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Co-fluctuation patterns of per capita carbon dioxide emissions: The role of energy markets

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ABSTRACT

This paper applies principal component analysis to investigate the linkages, or dominant co-fluctuation patterns, of per capita carbon dioxide emissions across countries for the time period 1950–2000. Energy resource world markets are investigated as an offsetting mechanism possibly coordinating emission fluctuations between countries. The results of the analysis provide evidence that world energy resource markets are acting as a coordinating mechanism for emission fluctuations in most cases. The results also suggest that until recently the dominant emission co-fluctuation pattern for developed countries differs from the dominant emission co-fluctuation pattern for developing countries. The common fluctuation pattern found in the 1984–2000 time period suggests that an offsetting mechanism does exist and will help contain global per capita emissions into the future. The strong degree that emissions are linked between countries and energy markets acting as an offsetting mechanism suggests that to be successful a global agreement to address climate change must require emission reductions by all major emitters, not just the developed countries.

1. Introduction

There has been a significant amount of research into the statistical characteristics of national per capita carbon dioxide (CO2) emissions. This topic is important for projecting future global emissions and forecasting changes in the distribution among countries. Many studies have focused on tests of convergence of national per capita CO2 emissions (e.g., Aldy, 2006; Nguyen Van, 2005; Ordas Criado and Grether, 2011; Strazicich and List, 2003). Stationarity at the global and/or national level has been examined by McKitrick et al. (in press) and Romero-Avila (2008). A key question at present is the extent to which emissions growth in one country or region affects emissions elsewhere. McKitrick et al. (in press) find evidence that offsetting effects occur between countries, and may constrain global per capita emissions in the future. The purpose of this paper is to investigate more closely the extent to which national per capita CO2 emissions are linked across countries, and whether those linkages can be explained based on energy markets, openness to trade, and other factors.

This paper applies principal component analysis (PCA) to investigate the co-fluctuation patterns of per capita carbon dioxide emissions across countries. PCA allows for extraction of ranked orthogonal vectors from a data matrix, where ranking is by the percentage of underlying explained variance. If all countries' emissions respond linearly to the same external shocks, the first principal component (PC1) will explain a high proportion of variance in the whole data set. If countries' emissions are independent of each other over time, the first principal component will explain relatively little of the underlying variance. Hence we interpret the explained variance associated with the first principal component as an index of homogeneity of national per capita CO2 emissions.

Our hypothesis is that energy prices transmit information across borders in such a way as to increase coordination of emission fluctuations. This is tested by examining the effect of energy prices on the index of homogeneity. We find evidence in support of the hypothesis; however, the pattern of emission fluctuations differs between developing and developed countries until the most recent time period (1984–2000). We then examine the effects of openness to trade and government intervention, and find that neither of these factors have an identifiable coordinating effect on emission fluctuations between countries. Overall the evidence suggests that emissions are strongly linked between countries, and we discuss what this may imply about future emission growth and global agreements to address climate change.

The next section discusses the statistical characteristics of per capita CO2 emissions. Section 3.1 introduces the data, the analytical methodology, and analyzes a global sample, a developed country sample, and a developing country sample. Section 3.2 applies the methodology to samples of countries defined by region. Section 3.3 investigates the importance of openness to trade and government size. Section 4 concludes the paper.

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2. Background

There are several different motivations for examining the historical statistical characteristics of national per capita carbon dioxide emissions. One is that numerous studies projecting future climate change assume growth in per capita CO2 emissions under assumptions that differ from what has been observed historically. For example, the Special Report on Emission Scenarios (SRES) produced by the Intergovernmental Panel on Climate Change (IPCC, 2000) includes projections of emissions using models that inherently assume absolute convergence in per capita emissions. But convergence has not been established in the historical data despite numerous attempts to test for it (Aldy, 2006; McKibben and Stegman, 2005; Nguyen Van, 2005; Ordas Criado and Grether, 2011; Stegman, 2005; Strazicich and List, 2003). The studies investigating convergence in per capita CO2 emissions use empirical techniques developed in the macroeconomic literature on income convergence (such as Barro and Sala-i-Martin, 1992; Carlino and Mills, 1993; Quah, 1996). Some of the research discussed in this section compares statistical properties of data used for climate change projections with those of historical data. As pointed out by Aldy (2006), whether or not there is a historical basis for projections of per capita emissions is very important for informing policy makers who are considering different proposals for, e.g., the distribution of emission entitlements in any global framework addressing climate change.

Ordas Criado and Grether (2011) provide the most comprehensive analysis out of the convergence studies. They apply non-parametric dynamic distributional analysis and find that between 1960 and 2002 national per capita CO2 emissions have actually diverged globally and predict that emissions will continue to diverge into the future. This result is certainly at odds with the SRES scenarios. However, they do find evidence that the per capita emissions of developed countries have converged conditional on macroeconomic variables.

