IS THERE AN ENVIRONMENTAL KUZNETS CURVE IN THE CARBON DIOXIDE EMISSIONS?

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**Abstract**

The environmental Kuznets curve (EKC) is a relationship across countries between the level of environmental pollution and per capita GDP. This paper investigates the strength of empirical evidence in favour of the existence for an EKC in carbon dioxide emissions, accounting for the model uncertainty created by the numerous candidate regressors proposed in the literature. Using model averaging methods, I find strong evidence in favour of the existence of EKC in carbon dioxide emissions. In contrast, evidence in favour of the significance of many of the additional regressors disappears once model uncertainty is accounted for and the robustness of the findings is examined. The conclusion reached is that social policy may influence environmental degradation, for which an eventual deterioration is signalled.

**Keywords:** Environmental Kuznets Curve; Model uncertainty; Income inequality.

**JEL classification:** Q56, C59, O13, O15.
1. INTRODUCTION

The Environmental Kuznets Curve (EKC) is the subject of a vast literature in environmental economics. It is defined as an inverted-U shaped empirical relationship across countries between per capita GDP and the level of environmental degradation.\(^1\) If EKC holds universally, then economic growth will eventually lead to environmental improvement.

According to EKC hypothesis, after a certain income per capita level (called turning point), the environmental quality would improve in accordance with economic growth, generating the inverted-U shaped function indicated in (c) of Figure 1. Based on economic theory, the dominant explanations that have been put forth to explain this relationship are: a) the high costs associated with pollution control and abatement constitute environment a luxury good and the turning point marks the stage where countries can “afford” it; b) as countries become richer the popular desire for a cleaner environment increases and so does the political pressure for stricter environmental regulations; and c) the EKC pattern reflects the transition of the countries from pollution-intensive industrialized economies to less-pollution intensive service-based economies.

However, the encouraging initial EKC empirical findings have been followed by a vast literature with conflicting empirical results. The findings of some papers (e.g. Shafik, 1994; and Schmalensee et al, 1997) show environmental pressure (EP) as a linear function of income per capita, as indicated by (a) and (b) in Figure 1, while authors such as de Bruyn et al. (1998), believe that EKC does not hold in its classical form. The inverted-U shape is only an initial stage of the relationship between economic growth and environmental pressure, since a certain income level, there would be a new turning point leading to the N-shaped EKC shape indicated by (d) in Figure 1.

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\(^1\) The first use of the term, Environmental Kuznets Curve, can be traced to a paper by Panayotou (1993) written for the World Employment Programme Research Working Paper series. The first use of it in an academic journal was by Selden and Song (1994). The original Kuznets ‘Inverted-U’ hypothesis refers to the relationship between income inequality and per capita income—that in early stages of economic growth the distribution of income worsens, while at later stages it improves (Kuznets, 1955).
Figure 1: Various relationships between environmental pressure (EP) and per capita income

![Diagram of various relationships between EP and income](image)

Source: de Bruin et al. (1998).

This diversity of findings leads to further research to explain the income/pollution relationship, either by creating more formal models than plain emissions-income regressions, or by adding control variables in the model - resulting from different lines of research. Despite the vast amount of empirical research generated by these approaches, there is remarkably little consensus on which of the additional determinants is the most salient in explaining environmental degradation. In addition, the theories proposing the additional regressors are open-ended, meaning that one theory is logically consistent with another.

The EKC is thus an area of research with model (theory) uncertainty: the true model is unknown and several competing approaches exist that attempt to quantify the exact relationship between environmental quality and income. In light of such model uncertainty, inference procedures based on a single regression model do not account for the possibility that the inclusion or exclusion of any subset of the regressors may significantly alter the conclusions one
The model averaging solution to model uncertainly is to base inferences on all competing models (i.e. sets of regressors), each weighted by the posterior probability that the model is indeed the true model.

The goal of this paper is to re-examine whether the relationship between carbon dioxide emissions and income per capita exhibits an EKC and also to identify which of the range of the possible candidate regressors the data provide the most favourable evidence for, using model averaging techniques. The robustness of empirical support for different determinants of environmental pressure is examined using two different econometric approaches in the EKC empirical literature: the reduced-form approach and the theory-based approach. The reduced-form approach relates the level of pollution to a flexible function of per capita income and other covariates - those covariates being suggested by a theory not necessarily expressed in a mathematical form, i.e. a system of equations. In the theory-based approach the equation to be estimated is derived from a specific theoretical structural model of the demand and supply of pollution and in this case the set of regressors is more or less predetermined.

My empirical analysis finds very strong support for the EKC using both these approaches. The income measures are the most robust variables affecting carbon dioxide emissions, whereas I find little evidence in favour of political economy proxies, international trade and other regressors proposed in the literature. The Gini coefficient is the only additional repressor that remains significant in explaining carbon dioxide emissions once the model uncertainty has been incorporated in the estimation method. This result suggests that a significant portion of the regressors proposed in the literature may appear empirically significant only because the empirical strategy does not account for model uncertainty.

The organization of this study is as follows: Section 2 provides the econometric framework in the EKC approaches, and Section 3 details the strategy for addressing model uncertainty using Bayesian method averaging. Section 4 describes the data used, Section 5 presents the estimation results and Section 6 concludes.
2. BASIC ECONOMETRIC FRAMEWORK

The literature on Environmental Kuznets curves (EKC) begins in 1992 with the paper by Grossman and Krueger and has exploded since with: i) papers estimating “traditional” EKCs (e.g. Grossman and Krueger, 1995; Shafik and Bandyopadhyay, 1992; Holtz-Eakin and Selden, 1995), ii) EKC critiques (e.g. Arrow et al, 1995; Stern et al, 1996; Stern, 1998) and iii) studies of the theoretical and empirical determinants of EKC (Selden and Song, 1994; Stokey, 1998; Suri and Chapman, 1998; and others3).

The ‘traditional’ papers focus on estimating a quadratic or cubic relationship between some measure of environmental degradation and per capita income, to test the inverted-U shape of the EKC. The literature that follows indicates a diversity of empirical results that some authors (e.g. List and Gallet, 1999; Spangenberg, 2001; Harbaugh et al, 2002; Millimet et al, 2003) consider as evidence against the mere existence of the EKC. However, the expressed critiques have not put a stop in the continuing growth of the literature, motivating the inclusion of a variety of additional regressors in estimating EKC.3

This paper attempts to assess whether an EKC exists and to weight the evidence of the different determinants of environmental degradation proposed in the EKC literature, using the Bayesian Method Averaging. It focuses on air pollution and, more specifically, on the level of the carbon dioxide emissions in the atmosphere.4 This is investigated by examining two approaches used to test EKC: a) reduced-form models and b) theory-based models.


4 The majority of EKC studies use air pollution indicators to measure environmental degradation, of which, carbon dioxide emissions are amongst the most frequently used (see, for example, Shafik and Bandyopadhyay, 1992; Holtz-Eakin and Selden, 1995; and Managi; 2004). Other papers use sulphur dioxide emissions or concentrations, whose data are available in varying levels of aggregation from various sources (see, for example, Grossman and Krueger, 1995; Antweiler et al, 2001; and Cole, 2004). Other air pollution indices used in EKC studies are: nitrogen oxides (List and Gallet, 1999; Hill and Magnani, 2002; Cole, 2004; Managi et al, 2009); suspended particulate matter (Dinda et al, 2000) and carbon monoxide (Cole et al, 1997). One of the main aspects of the Stern (1998) critique of the EKC literature is the emphasis on particular EKCs for specific environmental problems (i.e. air pollution), ignoring the rest.
In the reduced-form approach many possible determinants of pollution are tried and, even in the carbon dioxide EKC related papers, this stand of literature is vast and open-ended. Following a similar approach with Begun and Eicher (2006), this paper uses the theory-based model of Antweiler, Copeland and Taylor (2001) as a logical alternative to the reduced-form approach, since it examines specific theories proposed as the underlying determinants of an EKC.

