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MSc Economics

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Is there an Environmental Kuznets Curve for CO_2 emissions? A time series analysis on the US

Abstract

This paper examines the relationship between CO_2 emissions and income in the US. Using a time-series approach for the period 1971-2010, the *quadratic* Environmental Kuznets Curve (EKC) hypothesis is tested against alternative specifications of the emissions-income relationship. To account for potential omitted variable bias, four additional determinants of CO_2 emissions are included in the estimation. The findings lead to the rejection of the *quadratic* EKC in the case of the US in favour of a *cubic* emissions-income relationship. In particular, the existence of an *inverted N-shaped* relationship is corroborated in this study, with the key implication that economic growth appears to be a *solution* to the problem of CO_2 emissions in the US.

1 Introduction

Climate change is unequivocal. It is the most pressing environmental issue facing the world today and is proving difficult to resolve. Indeed, Stern (2007) describes it as *"the greatest and widest-ranging market failure ever seen"* for which urgent international cooperation is required to effectively mitigate the problem. Overwhelming scientific evidence now point to carbon dioxide (CO_2) emissions as the main driver of global warming. Despite international efforts such as the Kyoto Protocol in setting out explicit CO_2 emissions targets, global emissions are still rising. The fact remains that there needs to be a clearer understanding of what is contributing to emissions before nations can even begin tackling the problem, hence the rationale for this study.
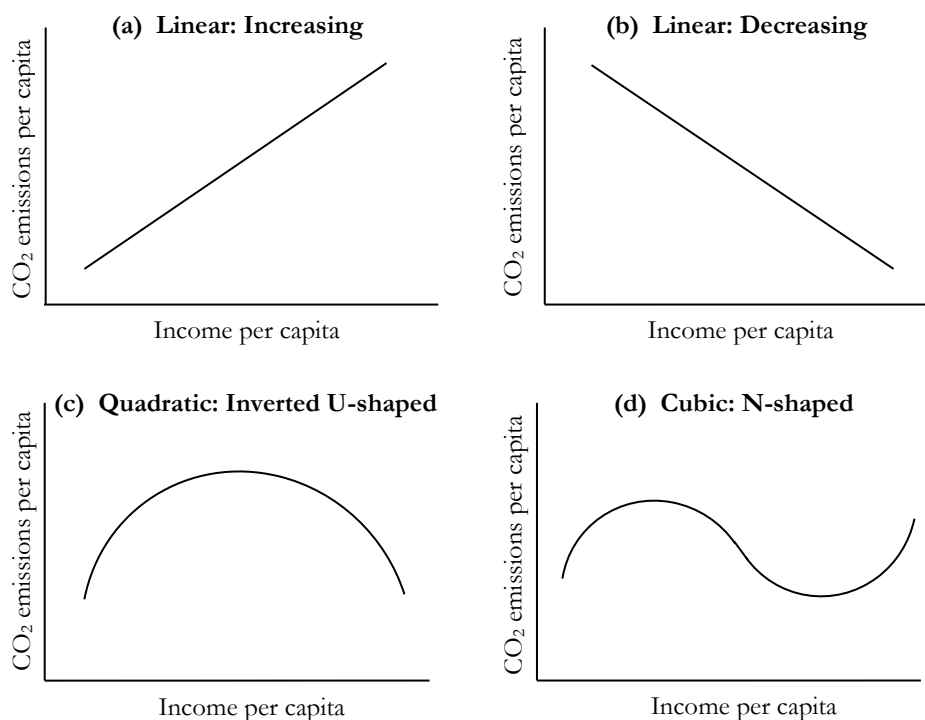
Fig.1. Possible emissions-income relationships

Recent literature has explored the link between CO_2 emissions and income, with a particular focus on the Environmental Kuznets Curve (EKC) hypothesis. This is an inverted U-shaped *(Fig.1c)* relationship between CO_2 emissions per capita and income per capita, analogous to the conventional Kuznets Curve (1955) relationship between inequality and income per capita.[1] Hence, the EKC conjectures that whilst CO_2 emissions pc intensifies initially with income pc, it eventually reaches a turning point and subsides in the later stages. This 'later' stage is often referred to as a *decoupling* of CO_2 emissions from economic growth, and suggests that beyond a certain income threshold, economic growth may actually *"become a solution rather than a source of the problem [of CO_2*

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[1] Per capita will be abbreviated to *pc* hereafter

emissions]" (Soytas et al., 2007). This *decoupling* phenomenon is possible if there is greater demand for environmental quality at higher pc income levels, which induces pollution abatement efforts.