Another motivation for investigation of the historical statistical characteristics of national per capita emissions is that there is a theoretical basis in environmental economics to expect emission convergence. The environmental Kuznets curve (EKC) hypothesis suggests that the relationship between national income and emissions follows an inverse 'u-shape' (Andreoni and Levinson, 2001; Grossman and Krueger, 1991, 1995; Lopez, 1994). The EKC hypothesis implies that emissions will converge as incomes converge. This can be incorporated into theoretical "green" growth models (e.g., Brock and Taylor, 2010) to predict conditional emission convergence associated with convergence in national income. Ordas Criado and Grether (2011) find evidence of conditional convergence among developed countries, but not when all countries are considered.

Another historical feature of interest of per capita CO2 emissions is the trend in the global average. McKitrick et al. (in press) find that world per capita emissions are stationary around a stable mean and have remained so for the past three decades. They then use this result to assign probabilities to the emission predictions of the IPCC SRES. They conclude that 33 of the 40 scenarios can be rejected, and the 7 scenarios that remain are all on the lower-end of emissions of the IPCC scenarios. They also find that emissions in 95 of 121 countries were stationary.[1] Since the emissions of 26 countries are found to be non-stationary while the global mean is stationary, emissions appear to be cointegrated. McKitrick et al. (in press) suggest this may be due to equilibrating effects of world energy markets (i.e., changes in emissions of the 26 countries systematically offset each other). If such an equilibrating mechanism exists, it may restrict or prevent an upward trend in global per capita carbon dioxide emissions in the future.

If integration with world energy markets leads to the cointegration of emissions among countries, then energy prices should help explain co-movements of per capita CO2 emissions between countries. If emissions are assumed to be positively correlated with energy consumption, increased emissions in one country should impact the world prices for energy resources positively, inducing reduced emissions in other countries. The more highly integrated a country is with world energy markets, the more responsive their emissions will be to pressure on prices. It is also conceivable that large income effects could cause the emissions of some countries (those with large endowments of energy resources) to increase in response to increasing world prices. If all countries are assumed to have similar levels of integration with energy resource world markets, then we would expect to see systematic responses to energy price changes, including pairwise off-setting of per capita emission fluctuations.

In the subsequent sections we empirically investigate the co-fluctuation patterns of per capita CO2 emissions across countries, in particular looking at world energy prices as a coordinating mechanism for emission changes across countries. We then add in other indicators of openness to markets to examine the effect they play in coordinating emission variations.

3. Data, methodology, and analysis

3.1. Data, methodology, and analysis: Global, OECD, and non-OECD samples

The analysis in this paper uses annual per capita emissions data[2] over the interval 1950 to 2000 for 132 individual countries.[3] The emissions data are measured in metric tons of carbon per capita produced from fossil fuel burning, gas flaring, and cement manufacturing. The emissions data were obtained from the Carbon Dioxide Information and Analysis Center (Marland et al., 2003). Seven countries with per capita emissions greater than 15 tons, in any year, were removed as outliers. Descriptive statistics for the emissions of the 132 countries used in the sample for the year 2000 are presented in Table 1. The per capita emissions of OECD countries are, on average, 2.5 times larger than those of non-OECD countries. The dispersion (standard deviation) of the per capita emissions of developed countries is lower than that of the per capita emissions of developing countries.

Prices for crude oil, natural gas, and coal were obtained from the Annual Energy Review produced by the Energy Information Administration (EIA) for the interval 1950 to 2000. The prices for crude oil are the average annual crude oil domestic first purchase prices for the United States (nominal USD per barrel). The natural gas prices are the average annual US natural gas wellhead prices (nominal USD per thousand cubic feet). The coal prices are the average annual US free-on-board prices of coal at the point of first sale (nominal USD per short ton). These nominal prices were converted into real prices using consumer price index (CPI) data from the US Department of Labor, Bureau of Labor Statistics. Applying the test proposed by Kwiatkowski et al. (1992), we fail to reject the null hypothesis of stationarity for all three price series at the 5% significance level. Furthermore, conducting the test proposed by Elliot et al. (1996), we reject the null hypothesis of a unit root in all three price series at the 1% significance level. The test statistics for both tests are reported in Appendix B.

The methodology begins by applying principal component analysis (PCA) to identify the dominant fluctuation patterns in the emission data. PCA has been widely used in many fields. In economics it has been applied, for example, in dynamic factor models for forecasting macroeconomic variables (Stock and Watson, 2002) and for examining business cycles (Forni and Reichlin, 1998). It has also been used to correct for cross-sectional dependence when testing for unit roots in panel data analysis (Bai and Ng, 2004). PCA has also been used recently to analyze fluctuation patterns of unemployment across

[1] Some of the 95 countries had emissions that were stationary around a stable mean. And some of the 95 countries had emissions that were trend stationary.

[2] See Appendix A for further information concerning all data used in this paper.

[3] A list of countries included can be found in Appendix B.