2.1 Reduced-Form Approach and Econometric Concerns

Many economic theories are expressed, deductively, as a system of equations, i.e. structural form models. The reduced form of any theory is the result of solving the system for the endogenous variables and this gives the latter as a function of the exogenous variables. Grossman and Krueger in their 1995 paper estimate several reduced-form equations that relate the level of pollution in a location to a flexible function of the current and lagged income in the country and to other covariates. An alternative to this reduced-form approach would be to model the structural equations relating environmental regulations, technology, and industrial composition to GDP, and then to link the level of pollution to the regulations, technology and industrial composition. The reason they choose a reduced-form approach is to have a direct estimate of the net effect of a nation's income on pollution and due to data restrictions.

5 The topic of theory open-endedness in the EKC area of research is addressed in Section 3.

6 Begun and Eicher (2006) introduce Bayesian model averaging (BMA) to the EKC analysis using sulphur dioxide concentrations data obtained from Antweiler et al (2001). Though I use a similar approach, my study sheds a different light on the literature, since there is no reason to expect a priori the results of Begun and Eicher to apply also to the carbon dioxide emissions. As indicated in Shafik and Bandyopadhyay (1992), sulphur dioxide concentrations are local air pollutants, costly to abate and their costs are not easy to externalize, i.e. is difficult to identify and charge the responsible parties for the harm caused. In contrast, carbon dioxide emissions are global air pollutants and their costs are relatively easy to externalize, e.g. via cap-and-trade policies (where a central authority sets a limit or cap on the amount of a pollutant that each firm has right to emit). Thus they are expected to respond in a quite different manner to proposed regressors, such as the ones referring to the pollution heaven hypothesis, explained further-on.

7 If the structural equations were estimated, they would need to solve back to find the net effect of income changes on pollution, and confidence in the implied estimates would depend upon the precision and potential biases of the estimates at every stage.
The Grossman and Krueger (1995) approach then became the norm and since then, the relationship between pollution and growth has been estimated using reduced-form equations that usually take the following panel data form:

$$E_{i,t} = a_o + a_1y_{i,t} + a_2y_{i,t}^2 + a_3y_{i,t}^3 + \sum_{p=1}^{P} \beta_p G_{p,i,t} + \sum_{j=1}^{J} \gamma_j F_{i,t} + \epsilon_{i,t},$$

(1)

where $E_{i,t}$ is the natural logarithm of a measure of environmental degradation in country $i$ at time $t$, $y_{i,t}$ is the natural logarithm of real per capita income, the term $\sum_{i=1}^{I} \gamma_j F_{i,t}$ captures the year-specific fixed effects, $G_{p,i,t}$ is a subset of the additional covariates described in the previous section and $\epsilon_{i,t}$ is a stochastic error term. The inverted U-shaped pattern suggested by EKC requires $a_1$ being positive, $a_2$ negative and $a_3$ positive.\(^9\)

One of the major econometric concerns emphasized in the EKC literature regarding the reduced-form approach (e.g. Stern, 2004; Costantini and Martini, 2010) is the proper identification of the econometric model: Estimations of EKC using only a subset of the alternative regressors ignore other covariates that may affect environment degradation or even be the real reason behind the observed inverse U-shaped patterns in environmental indicators. Hill and Magnani (2002) argue that the inclusion of specific variables (such as trade openness, income inequality and education) in the EKC equation provides important insights into the causes of pollution emissions. They refer to these variables as the reason that many EKC estimates suffer from omitted-variable bias.

Another econometric concern in the literature is potential heteroscedasticity: The data used are usually sparse and/or poor in quality and that leads in estimations using simplified assumptions. When the data used in cross-section studies are

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\(^8\) There are papers, such as the ones of Shafik (1994) and Stern et al (1996) that use cross-country regressions, instead. There are also papers that perform time series analyses for specific countries (e.g. Lindmark, 2002, for Sweden, and Egli, 2004, for Germany).

\(^9\) As noted in Costantini and Martini (2010), the cubic term derives from the empirical evidence found initially by Grossman and Krueger (1995), and later by de Bruyn et al (1998), that the relationship between income and some pollutants (e.g. sulphur oxides) becomes positive again for higher income levels. Thus, it actually suggests an N-shaped pattern.
aggregations of varying number of subunits, heteroscedasticity may result and their estimates may be inefficient. However, as reported by Stern et al (1996) and Stern (2004), in most of the EKC studies heteroscedasticity tests are not reported. Dijkgraaf and Vollebergh (2005) find that the crucial assumption of homogeneity across countries is problematic, since their tests decisively reject model specifications that feature even weaker homogeneity assumptions than are commonly used in the EKC models.

A third major econometric concern is potential endogeneity: As suggested by many papers (e.g. Arrow et al, 1995; Stern et al, 1996; Stern; 2004), estimating the reduced-form model expressed by equation (1) may suffer by simultaneity bias, since it is inappropriate to assume unidirectional causality from economy to environment and thus the previous estimates of EKC may be biased and inconsistent. Heerink et al (2001); and Managi et al (2009) address this problem using GMM in estimating EKC models, while other papers, such as Frankel and Rose (2002) and Costantini and Martini (2010), use 2SLS. Frankel and Rose consider both the income and trade variables to be endogenous in respect to the environmental degradation. They address the potential simultaneity of trade, environmental quality, and income by applying instrumental variable estimation, using a gravity model of bilateral trade and endogenous growth from neoclassical growth equations.

2.2 Theory-Based Approach

Another concern in the EKC literature is that the reduced-form specification of Grossman and Krueger cannot be used to examine separately the direct and the indirect effects of any variable (e.g. trade) to environmental degradation. Studies seeking to isolate the independent effect of trade openness to pollution include Antweiler, Copeland and Taylor (2001), which is cited as one of the most careful existing study explicitly focusing on the effects of trade on the environment (Frankel and Rose, 2002). They estimate a different type of econometric decomposition model that derives a reduced-form equation from a theoretical structural model of the demand and supply of pollution, in an attempt to determine the effects of trade on scale, composition, and technique effects that
yields precise, testable EKC implications and relationships. A major difference from the reduced-form approach is that in this case the set of regressors is more or less predetermined.

The Antweiler et al (2001) model, (ACT), is usually applied on data at the city/station level. Therefore, this paper uses a specification similar with the one used in Cole and Elliot (2003), who estimate the ACT model using country-level data:

\[
E_{i,t} = \lambda_0 + \lambda_1 I_{i,t} + \lambda_2 I_{i,t}^2 + \lambda_3 KL_{i,t} + \lambda_4 (KL_{i,t})^2 + \lambda_5 I_{i,t} * KL_{i,t} + \lambda_6 O_{i,t}
\]

\[+ \lambda_7 O_{i,t} * RI_{i,t} + \lambda_8 O_{i,t} * (RI_{i,t})^2 + \lambda_9 O_{i,t} * KL_{i,t} + \lambda_{10} O_{i,t} * (RKL_{i,t})^2
\]

\[+ \lambda_{11} O_{i,t} * RI_{i,t} * RKL_{i,t} + \lambda_{12} Polity_{i,t} + \lambda_{13} Site_{i,t} + \lambda_{14} t + \sum_{i=1}^{N} \gamma_i F_{i,t} + \epsilon_{i,t}
\]

\[E_{i,t}, \text{ as in equation (1), is a logged index of environmental degradation in country i at time t, } I_{i,t} \text{ is the three-year average of lagged GDP per capita in constant prices, } KL_{i,t} \text{ denotes a country’s capital–labour ratio, } O_{i,t} \text{ is the ratio of aggregate exports and imports to GDP (trade intensity), } RI_{i,t} \text{ is the relative lagged per capita income, } RKL_{i,t} \text{ denotes a country’s relative capital–labour ratio and } \epsilon_{i,t} \text{ is an error term. The remaining variables are explained below.}

The terms \( I_{i,t} \) and \( I_{i,t}^2 \) are used to capture the technique effect, i.e. the lowering of carbon dioxide emissions due to technological process. The technique effect is proxied by lagged per capita income, since countries with higher incomes in the past should be able to afford better technology today.\(^{10}\) The use of per capita income and per capita income squared to capture scale and technique effects is consistent with the reduced-form approach in testing the environmental Kuznets curve. The terms \( KL_{i,t} \) and \( (KL_{i,t})^2 \) are used to represent the composition effect, i.e. development and human capital accumulation generating shifts toward

\(^{10}\) ACT also allow for the estimation of the scale effect, i.e. increased aggregate production causing increased pollution, using GDP per squared kilometer (GDP/km\(^2\)) to proxy the scale effect. Since I use national pollution emissions, the use of GDP/km\(^2\) is no longer meaningful as a measure of scale, so the obvious measure of the scale effect is now the same as that for the technique effect. As a result, lagged per capita income in equation (1) captures both scale and technique effects.
less pollution-intensive industries. The squared term is included to allow capital accumulation to have a diminishing effect on the pollution, whilst the interaction term \( I_{i,t} \times KL_{i,t} \) captures the fact that the effect of income on pollution is likely to depend on the existing level of the capital-labour ratio, and vice versa.