In addition to the *quadratic* EKC relationship between CO_2 emissions pc and income pc, *linear (Fig.1a* and *1b)* and *cubic N-shaped (Fig.1d)* relationships have also been posited in the literature. Holtz-Eakin & Selden (1995) note the *free-rider problem* associated with CO_2 emissions, which makes an *increasing linear* relationship more likely. This is because contrary to other air pollutants such as sulphur dioxide (SO_2), CO_2 has global rather than local effects. Consequently, no individual country has an incentive to abate CO_2 emissions, thus diluting the tendency for CO_2 emissions pc to fall at higher income pc levels. Likewise, an *N-shaped cubic* relationship is possible if the upward tail that follows the initial inverted U-shaped curve is indicative of abatement efforts being exhausted (De Bruyn et al, 1998).

This paper examines the validity of the EKC hypothesis for CO_2 emissions in the case of the US. The US makes an interesting case study, as it is one of the largest emitters of CO_2 in the world. Yet, it is among the very few economies *not* to have signed onto the Kyoto Protocol on the grounds that it would hinder economic growth. Using annual time series data spanning 1971-2010, this paper tests the *quadratic* EKC against the alternative *linear* and *cubic* specifications of the emissions-income relationship. The results should shed light on the validity of US's claim that cutting CO_2 emissions is necessarily growth-reducing.

2   Empirical Model & Methodology

2.1   The General EKC Model

The following general model is proposed to test the EKC hypothesis:

$$ln\,co2_t = \beta_0 + \beta_1 lny_t + \beta_2(lny_t)^2 + \beta_3(lny_t)^3 + \beta_4 lnfc_t + \beta_5 lnac_t + \beta_6 lns_t + \beta_7 lnfdi_t$$
$$+ \beta_8 ln\,co2_{t-1} + \beta_9 year + \varepsilon_t\,, \tag{1}$$

where $lnco2_t$ is log-CO_2 emissions pc (in metric tons), lny_t is log-real GDP pc (in constant US dollars), $year$ is a deterministic time index, and ε_t is a white noise error term. With the exception of $year$, all the variables are specified in logarithmic form, which allows for a constant elasticities interpretation of the estimated coefficients.

The coefficients on the lny_t terms can be used to test the various emissions-income relationships discussed in Section 1. *Table 1* outlines these tests.

Table 1
Tests for emissions-income relationships

Emissions-income relationship	Expected sign of coefficients
Linear: Increasing	$\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$
Linear: Decreasing	$\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$
Quadratic: Inverted U-shaped	$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 = 0$ with turning point[2] at $lny_t^* = -\frac{\beta_1}{2\beta_2}$
Cubic: N-shaped	$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0$

To account for potential omitted variable bias, four additional explanatory variables are included in the estimation. $lnfc_t$ and $lnac_t$ represent *demand-side determinants* of CO_2 emissions. $lnfc_t$ measures log-fossil fuel consumption (as % of total energy consumption). This is an important variable given emissions predominantly arise from the combustion of fossil fuels such as coal. Thus, fc_t captures demand for CO_2-emitting energy and it is expected that $\beta_4 > 0$. $lnac_t$ measures log-alternative energy consumption (as % of total energy consumption). Alternative energy, such as solar power is a 'clean' substitute for fossil fuel and does not emit CO_2 as a by-product. Thus, $lnac_t$ captures demand for non-CO_2-emitting energy and it is predicted that $\beta_5 < 0$.

Two further regressors capture the *structural change* element of the US. lns_t measures log-value-added to services (as % of GDP) and is a proxy for structural change within the US. Friedl and Getzner (2003) argue that since the service sector generally specialises in less pollution-intensive activities than the manufacturing sector, an increase in lns_t should facilitate lower CO_2 emissions. Hence, it is expected that $\beta_6 < 0$. $lnfdi_t$ measures log-net FDI inflows (as % of GDP) and is a proxy for a country's openness. The advantage of this proxy is that it can be used to test the Pollution Haven Hypothesis (PHH). PHH describes the tendency for pollution-intensive industries to migrate to countries with weaker environmental regulations. Given that firms in developed countries tend to face higher environmental standards than their counterparts in developing countries, the PHH predicts that whilst *developing* countries will become a 'haven' for the polluting industries of the world and hence bear the burden of CO_2 emissions, the opposite effect will apply to *developed* countries. Thus, if the PHH holds, it is expected that $\beta_7 < 0$ for a developed country like the US, whose stringent environmental regulations should only attract non-polluting industries of the world, leading to lower CO_2 emissions.

