second stage—the stage during which environmental degradation is no longer a necessary byproduct and driver of economic growth—need not pursue what would be the rational first-stage policy of emissions-friendly governance.

Thus, the EKH suggests the rationality of a two-stage model of environmental policy. First, developing countries should embrace carbon emissions in order to speed their transitions to becoming developed countries. Second, developed countries should not consciously attempt to implement high-emissions policies, as, for such countries, wealth is no longer driven by highly environmentally degrading activities.

The EKH has been formally tested in numerous studies and with numerous approaches (Al-Mulali et al., 2015; Apergis & Ozturk, 2015; de Vita et al., 2015; Jebli et al., 2016; Lau et al., 2014; López-Menéndez et al., 2014). One approach is to utilize an autoregressive distributed lag (ARDL) model combined with Granger causality (Bölük & Mert, 2015). The advantage of such an approach is that is models the impact of changes in carbon emissions alongside the impact of past values of gross domestic product (GDP) per capita; given that GDP per capita is highly autocorrelated, its past values clearly need to be taken into account when measuring the impact of changes in carbon emissions. This kind of time-series approach is also useful for estimating the impact of a shock in carbon emissions on the subsequent *n* periods of GDP per capita.

Empirical Testing: The United States

However, for certain countries—such as the United States—the ARDL approach does not elucidate the nature of the relationship between economic growth and emissions. An ARDL test on American carbon emissions per capita (measured in metric tons) and GDP per capita, with GDP per capita treated as the dependent , indicated the lack of long-run cointegration, $p = .9484$. Table 1 below contains the bounds test (Pesaran, Shin, & Smith, 2001) result of this model.

Table 1

ARDL Bounds Test, USCO2→USGDP

```
Pesaran/Shin/Smith (2001) ARDL Bounds Test
H0: no levels relationship            F =  0.359
                                      t = -0.556

Critical Values (0.1-0.01), F-statistic, Case 3
```

	[I_0] L_1	[I_1] L_1	[I_0] L_05	[I_1] L_05	[I_0] L_025	[I_1] L_025	[I_0] L_01	[I_1] L_01
k_1	4.04	4.78	4.94	5.73	5.77	6.68	6.84	7.84

```
accept if F < critical value for I(0) regressors
reject if F > critical value for I(1) regressors

Critical Values (0.1-0.01), t-statistic, Case 3
```

	[I_0] L_1	[I_1] L_1	[I_0] L_05	[I_1] L_05	[I_0] L_025	[I_1] L_025	[I_0] L_01	[I_1] L_01
k_1	-2.57	-2.91	-2.86	-3.22	-3.13	-3.50	-3.43	-3.82

```
accept if t > critical value for I(0) regressors
reject if t < critical value for I(1) regressors
```

While ARDLs might have been useful in developing countries, which is the context in which such models appear to have been used more frequently (Al-Mulali et al., 2015; Apergis & Ozturk, 2015; de Vita et al., 2015; Jebli et al., 2016; Lau et al., 2014; López-Menéndez et al., 2014), they do not contribute as much to understanding the nature of the relationship between economic growth and carbon emissions in the United States and perhaps other developing economies, as is clear from Table 1 above.

One novel approach to the examination of the EKH is the use of Chow breakpoint testing (Chow, 1960) in order to (a) determine the location of the break, if any, between the two stages of EKH; and (b) utilize what is learned about the break in order to predict when other countries might shift from the first to the second stage of EKH.

Both of these results of Chow breakpoint testing are highly useful. First, it should be noted that the detection of the EKH has tended to be highly visual in nature, with researchers generating their own EKH curves and inspecting the results for evidence of a transition from the first to the second stage of the EKH. This approach is valid in the case of countries, or sets of countries, for which the EKH has an easily observable curve. However, the EKH curve is not always simple to interpret, as is clear from Figure 1 below.

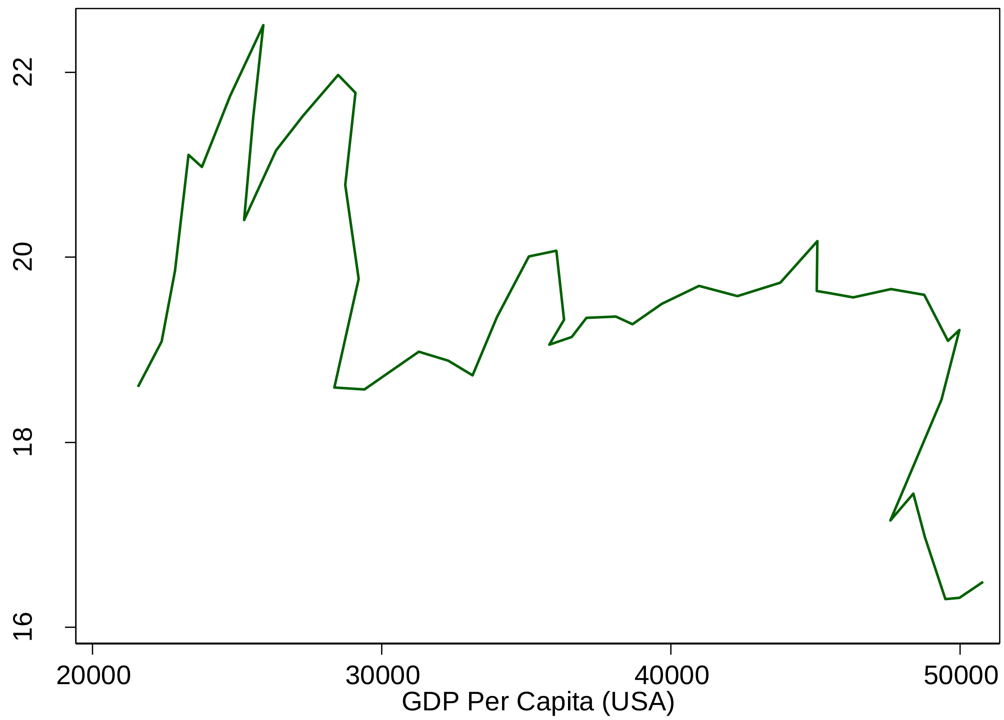

Figure 1. EKH curve for the United States, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

In Figure 1, the classic inverted-U shape (Al-Mulali et al., 2015; Apergis & Ozturk, 2015; de Vita et al., 2015; Jebli et al., 2016; Lau et al., 2014; López-Menéndez et al., 2014) of the EKH is distorted, and it is not clear when the United States entered the second stage of the EKH, the period during which emissions no longer need to be courted or tolerated in order to generate economic growth. A Chow breakpoint analysis can be applied to these data as follows. First, both the GDP per capita and Co2 emissions per capita figures can be log-transformed. Second, a ratio of the log-transformed Co2 emissions per capita to the log-transformed GDP per capita can be calculated. Third, this ratio can be graphed by year. The resulting graph (see Figure 2 below) does not take the classic inverted-U shape of the EKH, but it is substantially cleaner than the unadjusted graph (see Figure 1) and also keyed to the year, which allows time-series procedures such as Chow breakpoint analysis to be conducted on the data.

