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# A multiscale reassessment of the Environmental Kuznets Curve for energy and CO2 emissions

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ABSTRACT

This paper investigates the environmental Kuznets' curve hypothesis for total primary energy supply and CO2 from fuel combustion over the period 1971–2015.

Our analysis has two distinguishing features. Firstly, it adopts a robustness approach by (a) using both parametric and semi-parametric methods, and (b) analysing different geographical scales. Secondly, it strictly adheres to the EKC narrative by (a) not using control variables and (b) taking Energy and CO2 in absolute rather than in per capita terms, which is consistent with the fact that "Nature cares" about absolute pressures.

We show how evidence for EKC changes depending on the model specification, the sample, and the used variables. Hence, this paper contributes to explaining why the literature on the EKC gives mixed results.

The multiscale perspective and some theoretical considerations, however, tell how to perform the analysis appropriately. Thus, we can affirm that, both for CO2 and Energy, the fragile evidence of EKC that was emerging at the end of the last century has vanished with the new wave of globalization. There is only evidence of decreasing elasticities for very-high income countries.

Interestingly, the great recession might have produced structural reductions in TPES and CO2 in the affected countries. Finally, the case of Germany, which shows EKC patterns, indicates that active energy policies can reduce energy and CO2 without harming the economy.

## 1. Introduction

As is well known, the Environmental Kuznets Curve (EKC) is a hypothesized inverted-U relationship between environmental quality and income. The EKC debate started in the 1990s and is still very much alive. From 2010 to 2017 the number of articles in the SCOPUS database that mention the term "Environmental Kuznets curve" in their abstract and/or title grew at an average yearly rate of 19%, as compared with the articles mentioning "GDP", "prices", and "oligopoly" which grew at rates of about 7.8%, 5.3% and 2.2% respectively.

Empirical research on the EKC gave mixed results (Luzzati, 2015). This is explained by its multifaceted nature. For instance, differences are observed between global and local pressures, the latter being more easily the object of regulation (Roca et al., 2001). However, mixed evidence is also due to the variety of research strategies. Actually, criticism has often been levelled at the scant attention paid to robustness (e.g. Stern, 2004). Several facets of robustness have been investigated, for instance by applying non-parametric methods (e.g. Bertinelli and Strobl, 2005; Azomahou et al., 2006), by comparing alternative datasets and different parametric specifications (Galeotti et al., 2006), and by testing for time series stationarity (Galeotti et al., 2009).

The research presented here is a robustness exercise that involves both comparisons between parametric and non-parametric methods, and the validation of cross-country findings by looking at other levels of analysis (i.e. the world as a single unit and individual countries). This should mitigate the risk of statistical artefacts arising from pooling heterogeneous country patterns. Two other distinctive features of the research are that 1) the dependent variables are taken in absolute rather than per capita terms, and 2) the model does not include control variables. As discussed in greater detail in Luzzati and Orsini (2009), both these features follow from the original EKC narrative, according to which "higher levels of development [… will] result in levelling off and gradual decline of environmental degradation" (Panayotou, 1993, 1). In other words, the research question is "Will continued economic growth bring ever greater harm to the earth's environment? Or do increases in income and wealth sow the seeds for the amelioration of ecological problems?" (Grossman and Krueger, 1995, p. 353). It is self-evident that

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'environmental degradation' or 'ecological problems' cannot be proxied by per capita indicators. We need indicators in extensive terms because 'Nature' is affected by total human pressure, and not per capita. The appropriateness of investigating a reduced form in which per capita income is taken as the only explanatory variable (Azomahou et al., 2006, p. 1348) also comes from the EKC original issue. The issue is the relationship between income and environmental degradation and not the anthropogenic drivers of the environmental pressures or states, which would entail modelling the structural linkages explicitly.

In the present work, the above described research strategy is applied respectively to total primary energy supply (TPES) and to carbon dioxide emissions from fuel combustion (CO2). Our analysis covers more than one hundred countries for the time span 1971–2015.

On the contrary, the recent literature on CO2- and Energy-EKC has mainly focused on groups of countries, pooled either by the level of income and development or by geographic proximity. Zaman et al. (2016), Beck and Joshi (2015), and Kearsley and Riddel (2010) compared OECD and non-OECD countries. Nabaee et al. (2015) distinguished between groups of countries belonging or not to the G7. Some studies were specifically devoted to Middle-East and North-Africa countries (Farhani et al., 2014; Arouri et al., 2012) and the Asian continent (Heidari et al., 2015; Apergis and Ozturk, 2015; Saboori and Sulaiman, 2013). In other works, the research on EKC is developed on a wider number of groups of countries across all the continents (for instance, Zaman et al., 2016 for East Asia and Pacific and European Union; Kais and Sami, 2016 for Europe, Latin America, Caribbean, Middle-East, North Africa and Sub-Saharan Africa). Analyses dedicated to single countries have been performed in some other cases, for instance Sinha and Shahbaz (2018) for India, Shahbaz et al. (2017) for the U.S., Bento and Moutinho (2016) for Italy, Piłatowska et al. (2015) for Poland, Shahbaz et al. (2015) for Portugal, Shahbaz et al. (2014) for Tunisia and Iwata et al. (2010) for France.