The interactions with the trade intensity term \( (O_{i,t}) \) are included to test for the trade-induced composition effect. This is defined as: compositional changes in pollution arising from trade liberalization due to differences in capital–labour endowments and/or differences in environmental regulations proxied by the lagged income per capita. Since comparative advantage is a relative concept, a country’s capital–labour ratio and per capita income levels are here expressed relative to the world average. For both of these interacted variables a quadratic term is also included. It is expected that an increase in trade intensity would be associated with rising pollution for a country with low per capita income and with falling pollution for those with high incomes, i.e. \( \lambda_7 > 0 \) and \( \lambda_8 < 0 \). Similarly, trade liberalization is expected to increase pollution for countries with high capital–labour ratio and reduce pollution for those with lower capital–labour ratios, i.e. \( \lambda_9 < 0 \) and \( \lambda_{10} > 0 \). ACT predicts that \( \lambda_5 = 0 \) since trade liberalization per se should not affect pollution, while the sign of \( \lambda_{11} \) could be positive or negative.

\( Polity_{i,t} \) is a variable (or a set of variables) incorporating effects on environmental policy induced by political systems, while \( Site_{i,t} \) controls for site-specific factors (e.g., temperature, precipitation variation and population density). Unmeasured topographical features (unobservable country heterogeneity) are captured through the site or country-specific fixed effect terms: \( \sum_{i=1}^{N} \gamma_i F_{i,t} \).

The linear trend \( (t) \) is included to control for effects that are common-to-all-countries but nevertheless time varying. The data used for both reduced-form and theory-based models are described in detail in Section 4 and the Data Appendix.

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11 As noted by ACT, since the model is viewed as a random draw of countries or observation sites from a larger population, it may be more appropriate to use a random-effects estimator to capture the level effect. However, because this estimator treats the level effects as uncorrelated with the other regressors, it may suffer from inconsistency due to omitted variables. By comparison, the fixed-effects estimator does not suffer from this inconsistency problem, but it focuses exclusively on the variation over time in the data. An additional advantage of the fixed-effects approach is that controls for many time-invariant, site-specific and country-specific factors.
3. MODEL UNCERTAINTY

Despite their differences, both EKC modelling approaches described in the previous sections may be consistently expressed in matrix notation as:

\[ E_{i,t} = X'_{i,t} \beta + \varepsilon_{i,t}, \]  

(3)

where \( i = 1,2,\ldots, N \), \( t = 1,2,\ldots, T \), \( X_{i,t} \) is a \( k \times 1 \) vector encompassing all possible determinants of environmental degradation\(^\text{12}\) and \( \varepsilon_{i,t} \) the error term. The diverse range of the different approaches in empirically examining EKC (where different models employ different subsets of \( X_{i,t} \) in order to examine EKC) represents the level of model uncertainty that surrounds empirical research on this topic.

The existence of this uncertainty creates a substantive problem in the analysis of the EKC papers: the lack of evaluation of each of the proposed regressors against the regressors found by other authors to be empirically important. In other words, the theoretical background of the existing empirical literature is limited to the one implied by a single model and not on a model space whose elements span an appropriate range of environmental degradation determinants. Therefore this paper employs a model averaging method to account for the broad theoretical background that both EKC itself and of each additional regressor (line of research) must be assessed. This section provides a brief overview of the BMA procedure used and identifies how it addresses the model uncertainty in the case of examining EKC.

3.1 Model Averaging

The basic Bayesian model averaging (BMA) idea originates with Jeffreys (1961) and Leamer (1978), whose insights are developed and operationalized by Draper (1995) and Raftery (1995). BMA was first introduced to economics by Fernandez et al (2001), with an application to economic growth, where “despite the vast amount of empirical research generated by new growth theories, there is little

\(^\text{12}\) In that manner, equation (3) nests the reduced-form and the theory-based models in one model.
consensus on which mechanisms are most salient in explaining cross-country differences” (Durlauf, Kourtellos and Tan, 2008). As with the growth area of research, empirical work on the EKC is especially challenging, because of the nature of the proposed theories: these theories are open-ended. By theory open-endedness, Brock and Durlauf (2001) refer to the idea that, in general, the statement that a particular theory (regressor or regressors) is relevant does not logically preclude other theories (regressors) of being relevant. That means that an evaluation of the statistical relationship between environmental degradation and any regressor needs to account for the plethora of pollution determinants that exist in the empirical literature.

The above argument asserts that each subset of plausible regressors included in \( X_{i,t} \) represents a legitimate statistical model for empirical analysis. The true model, which in the context of this paper is the correct combination of regressors included in \( X_{i,t} \), is treated as an unknown. Thus, different combinations of EKC regressors constitute distinct models and the set of all possible combinations constitute the model space, with a size \( (S) \) equal to \( 2^k \). Let \( M = (M_1, M_2, ..., M_S) \) denote the set of all models considered and let \( \hat{\beta}_m \) denote the estimate of the vector of parameters of each model \( M_m \). Then, given the model space, one can determine the evidentiary support of a given model by “integrating out” the uncertainty with respect to the identity of the true model by taking a weighted average of model-specific estimates.

The model’s weight in the averaging process, \( \mu(M_m \mid D) \), is the posterior probability of model \( M_m \), i.e. the probability that \( M_m \) is the true model given the data \( D \) and the model space \( M \). Letting \( \mu(M_m) \) denote the prior model probability and \( \mu(D \mid M_m) \) denote the likelihood of the data given the model, then by Bayes’ rule:

\[
\mu(M_m \mid D) \propto \mu(D \mid M_m) \mu(M_m), \tag{4}
\]

where \( \propto \) means “is proportional to”. Then the model averaging estimator is given by the posterior mean, derived by Raftery (1993):
The methodology surrounding Bayesian model averaging is specifically developed for linear models in Raftery, Madigan and Hoeting (1997). For an introduction to model averaging techniques, see the survey of Hoeting, Madigan, Raftery and Volinsky (1999).

3.2 Addressing the potential endogeneity in the EKC models

As described in previous sections, one concern in the EKC literature is that ‘key’ regressors, such as the income and trade variables, may be determined endogenously in respect to the environmental degradation. In that manner equation (3) is more precisely specified as:

$$E_{i,t} = X'_{1,i,t} \beta_1 + X'_{2,i,t} \beta_2 + \epsilon_{i,t},$$

where $X_{1,i,t}$ a $k_1 \times 1$ vector of endogenous pollution determinants and $X_{2,i,t}$ a $l_2 \times 1$ vector of exogenous/predetermined variables. In order to account for the endogeneity of $X_{1,i,t}$, equation (6) may be augmented with:

$$X_{1,i,t} = \Pi'_{1} Z_{1,i,t} + \Pi'_{2} X_{2,i,t} + V_{i,t} = \Pi' Z_{i,t} + V_{i,t},$$

where $Z_{1,i,t}$ is a $l_1 \times 1$ vector of exogenous/predetermined (instrumental) variables excluded from the equation (6), such that $l_1 \geq k_1$ and $V_{i,t}$ is the vector of errors. Let this system be exactly identified, so that $l_1 = k_1$. Then, assuming also that $(\epsilon_{i,t}, V_{i,t})$ is i.i.d. and that $E(Z'_{i,t} V_{i,t}) = 0$ and $E(Z'_{i,t} \epsilon_{i,t}) = 0$, equation (6) may be estimated using 2SLS.