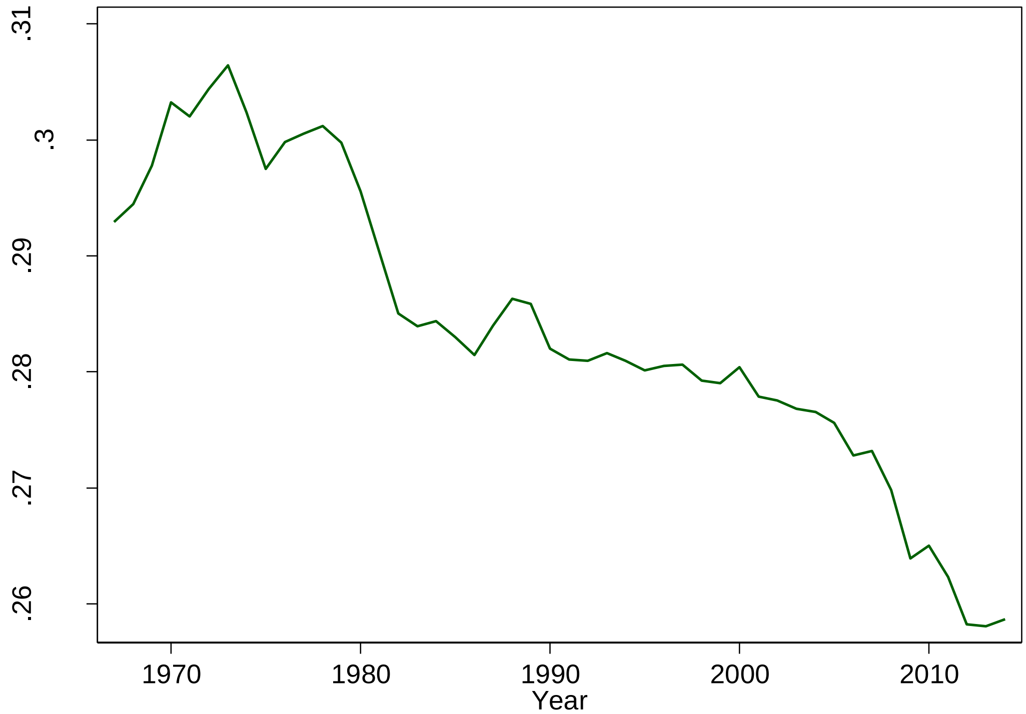

Figure 2. Ratio of log-transformed Co2 emissions to log-transformed GDP per capita for the United States, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

Essentially, the use of a Co2 / GDP per capita ratio sorted by year allows the identification of a breakpoint following ordinary least squares (OLS) regression analysis. In the case of the United States, the regression of year on ratio is statistically significant, $F(1, 46) = 341.19$, $p < .001$, with the yearly decline in the Co2 / GDP per capita ratio being -0.0009. Following this regression, the breakpoint for the ratio appears to come in 1980:

Table 2

Estimated Breakpoint for the U.S. Co2 / GDP Ratio

```
Full sample:                  1 - 48
Trimmed sample:               9 - 41
Estimated break date:         1980
Ho: No structural break
```

Test	Statistic	p-value
swald	23.0944	0.0003

```
Exogenous variables:            Year
Coefficients included in test: Year _cons
```

Thus, for the United States, 1980 was potentially the final year in which the Co2 / GDP ratio was still part of the inverted-U dynamic of the EKH. Or, put more simply, the U.S. can be said to have been in the second stage of the EKH from 1980 onwards, meaning that 1980 was the last year in which carbon-friendly policies could have been useful in terms of driving economic growth. If this analysis is correct, then demands for increased carbon emissions in the United States as a means of spurring economic growth are likely to be irrational. Thus, in the United States, the demand for increased carbon emissions through the relaxing of regulation is better understood not as a rational economic policy but as the expression of an anti-environmental political stance disguised as economic policy.

An added point of interest in empirical testing of the relationship between economic growth and carbon emissions in the United States is the apparent one-way causality of this relationship. As indicated in Table 3, U.S. GDP per capita (USGDPPC) Granger-causes U.S. carbon emissions per capita (USCO2), but U.S. carbon emissions do not Granger-cause U.S. GDP per capita. The absence of a statistically significant Granger-causal effect of carbon emissions on U.S. GDP per capita further suggests the pointlessness of seeking additional economic growth through the kinds of policies that would allow an increase in emissions.

Table 3

Granger Causality Tests, U.S. Carbon Emissions and GDP Per Capita

VAR Granger Causality/Block Exogeneity Wald Tests
Sample: 1967 2014
Included observations: 46

Dependent variable: USCO2

Excluded	Chi-sq	df	Prob.
USGDPPC	8.151478	2	0.0170
All	8.151478	2	0.0170

Dependent variable: USGDPPC

Excluded	Chi-sq	df	Prob.
USCO2	3.515424	2	0.1724
All	3.515424	2	0.1724

The same procedures applied to examining the relationship between economic growth and carbon emissions in the United States have next been applied to China, and, after China, to the world.

Empirical Testing: China

The case of China is of interest for a number of reasons. First, as the second-largest economy in the world, China is intrinsically worthy of analysis. Second, China still appears to be on the first EKH stage (see Figure 3 below), raising the question of when China might transition to the second stage.

