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A cointegrating polynomial regression analysis of the material kuznets curve hypothesis

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ABSTRACT

This paper investigates the Material Kuznets Curve (MKC) hypothesis, postulating an inverted U-shaped relationship between a country's level of economic development and its intensity of material use, by means of nonlinear cointegration analysis. We use consumption data for aluminum, lead and zinc for eight OECD countries spanning from 1900 to 2006 and employ the tests and estimation techniques for nonlinear cointegration developed by Saikkonen and Choi (2004), Wagner (2013) as well as Wagner and Hong (2016). We find evidence for the prevalence of a cointegrating quadratic MKC for about half of the country-metal pairs.

1. Introduction

Investigating the nexus between economic growth and environmental degradation, caused for example by the emission of greenhouse gases and other pollutants, is at the heart of a great deal of empirical studies. Inspired by the seminal work of Grossman and Krueger (1991, 1995), as well as Holtz-Eakin and Selden (1995), a prominent topic of the literature is the so-called Environmental Kuznets Curve (EKC) hypothesis,[1] postulating an inverted U-shaped relationship between a country's economic activity, typically measured by gross domestic product (GDP) per capita as explanatory variable, and per capita measures of various kinds of pollutants as dependent variables. The logic underlying the EKC hypothesis is that in early stages of economic development, environmental degradation and pollution increase with economic development, but beyond some income level the positive trend reverses and further economic growth leads to environmental improvement (Stern, 2004). This level may vary across countries and environmental indicators.

A quite similar reasoning applies to the relation between economic development and the use of materials, for which Focacci (2005) coins the notion Material Kuznets Curve (MKC), see also Crowson (2017),Jaunky (2012) or Radetzki and Tilton (1990): In the early stages of development countries are to a large extent based on agriculture, which is less material-intensive than construction and manufacturing that become increasingly important in later stages of development. Finally, with demand shifting more towards services once a certain level of satiation with houses, factories, infrastructure and machinery occurs, the increase of material intensity tends to slow down and may eventually even decrease. Starting with Malenbaum (1978), who studies the MKC hypothesis for a large set of metals, the MKC literature enjoys growing popularity. Table 1 (with a continuation in Table A.1 in the appendix) gives an overview for recent examples.

For many countries, the logarithm of GDP per capita is well described as a process integrated of order one. Therefore, modeling the postulated inverted U-shape of the MKC necessitates in its simplest parametric form the inclusion of log GDP per capita as well as its square – and in more general formulations also higher powers – as explanatory variables. It is by now well-known in the literature that powers of integrated processes are not themselves integrated processes (for more details in this respect see Müller-Fürstenberger and Wagner, 2007 and Wagner, 2008, 2012). From Wagner (2015),Wagner and Hong (2016) and Stypka et al. (2017) it follows that using estimation and inference

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[1] The term EKC is coined *in analogy* to the inverted U-shaped relationship between the level of economic development and the degree of income inequality postulated by Kuznets (1955) in his presidential address to the American Economic Association.

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Table 1
Overview of selected recent studies on the MKC hypothesis.

	Unit root tests	Cointegration tests	Estimation Methods	Support of MKC Hypothesis
Bringezu et al. (2004)	–	–	OLS, FGLS, FE, RE	Yes
Canas et al. (2003)	–	–	FE, RE	Yes
Crompton (2015)	Im-Pesaran-Shin, Choi	Pesaran	FE	Yes
Focacci (2005)	–	–	OLS	No
Guzmán et al. (2005)	Augmented Dickey-Fuller	Phillips-Ouliaris	FGLS, NLLS	Yes
Jaunky (2012)	Elliot-Rothenberg-Stock, Zivot-Andrews, Narayan-Popp, Levin-Lin-Chu, Im-Pesaran-Shin, Im-Lee-Tieslau, Pesaran, Chang-Song	Nyblom-Harvey, Pedroni, Westerlund	FE, RE, Prais-Winsten	Yes
Jaunky (2014)	Nadarayan-Popp	Chang-Song, Di Iorio-Fachin	OLS, FGLS, FE, RE	Yes
Wårell (2014)	Pesaran	Westerlund	OLS, FE	Middle-income countries only

Note: *Fixed Effects (FE), Feasible Generalized Least Squares (FGLS), Nonlinear Least Squares (NLLS), Ordinary Least Squares (OLS), Random Effects (RE).*

methods developed for linear cointegrating regressions in a cointegrating polynomial regression setting leads in particular to invalid inference concerning cointegration. Consequently, to prevent misguided conclusions concerning the existence and shape of an MKC, appropriate unit root and cointegration tests as well as cointegration estimation techniques need to be used to suit to the, in the words of Wagner and Hong (2016), *cointegrating polynomial regression* (CPR) context.[2]

