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Modelling the Global Diffusion of Energy Efficiency and Low Carbon Technology

David I. Stern

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About the authors

David Stern is a Hub Researcher based at the Research School of Pacific and Asian Studies, Australian National University, Canberra ACT 0200, Australia

Email: sterndavidi@yahoo.com

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Table of Contents

Abstract

The aim is to measure and understand the long-term factors behind trends in energy and carbon intensity in different economies and how improvements in energy efficiency diffuse globally. Of particular interest is the rate of diffusion from developed to developing countries and the factors that affect that diffusion. Countries included will be Australia, major European economies, USA, Canada, Mexico, Japan, China, and India. The conference presentation will present initial results from this project.

Key Words: Energy efficiency, carbon emissions, environmental Kuznets curve, economic growth

JEL Codes: Q43, Q55, Q56

Introduction

There has been much debate about carbon emissions scenarios with the Stern Review being criticized for adopting relatively high emissions projections compared to the accepted IPCC scenarios. But a year later Nicholas Stern argued that the scenarios he used – which were near the median of the IPCC SRES scenarios - were not extreme enough (Stern, 2008). The Garnaut Review (Garnaut, 2008) argues for higher emissions scenarios on the basis of recent energy intensive rapid economic growth in developing economies, and particularly in China, the so-called "Platinum Age" (Garnaut *et al*., 2008). This Platinum Age scenario has higher emissions growth than any of the SRES scenarios while the Australian Treasury Report used a scenario that is similar up till 2050 to the highest emission growth SRES scenario – A1F1 (Treasury, 2008). Ma and Stern (2008) find that about half the post-2000 increase in energy intensity in China can be explained by "negative technological change" and the remainder by a shift to more energy intensive industries. On the other hand, research shows convergence in energy efficiency and pollution intensity over time among developed economies (Strazicich and List, 2003; Stern, 2005) and perhaps between developed and developing countries (Westerlund and Basher, 2008; Stern, 2007). Is it reasonable to project – as the Australian Treasury Report does - that in 2050 China will have both the same GDP per capita and emissions per capita as the US had in 2005, while US GDP per capita doubles and emissions remain constant? While China is relatively coal dependent and is likely to retain more manufacturing than the US has today its cities are more likely to resemble Hong Kong or Singapore than Atlanta or Denver and there are forty years for technological change to improve energy efficiency. Furthermore, economic growth in China looks set to slow down in the face of the current global financial crisis. It is, therefore, important to understand whether the recently observed carbon intensification of growth is a short-term anomaly or a phenomenon that will persist for a longer period of time.

The aim of this study is to measure and understand the long-term factors behind trends in energy and carbon intensity in different economies and how improvements in energy efficiency diffuse globally. This study will use a structural time series model to decompose the changes in carbon intensity into underlying variables including structural and technological change, examine the trends in the diffusion of lower energy and carbon intensity technology from developed to developing countries, and examine the factors that are related to the pace of diffusion. The analysis will also show how fast countries adopt energy efficiency and carbon reducing technologies, whether there is a convergence towards best practice over time, and how far behind the technology leader different countries are. Projections of future emissions can be derived by embedding these models in an economic growth model. A better understanding of these patterns of diffusion and adoption will also be useful in improving detailed bottom-up models of emissions.

Methods

Overview

The proposed research consists of three stages:

1. Development and estimation of emissions frontier models similar to that in Stern (2005) and Stern (2007) for carbon emissions and energy use. These models allow us to break down changes in emissions into the contributions of changes in factors such as economic scale, structure, and energy input mix as well as the effects of changes in best practice technology and the degree and rate of adoption of best practice by each individual country. The degree of adoption represents the effective stringency of environmental policy in each country. Data will include at a minimum most of the European countries included in Stern (2005) as well as USA, Canada, Mexico, Australia, Japan, China, and India.

2. Development and estimation of a model that explains the differential patterns across countries observed in the energy and carbon efficiency trends.

3. Embedding of the first two models in a growth model framework such as the Green Solow Model (Brock and Taylor, in press) for projection of future emissions scenarios.

Emissions Frontier Model

An emissions frontier model is a specialized version of the production frontier models that are used to represent production with multiple outputs and inputs in economics. In addition to the usual economic outputs of useful goods and services, there are also outputs of undesirable pollutants. The advantage of these models is that we do not need to have detailed industry sector information on pollutant emissions in order to estimate the effects of changes in industry structure on pollution. These models can be estimated for individual firms, industries, or countries, or for the world as a whole. The conventional approach to estimating these models for industries allows each individual firm to have a fixed level of inefficiency relative to the best practice or frontier technology. Technological change can improve that best practice technology over time, but individual firms cannot change their relative positions. Stern (2005, 2007) uses a state space model estimated with the Kalman filter to allow each firm or country to follow its own path over time. So not only does the productivity of the best practice technology change over time, so does each country's relative performance. Countries may converge towards the best performers or not converge over time.