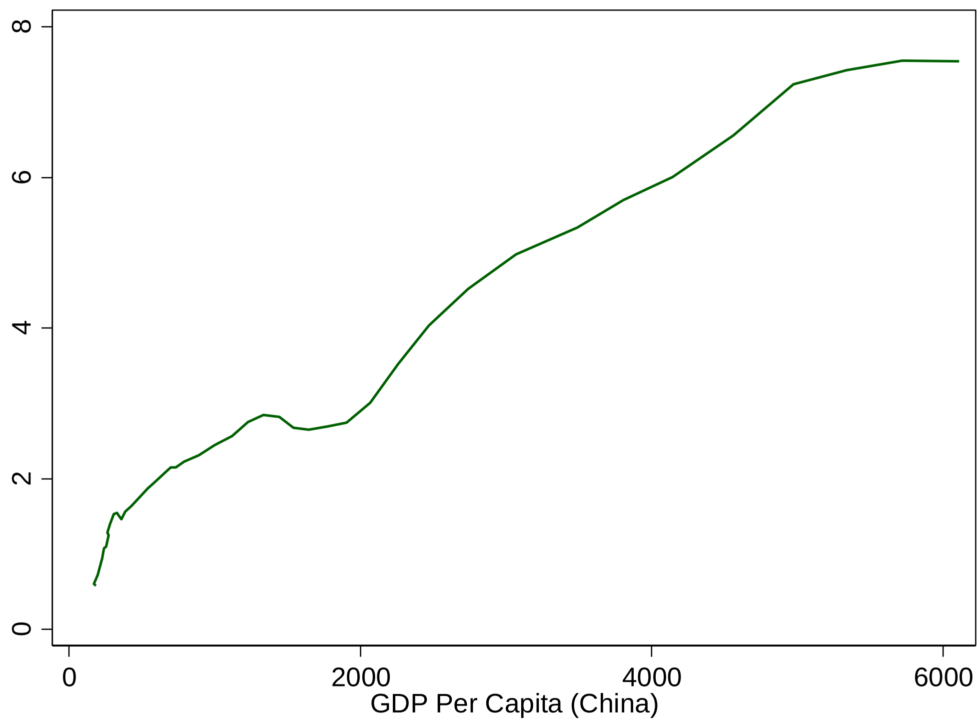

Figure 3. EKH curve for China, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

The relationship between Chinese GDP per capita and Co2 emissions per capita is highly linear, $F(1, 46) = 2{,}030.72$, $p < .0001$. The coefficient of determination of this relationship is 0.98, indicating that 98% of the variation in Chinese GDP per capita can be explained through variation in Chinese emissions per capita. Every added one metric ton of carbon emissions in China is associated with a rise in China GDP per capita of $824.98. This relationship suggests the current rationality of Chinese emissions policies, which are lax (Dhakal, 2009; Ou, Zhang, & Chang, 2010; Zhang, He, & Huo, 2012), and it also calls at least one previous set of results (Jalil & Mahmud, 2009) into question. Jalil and Mahmud found evidence for the existence of a classic inverted-U relationship between Chinese emissions and real GPD per capita on the basis of 1975-2005 data; such a relationship does not appear to exist, at least based on the use of 1967-2014 data and the variables of Co2 emissions per capita and GDP per capita.

One point of similarity between China and the United States is the nature of the Granger-causal relationships between GDP and carbon emissions. As was the case for the U.S., in China, GDP per capita Granger-causes carbon emissions per capita, but emissions do not Granger-cause GDP per capita.

Table 4

Granger Causality Tests, U.S. Carbon Emissions and GDP Per Capita

VAR Granger Causality/Block Exogeneity Wald Tests
Sample: 1967 2014
Included observations: 46

Dependent variable: CHINACO2

Excluded	Chi-sq	df	Prob.
CHINAGDPPC	8.558417	2	0.0139
All	8.558417	2	0.0139

Dependent variable: CHINAGDPPC

Excluded	Chi-sq	df	Prob.
CHINACO2	2.019688	2	0.3643
All	2.019688	2	0.3643

The results of Granger causality testing suggest that, despite the high correlation between Chinese GDP and Chinese carbon emissions, the relationship appears to be one in which growth raises emissions without emissions having the same kind of reciprocal effect on growth. The results of Granger testing offer some reasons to be skeptical about an emissions-driven growth strategy for China.

Figure 4. Ratio of log-transformed Co2 emissions to log-transformed GDP per capita for China, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

For the Chinese ratio of log-transformed Co2 emissions to log-transformed GDP per capita, the breakpoint comes in 1975. It can therefore be concluded that China definitively entered the first stage of EKH in 1975, and that it remained in this stage as of 2014.

One point of interest in the EKH curve for China is the apparent quadratic fit, which, in turn, can be used to predict when China might enter the second EKH curve (that is, the point at which economic growth no longer seems to need carbon emissions).

