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Growing green? Forecasting CO_2 emissions with Environmental Kuznets Curves and Logistic Growth Models

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ABSTRACT

Environmental sustainability was established by the United Nations as a Millennium Development Goal (MDG7), including a wide variety of targets referred to the access to safe drinking water, the reduction of biodiversity loss, the improvement of lives of slum dwellers and the integration of principles of sustainable development into the country policies.

Despite some progress towards meeting this goal, new challenges have appeared, endangering the development and environmental achievements. Therefore, United Nations and the international community are working on the Sustainable Development Goals (SDG) as a new framework placing environmental sustainability at its core.

In this context, the analysis of environmental forecasts plays a main role. More specifically, taking into account that the carbon dioxide emissions have increased by almost 50 per cent since year 1990, special attention must be paid to the evolution and projections of emissions for different countries.

In this paper we focus on environmental forecasting, based on the extended Environmental Kuznets Curve (EKC) and the Environmental Logistic Curve (ELC). Considering a sample of 175 countries we perform a competition between both methods, analysing their goodness of fit and their forecasting accuracy. The empirical results provide significant evidence about the adequacy of EKC and ELC for explaining CO_2 emissions in different countries, also allowing us to obtain some ex-ante projections.

1. Introduction

The Environmental Outlook to 2050 published by the OECD (2012) highlights the need for new models of development, centered on human wellbeing and the interface with the natural environment. The analysis of future social, environmental and economic costs and benefits confirms the overwhelming "costs of no action" that have already been anticipated in the Stern Review (Stern, 2007).

Ensuring environmental sustainability has also been included as goal number 7 in the United Nations Millennium Development Goals (MDGs), establishing target 7A as "Integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources". Despite some successful global actions, described among others in López and Pérez (2013), according to the Millennium Development Goals Report 2014 (United Nations, 2014) major trends that threaten environmental sustainability continue, since global emissions of carbon dioxide (CO_2) maintain their upward tendency, reaching 32.3 billion metric tons in 2011, a 48.9% rise above their 1990 level. The report also stresses that growth of CO_2 emissions accelerated after 2000, with emissions increasing 35% from 2000 to 2011 compared to 10% from 1990 to 2000, and this has been due mostly to the fast growth in emissions from developing countries.

Furthermore, as the 2015 deadline for the MDGs approaches, the United Nations and the international community are working on a new development framework, expected to place environmental sustainability at its core by integrating the Sustainable Development Goals (SDGs) agreed at the Rio + 20 UN Conference on Sustainable Development (UNCSD, 2012).

In the described context, the analysis of environmental trends and projections, mainly referred to CO_2 emissions, is an extremely relevant goal and different forecasting procedures have been proposed, including econometric models, time series analysis, energy systems and simulation techniques, among others.

A summary of recent works in this field, classified according to the related forecasting procedures, is collected in Table 1.

As it can be seen, most of the empirical applications dealing with environmental forecasting include simulation analysis and/or

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Table 1
CO_2 emissions forecasting. Summary of recent papers.

Method	References
Environmental Kuznets Curves (EKC)	Aldy (2006), Auffhammer and Carson (2008), Halicioglu (2009), Jaunky (2011), Pao and Tsai (2011), Durante et al. (2012)
Econometric Models	Schmalensee et al. (1998), Auffhammer and Carson (2008), Soytas and Sari (2009), Jaunky (2011), Minx et al. (2011), Pongthanaisawan and Sorapipatana (2013), Tang et al. (2013), Liu et al. (2014)
Time Series (exponential, ARIMA, VAR, VEC, GARCH...)	Aldy (2006), Soytas and Sari (2009), Pao and Tsai (2011), Tiwari (2011), Chitnis and Hunt (2012), García Martos et al. (2013), Lotfalipour et al., 2013, Liu et al. (2014), Bozkurt and Akan (2014), Silva (2014)
Grey Models	Lin et al. (2011), Pao and Tsai (2011), Pao et al. (2012), Lotfalipour et al., 2013, Silva (2014), Liu et al. (2014), Wu et al. (2015)
Energy Systems	Lee et al. (2013), Silva (2014), Vaillancourt et al. (2014), Turconi et al. (2014)
Simulation and Scenarios	Oniszk-Popławska et al. (2003), Karki et al. (2005), Hayashi et al. (2006), Okamura et al. (2007), Giljum et al. (2008), Guan et al. (2008), Kowalski et al. (2008), Puliafito et al. (2008), Barker et al. (2010), Carvalho et al. (2010), Shimoda et al. (2010), Lutz et al. (2010), Minx et al. (2011), Kinga et al. (2011), Mao et al. (2012), Pongthanaisawan and Sorapipatana (2013), Porzio et al. (2013), Yue et al. (2013), Lee et al. (2013), Li and Zhu (2014), Turconi et al. (2014), Tan et al. (2014), Cui et al. (2014), Yu and Lu (2015), Cheng et al. (2015), Dong et al. (2015), Liu and Lu (2015)

scenario design, with different levels of complexity, while the Environmental Kuznets Curve (EKC), despite its popularity for environmental modeling, has been scarcely used for forecasting purposes.