I incorporate the potential endogeneity of the EKC models in my estimations by employing a variant of the 2SLS model averaging (2SLS-MA) estimator proposed
in Durlauf, Kourtellos and Tan (2012). The authors of this paper employ a “hybrid” approach to model averaging by “integrating out” the uncertainty over models by taking the average of model specific 2SLS (“frequentist”) estimates, weighted by Bayesian model weights constructed to be analogous to the posterior model probabilities defined in the previous subsection. As in the model averaging (MA) estimator, the set of all possible combinations of the regressors in equation (6) set the model space. More precisely, given the fairly large model space, I use the determinist algorithm of “leaps and bounds”, which provides a number of best models of each model size to approximate the model space (see Raftery, 1995).

Then, for each model $M_m$, I obtain an associated first stage model given by a model-specific version of equation (7). Then, if $X_m$ is defined as the vector of model-specific regressors, $Z_m$ as the vector of model specific exogenous/predetermined variables (including the instruments) and $P_m = Z_m(Z_m'Z_m)^{-1}Z_m'$ as the projection matrix, the 2SLS model averaging (2SLS-MA) estimator is given by the posterior mean:

$$
\hat{\beta}_{D,M}^{2SLS-MA} = \sum_{M} \hat{\mu}(M_m | D)(X_m'P_mX_m)^{-1}X_m'P_mE,
$$

where $\mu(M_m | D)$ are the model-specific (second-stage) weights constructed to be analogous to the posterior model probabilities and depend on the fitted values $P_mX_m$, rather than data $X_m$. The latter is an important difference between (8) and the standard LS model averaging estimator defined in equation (5). Similarly, the posterior variance of the parameter vector, $\hat{\mu}_{m,D}$, is obtained by:

13 Their 2SLS-MA estimator is a set of S-PLUS functions that are available online at: https://sites.google.com/site/kourtellos/resear/research/Programanddatafiles.zip?attredirects=0.

14 To ensure that enough models are included in the approximation of the model space, I set the leaps and bounds mechanism is set to return the 1000 best models for each size.

15 Note that for each model $M_m$: $k_m = k_{1,m} + l_{2,m}$ and $l_m = l_{1,m} + l_{2,m}$ such that under exact identification: $k_m = l_m$. 
\[ V_{D,M}^{\beta} = \sum_{m} V_{D,m}^{\beta} \hat{\mu}(M_m \mid D) + \sum_{m} (\hat{\beta}_{2SLS}^{2SLS} - \hat{\beta}_{2SLS-MA}^{2SLS-MA})^2 \hat{\mu}(M_m \mid D), \tag{9} \]

Where the model-specific posterior variance of the 2SLS estimator, under homoskedasticity, is given by \( V_{D,m}^{\beta} = (X_m' P_m X_m)^{-1} \hat{\sigma}_{\epsilon D,m}^2 \) and \( \hat{\sigma}_{\epsilon D,m}^2 \) is the variance estimate for each model \( M_m \). The posterior variance is then used to compute standard errors for the model averaged estimates.

### 3.3 Model weights

The model weights \( \hat{\mu}(M_m \mid D) \) are constructed using Bayes’ rule in equation (4), so that each weight is the product of the integrated likelihood of the data given the model, \( \hat{\mu}(D \mid M_m) \), and the prior probability of the model, \( \mu(M_m) \). Following Raftery (1995) and Eicher, Lenkoski and Raftery (2009), the integrated likelihood of the data given the model is approximated using the Bayesian Information criterion (BIC), so that:

\[
\log \hat{\mu}(D \mid M_m) = -\frac{N}{2} \log \hat{\sigma}_{\epsilon D,m}^2 - \frac{1}{2} l_m \log(N) + O(N^{-1}) \tag{10}
\]

I use the standard practice in the model averaging literature, which is to assign a uniform prior over the model space. This approach is equivalent to assuming that the prior probability that a given variable is present in the “true” model is 0.5 independent of the presence or absence of any of the other included regressors.

### 3.4 Posterior Inclusion Probabilities

In addition to the posterior means and standard deviations, BMA provides the posterior inclusion probability of a candidate regressor, \( pr(\beta_k \neq 0 \mid D, M) \). The posterior inclusion probability is a probability statement of a primal concern: what is the probability that each regressor has a non-zero effect on the dependent variable.
4. DATA

An unbalanced panel data set of 35 countries over four periods, 1971-75 \((N_1 = 31)\), 1976-1980 \((N_2 = 33)\), 1981-85 \((N_3 = 35)\), and 1986-90 \((N_4 = 35)\) is used.\(^{16}\) This is actually an extension/update of the data set created by Antweiler, Copeland and Taylor. The dependent variable is average carbon dioxide emissions per capita \((CO_2)\) in these periods, collected from the Carbon Dioxide Information Analysis Center, Environmental Sciences Division at the Oak Ridge National Laboratory. The choice of alternative regressors is determined by both data restrictions and the existing literature, which is followed as closely as possible. Note that some regressors are motivated by several alternative theories and also that some are included in both the reduced-form and the theory-based specifications.

As described previously, the common thread that runs through all the EKC models is the estimation of a non-linear relationship between per capita income and the chosen measure(s) of environmental degradation. Following Begun and Eicher (2008), I use two alternative measures of income: the three-year average of lagged GDP per capita in constant prices, \(I_{it} = (Y^R_{it-1} + Y^R_{it-2} + Y^R_{it-3})/3\), suggested in Antweiler et al (2001) and the average value of the natural logarithm of GDP per capita in current prices \((Y^l_{it})\).\(^{17}\) The data source for both measures is the World Penn Tables (Heston, Summers and Aten; 1995, 2011).

In order to account for the possible endogeneity of income in the EKC regressions suggested by Stern et al (1996), both measures of income are instrumented using lagged values, i.e. the average values of \(I_{it}\) and \(Y_{it}\) in the intervals: 1966-70, 1971-75, 1976-1980 and 1981-85.

Before BMA is employed, each proposed additional regressor must be motivated by a well-established theory or line of research to justify its inclusion alongside the ‘traditional’ income variables. Operationally, and for an easier analysis of the empirical findings in the subsequent section, I organize the proposed additional control variables (possible determinants of environmental degradation) into 6

\(^{16}\)Selden and Song (1994) and Begun and Eicher (2008) also use five-year averages. This is also common in the economic growth literature; since it allows addressing the error associated with business cycle fluctuations that are inherent in income data (see Barro, 1990).

\(^{17}\)Using both current and lagged values of income per capita is also consistent with the literature where authors estimate the EKC using a dynamic specification (see Grossman and Kruger, 1995; Agras and Chapman, 1999; Coondoo and Dinda, 2002; and Perman and Stern, 2003).

1. The impact of Trade on the environment is being approached in many ways in the empirical literature, one of them by examining whether differences in environmental regulations may explain the relocation of pollution-intensive industries (Jaffe et al, 1997). Eskeland and Harrison (2003) suggest that the EKC pattern maybe due to “pollution dampening”: This argument, also referred to as the “pollution heaven hypothesis” states that developed countries may reduce the level of their environmental pollution by moving the pollution-intensive industries to developing nations with less strict environmental regulations, causing their pollution levels to eventually decline and thus creating an inverse-U shape of the emissions of harmful gases in the atmosphere as a function of income.

International trade is measured as the sum of exports and imports expressed as a percentage of GDP from the Penn World Tables 7.0. As Frankel and Rose (2002) point out, the observed positive correlation between openness to trade and some measures of environmental quality could be due to the endogeneity of trade, rather than causality. Therefore, I instrument trade openness using lagged values, i.e. the average sum of exports and imports expressed as a percentage of GDP in the intervals: 1966-70, 1971-75, 1976-1980 and 1981-85. As an additional proxy for the effect of international trade of environment degradation, I use the ratio of investment to GDP for the periods: 1971-75, 1976-80, 1981-1985 and 1986-1990, since, as argued in Harbaugh et al (2002), increased openness may lead to increased competition, which could cause more investment in
efficient and cleaner technologies to meet the environmental standards of
developed nations.\textsuperscript{18}

2. As indicated previously, the \textit{Composition of GDP} may also explain the
observed EKC patterns. Panayotou (1993) indicates that when development and
human capital accumulation generates a shift towards cleaner industries
(services or information technology), the ensuing change in the composition of
output may reduce the environmental degradation. Thus, structural changes in
the economy lead to different environmental pressures.\textsuperscript{19}

The production structure is measured in the reduced-form model using the
physical capital stock per worker, available in the Penn World Tables, for the
periods: 1971-75, 1976-80, 1981-1985 and 1986-1990. This variable is also
included in the theory-based approach, as suggested in Section 3.2. The relative
capital-labour ratio (used in the interactions terms employed to examine the
trade-induced composition effect) is calculated by dividing the absolute term by
the corresponding world average. The same approach is followed in the
calculation of the relative income variable.

