Nonstationarity in the Specification of the Environmental Kuznets Curve

Hector O. Zapata
Professor
Department of Agricultural Economics and Agribusiness
LSU AgCenter
101 Agricultural Administration Building
Louisiana State University
Baton Rouge, LA 70803
Phone: (225) 578-2766
Fax: (225) 578-2716
E-mail: hzapata@agcenter.lsu.edu

Krishna P. Paudel
Assistant Professor
Department of Agricultural Economics and Agribusiness
LSU AgCenter
225 Agricultural Administration Building
Louisiana State University
Baton Rouge, LA 70803
Phone: (225) 578-7363
Fax: (225) 578-2716
E-mail: kpaudel@agcenter.lsu.edu

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Hector O. Zapata and Krishna P. Paudel

Abstract: Numerous studies have addressed the question of the econometric specification of the Environmental Kuznets Curve (EKC). This paper adds preliminary results on nonstationarity and its effect on functional form using a panel data set for the U.S. by state from 1929 to 1994. It is found that unit-root tests strongly support a unit root in pollutants (sulfur dioxide and nitrogen oxide) and income when testing individual states. The results from panel data unit root tests provide mixed evidence about nonstationarity in EKC data.

Key words: Environmental Kuznets curve, fixed and random effects, parametric models, water pollution, watershed, nonstationarity, unit-roots.

Introduction

Environmental Kuznets Curve is a hypothesized relationship between pollution and income (Grossman and Krueger, 1995; Moomaw and Unruh, 1997; Vincent, 1997; Hilton and Levinson, 1998; Hettige, Mani, and Wheeler, 2000; Stern and Common, 2001; Harbaugh, Levinson, and Wilson, 2002). The hypothetical relationship is that as income increases, pollution increases up to a point, after this point, commonly known as a threshold point, pollution would decline as income starts increasing. Therefore, the curve takes an inverted U-shape. The results of empirical studies on EKC have shown a mixed relationship between income and pollution measures, although in several studies concave functions have been reported. However, several other studies, have found convex, downward sloping, and flat functions (Grossman and Krueger, 1995; Hettige, Mani, and Wheeler, 2000).

Most often EKC behavior has been studied in relationship to air pollutant and income using a panel data modeling approach. Among these, studies exploring the SO_2 and income relationship are quite prevalent. There are few studies conducted to understand whether the EKC exist for NO_x and SO_2 emissions (Roca et al., 2001; List and Gallet 1999; Pepper, Sankovski, Leggett, 2005; Perman and Stern 2003; Stern 2002; Stern 2005).

Most of the studies on NO_x and SO_2 have used panel data estimation without properly accounting for the time series properties of the data series. Few studies which have addressed the time series properties in the EKC framework are by Stern (2002) and Stern and Common (2001). A recent study (Perman and Stern, 2003) finds that individual and panel cointegration tests cast doubt on the general applicability of the inverted U-shape relation between various indicators of environmental degradation and income per capita. They report that even in the case when there is cointegration, many of the relationships for individual countries are not concave. We could not find empirical work on individual and panel data unit roots research for individual states in the U.S. Given the reasonable length of the sample data used in this EKC study, it may be reasonable to suspect nonstationarity in the data, hence estimation of the EKC may to to spurious regression results. Further, the explanatory variable income included in the model may be an integrated variable and hence its nonstationarity needs to be tested. Using a classical panel regression would imply that all variables are stationary which may not be the case. If latter is true, then one needs to use cointegration and error correction models to estimate the relationship between pollution and income. Cointegration can test the model specification and if the model is cointegrated, the parameters can be interpreted just like the case of a classical regression.

The goal in this study is to formally test the time series properties of the data and then develop a needed dynamic model to address estimation problems related to unit roots and cointegration if applicable. To carry out this objective, we use a panel data set on U.S. state level sulfur dioxide and nitrogen oxide emission from 1929-1994.

Our paper is structured as follows. Section 2 provides the description on the modeling approach and a concise summary on panel data unit roots literature, Section 3 presents data description, Section 4 shows the results, Section 5 concludes.

