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Communication

Global CO_2 efficiency: Country-wise estimates using a stochastic cost frontier

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ABSTRACT

This paper examines global carbon dioxide (CO_2) efficiency by employing a stochastic cost frontier analysis of about 170 countries in 1997 and 2007. The main contribution lies in providing a new approach to environmental efficiency estimation, in which the efficiency estimates quantify the distance from the policy objective of minimum emissions. We are able to examine a very large pool of nations and provide country-wise efficiency estimates. We estimate three econometric models, corresponding with alternative interpretations of the Cancun vision (Conference of the Parties 2011). The models reveal progress in global environmental efficiency during a preceding decade. The estimates indicate vast differences in efficiency levels, and efficiency changes across countries. The highest efficiency levels are observed in Africa and Europe, while the lowest are clustered around China. The largest efficiency gains were observed in central and eastern Europe. CO_2 efficiency also improved in the US and China, the two largest emitters, but their ranking in terms of CO_2 efficiency deteriorated. Policy implications are discussed.

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1. Introduction

This paper estimates global carbon dioxide (CO_2) efficiency using a stochastic cost frontier model with data on CO_2 emissions in about 170 countries during years 1997 and 2007. Monitoring progress in CO_2 efficiency has high policy relevance since reversing the buildup of greenhouse gases (GHG) in the atmosphere requires coordinated action from the global community. Countries involved in the United Nations Climate Change process recognize the need for deep cuts in GHG emissions, yet at the same time are reluctant to sacrifice economic growth. The shared vision in Cancun calls for continued high growth and emission reductions, to be achieved by technical innovation and profound structural change of the world economy:

> '… *addressing the climate change requires a paradigm shift towards building a low-carbon society that offers substantial opportunities and ensures continued high growth and sustainable development, based on innovative technologies and more sustainable production and consumption and lifestyles, while ensuring a just transition of the workforce that creates decent work and quality jobs*'.[2]

The difficulty of reaching agreement about emission cuts is exacerbated by the vast income gap between the developed and developing world. The economic growth of developing countries such as China, India, Brazil and Russia increasingly burdens the global environment, but it also lifts millions of people from poverty (see Goel and Korhonen, 2011). Terminating the catching-up process is both unrealistic and unfair, since it would deny people in the developing world the level of economic welfare that is enjoyed elsewhere.

What is needed, then, is a measure of global environmental progress that takes into account both the need for deep emission cuts and the benefits for economic development. Environmental (energy) efficiency is such a measure, and it has accordingly gained prominence in the global environmental policy debate.[3] Efficiency scores for geographical areas have been estimated by stochastic frontier analysis by a number of authors with variable model specifications (Zofio and Prieto, 2001; Rezek and Rogers, 2008; Filippini and Hunt, 2010; Vaninsky, 2010 are closest to our work).[4] Previous studies demonstrate marked variation in efficiency scores within and across industrialized countries. However, they also reveal sensitivity of the estimation results to the model specification. It has not been clear how this sensitivity should be interpreted. The sampling bias towards the more developed countries has also been a concern.

Our main contribution is that we uncover a novel link between environmental policy and the stochastic frontier specification, which calls for a re-interpretation of the previous results. We find that the efficiency estimates produced with different model

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[3] See, for example, International Energy Agency (2009, 2010), Energy Information Administration (2009), Kaya and Yokobori (1997).

[4] See Rezek and Rogers (2008) and Färe et al. (2005) for a discussion of alternative methods.

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specifications correspond with different environmental policies. The across-model variation in efficiency estimates reflects sensitivity of efficiency estimates to policy, rather than the inability of the underlying approach to yield consistent estimates of some 'one and only' environmental efficiency.

It follows that to measure progress along any specific policy path, the stochastic frontier model should be specified in correspondence with that policy. In this regard, the earlier model specifications are problematic from the perspective of the Cancun vision since they treat the global economic structure as an independent process, rather than a parameter of environmental policy. The efficiency estimates produced by previous studies have been insensitive to key environmental processes and thereby, from the Cancun point of view, are upward biased. Therefore, we re-specify the stochastic frontier model so that the efficiency estimates better reflect the present day environmental objectives.

Our second main contribution is that we apply the new approach to study environmental progress in a large sample of about 170 countries, including all major polluters, thereby avoiding possible estimation bias. Three econometric models are estimated corresponding with alternative interpretations of the Cancun vision. The estimations reveal global progress along the Cancun path during a preceding decade. Specifically, the estimation results indicate significant environmental progress: a decrease in the CO_2 frontier, the global benchmark (minimum) level of CO_2 emissions, and an increase in average environmental efficiency. The decrease in the frontier signals that innovation, related to new technologies and more broadly to economic structure, has contributed significantly to the reduction of CO_2 emissions during the estimation period. The increase in environmental efficiency indicates 'environmental catching up' towards the frontier. CO_2 efficiency also improved in the two largest emitters, USA and China, but their ranking in terms of CO_2 efficiency deteriorated. In 2007, the highest efficiency levels were observed in Africa and Europe, while the lowest were clustered around China. Due to rapid economic growth, the speed of progress needs to be increased significantly if global environmental objectives are to be reached. Identification of specific efficiency levels by countries is likely to facilitate more informed policy initiatives.