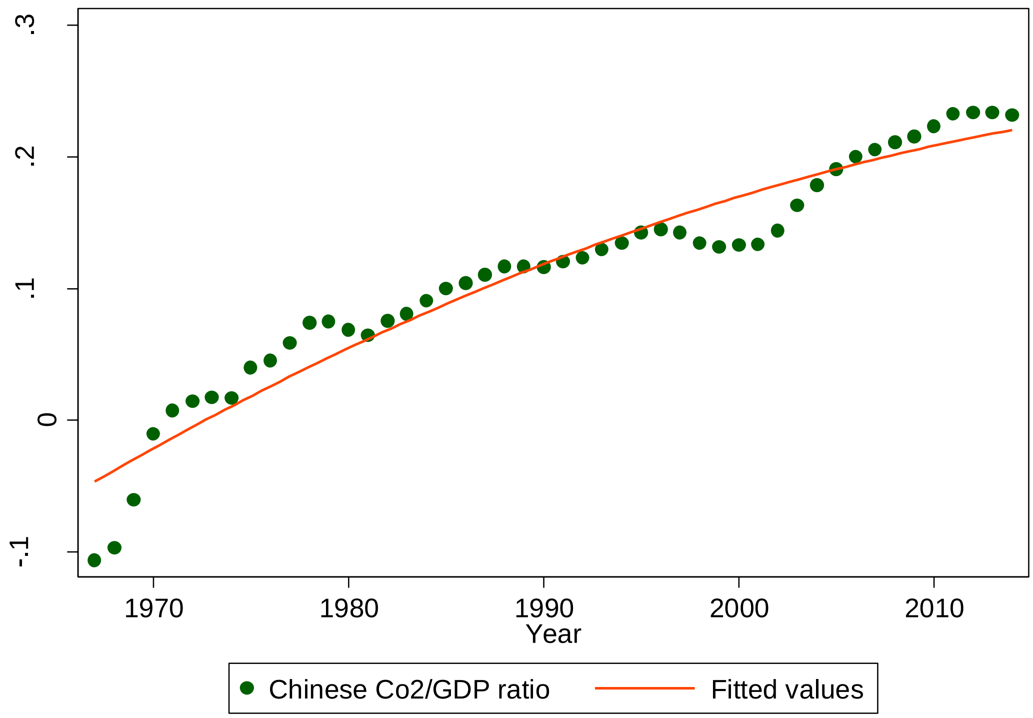

Figure 5. Potential quadratic pattern in the ratio of log-transformed Co2 emissions to log-transformed GDP per capita for China, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

The quadratic regression equation formula for China is as follows:

Ratio = (Year)(0.0068) + (Ratio^2)(-0.91) - 13.17

Based on the quadratic fit, the high point of China's Co2 emissions per capita to GDP per capita ratio was 2013, the year in which this ratio was 0.0546. In 2014, the ratio fell to 0.0538. Therefore, China appears to have recently made the transition to the second EKH stage. For Chinese policy, the main implication of this finding is that carbon-favoring regulations or approaches are no longer necessary.

One method of testing the EKH is to graph the curve of income versus emissions and observe the shape of the emerging curve. However, this approach is of limited predictive value, because the X-axis measures income, not time. Creating a Co2 / GDP ratio allows for the generation of a simple but explanatorily powerful predictive model, as the shape of the generated curve can be modeled by any number of techniques (such as quadratic regression for China), and changes in the regression regime can easily be identified.

Empirical Testing: The World

The shape of the EKH curve for the world is very interesting, as there is evidence for the inverted-U shape until the threshold of around $8,000, after which the relationship between Co2 emissions and GDP capita once again becomes linear.

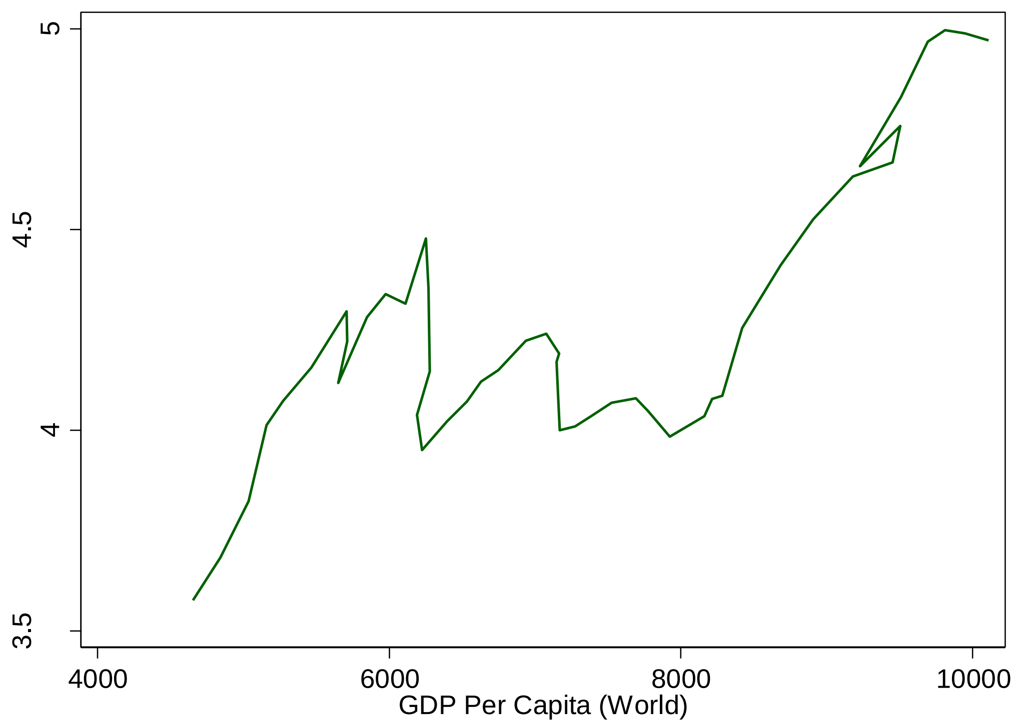

Figure 6. EKH curve for the world, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

After log-transformation and placement into a time-indexed ratio, the data suggest that the EKH curve for the world is either a random walk or a highly distorted U-curve that entered the second EKH stage as of 2013.