Methodology

There have been numerous theoretical and empirical studies of an income-pollution relationship, which is usually referred to as the EKC (Grossman and Krueger, 1995; Stern and Common, 2001; Harbaugh, Levinson, and Wilson, 2002). The EKC curve is assumed to take an inverted U-shape and is typically represented by:

$$p_{it} = \alpha + \sum_{k=1}^{m} \beta_k y_{it}^k + \beta_{m+1} W_{it} + \beta_{m+2} D_{it} + u_{it}$$

where p is per capita air pollutant (nitrogen oxide and sulfur dioxide), y is real per capita income, i and t represent indices of state and time, respectively. W represents a weighted income variable used to represent the spillover effect of pollution. If spillover effects are present, the coefficient associated with this variable would be positive and significant. The method used to calculate the weighted income variable is detailed in the data section. We estimated the model with quadratic and cubic specifications so that when m=2 the income pollution relationship is specified as quadratic and when m=3 the income pollution relationship is specified as cubic.

Uncertainty about nonstationarity in the time dimension of pollutants motivated us to tests for unit-root behavior in pollutants (nitrogen oxide and sulfur dioxide) and income. The proposition in the econometrics of nonstationary panel data is to combine a method of dealing with nonstionary data from the time series side and increase data and power from the cross-section.

Extensive econometric research has been recently introduced in the analysis of unit roots and cointegration in panel data (e.g., Levin and Lin, 1992, 1993; Im *et al*., 1997; and Pedroni, 1999). A compact summary of the above papers and testing procedures is presented in Banerjee (1999). A program in GAUSS has been developed by Kao and can be accessed freely on the Internet. The papers by Kao and Kao and Chiang and the user's manual by Kao are excellent summaries on this work. The survey by Baltagi and Kao are appropriate reading also.

Data

We utilized data collected by Millimet, List, and Stengos (2003) on NO_x and SO_2 criterion pollutant. The detailed description on how data were collected is given in that article. Here, we outline few major points about the data used in this study. The EKC test using this data set is more useful because U.S. data would probably yield more reliable estimates compared to the data used in cross country studies obtained from the Global Environmental Monitoring Systems.

The NO_x and SO_2 data are originally published by the EPA for 1929-1994 in their publication outlet titled "National Air pollutant Emission Trends, 1900-1994." The historical NO_x data do not track well with the most recent "Trends 1970-2001" curve and the disparity between national total and historical estimates diverge significantly. Furthermore, the revisions for most of the recent years have been applied only at national level. As for the SO_2 methods for compiling estimated emissions have become increasingly sophisticated and accurate. As a consequence, only for SO_2 do estimates for recent years appear to be smooth continuation of the earlier estimates. There were two major regimes in which the emission estimation are calculated- 1929 to 1984 and 1985 - 1994. Pollutant information for the time period 1985-1994 is collected from county and plant level and then aggregated to obtain the final state level estimates. For the earlier period, national level estimations were obtained first which were then divided into state level information using the production activities in a given state.

Results

Augmented Dickey-Fuller and Phillips Perron tests of individual states using a no trend and trend model confirm the presence of a unit-root in sulfur dioxide, nitrogen oxide, and income. Based on the finding one would suspect that cointegration may exist on the time series dimension. As argued in the literature, the panel data unit root tests are more robust, and therefore, more reliable that the unit specific tests. Kao's approach to panel unit-roots was applied to the whole panel and results are presented in table 2. First column on table 2 are the Harris and Tzaralis' test for a model without intercept (HT1), a model with intercept but no time trend (HT2), and a model with intercept and time trend (HT3). The lower part of table 2 contains the Im, Pesaran and Shin (1995, 1997) t-type unit root tests that allow for heterogeneity in the panel. The "a" tests are for a model without a time trend whereas the "b" tests are for a model with a time trend, and both tests (1995 and 1997) are for the ADF t type tests. The entire sample (1929-94) is reported first, followed by the post-world war II period.

Whole sample Analysis. The first striking observation from these results is that the HT tests all reject the null hypothesis of panel unit roots at any level of significance. Allowing for panel heterogeneity and serial correlation (IPS tests) provides mixed results.