3. \textit{Political Economy} may also play a role in environmental betterment. Barrett
and Graddy (2000) find that an increase in civil and political freedoms
significantly reduces some measures of pollution. One reason for this result may
be that for a popular desire to clean up the environment, high incomes are not
enough. There must also be effective government regulation, which usually
requires a democratic system to translate the popular will into action, as well as
the rule of law and reasonably intelligent mechanisms of regulation.

Political economy is measured in both approaches using three variables:
Following Managi (2004) and Begun and Eicher (2008), the Polity IV ‘Constraint

\textsuperscript{18} Investment is one of the variables motivated by more than one lines of research in the area of
EKC. Shafik and Bandyopadhyay (1992) use it to account for the intensity of environmental
regulations, arguing that economies that experience rapid economic growth and investment may
have worse environmental quality relative to the average for their income level if regulations are
slow to respond to the changing circumstances.

\textsuperscript{19} Copeland and Taylor (2003) develop a model that shows that the reliance on capital
accumulation in the first stages of development, as opposed to human capital accumulation in later
stages, may generate an EKC.
on Executive’ index (Marshall and Jaggers, 2003), the average years of total schooling from Barro and Lee (2010)\textsuperscript{20} and a site-specific dummy for communist regimes suggested in Antweiler et al (2001). Since it takes some time for educational achievement to translate into environmental activism, for each country in the sample I use the average years of total schooling over the prior five years.

4. The \textit{Macroeconomic Policy} on issues such as income inequality and the national debt may also have an impact on environmental degradation. Boyce (1994) hypothesizes that greater equality of income results in lower levels of environmental degradation, since redistributing income will affect society’s demand for environmental quality and thus induce a policy response in that direction. On the other hand, Heerink et al (2001) argue that when in a non-linear relation between income and degradation can be found at the micro (household) level, redistributing income from rich to poor households may actually deteriorate environmental quality. This argument is also supported by Scruggs (1998) on both theoretical and empirical grounds.

Policy is measured using two proxies: the Gini coefficient from the Deininger and Squire (1996) data set, following Heerink et al (2001), and the gross general government debt expressed as a percentage of GDP, following Shafik and Bandyopadhyay (1992) and Shafik (1994). In the latter papers it is argued that the burden of debt servicing may force poor countries to degrade excessively their natural sources, eventually harming the environment, instead of making social decisions about the provision of environmental public goods.

5. Climatic conditions and other \textit{Country-Specific Variables}, such as population growth, can also explain cross-country and time differences in the levels of pollution, even after controlling for the effect of income. As argued by Neumayer (2002), one would expect cold countries to have greater heating requirements and hot countries to have greater cooling requirements, all other things equal and thus have higher emissions than countries with less extreme climatic

\textsuperscript{20} Educational achievement may increase environmental awareness of the people, hence exert pressure on politicians to introduce environmental regulations. Note that in the theory-based approach the intensity of environmental regulations is also examined by the income variables.
conditions. Population growth may have a result in growth of emissions (independently of the growth in per capita incomes) via the demand for public goods that are pollution-intensive, such as infrastructure and defense, as argued, for example, by Ravallion et al (1997).

Country-specific factors are measured in both approaches with the percentage of a country’s land area classified as tropical or sub-tropical via the Koeppen-Geiger system. I also use total population from the Penn World Tables 7.0 to capture other country-specific determinants. Unmeasured topographical features may be captured through the site-specific fixed effect terms.

6. I also include as a theory, Regional Heterogeneity, which consists of a dummy variable for South American countries, one for East Asian countries and one for South-East Asian countries. I refer the reader to the Data Appendix for a detailed description of the variables and data.

7. Common-to-all-countries factors are proxied in both approaches with period-specific dummies. In the country-specific fixed effects specifications a linear trend is used, instead. As suggested in Antweiler et al (2001), such factors reflect secular changes in global awareness of environmental problems, innovations, diffusion of technology and the evolution of world energy prices.

5. EMPIRICAL FINDINGS

I present my main findings in Tables 1 and 2 that show BMA two-stage least squares (2SLS; Columns 1 and 2), BMA least squares (LS; Columns 3 and 4), as well as Classical two-stage least squares (2SLS; Column 5) and least squares (LS; Column 6), estimations. I retain time period dummies in all specifications to capture the time fixed effects. All estimates are modelled using robust (White)

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21 Antweiler et al (2001) use city-level data on average temperature and precipitation. Since there is no such thing as national weather or national rainfall, I use this variable in order to capture the climate effect on a country-level.

22 To maintain as much consistency as possible with other studies on EKC the following estimations and exercises are also performed allowing for country-specific fixed effects. The results from the country fixed effects specifications can be seen to be very similar in terms of sign and significance to those estimated using time fixed effects. Note, however, that the regional heterogeneity dummies are absorbed into the coefficients of the country-specific fixed effects. The results from the country fixed effects specifications are available upon request.
standard errors in order to correct heteroscedasticity of the error term indicated by Stern (2004), inter alia. The classical estimation exercises are referred in the literature as “kitchen sink exercises”, i.e. they refer to the largest possible model in each model space (all variables included) and are reported for comparison. The empirical findings in Table 1 refer to the reduced-form approach, described in Section 3.1, while the estimations in Table 2 refer to the theory-based approach described in Section 3.2.

5.1 Findings from the Reduced-Form Approach

The key finding from the BMA results is that the regressors that appear to matter most for carbon dioxide emissions are the income variables. The posterior probabilities of inclusion of all the “standard” EKC variables are equal or near to 1, while the values of the coefficient continue to suggest an inverse-U pattern. In terms of probability of being included in the “true” model, for the additional regressors I find posterior probabilities of inclusion greater than the 0.5 prior for Macroeconomic Policy (1.00; because of the Gini Coefficient), Regional Heterogeneity (1.00; because of the East Asia dummy), Production Structure (0.91) and International Trade (0.88; because of the trade intensity variable).

The key finding from the “kitchen sink” results is the additional support for income being a key driver of carbon dioxide emissions. The income variables (\( I, I^2 \) and \( I^3 \)) are significant at the 1% level and their coefficients have values suggesting the inverted U-shaped pattern suggested by the Environmental Kuznets curve. However, there is only weak evidence in favour of the alternative income variables used (\( y^N \)). Note that \( I \) is composed from lagged values of GDP, while \( y^N \) is a measure of current output. In that manner, this is evidence in favour of contemporaneous economic activity being less important in determining carbon dioxide emissions than the indirect effects of rising income over time.

In the 2SLS “kitchen sink” results there is also evidence for international trade having a positive effect on environment, something which is consistent with the hypothesis that trade allows countries to attain more than they want, which include environmental goods in addition to market-measured output. This is contrary to the predictions of the pollution heaven hypothesis, i.e. trade allowing rich countries moving their pollution-intensive industries to poorer nations with less restrictive environmental regulations (Antweiler et al, 2001). However, the
trade coefficient is not significant in the 2SLS “kitchen sink” (and BMA) results, which is evidence in favour of the argument of Frankel and Rose (2002) that trade is determined endogenously in respect to the environmental degradation.