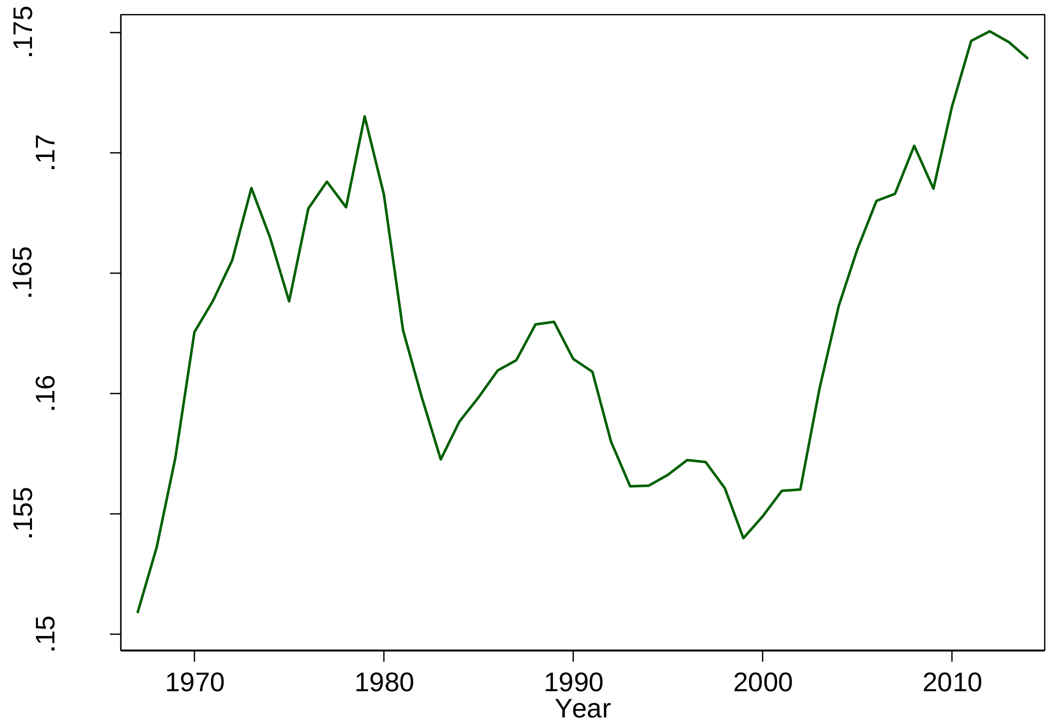

Figure 7. Ratio of log-transformed Co2 emissions to log-transformed GDP per capita for the world, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

At the world level, therefore, the EKH has an inconclusive shape.

Carbon Emissions and Economic Policy

The empirical analyses offered in the first section of the paper have important implications for emissions policies. Perhaps the most important implication involves the rationality of carbon trading. If the EKH is correct, then, at some point, countries will enter a period during which they will not obtain additional increases in income on the basis of increased Co2 emissions. There are at least two policy implications that follow. The first implication is that some countries are likely to be emissions over- or under-users depending on where they might be on the EKH, and that policy might be required to correct economically irrational behavior in this regard. The second implication is that the identification of carbon emissions trading partners might be more efficient if pairing stage-1 EKH countries with stage-2 EKH countries.

Consider the data (EU, 2017) on surrendered emission reduction units (ERUs) in various European countries for the trading period 2008-2012. These data, presented in Table 5 below, identify the European countries that were most likely to pay in order to use more carbon emissions units than they were allotted by regulation. Once these data are converted to per capita figures (see Table 6 below) and tabulated by each country's position on the EKH curve, they can be used to identify advanced economies that are disproportionately reliant on carbon emissions to drive economic growth.

As expected, the histogram (see Figure 8) for the European countries in Table 5 indicates a clustering close to 0. As advanced economies, these countries are more likely to be on the downslope of the EKH and therefore not reliant on carbon emissions for growth. However, although there are no outliers *per se* (see Figure 9), there are clearly some countries that are surrendering more emissions, even after controlling for population. These data suggest that, for some European countries, there is an over-reliance on carbon emissions that is not likely to be justified by the need for economic growth. In terms of policy, therefore, it would be appropriate for both heavy and light carbon emissions credits users to revisit their policies in light of their EKH curves. The prediction that emerges from Table 6, for example, is that a country such as Slovenia is an over-user of ERUs. After the presentation of the tables and figures related to ERU measurement for the sample of 30 European countries, the case of Slovenia has been analyzed through the construction of an EKH curve for that country. This EKH curve can help to cast further light on whether current policies related to emissions in Slovenia are economically rational.

Table 5

ERUs by Country, Europe (2008-2012 Trading Period)

Country	Surrendered ERUs
Austria	4988952
Belgium	5397712
Bulgaria	13587718
Croatia	0
Cyprus	854130
Czech Republic	18735943
Denmark	7450563
Estonia	2268127
Finland	4075998
France	19008759
Germany	132857556
Greece	11322449
Hungary	2792995
Iceland	0
Ireland	2874551
Italy	29167171
Latvia	467620
Liechtenstein	0
Lithuania	3477985
Luxembourg	8066
Malta	1071529
Netherlands	11027404
Poland	30702902
Portugal	4567634
Romania	16294449
Slovakia	292783
Slovenia	4683998
Spain	23585622
Sweden	2113323
United Kingdom	22105493

Table 6

Population-Adjusted ERUs by Country, Europe (2008-2012 Trading Period)

Country	Surrendered ERUs	Population (2014)	ERUs Per Capita
Austria	4988952	8541575	0.584079
Belgium	5397712	11209057	0.481549
Bulgaria	13587718	7223938	1.88093
Croatia	0	4238389	0
Cyprus	854130	1152309	0.741233
Czech Republic	18735943	10525347	1.78008
Denmark	7450563	5643475	1.32021
Estonia	2268127	1314545	1.72541
Finland	4075998	5461512	0.746313
France	19008759	66331957	0.28657
Germany	132857556	80982500	1.64057
Greece	11322449	10892413	1.03948
Hungary	2792995	9866468	0.28308
Iceland	0	327386	0
Ireland	2874551	4617225	0.622571
Italy	29167171	60789140	0.479809
Latvia	467620	1993782	0.234539
Liechtenstein	0	37127	0
Lithuania	3477985	2932367	1.18607
Luxembourg	8066	556319	0.014499
Malta	1071529	427364	2.5073
Netherlands	11027404	16865008	0.653863
Poland	30702902	38011735	0.807722
Portugal	4567634	10401062	0.439151
Romania	16294449	19908979	0.818447
Slovakia	292783	5418649	0.054032
Slovenia	4683998	2061980	2.2716
Spain	23585622	46480882	0.507426
Sweden	2113323	9696110	0.217956
United	22105493	64613160	0.342121