For example, a model without a trend fails to reject the unit root hypothesis for sulfur dioxide and nitrogen oxide but not for income. Adding a trend to the unit root model, however, rejects the null hypothesis of a unit root for both pollutants and income using either version (1995, 1997) of the IPS tests.

Post WW II sample. The main difference between the entire sample results and the post World War II data is that a unit-root in sulfur dioxide is supported by all IPS tests in the post WW II data. The HT1 test supports a unit root in the panel data for nitrogen dioxide post WW II, but this result imposes the unrealistic assumption of cross-sectional homogeneity in nitrogen oxide effects.

To sum up, sulfur dioxide is the only variable for which panel unit roots seem to be present. Although nitrogen oxide and income are single unit (time dimension) nonstationary, the panel data unit-root tests do not support that.

Summary and Implications

The original purpose of this study was to identify the panel data nonstationary properties of pollution variables (sulfur dioxide and nitrogen oxide) and income in a search for Kuznets curve behavior in the relationship between environmental pollution and economic growth (income). The results in this paper provide empirical support to unit root behavior, using panel data unit-root tests, on sulfur dioxide but not for nitrogen oxide and U.S. per capita income for the 1929-94 period. In the time series jargon, sulfur dioxide is I(1) whereas nitrogen oxide and per capita income are I(0). These results are at odds with the overwhelming unit-root behavior found in individual state unit root tests.

These empirical findings have important implications for the study of dynamics in the EKC specification. First, the results do not support the existence of cointegration between pollution and income, and therefore, the specification of an error-correction model for these data is not justifiable. As a result, there is no long-run co-movement between environmental pollution (sulfur dioxide and nitrogen oxide) with income. Contrary to the findings in Perman and Stern for a panel of 74 countries, this study does not find support for a spurious effect in previous EKC specifications. If the EKC relationship is misspecified, it does not appear to be driven by dynamic misspecification of the cointegrating type. Perhaps more significant is the strong support for a unit-root in the sulfur dioxide data for the U.S. The implication of this finding is that the dependent variable in the EKC function is I(1) whereas the income variable and its powers would be I(0). Therefore, other estimation techniques with mixed units roots may be a fruitful area of future research in the specification of the EKC.

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Table 1. Augmented Dickey Fuller Unit Root Tests with and without a Time Trend for Sulfur Dioxide, Nitrogen Oxide, and Per Capita Income, U.S. by State, 1929-1994.

