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Assessing the functional relationship between CO_2 emissions and economic development using an additive mixed model approach

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ABSTRACT

Researchers have suggested that the relationship between the emission of carbon dioxide per capita and the real gross domestic product per capita follows an inverted-U-shaped (so-called environmental Kuznets) curve. Studies have generally used polynomial regression (quadratic or cubic form) to investigate this relationship. It has been recognised that polynomials are not that flexible and that, by choosing the degree of the polynomial, researchers make a priori assumptions. In this paper, we investigate the environmental Kuznets curve hypothesis using a flexible approach from additive mixed models. Such models are well-suited to handle nonlinear covariate effects flexibly and to simultaneously deal with temporal error structure. We consider the following countries: Australia, Austria, Canada, Denmark, Finland, France, Italy, Spain and Switzerland. Our results show the existence of the classic environmental Kuznets curve for France and Switzerland, and of a nonlinear (increasing) relationship for Australia, Italy and Spain. For Austria, the evidence reveals a weak N-shaped relationship. New nonlinear shapes are found for Finland (inverted-L-shape relationship), Canada (a special case of the inverted-L-shape relationship), and Denmark (M-shape relationship). Our findings are complemented by the calculation of the elasticity of the carbon dioxide emission per capita as a percentage of each level of real gross domestic product per capita.

1. Introduction

Carbon dioxide (CO_2) is one of the most abundant greenhouse gases in the earth's atmosphere. This is one of the main reasons why, during the last two decades, a number of studies have appeared explaining how the excessive emission of CO_2 from fossil fuels is contributing to important climatic and environmental changes, such as the increase in average global temperatures and sea levels (e.g., Davis et al., 2010; Lacis et al., 2010; Magnus et al., 2011). Some scholars have shown that the change in the global mean temperature due to CO_2 emissions is irreversible on human timescales (e.g., Eby et al., 2009; Frolicher and Joos, 2010), and Gillett et al. (2011) predicted that changes in temperature and precipitation will continue to worsen for many centuries after a complete cessation of CO_2 emissions. The results of these studies sound like an 'alarm bell'. Thus, economists and policy-makers should pursue strategies based on a path of innovation and 'green growth' (with a resource-efficient and low-carbon economy) to preserve the earth's ecosystems (e.g., Parson and Keith, 1998). In this regard, for example, the EU Heads of State and Government set three key targets to be met by 2020, known as the '20-20-20' targets: '*(a) a reduction in European Union (EU) greenhouse gas emissions of at least 20% below 1990 levels, (b) 20% of EU energy consumption to come from renewable resources, (c) a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency*' (European Commission, 2008, 2010).

Since Grossman and Krueger's (1991) seminal study, a large volume of scientific research has investigated the hypothesis of an inverted-U-shaped relationship between a measure of environmental quality (such as, CO_2 emissions per capita) and the gross domestic product (GDP) per capita. This hypothesis assumes that in the early stages of a country's industrialisation, pollution tends to increase rapidly because the country's priority is high material output and income, and minor attention is paid to the environmental impact of industrialisation. However, as national GDPs rise, we should observe the need of a cleaner environment. If individuals, businesses and institutions are willing to invest in improving environmental quality, pollution levels should decrease (e.g., Dinda, 2004; Kijima et al., 2010). On the basis of the resemblance between this relationship and the Kuznets hypothesis (Kuznets, 1955), Panayotou (1993) first coined the term environmental Kuznets curve (EKC).

Some scholars also hypothesised a case in which the relationship does not show an inverted-U-shape, but an N-shape. In this case, we should observe an increase in emissions in the first phase of the relationship, a decrease up to a certain level in the second phase,

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and finally a return to growth (e.g., Kijima et al., 2010). Amongst the studies that have found an inverted-U-shaped or an N-shaped relationship for CO_2 emissions, we can cite Sengupta (1996), Martinez-Zarzoso and Bengochea-Morancho (2004), Verbeke and De Clercq (2006), Wang (2011), Narayan and Narayan (2010), and Iwata et al. (2010). On the contrary, Bertelli and Strobl (2005), Cole (2005), Azomahou et al. (2006), He and Richard (2010) and Vollebergh et al. (2009) found weak or no evidence of an EKC.

Several factors may explain the different results: the countries considered for analysis (developed or developing), the historical period considered, the measurement method of the CO_2 emissions, and the method employed to estimate the relationship. Researchers have usually investigated the EKC hypothesis by employing reduced-form models, in which the emission of CO_2 per capita is a quadratic or cubic function of the real GDP per capita. A group of studies considered fixed or random effects in the parameter estimation using cross-country panel data (e.g., Cole, 2005; Galeotti et al., 2006; Diaz-Vanzquea, 2009; Stern, 2010), and others used an error-correction model (ECM) approach to account for the possible presence of co-integrating relations (e.g., Jaunky, 2011; Narayan and Narayan, 2010). However, some researchers have proposed more flexible methods to relax the restrictions of specific functional forms, such as polynomial regression, and thus to minimise specification errors.