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[2] found by setting the derivative of equation [1] wrt lny_t to zero

Finally, variables $ln\,co2_{t-1}$ and $year$ are included to account for *persistence* and *deterministic trending* in CO_2 emissions pc, respectively. Persistence is present if $|\beta_8| < 1$, meaning that current CO_2 emissions pc is driven by its lagged values. Moreover, a statistically significant $year$ variable is indicative of emissions varying merely due to the passage of time.

2.2 The Data

The annual time-series dataset covering 1971-2010 is attained from the World Bank's online database, giving way to 40 observations in total. Collecting from a single, reliable source (as opposed to multiple sources) has the advantage of ensuring consistency in the way variables are defined and measured, thus minimising measurement bias in the estimation. However, better quality data is at the expense of a restricted dataset. For example, no data is available for fossil fuel consumption and alternative energy consumption prior to 1971, and as such imposes a lower bound on the sample range. Another weakness of the data is the small number of observations[3], which may undermine the precision with which the population parameters are estimated.

2.3 Stationarity

Due to the time-series nature of the dataset, unit root tests must be carried out to determine stationarity before proceeding to the estimation. The Augmented Dickey-Fuller (ADF) test is one method of identifying unit roots. *Table 2* shows the results of the ADF test with trend and intercept. All variables are found to be integrated of order one (I(1)), since they are non-stationary in levels but become stationary when first-differenced.

Table 2
ADF test for unit root: trend and intercept

Variables	Level	1st difference
$lnco2_t$	0.6690	0.0007***
lny_t	0.8742	0.0009***
$lnfc_t$	0.8280	0.0001***
$lnac_t$	0.0594*	0.0005***
lns_t	0.2211	0.0000***
$lnfdi_t$	0.1025	0.0000***

Note: Values presented are MacKinnon one-sided P-values. H_0 = variable follows a unit root process. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

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[3] No monthly or quarterly data was available

2.4   Cointegration

Given that all variables are I(1), a levels-on-levels regression of the General EKC Model may be *spurious*, in that a significant relationship is detected between a set of independent non-stationary series just because they are all trending over time. According to Granger and Newbold (1974), a spurious regression is characterised by a high R^2-value together with significant positive autocorrelation in the residuals. In the case of a spurious regression, the estimated OLS coefficients will be inconsistent and the usual t-stats will be misleading. However, if the I(1) variables in the regression are *cointegrated,* in that a linear combination of them is I(0), then the OLS regression will not be spurious and the usual t-stats and interpretations apply.

The Engle-Granger (1987) test is used to detect cointegration between a set of I(1) variables. This is an application of the ADF test to the *residuals* of the General EKC Model estimation. Cointegration is present if the null hypothesis of a unit root in the residuals is rejected, i.e. if the residuals are I(0). If this is the case, then the claim of spurious regression can be ignored and the usual OLS estimates and interpretations hold for the General EKC Model.

2.5   The Error Correction Model

If cointegration is found to be significant, then a natural extension is to run an Error Correction Model (ECM). An ECM is more enriching as an estimation tool as it captures the *dynamic* relationships between CO_2 emissions and its determinants. The following ECM is estimated:

$$\Delta lnco2_t = \alpha_0 + \alpha_1 \Delta lny_t + \alpha_2 \Delta (lny_t)^2 + \alpha_3 \Delta (lny_t)^3 + \alpha_4 \Delta lnfc_t + \alpha_5 \Delta lnac_t + \alpha_6 \Delta lns_t$$
$$+ \alpha_7 \Delta lnfdi_t + \alpha_8 \Delta lnco2_{t-1} + \delta EC_{t-1} + u_t \qquad [2]$$

where EC_{t-1} is the lagged residuals (ε_{t-1}) obtained from estimation of the General EKC Model, and u_t is a white noise error term. The *cointegrating vector* (which is contained in the EC_{t-1} term) is then given by $[1, -\beta_1, -\beta_2, -\beta_3, -\beta_4, -\beta_5, -\beta_6, -\beta_7, -\beta_8, -\beta_9]$, which correspond to the coefficients from the General EKC Model.