I also find that policy proxies are significant on the level of environmental degradation. There is very strong evidence that income inequality negatively affects the environment. This is consistent with the argument of Boyce (1994) that redistributing income will affect society’s demand for environmental quality and thus induces a policy response in that direction, contrary to the predictions of Scruggs (1998) and the empirical findings of Heerink et al (2001). Nevertheless, the coefficient of debt ratio is found negative, contrary to the findings of Shafik and Bandyopadhyay (1992). Production Structure is also indicated to affect environmental degradation. I find the coefficient of the capital-labour ratio to be highly significant at the 1% level and negative, contrary to what the composition of output explanation of EKC predicts; I do not see a natural explanation for this. Of the political economy proxies engaged only the level of education is found to have a significant effect on the environment in the “kitchen sink” results.

The “kitchen sink” results are encouraging in the sense that they strongly suggest the existence of an EKC pattern in the carbon dioxide emissions. Also in that additional variables suggested by different lines of research in the related literature appear significant in explaining differences in the levels of environmental degradation across time and countries. However, these results are contingent on the use of a very specific EKC model, i.e. these claims are based on very specific choices of which pollution determinants are included in the analysis (all of them in this case). As discussed in Section 4, there is no reason to come down so heavily on the side of any particular model, no matter how many regressors it includes, since that approach ignores the intrinsic model uncertainty.

In contrast, the BMA results do account for the model uncertainty in the area of EKC, and they indicate that among the only regressors that matter for carbon dioxide emissions are the income variables. The posterior evidence for inclusion for regressors deemed significant by “kitchen sink” estimations: education (0.082) and debt (0.361) are essentially marginal and far lower than the 0.5 prior. It appears therefore that the main outcome of accounting model uncertainty is in
fact to re-confirm the existence of EKC and that the national income remains a crucial driver of the carbon dioxide emissions.

5.2 Findings from the Theory-Based Approach

The results for the regressors motivated by the theory-based approach of Antweiler, Copeland and Taylor (ACT) are presented in Table 2. Antweiler et al (2001) develop this model to examine the scale, technique composition effects in the environment and also to divide the impact of trade on environment by each of these channels (i.e. the trade-induced composition effect).

The results are similar with the ones from the reduced-form approach, in the sense that income, trade and regional heterogeneity variables appear to matter for carbon dioxide emissions. The posterior probabilities of inclusion in the true model are equal to 1.00 for $I$ and its interaction with the capital-labour ratio, 0.99 for the interaction of trade with the capital-labour ratio and 1.00 for the East Asia dummy. I also find posterior probability of inclusion greater than the 0.5 prior for the tropical climate variable, a site-specific factor and some weak evidence in favour of two trade interaction terms. The major difference from the reduced-form model results is that they indicate the squared income variable ($I^2$) to have a posterior probability of inclusion less than 0.5.

In “kitchen sink” results the coefficients of $I$ and $I^2$ are found both positive. As indicated in Section 3.2, in the theory-based approach the absolute income variables capture the joint scale and technique effect. Thus these results imply that the scale effect dominates the technique effect. Cole and Elliott (2003) attribute this result to the fact that carbon dioxide emissions have not been subjected to the same degree of regulation as other air pollutants, such as the sulphur dioxide concentrations. As a result, carbon emissions have been increasing steadily with economic growth.

There is no strong evidence for composition effect from the “kitchen sink” results, since (contrary to the results of Cole and Elliott, 2003) there is no statistically significant relationship between emissions and the capital-labour ratio terms. The notable exception is the income interaction term which captures the fact that the effect of income on pollution is likely to depend on the existing level of capital abundance. There is also no robust evidence for a trade-induced composition effect.
effect, since only one out of the six related variables (trade and interactions) is found statistically significant in the “LS kitchen sink” results, while in the 2SLS “kitchen sink” results this limited evidence vanishes altogether. The significance of the interaction of trade with the capital-labour ratio suggests the existence of compositional changes in pollution arising from trade liberalization due to differences in capital–labour endowments. In different words, this result does suggest that trade plays an important indirect role in determining pollution since it is revealed that trade moderates the composition effect.

The coefficient of the tropical climate proxy is indicated significant and negative, contrary to the evidence in the literature that hot countries have greater cooling requirements, higher energy consumption and thus higher carbon dioxide emissions (Neumayer, 2002). The educational level and the debt ratio now are indicated as having no explanatory power over the carbon dioxide emissions. The coefficients of the period dummies (not reported for parsimony) are found significant, a result that points against the existence of factors that help in reducing (or increasing) environmental degradation that are common in all the countries.

The results from the theory-based approach suggest that a significant portion of the regressors proposed by Antweiler et al (2001) to explain environmental degradation are not significant in explaining carbon dioxide emissions. This finding is consistent with the empirical results of Cole and Elliott (2003), which attribute this to the fact that ACT model is designed with local, rather than global, pollutants in mind and hence it could be argued that is ACT for carbon dioxide emissions. This also provides evidence that a complex theory with a large number of proposed regressors may not be necessary in explaining EKC. In that manner, alternative theories, such as the Green Solow model (Brock and Taylor, 2004; 2005), should not be discarded simply because they do not suggest additional EKC regressors.

5.3 Robustness

In Tables 3 and 4, I report results assessing the robustness of my MA results to alternative model prior specifications as well as approximations to the integrated
likelihood. Column 1 of Tables 3 and 4 reproduces the baseline MA results (Column 2 of Tables 1 and 2).

Table 3 reports the robustness estimations for the reduced-form approach results. Columns 2 to 5 contain results for cases where particular subsets of variables are assumed a priori to always be included in the “true” model. For instance, the MA exercises for which results are reported in column 2 assume that the (lagged) income variables ($I_1$, $I_2$ and $I_3$) are included in all models in the model space. Similarly, column 3 reports results for MA exercises where the canonical EKC variables (lagged and current income) are always included in all models. Columns 4 and 5 report results for exercises where, respectively, all Policy and all Regional Heterogeneity variables are retained in all models in the model space. Finally, column 6 reports results for exercises where instead of using the BIC approximation for the integrated likelihood, I use the AIC instead. The effect of using the AIC instead of the BIC is to allow for smaller penalty on larger models.

I find that my baseline reduced-form results are largely robust to those perturbations. When model uncertainty is accounted, the results support the existence of an N-shaped EKC in the carbon dioxide emissions, i.e. a positive coefficient for $I_1$, a negative coefficient for $I_2$ and a positive coefficient for $I_3$ - all of them significant at the 1% level. It turns out that of the additional regressors; only the Gini coefficient and the East Asia dummy appear robustly significant in explaining the carbon dioxide emissions. Trade intensity, which also has posterior probability of inclusion greater than the 0.5 prior, appears insignificant in all the exercises. Thus, the estimates accounting for the model uncertainty in the area of EKC indicate that the only regressors that robustly matter for carbon dioxide emissions are income and regional variables. This finding, no matter how extreme it sounds, is not inconsistent with the existing literature, in the sense that no matter how many regressors are added to the EKC equation, in the end, many studies conclude that income has the most significant explanatory power on the environmental quality of all the explanatory variables tested (Agras and Chapman, 1999).

Table 4 reports the robustness estimations for the theory-based approach results. As in Table 3, Columns 2 and 3 contain results for cases where particular subsets of variables are assumed a priori to always be included in the “true”
model. For instance, the MA exercises for which results are reported in column 2 assume that the income variables ($I$ and $I^2$) are included in all models in the model space. Similarly, column 3 reports results for MA exercises where the trade interaction terms (which in the ACT model express the trade-induced composition effect) are always included in all models. Columns 4 and 5 report results for exercise where model space includes particular variables not suggested by the ACT theory. In that manner, the results in columns 4 and 5 nest the ACT model within a larger model space which includes variables deemed significant by other EKC approaches. Columns 4 and 5 report results for exercises where, respectively, $I^3$ and the Gini coefficient plus $I^3$ are included in all models in the model space. As in Table 3, column 6 reports results for exercises using the AIC instead of the BIC approximation for the integrated likelihood.

Contrary to the baseline reduced-form results, the theory-based are not largely robust to those perturbations. When model uncertainty is accounted, the variables appearing robustly significant are income, interaction of trade with the capital-labour ratio and East Asia. The income-capital interaction term and tropical climate variable, which in Table 2 have posterior probability of inclusion greater than the 0.5 prior appear insignificant in exercises where the ACT model is nested within a larger model space. The key result from columns 4 and 5 is that when model uncertainty is accounted for the $I^2$ variable appears significant and negative, thus re-confirming the existence of an EKC in the carbon dioxide emissions evidence from the empirical findings of Section 5.1.