Kingdom

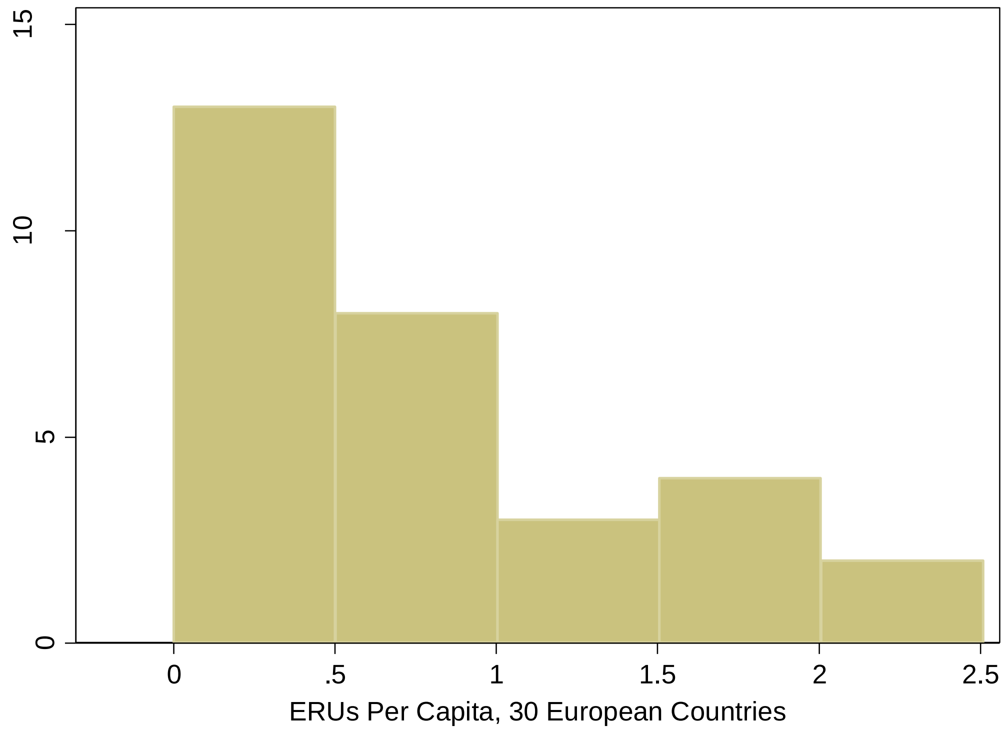

Figure 8. Histogram, ERUs per capita in 30 selected European countries.

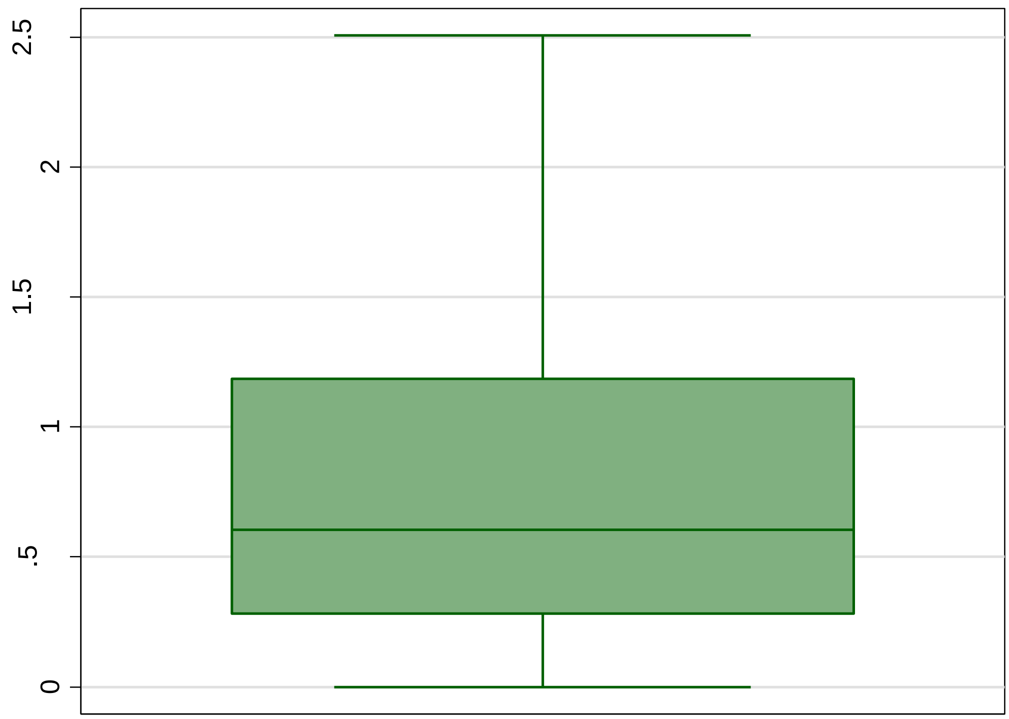

Figure 9. Boxplot, ERUs per capita in 30 selected European countries.

Iceland was one of the countries in the dataset that had no surrendered emissions. Theoretically, then, Iceland should be on the downslope of the EKH. Figure 10 below contains a line of quadratic best fit on the log-transformed Co2 per capita / GDP per capita ratio for Iceland. The fitted curve resembles the shape that the EKH ought to take, that of an inverted U. In fact, Iceland is far along into the second EKH stage, which would, in turn, indicate that Iceland is acting rationally in terms of ensuring that it has no surrendered ERUs.

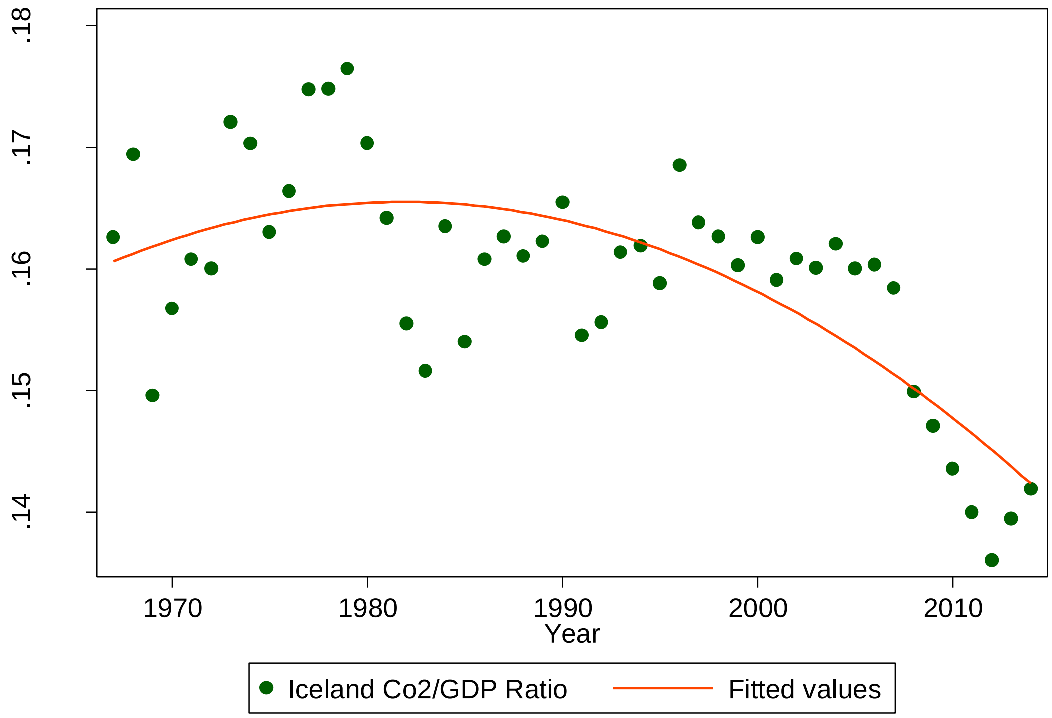

Figure 10. Potential quadratic pattern in the ratio of log-transformed Co2 emissions to log-transformed GDP per capita for Iceland, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