However, similar to large parts of the empirical EKC literature, Table 1 shows that existing MKC studies either do not use unit root and cointegration techniques at all or employ linear, rather than nonlinear, unit root and cointegration techniques. This paper fills this gap by employing methods for cointegrating polynomial regression analysis to investigate the MKC hypothesis between a country's (logarithm of) real GDP per capita and the ratio of metal consumption to GDP (intensity of use, IOU). The analysis is performed using consumption data on aluminum, lead and zinc for eight OECD countries spanning from about 1900–2006. Specifically, we apply the cointegration tests of Wagner (2013) and the estimation techniques developed by Saikkonen and Choi (2004), and Wagner and Hong (2016). For all country-metal combinations for which the MKC hypothesis, i.e., a CPR relationship between GDP and IOU cannot be rejected, we find the expected inverted U-shaped relationship. Whilst our analysis merely serves as a reduced form starting point, the evidence collected here indicates that more detailed empirical MKC analysis using appropriate cointegration methods is a useful research avenue.

The rest of the paper is organized as follows: Section 2 starts with some preliminaries concerning the empirical setting considered and then presents the results. Section 3 briefly summarizes and concludes. The appendix contains some additional information, graphs and results tables.

2. MKC analysis

2.1. Some preliminaries

Notwithstanding super-consistency of least-squares-type estimators in cointegration-type situations, the use of long time series data is beneficial for the performance of such estimators and tests based upon them. This implies that the set of countries as well as the set of metals considered are both relatively small since only for few countries and metals long time series are available. To be precise, we consider aluminum, lead and zinc for the following eight OECD countries: Australia, France, Germany, Italy, Japan, Switzerland, the UK and the US. This allows for a sample range from about 1900–2006. The metals consumption data are drawn from the World Bureau of Metals Statistics (WBMS) and the GDP per capita data, in Geary-Khamis Dollars (GK-$) with base year 1990, are obtained from Bolt and Zanden (2014). The precise sample ranges for the countries and metals considered are given in Table A.2 in the appendix.

Visual inspection of the data in the form of scatter plots, given in Figs. A1–A3 in the appendix, leads to two observations. First, there is an overall tendency for an inverted U-shape. Second, there is considerable heterogeneity across countries. Thus, we consider country-specific estimation of the standard quadratic form, given by[3]

$$m_t = c + \delta \cdot t + \beta_1 \cdot y_t + \beta_2 \cdot y_t^2 + u_t, \tag{1}$$

where m_t denotes the logarithm of the intensity of use of metal m (aluminum, lead or zinc) in year t, measured in (logs of) metric tons per million GK-$, y_t denotes GDP per capita (in logs of GK-$), t is a linear time trend and u_t denotes the error term.[4]

Given that log GDP per capita is frequently found to be a process integrated of order one, the above relationship (1) is a *cointegrating polynomial regression* (CPR) if u_t is stationary. In case of a CPR relationship, there is an inverted U-shaped MKC when β_2 is negative. The per capita GDP value of the turning point is given by $\exp\left(-\frac{\beta_1}{2\beta_2}\right)$.

The first two steps to establish whether relationship (1) is a CPR are thus to test whether log GDP per capita is an integrated process of order one and if so, whether the error process u_t in (1) is stationary. For the second step it is important to use tests for nonlinear cointegration as developed, e.g., by Wagner (2013) and Wagner and Hong (2016), an aspect we return to below.

2.2. Unit root and cointegration testing

The results in Table 2 show that the unit root null hypothesis cannot be rejected for log GDP per capita for any of the eight considered countries with either the Phillips-Perron (PP) test of Phillips and Perron (1988) or the augmented Dickey-Fuller (ADF) test of Dickey and Fuller (1981). Testing also log intensity per capita m_t for a unit root would be in contradiction to the posited model which implies that m_t is a polynomial function of an integrated process rather than an integrated process itself.

Given the unit root nature of log GDP per capita we next test

[2] In terms of econometric analysis, the present paper is similar in scope for the empirical MKC literature as Wagner (2015) for the empirical EKC literature.

[3] Multi-country cointegration analysis allowing for parameter heterogeneity and cross-sectional dependence as well as for pooled estimation over subsets of cross-sections can be performed in a seemingly unrelated cointegrating polynomial regression (SUCPR) model, see, e.g., Wagner and Grabarczyk (2017) for an application to the EKC for CO_2 emissions. Performing a corresponding analysis for the MKC is on the agenda for future research.

[4] The inclusion of a linear time trend is standard in the EKC literature and is supposed to capture autonomous energy efficiency increases. While this may be less relevant for MKC analysis, we include a linear trend to allow for a more flexible specification. Furthermore, note that the results are qualitatively unchanged (e.g., with respect to country-metal pairs where cointegration prevails) when considering the cubic instead of the quadratic specification.