The Role of Environmental Factors in Growth Accounting: a Nonparametric Analysis*

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Abstract

This paper explores a relatively new methodology, the directional distance function method, to analyze productivity growth. The method explicitly evaluates the role undesirable outputs of the economy, such as carbon dioxide and other green-house gases, have on the frontier production process which we specify as a piece-wise linear and convex boundary function. We decompose productivity growth into efficiency change (catching up) and technology change (innovation). We test the statistical significance of the estimates using recently developed bootstrap methods. We also explore implications for growth of total factor productivity in the OECD and Asian economies.

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1 Introduction

In traditional productivity analysis environmental by-products of the production or development process are ignored and, as such, are assumed to be freely disposable. Using a recently developed technique, the directional distance method, we analyze the affect of the valuation of carbon dioxide on the productivity growth of OECD and Asian economies. We next turn to how these econometric developments may affect our comfort in and use of productivity forecasts for growth in the U. S., OECD, and in Asia. Our paper speaks to the international debate on trade-offs between growth and environmental protection.

We decompose productivity growth into changes in technical efficiency over time and shifts in technology. These allow us to identify the major factors in each country's growth process. Since we do not observe the true production frontier but estimate it from our sample, we also provide a statistical interpretation of the indices via recently developed bootstrap methods introduced by Simar and Wilson (1999, 2000).

Radial technical efficiency measures were first developed by Farrell (1957). Caves, Christensen, and Diewert (1982) defined the input-based Malmquist productivity index as the ratio of two input distance function while assuming no technical inefficiency in the sense of Farrell (1957). Färe, Grosskopf, Norris, and Zhang (1994) extend the Caves et al. approach by dropping the assumption of no technical inefficiency and developed a Malmquist index of productivity that could be decomposed into indices describing changes in technology and efficiency. This approach has been used widely. These indices have been used to study issues ranging from deregulatory dynamics in the U. S. airline industry (Alam and Sickles, 2000) to the convergence of per capita incomes of the OECD countries (Färe et al., 1994).

Chung, Färe, and Grosskopf (1997) introduce a directional distance function approach, the Malmquist-Luenberger index, to analyze models of joint production of goods and bads. This method credits firms for reductions in bads and increases in goods. The Malmquist index can also be applied to the undesirable output case by modifying the direction in which the goods and bads are traded-off. Boyd, Färe and Grosskopf (1998) have recently analyzed OECD countries assumed to possess a two input/two output technology using deterministic Malmquist and Malmquist-Luenberger indices.

We apply Malmquist and Malmquist-Luenberger index methods to a sample of OECD and Asian countries that are assumed to possess a three input two output technology over the period 1980-1990 and 1980-1995, respectively. We analyze how productivity growth is affected by lifting the free disposability assumption and test the statistical significance of the indices of productivity growth using newly developed bootstrap methods. Historically the growth in an economy has been due to the growth of inputs, or growth at the intensive margin, and growth in the productivity of those inputs, or growth at the extensive margin. Factors that influence the latter will influence wealth creation as well as the ability of the economy to maintain wealth levels as it reallocates resources to pay for pollution abatement. In China, especially, these reallocations may be substantive since its energy endowments are largely coal deposits. Changes in the rate of growth in the Chinese economy due to pollution controls will clearly impact its derived demand for energy as a main input in the production process. Thus the explicit treatment of pollution in the production process will modify existing forecasts for Chinese energy demand.

The paper is organized as follows. We begin with the review of the distance functions and productivity index models in section 2. This is followed by a discussion of the bootstrapping algorithm in section 3. Section 4 contains a discussion of data and results. Section 5 concludes.

2 The Productivity Indices

To define the output based productivity index, we assume that the production technology F^t for each time period $t = 1, ..., T$, transforms the inputs, $x^t \in R^l_+$, into outputs, goods $y^t \in R^m_+$ and bads $b^t \in R^n_+$,

$$F^t = \left\{(x^t, y^t, b^t)|\ x^t \text{ can produce } (y^t, b^t)\right\} \tag{1}$$

The production technology consists of the set of all feasible input and output vectors. In order to address the fact that the reduction of bad outputs is costly, we impose weak disposability of outputs, i.e.

$$(x^t, y^t, b^t) \in F^t \text{ and } 0 \leq \theta \leq 1 \text{ imply } (x^t, \theta y^t, \theta b^t) \in F^t \tag{2}$$

Thus a reduction of undesirable outputs can be attained by the reduction of goods, given fixed input levels. Clearly, if undesirable outputs could be disposed of freely, we could reduce only undesirable outputs.

Null-jointness of desirable and undesirables outputs is defined as

$$(x^t, y^t, b^t) \in F^t \text{ and } b^t = 0 \text{ then } y^t = 0 \tag{3}$$

If (x^t, y^t, b^t) is a feasible set and if undesirable outputs are not produced, then by null-jointness the production of desirable outputs is not feasible.