5.4 The Shape of the Environmental Kuznets Curve

The empirical findings of this study indicate an N-shaped EKC, implying that the level of carbon dioxide emissions in the atmosphere initially improves and then deteriorates again at very high income levels (i.e. the (d) scenario in Figure 1). An N-shaped EKC is not something new in the literature. Grossman and Krueger (1992) conclude that a cubic functional form provides the best fit for two indicators of local air pollution (even if they note that the cubic part of the functional form becomes relevant for only two countries in their sample). Moomaw and Unruh (1997) consider a cubic EKC model obtaining an N-shaped relationship with a first turning point at $12,813$ and a second one at $18,133$, implying a very narrow income range for CO2 declines. More recently, the
analysis of Costantini and Martini (2010) indicates that the cubic form of the EKC is valid and robust for the CO2 emissions.

**Figure 2: Environmental Kuznets Curve for Carbon Dioxide Emissions**

As indicated in Figure 2, the initial worsening of carbon dioxide emissions in the sample of this study occurs up to a per capita income level of about $9,600 and is probably associated with the growing development, industrialization and consequent use of the natural resources. According to the most dominant EKC explanations the improvement results when countries become richer, they can afford the high costs associated with the environmental abatement and they develop a higher demand for environmental quality, thus inducing a policy response in that direction.

The cubic shape of carbon dioxide emissions indicates that emissions begin to rise again once an income turning point is passed. This income turning point is $17,600 and this eventual increase in the carbon dioxide emissions in high income levels (outside the sample of this study) is more difficult to explain. Costantini and Martini (2010) indicate that for carbon dioxide emissions the cubic form is associated to the increasing environmental efficiency in the productive sector – the technological effect – and the shift from heavy industries to services – the structural effect – which determine the descending part of the curve, and to the increasing demand for energy products as income raises further (the second ascending part of the curve).
6. CONCLUSION

This study re-examines the evidence for an Environmental Kuznets Curve using the updated Oak Ridge National Laboratory data in the carbon dioxide emissions. The literature on the income-pollution relationship is characterized by model uncertainty as both the number of proposed theories and the range of candidate regressors is large. I apply Bayesian model averaging methods to address model uncertainty using both reduced-form and theory-based approaches as an econometric framework. Overall I find strong and robust evidence for an EKC, which is generally consistent with the related empirical literature. There are many reasons why EKC holds, one of the most dominant being that as countries become richer they have a higher demand for environmental quality, thus inducing a policy response in that direction. This argument is also supported by the fact that amongst the only regressors other that the “standard” EKC variables supported by the BMA results is the Gini coefficient for income inequality – since greater equality of income may also affect society’s demand for environmental quality. The fact that the significance of many of the remaining potential pollution determinants (including the ones derived from elaborated theories) is not supported by the BMA results indicates that the particular regressors may be significant in the related literature only because the empirical strategy does not account for model uncertainty. The resulted EKC in N-shaped, signaling an eventual deterioration of the air pollution from carbon dioxide emissions.
REFERENCES


------. (2011), Penn World Table Version 7.0, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.


### Data Appendix

#### Table A.1: Variable Description

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Source</th>
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<tbody>
<tr>
<td>Trade Intensity (O)</td>
<td>Average values of the sum of exports and imports expressed as a percentage of GDP. The instruments for trade intensity include the average values for 1966-70, 1971-75, 1976-1980 and 1981-1985.</td>
<td>Penn World Tables 7.0</td>
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<tr>
<td>Relative Capital-Labour Ratio (RKL)</td>
<td>Average values of the capital-labour ratio divided by the corresponding world average for the given year, for the periods 1971-75, 1976-80, 1981-1985 and 1986-1990. The &quot;world average&quot; data were kindly provided by Professor Werner Antweiler.</td>
<td>Penn World Tables 5.6, Antweiler et al (2001)</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
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<tr>
<td>Communist (CC)</td>
<td>Dummy variable: Country was/is communist. In the Antweiler, Copeland and Taylor (2001) dataset this variable is equal to one if the country is either China, Czechoslovakia, Poland, or Yugoslavia. All these countries, but China, are excluded from this dataset, due to lack of other data.</td>
<td></td>
</tr>
<tr>
<td>Tropical Climate (CLIM)</td>
<td>The percentage of land area classified as tropical and subtropical in the Koeppen-Geiger system.</td>
<td>The Center for International Development (CID) at Harvard University</td>
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<td>Regional Dummy Variables</td>
<td>Dummy variables for South America, for East Asia (China, Japan and Korea) and South-East Asia (Indonesia, Philippines and Thailand).</td>
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### Table A.2: List of Countries

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### Table A.3: Descriptive Statistics

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<td>Carbon Dioxide Emissions (CO2)</td>
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<td>Table 1: Reduced-Form EKC Models: BMA and Classical Estimation Results</td>
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<td>8.37079*** (0.77085)</td>
<td>1.00000</td>
<td>8.31612*** (0.80443)</td>
<td>8.3179*** (1.56462)</td>
<td>6.99592*** (1.46431)</td>
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<td>$I^2$</td>
<td>0.99888</td>
<td>-6.55438*** (0.97295)</td>
<td>0.99904</td>
<td>-6.58904*** (0.97881)</td>
<td>-6.49925*** (1.66461)</td>
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<td>0.99894</td>
<td>2.08065*** (0.37110)</td>
<td>2.00197*** (0.54727)</td>
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<td>0.09197</td>
<td>0.01241 (0.06125)</td>
<td>-0.03205 (0.17041)</td>
<td>0.15348 (0.15267)</td>
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<td>$(y^N)^2$</td>
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<td>-0.02495 (0.03987)</td>
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<td>-0.03898 (0.04801)</td>
<td>-0.00520 (0.09621)</td>
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<tr>
<td>$(y^N)^3$</td>
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<td>-0.01072 (0.01467)</td>
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<td>Trade Intensity (O)</td>
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<td>0.18578 (0.11413)</td>
<td>0.94264</td>
<td>0.32022** (0.14289)</td>
<td>0.19051 (0.16025)</td>
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<td>Investment (INV)</td>
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<tr>
<td>Capital-Labour Ratio (KL)</td>
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<td>-0.11546** (0.05893)</td>
<td>0.89905</td>
<td>-0.11421** (0.05875)</td>
<td>-0.13709*** (0.05058)</td>
<td>-0.14515*** (0.05445)</td>
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Table 1 (Cont’d): Reduced-Form EKC Models: BMA and Classical Estimation Results

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<th>Classical Estimation</th>
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<td><strong>Site-Specific Factors:</strong></td>
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<tr>
<td>Tropical Climate (CLIM)</td>
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<td>-0.09249 (0.13549)</td>
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<td>Population Growth Rates (POP)</td>
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<td>0.08097</td>
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<tr>
<td>East Asia (EA)</td>
<td>1.00000</td>
<td>0.51059*** (0.09901)</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

Note 1: Columns (1)-(4) present the results using BMA (discussed in Section 3) while columns (5)-(6) present the results using Classical estimation. The description of the variables and the instruments used is given in Section 4 and in the Data Appendix. Period dummies are included in each specification, but coefficients are not shown. The complete set of results is available upon request.

Note 2: Posterior robust (White) standard errors are in parentheses. *** denotes significance at 1%, ** at 5%, and * at 10%.
Table 2: Theory-Based EKC Models: BMA and Classical Estimation Results

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<th>Classical Estimation</th>
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<td>Posterior Mean and Std. Error (2)</td>
<td>Posterior Inclusion Probability (3)</td>
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<td>Income (I)</td>
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<tr>
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<td>O * (RKL)^2</td>
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<td>O * RI * RKL</td>
<td>0.75120</td>
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**Notes:** ***p < 0.001, **p < 0.01, *p < 0.05.
Table 2 (Cont’d): Theory-Based EKC Models: BMA and Classical Estimation Results

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<td>Posterior Mean and Std. Error (2)</td>
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<td>Tropical Climate (CLIM)</td>
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Note 1: Columns (1)-(4) present the results using BMA (discussed in Section 3) while columns (5)-(6) present the results using Classical estimation. The definition of each variable is given at Section 2.2, while the data and instruments used are described in detail in Section 4 and the Data Appendix. Period dummies are included in each specification, but coefficients are not shown. The complete set of results is available upon request.