Regarding the time series approaches, a wide variety of techniques have been applied, ranging from exponential smoothing to the more sophisticated multivariate VAR and GARCH models, with an increasing popularity of Grey Models, which have been considered separately. However, no evidence has been found about the use of the logistic growth model for environmental forecasting.

Since environmental degradation appears to be closely related to economic growth, this paper focuses on environmental modeling and forecasting based on two alternative growth models: the Environmental Kuznets Curve (EKC) and the Environmental Logistic Curve (ELC).

The methodological framework is presented in the next section, where we describe the two proposed models, their main characteristics and the estimation procedures. Section three provides an empirical application, estimating both models for a sample of 175 countries, and selecting a high-quality subsample (comprised of 108 countries with coefficient of determination higher than 60%) for which ex-post environmental projections are obtained.

The estimation and forecasting results are discussed in section four, where we also provide some insights and future prospects for those countries showing a suitable forecasting behavior. The paper finishes with a summary of the main findings.

2. Material and methods. From EKC to ELC

According to the OECD, Green Growth is about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. Although this process includes several dimensions and it is not easily described by single indicators, Gross Domestic Product (GDP) remains as the most widely used measure for growth while greenhouse gas emissions (GHG) is considered a key indicator of environmental sustainability, since it properly reflects the impact of the production, distribution and use of energy at different spatial and economic levels.

The relationship between economic growth and environmental indicators has often been represented by the Environmental Kuznets Curve (EKC), inspired in the inverted U-shaped relationship between inequality and per-capita income proposed by Simon Kuznets (1955). According to the Kuznets curve, economic inequality increases in the first levels of economic growth and then decreases after a certain point of return and, in a similar way, the Environmental Kuznets Curve proposed by Grossman and Krueger (1996) assumes that environmental quality initially worsens with the increases in per-capita income, but then improves after an Income Turning Point (ITP) so that at high-income levels economic growth leads to environmental improvement.

The adequacy of the Environmental Kuznets Curve has led to a controversial debate both theoretical and empirical. The experimental studies referred to the EKC provide a broad diversity of findings, since the results are sensitive to the available information, the considered pollution indicators, the proposed functional form and the econometric methodology.

In general terms, the proposed model for the Environmental Kuznets Curve is a polynomial function of degree three given by the expression: $Y_t = \beta_0 + \beta_1 X_t + \beta_2 X_t^2 + \beta_3 X_t^3$, where X represents the level of economic development, usually measured through the per capita Gross Domestic Product (GDPpc) while Y corresponds to the indicator of environmental degradation and could be referred to air pollution, deforestation, municipal waste, fine smoke or water pollution. Nevertheless emphasis is usually made in greenhouse gas emissions, and mainly Carbon Dioxide (CO_2).

Since regressions that allow levels of indicators to become zero or negative are inappropriate, a restriction is usually applied by introducing the EKC variables in logarithmic terms.

Assuming a third degree polynomial EKC specification, the model estimation can provide different possibilities according to the signs of the estimated coefficients. The most common patterns are summarised in the following table (Table 2):

The vast diversity of empirical findings referred to the Environmental Kuznets Curve has been summarised in some surveys and meta-analyses as He (2007), Jordan (2010), Cavlovic et al. (2000), Bo (2011) and Koirala et al. (2011). According to a recent study by López et al. (2014) the Kuznets inverted U shape is confirmed by 55.7% of the studies while the more flexible N and inverted N patterns appear to be valid in 16.4% and 3.3% of the cases respectively. Regarding the evidence against the EKC, 11.5% of the studies show increasing trends. A synthesis of these results is represented in Fig. 1.

The proposal of an environmental logistic model based on the Environmental Kuznets Curve appears in Sobhee (2004). Assuming a polynomial of degree three, this author suggests a specification where emphasis is made on the rate at which total environmental degradation occurs, that is, marginal environmental degradation (MED). The assumption of a quadratic MED leads to a logistic EKC where, prior to a given income threshold, MED rises, attains a maximum at the threshold and finally falls beyond it.

Despite its logistic pattern, Sobhee's proposal is still based on a third degree polynomial Environmental Kuznets Curve. However,