An example of an emissions frontier model of this type is given by the following equation:

$$\ln E_{it} = \ln A_{it} + \sum_{k=1}^{4} \gamma_k \ln y_{kit} + \gamma_x \ln\left(\sum_{j=1}^{n} \beta_j x_{jit}\right) + u_{it}$$

This equation is estimated as a group of seemingly unrelated time series equations, one for each country, using the Kalman filter. The variables and parameters are defined as follows:

E_{it} is emissions of the pollutant in question in country i and year t.

A_{it} is the state of technology in emissions abatement in country i in year t modeled as a random walk using the Kalman filter.

y_{kit} are output variables.

x_{jit} are the input variables.

u_{it} are random error terms.

The and are regression type parameters that have various restrictions imposed on them. This is a regression type model with the addition of the random walk A_{it}. The Kalman filter is an algorithm that we can use to estimate models with unknown time-varying variables or parameters. We can model these individual technology trends so that they are affected by both independent and common "shocks" which drive the random walks. To the degree that the random walks are independent, technology does not diffuse but evolves independently in each country and vice versa. The values of the A_i in a given year indicate the relative level of technology or productivity in each country and implicitly the stringency of each country's environmental policy. In contrast, a simple measure of energy or carbon intensity does not take into account the economic structure or energy endowment of a country.

Explaining the Diffusion Patterns

In this approach, emissions abatement is determined by the level of abatement technology adopted. Therefore, in order to understand the reasons why countries are found at different distances from the best practice frontier we need to develop a framework that models the choice of technology adopted. Recent theory and empirical results in development economics (Parente and Prescott, 2000; Easterly, 2002) take a similar approach. Differences between countries in income per capita cannot be explained by differences in capital stocks, or even human capital, alone. Total factor productivity differs across countries. The level of technology adopted depends on barriers raised against the adoption of foreign technology. In Parente and Prescott's (2000) model of income differences between countries all countries have access to the same technology but policy barriers result in lower TFP in poorer countries than in wealthier countries. They believe that these barriers effectively raise the cost of adopting best practice technology. In the area of environmental technology the lack of correction of market failure raises a barrier against technology adoption. Environmental policies would be expected to effectively lower the cost of adopting best practice technology over the absence of environmental policy, when abatement is costly and there are no incentives to adopt it. So while in Parente and Prescott's growth model government introduced distortions reduce TFP, in my model government's lack of action results in lower emissions productivity in some countries due to the environmental externality distortion.

Copeland and Taylor (2004) and Andreoni and Levinson (2001) provide general frameworks in the emissions context that can be modified for my technology choice approach. Stern (2005) carried out some exploratory research on the relationship between extracted technology trends and the variables that the literature suggests might be important. Smith (2005) provides a simple diffusion model that might also provide a starting point. The two stage approach helps deal with the endogeneity problem discussed by Copeland and Taylor (2004) – countries with significant pollution problems tend to adopt stringent environmental policies and therefore regressions of pollution on the underlying variables that determine that policy can be significantly biased. Distance from the frontier is effectively a measure of policy stringency. The combined model of the frontier and distance from the frontier should be very informative for workers in the field of integrated assessment who want to model how and why emissions reducing technology diffuses across countries.

Growth Model

An emissions projection can be produced by embedding the estimated models from the first two sections of the study in an economic growth model. The Green Solow Model (Brock and Taylor, in press) is a simple model, which might serve this purpose. This is the classic Solow growth model with the addition of pollution generation and abatement activities. Brock and Taylor model technological progress in emissions abatement as a simple linear time trend. This assumption will be replaced with the model developed in this study and simulations of emissions can be run from a base year under a variety of assumptions. The model can also be validated on historical data.

Discussion

A variety of methods are used to create scenarios for future carbon emissions. At one end of the spectrum are very detailed bottom-up engineering and economic models. These embody a lot of detailed information on industry sectors and technology options. The engineering models tend to downplay behavioral responses while the economic models such as computable general equilibrium models emphasize them. But both economic and engineering models of this type must rely on a large number of assumptions derived from expert opinion. Usually these assumptions are developed on a country-by-country basis and common features in the data across countries are not exploited.

At the other extreme are simple top-down aggregate economic models such as the environmental Kuznets curve that are estimated statistically from the data but provide little detail and are of not much policy use as a result. The EKC model emphasizes some common global features in the data at the expense of almost any local variation – the exception being different constant terms and random errors (of equal variance) for each country. The proposed research has more of a balance between emphasizing global commonalities and processes and local detail and variation.

In addition to comparing the results of the study to global scenarios such as the Australian Treasury we can evaluate smaller scale studies too. For example, Auffhammer and Carson (2008) estimate a model of Chinese carbon emissions using a panel of provincial level data and use it to forecast future emissions. They find that predicted emissions based on this disaggregated model are much higher than those predicted by a simple national aggregate model. As expected, they can reject the hypothesis that the aggregated model explains the provincial data better than the disaggregated model. But would this result hold up when we take into account the commonalities among countries and information about how technology diffuses across countries? In this way, my results can act as an additional check on more detailed country level studies.

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