The ECM has both long-run and short-run properties built into it. The former is embedded in EC_{t-1}, which captures the long-run equilibrium relationship between $lnco2_t$ and its determinants. The short-run dynamics are captured partly by coefficient δ (which reflects the speed at which equilibrium errors are corrected), and partly by coefficients α_1 to α_7 (which measure the contemporaneous response of $lnco2_t$ to a change in each of the regressors, ceteris paribus).

3   Model Estimation and Results

3.1   The General EKC Model

Six variations of the General EKC Model [1] are estimated via OLS, with the results presented in *Table 3*. Models (1), (2) and (3) are the *baseline* models that correspond to the linear, quadratic and cubic specifications of the emissions-income relationship. These models contain only the log-GDP pc variables as well as variables $ln\,co2_{t-1}$ and $year$. By contrast, models (1a), (2a) and (3a) build onto the former by including the additional determinants of $lnco2_t$, namely $lnfc_t$, $lnac_t$, lns_t and $lnfdi_t$.

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Table 3

Estimation of the General EKC Model

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Explanatory variables	Linear		Quadratic		Cubic	
	Model (1)	**Model (1a)**	**Model (2)**	**Model (2a)**	**Model (3)**	**Model (3a)**
Constant	20.6301*** [4.3769]	23.0023*** [5.3468]	56.7666*** [14.8296]	-8.8073 [34.8018]	1006.131* [546.0357]	2076.381** [920.8774]
lny_t	0.5857*** [0.1357]	0.8369*** [0.1512]	-4.9034** [2.1967]	5.5943 [5.1450]	-279.3429* [157.8055]	-597.379** [266.1663]
$(lny_t)^2$			0.2728** [0.1076]	-0.2315 [0.2503]	26.7064* [15.1986]	57.8075** [25.6166]
$(lny_t)^3$					-0.8485* [0.4878]	-1.8613** [0.8215]
$lnfc_t$		0.2130 [0.7931]		0.7080 [0.9582]		0.8903 [0.9019]
$lnac_t$		-0.0442 [0.0492]		-0.0537 [0.0504]		-0.0148 [0.0503]
lns_t		-0.0023 [0.3028]		0.0301 [0.3055]		-0.8150* [0.4702]
$lnfdi_t$		-0.0136 [0.0084]		-0.0138 [0.0084]		-0.0193** [0.0083]
$lnco2_{t-1}$	0.6491*** [0.0939]	0.4507*** [0.1182]	0.4795*** [0.1101]	0.4494*** [0.1185]	0.4485*** [0.1084]	0.3114** [0.1267]
$year$	-0.0129*** [0.0028]	-0.0155*** [0.0027]	-0.0169*** [0.0031]	-0.0130*** [0.0038]	-0.0168*** [0.0030]	-0.0105*** [0.0038]
Adj R^2	0.8382	0.8764	0.8599	0.8758	0.8678	0.8908
S.E. of regression	0.0232	0.0203	0.0216	0.0203	0.0210	0.0191

Note: OLS estimates of coefficients. Values in parentheses are standard errors. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The Engle-Granger (EG) tests for cointegration *(Table 4)* show that the residuals are I(0) (i.e. not autocorrelated) in all six models, and hence cointegration is present. This implies that the potential problem of spurious regressions mentioned in Section 2.4 is avoided and the OLS

estimates and interpretations hold. Furthermore, omitted variable tests[4] show joint significance of the additional variables $lnfc_t$, $lnac_t$, lns_t and $lnfdi_t$. This confirms the presence of omitted variable bias in our *baseline* models, thus providing rationale for estimating the *advanced* models.

Table 4
Engle-Granger test for cointegration: ADF test on residuals

Linear		Quadratic		Cubic	
Model (1)	**Model (1a)**	**Model (2)**	**Model (2a)**	**Model (3)**	**Model (3a)**
0.0057***	0.0171**	0.0276**	0.0137**	0.0068***	0.0013***

Note: Values presented are MacKinnon one-sided P-values. H_0 = residuals follow a unit root process; hence there is no cointegration between variables in a given model. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

Each model is presently considered in turn. Firstly, it is evident from *Table 3* that the *baseline linear model (1)* is significant, since the coefficient on the log-GDP pc variable lny_t is significant at the 1% level. However, this coefficient is of the wrong sign. From *Fig. 2*, it is obvious that an overall *negative* relationship exists between log-CO_2 emissions pc and log-GDP pc. Yet the coefficient on lny_t is estimated to be *positive*, which is clearly nonsensical and leads to the rejection of model (1). This problem persists in the *advanced linear model (1a)* case, despite the inclusion of additional regressors. Consequently, model (1a) is also rejected.