State	Sulfure Dioxide		Nitrogen Oxide		Income	
	No Trend	Trend	No Trend	Trend	No Trend	Trend
AL	0.058	-1.714	-1.229	-0.0024	-1.514	-1.597
AZ	-0.930	-2.249	-1.753	-1.576	-1.575	-0.253
AK	-1.824	-1.288	-0.182	-3.609	-1.440	-1.246
CA	-1.903	-1.129	-1.350	-2.081	-1.409	0.887
CO	-2.168	-1.140	-1.394	-0.338	-1.488	-0.784
CT	-1.854	-2.371	-1.298	-0.116	-1.602	-1.498
DL	-2.293	-2.284	-1.629	-1.916	-1.787	-1.539
FL	-1.626	-2.282	3.082	-2.784	-1.587	-0.662
GA	-0.690	-2.667	-0.959	0.940	-1.585	-1.200
IH	-1.425	-0.086	-1.564	-1.380	-1.610	-1.669
IL	-1.694	-1.000	-1.497	-0.388	-1.591	-1.025
ID	-2.511	-2.506	-1.546	-0.976	-1.707	-1.222
IA	-2.163	-1.842	-1.492	0.028	-1.682	-1.465
KS	2.403	-1.727	-1.502	-0.114	-1.570	-0.232
KY	-1.479	-0.994	-1.164	-0.965	-1.593	-1.046
LA	-2.135	-2.173	-1.253	-0.361	-1.558	-0.654
ME	-1.750	-1.457	-1.934	-1.591	-1.558	-1.444
MD	-1.918	-2.124	-1.921	-1.450	-1.525	-0.942
MA	-3.570	-3.232	-1.525	-1.377	-1.564	-1.345
MI	-1.754	-1.539	-1.244	0.480	-1.713	-1.429
MN	-2.395	-2.557	-2.012	-3.396	-1.619	-1.152
MS	-0.590	-0.919	-1.792	-0.105	-1.559	-1.578
MO	-1.775	-2.364	-1.279	-0.382	-1.566	-0.911
MT	-0.820	-2.804	-1.605	-2.093	-1.720	-0.554
NE	-0.913	0.803	1.064	-2.145	-1.592	-1.760
NV	-0.975	-2.277	-1.034	-1.770	-1.751	-1.472
NH	-2.636	-2.586	-0.740	-3.091	-1.481	-1.306
NJ	-1.534	-0.056	-1.742	-2.663	-1.654	-1.381
NM	-1.107	-2.572	-1.159	1.342	-1.526	-0.371
NY	-2.011	-2.674	-2.739	-2.594	-1.641	-1.494
NC	-1.633	-1.313	-1.140	1.730	-1.662	-1.672
ND	0.177	-1.690	-1.514	-1.696	-1.797	-2.054
OH	-1.576	-1.863	-0.438	-2.108	-1.672	-1.072
OK	-1.687	-1.281	-1.412	-1.987	-1.468	0.644
OR	-1.281	0.851	-2.076	-2.340	-1.667	-0.861
PA	-1.751	-2.009	-0.860	0.549	-1.544	-1.480
RI	-1.415	-2.211	-3.906	-3.830	-1.681	-1.222
SC	-2.318	-2.154	-1.097	-1.098	-1.624	-1.218
SD	-1.642	-2.352	-1.333	0.457	-1.857	-2.588
TN	-1.916	-1.955	-1.253	-2.109	-1.823	-1.668
TX	-1.417	-0.538	0.797	0.320	-1.455	1.000
UT	-0.768	-3.366	-1.929	-1.251	-1.679	-1.248
VT	-1.829	-1.030	-2.066	-2.010	-1.569	-1.248
VA	-1.233	-2.275	-1.391	-0.753	-1.542	-0.828
WA	-2.064	-1.399	-1.187	-1.431	-1.646	-0.721
WV	-1.418	-0.809	-1.309	0.234	-1.572	-1.256
WI	-2.380	-2.512	0.802	-1.961	-1.589	-1.118
WY	-1.265	-1.074	-0.738	-2.481	-0.865	-2.663

Table 2. Panel Data Unit-Root Tests, Sulfur Dioxide and Nitrogen Oxide, U.S. by State, 1929-1994						
	Sulfur Dioxide		Nitrogen Oxide		Income	
Harris & Tzaralis	**1929-1994**	**WW II**	**1929-1994**	**WWII**	**1929-1994**	**WWII**
HT1	-4.8859	-2.8593	-3.9747	-0.7283	5.7740	3.1494
	(0.0000)	(0.0012)	(0.0000)	(0.2331)	(0.0000)	(0.0008)
HT2	4.4283	3.8105	-8.2851	-13.9225	7.8683	5.0130
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
HT3	-80.0527	-40.9493	-80.8927	-40.8714	-82.4555	-41.2829
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Im, Pesaran & Shin						
IPS95a	-1.1192	0.2615	0.8686	-4.9571	14.1551	3.2055
	(0.1315)	(0.3968)	(0.1925)	(0.0000)	(0.0000)	(0.0007)
IPS95b	-1.7818	-0.9364	-1.7244	-2.0069	-5.9219	-0.0741
	(0.0374)	(0.1745)	(0.0423)	(0.0224)	(0.0000)	(0.4705)
IPS97a	-1.1352	0.2540	0.8527	-4.9680	14.1391	3.1997
	(0.1282)	(0.3998)	(0.1969)	(0.0000)	(0.0000)	(0.0007)
IPS97b	-1.7976	-0.8834	-1.7400	-1.9600	-5.9542	-0.0160
	(0.0361)	(0.1885)	(0.0409)	(0.0000)	(0.0000)	(0.4936)

Datails on model specification under the null hypothesis can be found in Kao (1999) and in the User's Guide to NPT 1.3.