The country with the highest ERUs per capita was Malta. The time-transformed EHK curve for Malta indicates that the country is still close to the first stage of the EHK. In the time period from 2003-2008, it was justified for Malta to surrender ERUs, as the country was just about to make the transition to the second stage of the EHK. However, if Malta were to continue to pursue an emissions-based strategy in a post-2014 recording period, it would probably be irrational, as the country is now on the downslope of the EHK.

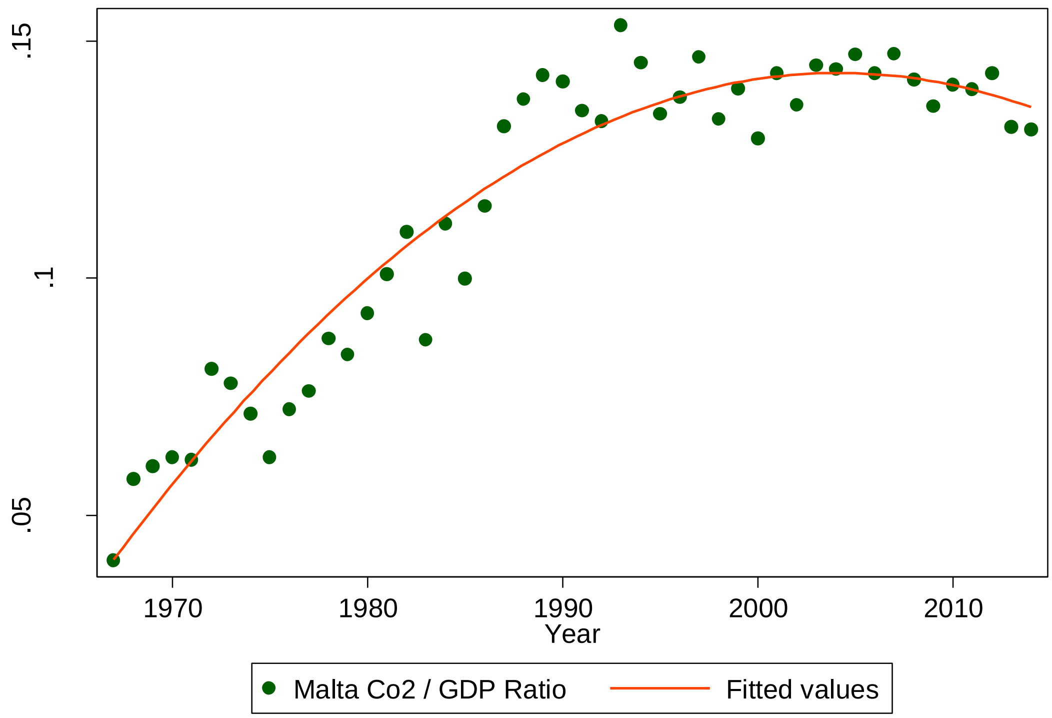

Figure 11. Potential quadratic pattern in the ratio of log-transformed Co2 emissions to log-transformed GDP per capita for Malta, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

Thus, both Malta and Iceland can be described as engaging in rational emissions behavior based on their respective locations on the EKH curve. As Malta was still on the upslope in the 2003-2008 period, it was correct to pursue a policy that resulted in the surrender of large numbers of ERUs per capita, as doing so could have been a means of speeding Malta's tradition to the downslope of the EKH. For Iceland, which has been on the downslope of its EKH curve for many years, it is similarly rational to eschew surrendering ERUs and, instead, pursue policies that do not emphasize emissions-driven growth. On the other hand, Germany, which was a leading emitter in the 2003-2008 period vis-à-vis its regulatory obligations (see Table 6 above), is also on the downslope of its HKC curve, which suggests that Germany emissions policy is currently irrational.