Examples in the panel data framework include models estimated with kernel estimators (e.g., Azomahou et al., 2006; Bertelli and Strobl, 2005; Roy and Van Kooten, 2004; Taskin and Zaim, 2000; Vollebergh et al., 2009) and spline regression without a penalisation term (Wang, 2011). However, when studies use panel data techniques, particular attention must be paid to heterogeneity (sometimes unobserved) between countries because, as List and Gallet (1999) showed, different countries could exhibit different turning points (if presents) of the relationship between environmental quality and income. Thus, an approach with standard panel data techniques, which assumes that one form fits all EKCs, can lead to a biassed interpretation of results. As Stern et al. (1996) suggested, a valid approach to overcome the heterogeneity issue between countries is to study the EKC hypothesis of individual countries. This approach allows researchers to model the relationship between a measure of environmental degradation and income taking into account the specific historical experiences of each country. In the literature, only a small number of studies have investigated individual countries. Specifically, studies have mainly estimated this relationship using ECMs (e.g., Jalil and Mahmud, 2009; Iwata et al., 2010; Fodha and Zaghdoud, 2010) or more flexible models that use kernel estimators (e.g., He and Richard, 2010).

Note that most of the above mentioned studies neglected to test the quality of the residuals of the estimated models. This step is crucial to assess the quality of the results obtained from the fitted model. For example, because the data for this investigation were collected over time, it is likely that a serial correlation may have affected the final results. In our study, we investigated the EKC hypothesis for each of the following countries: Australia, Austria, Canada, Denmark, Finland, France, Italy, Spain and Switzerland. We proposed the following tools of analysis:

- A flexible model specification from the class of Additive Mixed Models (AMMs). An AMM can be seen as a linear mixed model, in which part of the linear predictor is specified in terms of smooth functions of covariates. Such models are well-suited to handle covariate effects flexibly, using penalised splines, and to simultaneously deal with autocorrelation in residuals via the use of an autoregressive moving average process (e.g., Ruppert et al., 2003).
- In a mixed model framework, the random effect variances can control the shrinkage of the smooth functions towards their means. In this way, we can apply tests for a zero random effect variance to investigate important issues (Crainiceanu and Ruppert, 2004). In our case, for example, we tested whether the form of a smooth term deviates significantly from a given polynomial.
- We complemented our analysis by calculating the elasticity of CO_2 emissions as a percentage for each level of real GDP using a Bayesian approach.

To the best of our knowledge, the model specification and the testing tool adopted here are novel in EKC research. Our main results show that the estimated AMMs improved the interpretation of the relationship from the classical parametric approach. In particular, we found that only France and Switzerland show the inverted-U-shaped relationship and that Australia, Italy and Spain show a nonlinear (increasing) relationship. For Austria, we found evidence of a weak N-shaped relationship. Our results also revealed new nonlinear shapes in the historic range of real GDP for Finland (inverted-L-shaped relationship), Canada (a special case of inverted-L-shape), and Denmark (M-shaped relationship). The inverted-L-shape was characterised by an early stage of increased CO_2 emissions, followed by a second stage with levels of emissions that were substantially stable for the highest values of real GDP. Canada was a special case of an inverted-L-shape because it was characterised by emissions of CO_2 in the second stage that exhibited a horizontal wave behaviour with two 'humps'. The M-shaped relationship can be considered a special case of the inverted-U-shape. The main difference is that the turning point was characterised by a wave behaviour with two humps (more or less accentuated).

The rest of the article is organised as follows. Section 2 describes the data. Section 3 introduces the model specification, the econometric strategy and the testing tool for investigating whether the form of a smooth term deviates significantly from a more simple regression function. Section 4 presents the results and a discussion.

2. Data

We investigated the EKC hypothesis using annual data for the period 1960–2008 for the following countries: Australia, Austria, Canada, Denmark, Finland, France, Italy, Spain and Switzerland. These countries were selected because of their trends and mix of fossil fuel CO_2 emissions as related to economic development. Moreover, Australia, Canada, France, Italy and Spain are amongst the top 20 emitting countries as measured by total fossil fuel CO_2 emissions for 2008. The data sources were the Carbon Dioxide Information Analysis Center (CDIAC) for CO_2 emissions per capita (total fossil fuel CO_2 emissions/population size; henceforth CO_2) and the European Commission (EC) for the real GDP per capita (GDP in constant 2000 prices/population size; henceforth real GDP). The total fossil fuel CO_2 emissions are expressed in thousands of metric tons of carbon. The data published by CDIAC were estimated primarily using the energy statistics published by the United Nations, using the methods of Marland and Rotty (1984). These data include the emissions derived from combustion of gas, liquid and solid fossil fuels, gas flaring, and cement production. GDP is one the relevant indicators used to monitor the health of a country's economy. It is the sum of all market activities of a country (private consumption + government spending + gross investment + (exports − imports)) over a specific period of time. Because our analysis focused on individual countries rather than cross-country panel data, we preferred to use real GDP expressed in national currency units rather than in purchasing power parities (PPPs). The PPP is a useful tool for international economic comparisons. However, an economic variable expressed in PPPs should be interpreted with caution because, when researchers convert an economic variable expressed in national currency units into PPP, the estimation procedures can produce some inaccuracies (e.g., Rogoff, 1996; Taylor and Taylor, 2004).

Before planning the econometric strategy, we performed a preliminary analysis on the time series (using both graphical and testing