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Research article

Multi-sectorial convergence in greenhouse gas emissions

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ABSTRACT

This paper uses the World Input-Output Database (WIOD) to test the hypothesis of *per capita* convergence in greenhouse gas (GHG) emissions for a multi-sectorial panel of countries. The empirical strategy applies conventional estimators of random and fixed effects and Arellano and Bond's (1991) GMM to the main pollutants related to the greenhouse effect. For reasonable empirical specifications, the model revealed robust evidence of *per capita* convergence in CH_4 emissions in the agriculture, food, and services sectors. The evidence of convergence in CO_2 emissions was moderate in the following sectors: agriculture, food, non-durable goods manufacturing, and services. In all cases, the time for convergence was less than 15 years. Regarding emissions by energy use, the largest source of global warming, there was only moderate evidence in the extractive industry sector—all other pollutants presented little or no evidence.

1. Introduction

The relationship between economic growth and the environment has received renewed attention in the environmental literature. Some of the main empirical controversies within the topic are related to the environmental Kuznets curve (EKC), which supposes a *U-shaped* relation between *per capita* emissions and income, and the convergence hypothesis in greenhouse gas (GHG) emissions, which aims to verify whether countries are converging toward a steady state of emissions. This paper is related to the latter issue.

In this context, the pioneering work on this topic is credited to Strazicich and List (2003), who used an ordinary least squares (OLS) estimator and unit root tests for panel data for a sample of the members of the Organization for Economic Co-operation and Development (OECD). They found evidence in favor of the convergence hypothesis. A similar controversy in the empirical literature on economic growth can be observed in the more current environmental literature: papers by Romero-Ávila (2008), Westerlund and Basher (2008), and others found significant evidence in favor of convergence. However, Aldy (2006) and Criado and Grether (2011), among others, do not support the hypothesis. As pointed out by Petterson et al. (2015), one of the sources of this divergence in the results is the sample size: as it increases, the evidence of convergence decreases. Another is the econometric method used: OLS and unit root tests for panel data tend to confirm convergence, whereas more elaborate techniques such as Markov chains and other dynamic analyses do not.

The literature tends to focus on the single- and cross-country dimensions of CO_2 emissions while leaving out other relevant perspectives such as analyses of sectorial convergence and other sources of GHG emissions. This can be partially explained by the scarcity of multi-sectorial databases to enable a comprehensive and consistent estimation of the hypothesis across countries and sectors. This situation is changing with the availability of new databases, such as the World International Input-Output Database (WIOD) (Timmer et al., 2015), which provides estimates for sectorial environmental data, including emissions of the main GHGs. The present paper uses the WIOD to conduct the first multi-sectorial empirical test for the convergence hypothesis.

Although it is well known that the uniformly mixed characteristics of GHG emissions make their sectorial distribution irrelevant to understanding environmental impact, a *per capita* distribution of GHG

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emissions rights may nevertheless affect the politics of negotiating multi-sectorial agreements within and between countries; thus, a multi-sectorial test for the convergence hypothesis in GHG emissions is particularly relevant. The most recent round of these discussions was at the 2015 Paris Climate Conference, where over 190 developed and developing countries agreed upon the need to collectively chip in by curbing the GHG emissions responsible for global warming.

From a theoretical perspective, a multi-sectorial empirical test is equally relevant. For instance, many models of computable general equilibrium assume a certain degree of convergence between countries and sectors in order to estimate trend scenarios for climate change. However, if *per capita* emissions are not converging, these models can be seriously incorrect, generating bad policy recommendations.

This paper contributes to the environmental economics literature by estimating dynamic multi-sectorial panel data that shed some light on the debate over the convergence hypothesis in *per capita* GHG emissions (not only CO_2). For this purpose, a theoretical convergence function is derived based on a joint production mechanism; then, a model is estimated using a panel of 33 sectors of the WIOD, which are available for a set of 39 countries from 1996 to 2007. The database has many limitations, but it does provide new elements and results that should be considered when evaluating current sectorial GHG emissions.

The remainder of the paper is organized as follows: Section 2 briefly outlines the related literature, Section 3 presents the identification strategy, sample and the data source, Section 4 discusses the main results, and Section 6 includes the final remarks.

2. Related literature

The empirical literature on the convergence hypothesis in GHG emissions only dates back to the early 2000s, and it focuses mainly on CO_2 emissions. Regarding econometric techniques, the literature is less autonomous, as it is influenced by past developments in the theory of economic growth. This is not a coincidence—emissions and income are strongly correlated.