"CO2 emissions" was the most used dependent variable in the models estimated for the detection of the EKC (e.g. Zaman et al., 2016, Kais and Sami, 2016, Saidi and Hammami, 2015, Apergis and Ozturk, 2015, Piłatowska et al., 2015, Farhani et al., 2014, Arouri et al., 2012 and Iwata et al., 2010). In other cases the analysis was enriched with energy as dependent variable. In particular, Bento and Moutinho (2016) adopted non-renewable and renewable electricity production, Beck and Joshi (2015) used primary energy before transformation into other end-use fuels, while Heidari et al. (2015), Nabaee et al. (2015), and Saboori and Sulaiman (2013) used kg of oil equivalents per capita.

The results of the recent EKC literature are still mixed as in previous studies, mainly due to differences in the setups. Specifically, an EKC for energy does not emerge according to Arouri et al. (2012), Kearsley and Riddel (2010) and Barra and Zotti (2017). Indeed, in the first two studies, the turning points for different countries lie on very heterogeneous ranges of values, while the latter showed that the evidence of an inverted U-shaped relationship disappears after taking into account the issue of (non-) stationarity of the time series. On the contrary, an EKC shape is supported for CO2 emissions by Sinha and Shahbaz (2018), Shahbaz et al. (2017), Zaman et al. (2016), Kais and Sami (2016), Apergis and Ozturk (2015), Piłatowska et al. (2015), Farhani et al. (2014), Shahbaz et al. (2014), Saboori and Sulaiman (2013) and Iwata et al. (2010), and both for CO2 emissions and energy by Bento and Moutinho (2016) and Heidari et al. (2015). Finally, some works show differences in the results depending on the analysed units. In particular, according to Beck and Joshi (2015) an EKC is detected for African and Asian countries, while it is not for OECD countries. Differently, Nabaee et al. (2015) found an EKC for G7 countries and not for developing countries.

The number of recent works in which several countries are analysed is relatively low, while the time span usually does not exceed 25 years. Moreover, the main focus remains on CO2, while the importance of energy use in the overall relationship between humans and ecosystems remains neglected. On the contrary, the massive use of fossil fuel started with the Industrial Revolution is the primary cause of most human impacts, to the point that many scholars argue that it started a new geological phase, the Anthropocene (Crutzen, 2002; Steffen et al., 2011). The availability of energy has made possible huge increases in the material size of our economy and society (e.g. Smil, 2000; Krausmann et al., 2009). Moreover, there is consolidated clear-cut evidence that chemical processes linked to fossil fuel use are at the basis of most forms of pollution.[1]

In the present paper, the time span is significantly longer, from 1971 to 2015, covering the process of globalization starting with the WTO, the economic growth of emerging countries like China, the impressive technological change occurring in recent years, and the Great Recession (2007–2012). Finally, the analysis of the CO2-income relationship allows us also to assess re-carbonization due to the increasing consumption of carbon-rich fuels in emerging countries.

The paper is organized as follows. Section 2 discusses the dataset; Section 3 presents the analyses of the world as a single unit; Section 4 presents the panel data analysis; Section 5 focuses on country patterns, while Section 6 concludes.

## 2. Dataset

The International Energy Agency publishes online the dataset associated with the yearly report "CO2 Highlights" (IEA, 2017). Also BP makes a wide set of statistics on energy available.[2] BP and IEA use different protocol methods of accounting that are discussed in detail by Giampietro and Sorman (2012). They also show that energy accounting is subject to a series of epistemological problems because of the qualitative differences of the different energy forms. Those problems are not too relevant to the purposes of the present paper, mainly because our focus is on primary energy supply. This is empirically confirmed by the similarity of the two datasets (see the Appendix, A.3). We chose to work with the IEA Series because the same IEA dataset contains also data on emissions and to make our results closely comparable with a previous paper of ours (Luzzati and Orsini, 2009). IEA (2017) contains the series for total energy supply (TPES), CO2 and other variables derived from other statistical sources, including GDP and population. The time-span is 1971–2015. Data cover 145 countries and several regional aggregates; however, the entire time span is covered only for 113 countries. By adding two aggregates, the countries belonging to former USSR and Yugoslavia respectively, we ended up with 115 units.[3]

GDP is taken in purchasing power parity[4] due to the cross-country nature of the analysis. GDP is expressed in thousand dollars, TPES in PJoules and CO2 emissions in million tons. Fig. 1 gives a snapshot of the dataset. Per capita income is on the x-axis, while total TPES and CO2 are reported on the y-axis. Values are in logarithm for a better visualization of the data. All figures and tables in the paper refer to the period 1971–2015 unless otherwise stated.

A first look at the series suggested the presence of potential outliers, that is, observations that differ markedly from others and for which regression residuals are large for any possible specification. In some instances, they are influential, that is, their inclusion in the dataset

[1] This is acknowledged also by national agencies and international institutions on the environment. See, e.g., https://www.epa.gov/environmental-topics/chemicals-and-toxics-topics.

[2] https://www.bp.com/en/global/corporate/energy-economics.html.

[3] 22 of the 30 countries for which the series are incomplete, refer to countries from the former Soviet Union (15) and the former Yugoslavia (7). Since disaggregated data are not available, we had to group them and prolong the time series of the former Soviet Union and former Yugoslavia.

[4] GDP in PPP terms is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States. The IEA 2017 dataset refers to GDP in 2010 US$. For details see the technical notes of the IEA (2017).