Although the *baseline quadratic model (2)* is significant at the 5% level (given significant coefficients on the log-GDP pc variables), it does not support the hypothesis of *an inverted U-shaped* EKC. This is because the coefficients on lny_t and $(lny_t)^2$ have the opposite signs to those predicted by the EKC, even though both are statistically different from zero. By contrast, inclusion of additional regressors in the *advanced quadratic model (2a)* elicits quite the opposite problem. Whilst the signs of the log-GDP pc coefficients are consistent with the EKC, the coefficients are now both statistically insignificant. In fact, none of the regressors in model (2a) have any significant explanatory power, except for $ln\,co2_{t-1}$ and $year$. Clearly, the EKC hypothesis is unfounded under both versions of the quadratic model ((2) and (2a)), and consequently they are rejected.

In the cubic case, the baseline model (3) and its advanced counterpart (3a) have the same qualitative predictions regarding the emissions-income relationship. However, the latter is more significant, with coefficients on the log-GDP pc variables significant at the 5% level, as opposed to 10%. Model (3) is therefore rejected in light of a better *advanced* model (3a). Interestingly, model (3a) yields coefficients on lny_t, $(lny_t)^2$ and $(lny_t)^3$ that appear to go against the hypothesis of an N-

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[4] Appendix A

shaped emissions-income relationship, where $\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0$. Instead, the coefficients corroborate an *inverted* N-shaped relationship, where the signs are reversed (Friedl and Getzner, 2003). This is apparent in *Fig. 2*, in which an initial *U-shaped* emissions-income relationship is followed by a downward tail, yielding an inverted N-shape overall. Intuitively, it could be that log-CO_2 emissions pc is at first falling due to domestic abatement measures, reaching a trough at a log-GDP pc level of $10.2. Beyond this income threshold, emissions start to rise as a result of domestic abatement efforts being exhausted, hence the initial U-shape. The downward tail beyond log-GDP pc of $10.6 can be explained if the US resolves its *domestic* abatement limitations by outsourcing pollution-intensive production to other countries, thereby reducing its own emissions. Model (3a) will be the Preferred Model for the US hereafter.
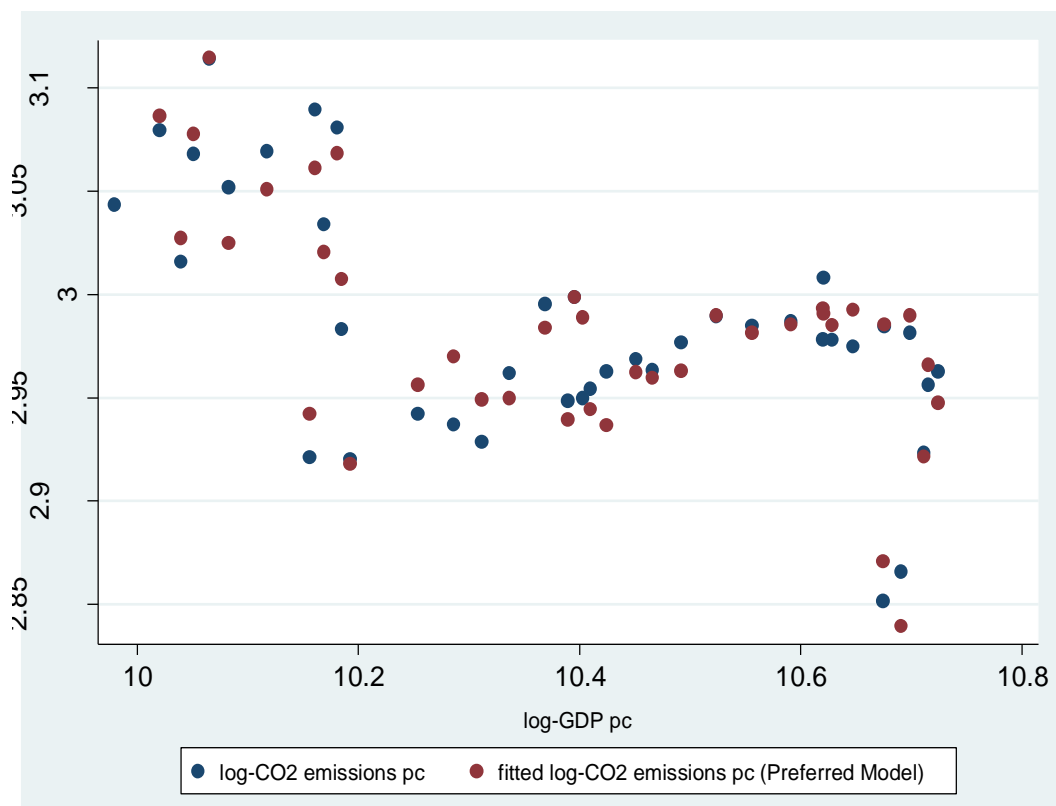