Strazicich and List (2003) conducted the first empirical test; they estimated cross-section and time series models using data from CO_2 emissions for 21 industrialized countries from 1960 to 1997. The authors found significant evidence that CO_2 emissions converged, although they did not determine their speed or time in years. Aldy (2006) focused on expanding this sample to 88 countries from 1960 to 2000. The author found evidence of convergence among 23 member countries of OECD, however, emissions appear to be diverging for the global sample. Furthermore, forecasts based on a Markov transition matrix provided weak evidence of future convergence for the global sample, indicating that emissions could be diverging in the short term.

Westerlund and Basher (2008) increased the period studied from 1870 to 2002; they used similar econometric techniques and sample sets. They found support for empirical convergence both in absolute and conditional terms. Their main contribution was to estimate the convergence rate, which increased after the 1970s. In turn, Romero-Ávila (2008) examined the existence of stochastic and deterministic convergence in CO_2 emissions for 23 countries using unit root tests for panel data. Overall, their analysis supported strong stochastic and deterministic convergence in emissions.

Pen and Sévi (2010) analyzed the energy intensity convergence for 97 countries from 1971 to 2003 using the criteria for stochastic convergence that Peasaram (2007) proposed. Unit root tests rejected the hypothesis of global convergence. For Midwest, OECD, and for subsets of European countries, the non-convergence was "less strongly rejected." The control for structural breaks in the time series offered marginal gains in favor of convergence.

Jobert et al. (2010) used a Bayesian estimator to analyze the convergence of CO_2 emissions for a sample of 22 European countries from 1971 to 2006. First, they found that the hypothesis of absolute convergence was supported, observing a slight upward convergence. Second, because the countries differed considerably in their convergence speed and volatility, the authors were able to identify *groups* of countries with common features.

Herrerias (2012) also analyzed the hypothesis using a distributive dynamic approach. The sample set was limited to 25 European Union (EU) countries from 1920 to 2007. It examined whether the convergence patterns would differ if weighted by the population and economic indicators of each country (the unobservable effects were not controlled). The unweight analysis indicated that the convergence patterns differed among countries before and after the Second World War, tending toward further convergence after the 1970s. Weighting the results showed that the convergence was much faster when these characteristics were explicitly considered; thus, convergence might be conditional.

Li and Lin (2013) evaluated the global convergence of *per capita* CO_2 emissions from 1971 to 2008. They observed absolute convergence within subsamples classified according to income level; however, a global sample containing 110 countries provided weak evidence of absolute convergence. In addition, their empirical strategy used *per capita* income to control for conditional convergence. In this case, the relationship between an increase in income and CO_2 emissions was different. More specifically, *per capita* emissions in developed countries remained steady as income increased; hence, the study's main result contradicted EKC.

Camarero et al. (2013) tested the convergence in the intensity of CO_2 emissions (CO_2 emissions relative to gross domestic product [GDP]) across OECD countries from 1960 to 2008 based on determinants of energy intensity (energy consumption/GDP) and a carbonization index (CO_2 emissions/energy consumption). Estimating convergence clubs, they found that differences in the convergence of CO_2 emissions were mainly determined by differences in the convergence of the carbonization index, and not by differences in the convergence of energy intensity.

As Petterson et al. (2015) recently pointed out, in general, simple models of cross-section and unit root tests for panel data reveal significant convergence evidence, whereas different statistical techniques, such as Markov chains, do not support convergence. Another issue is sample size: large samples do not report convergence evidence, which is only found in small groups of homogeneous countries such as the OECD members. When heterogeneous characteristics between countries are considered, the rate of convergence slows.

The present paper contributes to this body of literature by examining the convergence hypothesis using multi-sectorial panel data. First, it expands the sample size to 33 sectors among 39 countries over 11 years of observations. Second, it explicitly models other sources of GHG emissions. Third, its dynamic panel estimator circumvents any inconsistency problems of estimation based on conventional methods.

3. The identification strategy

This section describes the identification strategy, an approach based on Islam (1995). A joint production mechanism is assumed, in which the use of labor and capital in a production function generates two outputs: one good (economic growth), and one bad (GHG emissions). Therefore,

$$Y_{ij} = K_{ij}^{\alpha}\left(A_{ij}L_{ij}\right)^{1-\alpha} \rightarrow E_{ij}, \tag{1}$$

where Y is the output, K is the capital stock, A is the technological level, L is the number of workers, E is the bad output, and i and j