The paper proceeds with a discussion of the data and the methodology. This is followed by a presentation of the estimation results. Discussion and concluding remarks close the paper.

2. Data and methodology

On a conceptual level, we introduce a new approach to environmental efficiency estimation which complements earlier approaches. The new approach fills a gap between the environmental efficiency literature and global environmental policy. As discussed in the introductory section, environmental policy calls for changes in consumption habits and economic structure, but these have been treated as independent processes in previous environmental efficiency studies (Rezek and Rogers, 2008; Filippini and Hunt, 2010; Vaninsky, 2010). As a result, the set of pollution/production possibilities has been considerably broader in the policy debate than in the efficiency literature. From the policy perspective, environmental efficiency estimates have been upwards biased.

To overcome this problem, we introduce a new environmental efficiency metric that is specifically designed to correspond with specific environmental policy objectives. We make the assumption that environmental policy p aims at minimum emissions of Z, a pollutant of interest, in a production/pollution possibility set P. Denote Y as a vector that forms the basis of the set $P[Y]$, within which Z is minimized. The Y vector of environmental policy 'conditionalities' contains desirable outputs as well as other relevant factors that define the production/pollution set in accordance with environmental policy. $P[Y]$ includes all possible levels of pollution Z for each level of the conditionalities Y. Environmental efficiency that corresponds with environmental policy, EEp, may then be defined as:

$$EEp \equiv \max\{\theta : Z\theta \notin P[Y]\} \tag{1}$$

The formulation of EEp is analogous to how environmental efficiency has been traditionally employed in the literature (usually denoted by EE, see Reinhart et al., 2000, 2002). The only difference between EEp and the traditional EE is the set $P[Y]$, which is determined solely by policy. Accordingly, EEp indicates the distance from the policy objective of minimum emissions. Restricting this set by other considerations breaks the correspondence between environmental efficiency and the environmental policy of interest.

Our benchmark model is based on the following production/pollution possibility set:

$$CO_{2t,i} \geq \alpha_t * GDP_{t,i}^{\beta_t} * \exp(v_{t,i}) \tag{2}$$

where t is time, i refers to countries, v to idiosyncratic variation across countries, and α and β to parameters. CO_2 is the pollutant to be minimized, and GDP is the desirable output to be sustained. In our interpretation, this specification of $P[Y]$ is close to the Cancun vision of 'low carbon society with continued high growth'. The log–linear functional form of the 'CO_2 frontier' $\min(CO_2) = \alpha GDP^{\beta}$ is supported by empirical data.

We call the related measure of environmental efficiency 'CO_2 efficiency', to indicate the pollutant. CO_2 efficiency, denoted by $\exp(-u)$, is the ratio of the CO_2 frontier to the emissions:

$$\exp(-u_{t,i}) = \min(CO_{2t})/CO_{2t,i} \tag{3}$$

From (1) and (2) it follows:

$$\ln(CO_{2t,i}) = \alpha_t + \beta_t \ln(GDP_{t,i}) + v_{t,i} + u_{t,i} \tag{4}$$

Eq. (4) is a stochastic frontier cost model, which may be estimated from country level data on CO_2 emissions and GDP. The analysis yields estimates of the parameters α and β, the global CO_2 efficiency frontier $\alpha + \beta * \ln(GDP)$, and CO_2 efficiency $\exp(-u)$ at the country level. Standard estimation techniques require that v is normal, and u is either half normal or exponential. In estimations, u and v are assumed to be independent of each other and of the regressors (Kumbakhar and Lovell, 2000). Given a sufficiently comprehensive set of countries, which we have, global averages of the CO_2 frontier and CO_2 efficiency may be calculated from the country level efficiency estimates.

In this paper, we explore three alternative interpretations of the Cancun vision. In addition to the model with GDP as the sole conditionality, we estimate a bivariate model with population, and a trivariate model with land area.[5] Population may be viewed as a proxy for labor, which is mentioned in the Cancun vision. Data of the active labor force is only available for a small subset of countries in our data set. Inclusion of land area as a conditionality is based on the argument that travel generates emissions;

[5] It needs to be emphasized that under our formal approach, only conditionalities specified in the environmental policy of interest should be added as controls in the estimated equation. Else the correspondence of the pollution/production possibility set P and the environmental policy of interest p is distorted, and u is downwards biased from EEp. As noted by a referee, additional controls could yield more insights. Given the level of aggregation in the large pool of nations considered, the chosen variables seem appropriate for the focus of this study. Access to data at a finer level of detail could enable consideration of other relevant factors (for example, see Reinhart et al., 2002).