Fig.2. Actual and fitted emissions-income relationship in the US (1971-2010)

It is evident from the Preferred Model that of the four additional determinants of CO_2 emissions pc, only lns_t and $lnfdi_t$ are significant at the 10% and 5% level, respectively. Firstly, the coefficient on lns_t is expected and implies that a 1% increase in the value-added to services precipitates 0.82% fall in CO_2 emissions pc. Intuitively, this may be a result of the service sector specialising in less pollution-intensive activities than the manufacturing sector that it displaces. Secondly, consistent with predictions of the PHH in Section 2.1, the coefficient on $lnfdi_t$ is negative and suggests that a 1% increase in FDI into the US *reduces* CO_2 emissions pc by 0.02%.

Intuitively, US's stringent environmental standards means that it tends to attract FDI into the relatively less-polluting industries, thus producing less CO_2 as a by-product.

It is also worth highlighting the persistence variable $lnco2_{t-1}$ and time variable $year$ in the estimation, which are both highly significant. The coefficients on $lnco2_{t-1}$ are all positive and < 1, which imply the importance of past values of CO_2 emissions in determining current values. Moreover, the negative coefficients on $year$ emphasise the overall downward trend present in all six models. In the case of the Preferred Model, the coefficient of -0.0105 has the implication that for the sample period, CO_2 emissions pc are falling by 0.01% year-on-year.

Furthermore, residual diagnostics tests[5] are carried out on the Preferred Model. Firstly, the Breusch-Pagan test rejects the presence of heteroskedasticity. This preserves the G-M assumption of constant error variance, which is indicative of good model specification. By contrast, the Breusch-Godfrey LM test confirms the presence of serially-correlated residuals 1 lag apart (although the test becomes insignificant for higher order lags). This violates the G-M assumption of no autocorrelated errors, thus providing further rationale for estimating the ECM.

3.2 The ECM

Table 5 shows the results of the ECM estimation [2]. The error correction term EC_{t-1} is the lagged residuals obtained from estimation of the Preferred Model (3a) in Section 3.1. Part of the short-run dynamics is captured by the coefficient on the error correction term EC_{t-1}. In this case, the estimated coefficient of -0.6425 is not only significant at the 1% level, but is also of the correct (negative)[6] sign. In particular, it implies that approximately 64% of the disequilibrium error in CO_2 emissions pc in the previous year is corrected this year. This indicates a quick adjustment to long-run equilibrium. The corresponding cointegrating vector between $ln\,co2_t$ and the explanatory variables lny_t, $(lny_t)^2$, $(lny_t)^3$, $lnfc_t$, $lnac_t$, lns_t, $lnfdi_t$, $ln\,co2_{t-1}$, t is then [1, 579.370, -57.8075, 1.8613, -0.8903, 0.0148, 0.8150, 0.0193, -0.3114, 0.0105].

As for the short-run dynamics captured by the *contemporaneous* explanatory variables, none are significantly different from zero apart from $\Delta lnfc_t$, which is significant at the 10% level. The coefficient of 1.4752 on $\Delta lnfc_t$ suggests that a 1% growth in the consumption of fossil fuel precipitates an almost 1.5% growth in CO_2 emissions pc.