Note 2: Posterior robust (White) standard errors are in parentheses. *** denotes significance at 1%, ** at 5%, and * at 10%.
Table 3: Robustness of Reduced-Form EKC Models Estimation Results

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<th>BIC Always Kept</th>
<th>BIC EKC</th>
<th>BIC All Income</th>
<th>BIC Policy</th>
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<tr>
<td>Income (I)</td>
<td>8.37079***</td>
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<td>8.30152***</td>
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<td>8.62901***</td>
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<td>Capital-Labour Ratio (KL)</td>
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<td>Education (EDUC)</td>
<td>0.00177</td>
<td>0.00195</td>
<td>0.00264</td>
<td>0.00208</td>
<td>0.00595</td>
<td>0.00512</td>
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<tr>
<td></td>
<td>(0.00760)</td>
<td>(0.00824)</td>
<td>(0.00980)</td>
<td>(0.00841)</td>
<td>(0.01401)</td>
<td>(0.01289)</td>
<td></td>
</tr>
<tr>
<td>Policy:</td>
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<td></td>
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<tr>
<td>Income Inequality (GINI)</td>
<td>-0.52545***</td>
<td>-0.53170***</td>
<td>-0.12546***</td>
<td>-0.51120***</td>
<td>-0.49686***</td>
<td>-0.48963***</td>
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</tr>
<tr>
<td></td>
<td>(0.15270)</td>
<td>(0.14506)</td>
<td>(0.15031)</td>
<td>(0.14036)</td>
<td>(0.16159)</td>
<td>(0.14428)</td>
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</tr>
<tr>
<td>Debt Ratio (DEBT)</td>
<td>-0.04988</td>
<td>-0.04061</td>
<td>-0.00227</td>
<td>-0.13580*</td>
<td>-0.02187</td>
<td>-0.10751</td>
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<tr>
<td></td>
<td>(0.08684)</td>
<td>(0.07401)</td>
<td>(0.17033)</td>
<td>(0.07236)</td>
<td>(0.05437)</td>
<td>(0.09176)</td>
<td></td>
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<td>Site-Specific Factors:</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Tropical Climate (CLIM)</td>
<td>-0.09249</td>
<td>-0.07889</td>
<td>-0.52133</td>
<td>-0.11759</td>
<td>-0.01248</td>
<td>-0.13933</td>
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<td>(0.13549)</td>
<td>(0.12958)</td>
<td>(0.14906)</td>
<td>(0.14802)</td>
<td>(0.05757)</td>
<td>(0.14774)</td>
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<tr>
<td>Population Growth Rates (POP)</td>
<td>-0.15788</td>
<td>-0.02805</td>
<td>-0.02930</td>
<td>-0.09481</td>
<td>-0.25783</td>
<td>-0.41960</td>
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<tr>
<td></td>
<td>(1.25920)</td>
<td>(0.56076)</td>
<td>(0.06531)</td>
<td>(1.25288)</td>
<td>(1.52310)</td>
<td>(2.46783)</td>
<td></td>
</tr>
<tr>
<td>Regional Heterogeneity:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Asia (EA)</td>
<td>0.51059***</td>
<td>0.51475***</td>
<td>0.51550***</td>
<td>0.50566***</td>
<td>0.46383***</td>
<td>0.49109***</td>
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<tr>
<td></td>
<td>(0.09901)</td>
<td>(0.12366)</td>
<td>(0.12543)</td>
<td>(0.11977)</td>
<td>(0.12648)</td>
<td>(0.12287)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Table 3 presents the posterior means and std. errors for six different model averaging exercises for the EKC regression described in equation (1) of the text. Period dummies are included in each specification. Notice that column (1) is identical to column (2) of Table 1. Posterior robust (White) standard errors are in parentheses. *** denotes significance at 1%, ** at 5%, and * at 10%. 
Table 4: Robustness of Theory-Based EKC Models Estimation Results

<table>
<thead>
<tr>
<th>Information Criterion</th>
<th>BIC</th>
<th>BIC</th>
<th>BIC</th>
<th>BIC</th>
<th>BIC</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always Kept / Added</td>
<td>None</td>
<td>Income Variables</td>
<td>Trade Inte/tons</td>
<td>Add Inc. Cubed</td>
<td>Add Gini Coef.</td>
<td>None</td>
</tr>
</tbody>
</table>

**Scale and Technique Effect:**

- **Income (I)**
  - 3.92758***
  - (0.68854)
  - 3.97967***
  - (0.67971)
  - 3.84917***
  - (0.49537)
  - 6.16202***
  - (0.94338)
  - 6.8845***
  - (0.82857)
  - 4.0449***
  - (0.61573)

- **I^2**
  - 0.00328
  - (-0.01450)
  - -0.03431
  - -3.87601***
  - (0.20309)
  - (0.58955)
  - (0.22960)
  - (1.15829)
  - 0.09600

**Composition Effect:**

- **Capital-Labour Ratio (KL)**
  - 0.12763
  - 0.13441
  - 0.00359
  - 0.11361
  - 0.000275
  - 0.09460

- **(KL)^2**
  - 0.04943
  - 0.05314
  - 0.03279
  - -0.00396
  - -0.00515
  - 0.06550

- **I * KL**
  - -0.62168**
  - -0.64077***
  - -0.45917
  - -0.26273
  - -0.17473**
  - -0.70610**

**Trade-Induced Comp. Effect:**

- **Trade Intensity (O)**
  - -0.02706
  - -0.02777
  - -0.67652
  - -0.06206
  - 0.00811
  - -0.04150

- **O * RI**
  - -0.84734
  - -0.75116
  - 0.26489
  - -0.75868
  - -1.08995
  - -0.85600

- **O * (RI)^2**
  - -0.03488
  - -0.04999
  - -0.35033
  - -0.00770
  - -0.00479
  - -0.09740

- **O * RKL**
  - 2.98080***
  - 2.84298***
  - 3.26919***
  - 2.19182**
  - 2.53531***
  - 3.1019***

- **O * (RKL)^2**
  - -0.18117
  - -0.13709
  - 0.34522
  - -0.40942
  - -0.53483*
  - -0.20590

- **O * RI * RKL**
  - -0.92883
  - -0.94455
  - -1.70247
  - -0.28764
  - -0.19528
  - -0.88730

**Political Economy:**

- **Executives Constraint (EXEC)**
  - -0.00074
  - -0.00079
  - -0.00182
  - 0.00047
  - -0.00042
  - -0.00260

- **Education (EDUC)**
  - 0.00052
  - 0.00058
  - 0.00067
  - 0.00030
  - 0.00036
  - 0.00060

**Site-Specific Factors:**

- **Tropical Climate (CLIM)**
  - -0.34501***
  - -0.33224***
  - -0.25798
  - -0.28818**
  - -0.14781
  - -0.34830***

- **Population Growth Rates (POP)**
  - -0.13766
  - -0.13891
  - -0.18722
  - -0.55955
  - 0.00564
  - -0.62100

**Regional Heterogeneity:**

- **South America (SA)**
  - 0.02245
  - 0.01187
  - 0.00712
  - -0.00175
  - 0.00236
  - 0.05004

- **East Asia (EA)**
  - 0.43860***
  - 0.43926***
  - 0.45662***
  - 0.48627***
  - 0.44924***
  - 0.44246***

- **Southeast Asia (SEA)**
  - 0.00346
  - 0.00269
  - 0.00411
  - 0.00407
  - -0.01281
  - 0.02190

Note: Table 4 presents the posterior means and std. errors for six different model averaging exercises for the ACT regression described in equation (2) of the text. Period dummies are included in each specification. Notice that column (1) is identical to column (2) of Table 2. Posterior robust (White) standard errors are in parentheses. *** denotes significance at 1%, ** at 5%, and * at 10%.