2.1 The Malmquist Productivity Index

Following Shephard (1970), the output distance function at time t is defined as

$$\begin{aligned} D^t_0(x^t, y^t, b^t) &= \inf\left\{\theta|(x^t, y^t/\theta, b^t/\theta) \in F^t\right\} \\ &= \left(\sup\left\{\theta|(x^t, \theta y^t, \theta b^t) \in F^t\right\}\right)^{-1} \end{aligned} \tag{4}$$

where superscript t of distance function denotes time of production technology. By definition, $D^t_0(x^t, y^t, b^t) \leq 1$ if and only if $(x^t, y^t, b^t) \in F^t$. When $D^t_0(x^t, y^t, b^t) = 1$ the country is on the boundary of the production set and thus is employing the frontier technology.

To define the Malmquist index we need to define the distance function with respect to two different time periods:

$$D^t_0(x^{t+1}, y^{t+1}, b^{t+1}) = \inf\left\{\theta|(x^{t+1}, y^{t+1}/\theta, b^{t+1}/\theta) \in F^t\right\} \tag{5}$$

This measures the maximum proportional change of outputs required to produce (y^{t+1}, b^{t+1}) at the technology level in place at time t. This may not be feasible if the combination of the outputs, say y^{t+1}, b^{t+1} for a single desirable and undesirable output, is not on the hyperplane generated from outputs at time t.

The output-based Malmquist productivity change index is defined as

$$M_0^{t,t+1} = \left(\frac{D_0^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^t(x^t, y^t, b^t)} \cdot \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^{t+1}(x^t, y^t, b^t)} \right)^{1/2} \tag{6}$$

and is the geometric mean of the two output distance function's ratios with respect to time t and $(t+1)$. This can be rewritten equivalently as

$$M_0^{t,t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^t(x^t, y^t, b^t)} \cdot \left(\frac{D_0^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \cdot \frac{D_0^t(x^t, y^t, b^t)}{D_0^{t+1}(x^t, y^t, b^t)} \right)^{1/2} \tag{7}$$

where the first term measures the change in relative efficiency between t and t+1 (ECH), and the second term captures the shift in technology between the two periods (TCH). That is

$$\begin{aligned} ECH &= \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^t(x^t, y^t, b^t)} \\ TCH &= \left(\frac{D_0^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \cdot \frac{D_0^t(x^t, y^t, b^t)}{D_0^{t+1}(x^t, y^t, b^t)} \right)^{1/2} \end{aligned} \tag{8}$$

The standard Malmquist index assumes free disposability of undesirable outputs. Four different types of distance functions are needed by (6). The distance function of country k' at t will be estimated by the linear program:

$$\begin{aligned} \left(\widehat{D}_0^t(x^t(k'), y^t(k'), b^t(k'))\right)^{-1} &= Max\ \theta(k') \\ \text{Subject to} \qquad \theta(k') y_m^t(k') &\leq \sum_{k=1}^{K} z^t(k) y_m^t(k) \quad m = 1, ..., M \\ \sum_{l=1}^{L} z^t(k) x_l^t(k) &\leq x_l^t(k') \quad l = 1, ..., L \\ z^t(k) &\geq 0 \quad k = 1, ..., K \end{aligned} \tag{9}$$

where M, L, and K are the number of desirable outputs, inputs, and countries respectively. Since the free disposability of undesirable outputs is a rather strong assumption, especially in the context of environmental waste by-products, we can define another type of Malmquist index that relaxes this assumption. A Malmquist index can be constructed by measuring the productivity change of desirable outputs while holding undesirable outputs constant. This could be a good productivity measure when there exists production quota of undesirable outputs. The (more goods direction) distance function measures the relative distance to the highest feasible mix without changing the level of undesirable outputs. The four different distance functions needed to construct this index are $D_0^t(x^t, y^t, b^t)$, $D_0^{t+1}(x^t, y^t, b^t)$, $D_0^t(x^{t+1}, y^{t+1}, b^{t+1})$ and $D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})$. They are estimated by the linear program:

$$\left(\widehat{D}_0^t(x^t(k'), y^t(k'), b^t(k'))\right)^{-1} = Max\ \theta(k') \tag{10}$$

$$
\begin{aligned}
\text{Subject to} \qquad \theta(k')y_m^t(k') &\leq \sum_{k=1}^{K} z^t(k)y_m^t(k) \quad m = 1, ..., M \\
\sum_{n=1}^{N} z^t(k)b_n^t(k) &= b_n^t(k') \quad n = 1, ..., N \\
\sum_{l=1}^{L} z^t(k)x_l^t(k) &\leq x_l^t(k') \quad l = 1, ..., L \\
z^t(k) &\geq 0 \quad k = 1, ..., K
\end{aligned}
$$