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[5] Appendix B

[6] i.e. positive errors cause $\Delta lnco2_t$ to be negative and hence $lnco2_t$ to fall

Table 5
Estimation of the ECM

Explanatory variables	Preferred Model (3a)
Constant	-0.0097* [0.0055]
Δlny_t	-50.2687 [322.2437]
$\Delta(lny_t)^2$	5.2319 [31.1068]
$\Delta(lny_t)^3$	-0.1779 [1.0006]
$\Delta lnfc_t$	1.4752* [0.8503]
$\Delta lnac_t$	-0.0538 [0.0580]
Δlns_t	-0.5154 [0.3341]
$\Delta lnfdi_t$	-0.0050 [0.0066]
$\Delta lnco2_{t-1}$	0.1625 [0.1183]
EC_{t-1}	-0.6425*** [0.2252]
Adj R^2	0.7203
S.E. of regression	0.0151

Note: OLS estimates of coefficients. EC_{t-1} represents the residuals from estimation of Model (3a). Values in parentheses are standard errors. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

It is also evident from residual diagnostics tests[7] that the model is now free from both autocorrelation (even at lag 1) and heteroskedasticity. Thus, the ECM appears to be well-specified and is an improvement upon the General EKC Model estimated in Section 3.1.

4 Conclusion

4.1 Summary

The objective of this paper was to test empirically the CO_2 EKC for the US. Using annual time series data for 1971-2010, the *quadratic* inverted U-shaped EKC was tested against the alternative *linear* and *cubic* specifications of the emissions-income relationship. Given the presence of omitted variable bias, four additional explanatory variables were included in the estimation. The results led to the rejection of the quadratic EKC in the case of the US. Instead, the advanced cubic model (3a) was found to be the most appropriate in terms of econometric quality, corroborating the

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[7] Appendix B

existence of an *inverted N-shaped* emissions-income relationship. This supports the *decoupling* phenomenon mentioned in Section 1, with the implication that economic growth appears to be a *solution* to the problem of CO_2 emissions. Not only do our findings undermine US's claim that cutting CO_2 emissions is growth-reducing, but they also imply that the country should join the Kyoto Protocol given that economic growth and emissions reduction go hand-in-hand.

In addition to the effect of *income* on emissions, the results also suggest that the US could achieve lower CO_2 emissions by increasing FDI inflows *(Table 3)*.[8] Alternatively, the country could lower CO_2 emissions by increasing the relative size of its service sector. From the ECM estimation, it is moreover found that the country could put a brake on emissions growth by implementing policies aimed at reducing the rate of fossil fuel consumption *(Table 5)*, for example by imposing a higher fuel duty.

4.2   Caveats and Extensions

It is worth highlighting some limitations of the study that merit consideration in subsequent research. First is the issue of using *aggregate* data. Seeing as the US is a large country, it would be naive to assume that inter-state variations in the emissions-income relationship do not exist. As evidenced by Aldy (2005) in his study, different states follow different emissions-income paths. It would therefore be useful in future EKC studies to account for these inherent inter-state differences. Secondly, the results of this paper are unique to the US, and as such cannot be generalised to other countries. A natural extension would be to carry out a *panel* study of the EKC hypothesis on both developed and developing countries. Lastly, the findings are not robust to the sample period. Had a different sample period been chosen, alternative implications may have been drawn. Despite these limitations, this paper has all-in-all provided a statistically-robust analysis of the CO_2 EKC on the US, with the conclusion that the EKC was rejected.

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[8] This is in line with the predictions of the Pollution Haven Hypothesis

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Appendix A. Omitted Variable Test

Omitted variable test

Model (1a)	Model (2a)	Model (3a)
0.0141**	0.0271**	0.0475**

Note: The omitted variables tested are $lnfc_t$, $lnac_t$, lns_t and $lnfdi_t$. $H_0 =$ the additional variables are not jointly significant. P-values are presented. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

Appendix B. Residual Diagnostics

Residual diagnostics tests on the Preferred Model (3a)

Tests	P-values	
	General EKC Model	**ECM**
Breusch-Godfrey LM test for autocorrelation, lag 1	0.0710*	0.2384
Breusch-Godfrey LM test for autocorrelation, lag 2	0.1870	0.4977
Breusch-Godfrey LM test for autocorrelation, lag 3	0.3379	0.7064
Breusch-Pagan test for heteroskedasticity	0.6056	0.9826

Note: Autocorrelation: $H_0 =$ no serial correlation of lag p. Heteroskedasticity: $H_0 =$ homoscedasticity, i.e. constant variance. P-values are presented. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.