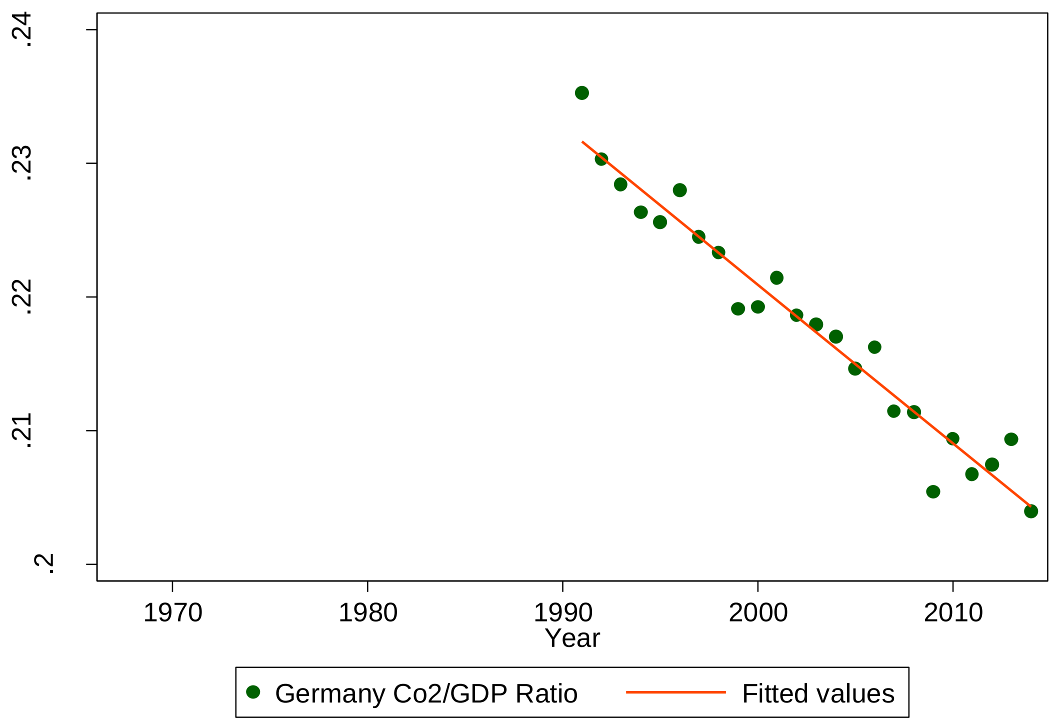

Figure 12. Potential quadratic pattern in the ratio of log-transformed Co2 emissions to log-transformed GDP per capita for Germany, 1967-2014. *Note*: original figure based on World Bank data (WB, 2017).

Admittedly, the concept of rational economic behavior at the country level is a simplification. There are likely to be individual considerations that could prompt a country such as Germany to trade carbon in a manner that does not appear consonant with its position on the EKH curve. On the other hand, it would also be the case that carbon-trading policy is not driven by policy-makers who are themselves informed by empirical analysis. Whatever considerations of rationality might or might not apply to a country in terms of its carbon-trading strategy and positioning on the EKH, the kinds of empirical analysis presented above can help researchers and policy-makers to better understand the broad outlines of an emissions strategy that is appropriately informed by theory.

Conclusion

Climate change is perhaps the most important existing threat to human survival (Cook et al., 2013; Levermann et al., 2013; Rogelj, Meinshausen, & Knutti, 2012; Trenberth et al., 2014; Yoshida, Gable, & Park, 2012). Climate change has taken place, and continues to take place, because of a paradigm of economic development in which the burning of fossil fuels is held to be a necessary component of economic growth, which, in turn, addresses the needs of the world's rising middle class (Heede, 2014; Ou et al., 2010). Therefore, one of the most important debates in economics, political science, and international relations is the debate over the relationship, if any, between economic growth and environmental degradation, as emissions are a major factor in climate change (Cook et al., 2013; Levermann et al., 2013; Rogelj et al., 2012; Trenberth et al., 2014; Yoshida et al., 2012). If carbon emissions are ineluctably associated with growth, then, at some point in the future, either unbridled human consumption will lead to a genuine environmental catastrophe, or consumption will be curtailed by regulation, changing lifestyles, and other social forces.

By contrast, if carbon emissions are not associated with economic growth, then there is no environmental cap on development. In theory, all countries could become service economies and pursue growth through means not associated with an increase in emissions. Thus, a great deal is at stake in determining whether the EKH is true.

Previous empirical studies (Al-Mulali et al., 2015; Apergis & Ozturk, 2015; de Vita et al., 2015; Jebli et al., 2016; Lau et al., 2014; López-Menéndez et al., 2014) have validated the EKH for several developing countries. In this study, the classic inverted-U curve of the EKH hypothesis was not identified for the United States, China, or the world. However, for the United States and China, it seems likely that the absence of a curve is a data artifact. The World Bank's carbon emissions data begin in 1967, which appears to be during the end of the era of America's time in the first EKH state. To be sure, the post-1967 data for the United States look like half of an inverted-U shape, and it is likely that the pre-1967 data would, if generated, represent the characteristic curve of the EKH. For China, on the other hand, not enough time seems to have passed for the country to have transitioned from the first to the second stage of the EKH, but, from the highly quadratic form taken by the existing data, it seems justified to predict that China has just entered the downslope of the EKH. The world data, finally, are a random walk, which is also a theoretically likely result of combining data from countries at different stages of their own EKH curves, and also other countries for which the EKH is not as likely to be explanatorily useful.

If the EKH is correct, then, in terms of policy, there are a number of important implications, from the global to the more local levels. First, in terms of carbon trading, there is likely to be an empirical basis for identifying optimal trading partners. A country that is on the downslope of the EKH would, for example, be best suited to a trading partner on the upslope of the EKH.

It might seem as if the general trajectory of carbon trading takes this format anyway, with the more advanced economies selling emissions credits to developing economies (Lau et al., 2014). However, based on the analyses presented in this paper, there are two important conclusions to be reached about global carbon trading. First, with respect to the EU, there appear to be some countries that have surrendered more carbon credits than they should have done and that should therefore revisit their carbon-driven economic growth policies. An analysis of surrendered credits and other variables relevant to carbon trading might reveal the existence of other such countries—for example, stage-2 EKH countries that appear to be embracing stage-1 policies, and vice versa. Second, if the EKH curve for a particular country takes a neat quadratic form or can otherwise be forecast with a relatively high degree of certainty, it is possible to identify appropriate carbon-trading partners that might not be apparent through other means. For example, according to the analysis of China presented earlier in this study, it seems justified to conclude that China is entering its EKH downslope, which, in turn, means that China should rely less on carbon emissions to drive growth during this period in its economy. Thus, China is actually a good candidate to sell carbon emission rights to a less-developed country.

The main drawback of previous methods of calculating the EKH curve has been the absence of a time component, which not only precludes forecasting but also impedes the identification of when, if at all, a country might have transitioned to the downslope of the EKH. Creating a log-transformed, time-series ratio variable is a means of overcoming these limitations and generating the kinds of findings and practical recommendations that were provided in this study.

Economically rational behavior is likely to be more important than social change in terms of determining the quality of the human response to climate change. Arthur Pigou famously noted that the short lifespans of individual humans can lead to economically rapacious behavior (Pigou, 1924), a tendency that requires either firm regulation or an economically rational alternative to capacity to obviate. Emissions trading is an attempt to introduce self-interested emissions-related behavior that is also sustainable (Brunner, 2008; De Gouw, Parrish, Frost, & Trainer, 2014; Gavard, Winchester, & Paltsev, 2016; Heede, 2014; Ranson & Stavins, 2016). In this domain, one role of statistical analysis is to identify behaviors that are incrementally more rational, allowing an increase in the collective payout of cooperative games related to emissions trading.

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