This formulation represents a constant returns to scale technology whose inputs and desirable outputs are strongly disposable and whose undesirable outputs are weakly disposable. The constant returns to scale technology assumption can be relaxed to allow nonincreasing returns to scale or variable returns to scale. Those assumptions are applied by adding the restrictions $\sum_{k=1}^{K} z^t(k) \leq 1$ or $\sum_{k=1}^{K} z^t(k) = 1$, respectively, instead of $z^t(k) \geq 0$. Here $z^t(k)$ is an intensity variable indicating at what intensity a particular country's (activities) resources may be employed in production. The change from weak to strong disposability of undesirable outputs entails changing the equality of the second constraint to the inequality $\sum_{n=1}^{N} z^t(k)b_n^t(k) \geq b_n^t(k')$. Similarly, an inter-period distance function $D_0^t(x^{t+1}, y^{t+1}, b^{t+1})$ can be estimated from the linear program:

$$
\begin{aligned}
\left(\widehat{D}_0^t(x^{t+1}(k'), y^{t+1}(k'), b^{t+1}(k'))\right)^{-1} &= Max\ \theta(k') \qquad (11) \\
\text{Subject to} \qquad \theta(k')y_m^{t+1}(k') &\leq \sum_{k=1}^{K} z^t(k)y_m^t(k) \quad m = 1, ..., M \\
\sum_{n=1}^{N} z^t(k)b_n^t(k) &= b_n^{t+1}(k') \quad n = 1, ..., N \\
\sum_{l=1}^{L} z^t(k)x_l^t(k) &\leq x_l^{t+1}(k') \quad l = 1, ..., L \\
z^t(k) &\geq 0 \quad k = 1, ..., K
\end{aligned}
$$

Note that the reference technology is constructed from observations at t. Also $(x^{t+1}, y^{t+1}, b^{t+1})$ need not belong to F^t, so $\widehat{D}_0^t(x^{t+1}(k'), y^{t+1}(k'), b^{t+1}(k'))$ can have values greater than 1.

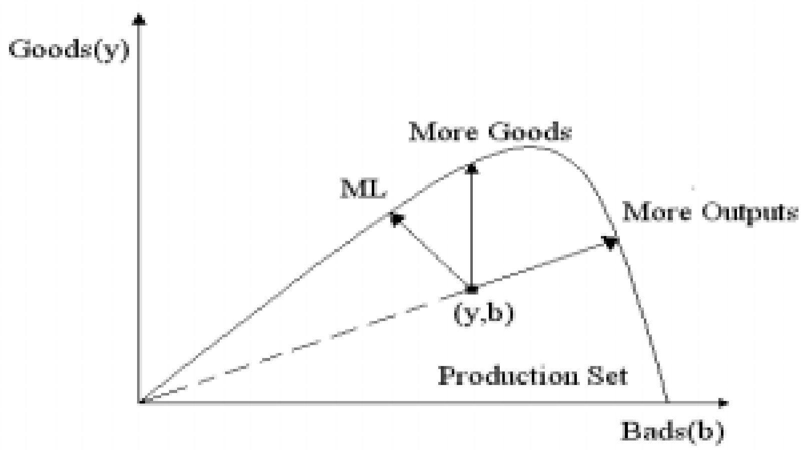
Another type of Malmquist index can be defined by not differentiating between the desirable and undesirable outputs. The (more outputs) distance functions simply find a maximum possible production point along the radial hyperplane. They can be estimated by solving the linear program:

$$
\begin{aligned}
\left(\widehat{D}_0^t(x^t(k'), y^t(k'), b^t(k'))\right)^{-1} &= Max\ \theta(k') \qquad (12) \\
\text{Subject to} \qquad \theta(k')y_m^t(k') &\leq \sum_{k=1}^{K} z^t(k)y_m^t(k) \quad m = 1, ..., M \\
\sum_{n=1}^{N} z^t(k)b_n^t(k) &\geq \theta(k')b_n^t(k') \quad n = 1, ..., N
\end{aligned}
$$

$$\sum_{l=1}^{L} z^t(k) x_l^t(k) \leq x_l^t(k') \quad l = 1, ..., L$$
$$z^t(k) \geq 0 \quad k = 1, ..., K$$

2.2 The Malmquist-Luenberger Productivity Index

The Malmquist-Luenberger productivity index is based on the output oriented directional distance function (Chung et al., 1997). This is different from the Malmquist index which changes the desirable outputs and undesirable outputs proportionally since we choose the direction to be $g = (y^t, -b^t)$, more good outputs and less bad outputs. The rationale of this kind of directional choice is that there might be institutional regulations limiting an increase in bad outputs, in particular pollutant emission. [Figure-1] shows three different reference directions for each index.



[Figure-1] Distance functions

Define the production technology in terms of the output sets, i.e.

$$P(x^t) = \left\{ (y^t, b^t) | \ (x^t, y^t, b^t) \in F^t \right\} \tag{13}$$

The directional distance function is defined as

$$\overrightarrow{D}_0^t(x^t, y^t, b^t; g) = \sup \left\{ \beta | (y^t + \beta g_y, b^t - \beta g_b) \in P(x^t) \right\} \tag{14}$$

where g_y and g_b are subvectors for y^t and b^t of the direction vector g.

The relationship between the two distance functions can be established by setting $g = (y^t, b^t)$

$$\begin{aligned} \overrightarrow{D}_0^t(x^t, y^t, b^t; y, b) &= \sup \left\{ \beta | (y^t + \beta g_y, b^t + \beta g_b) \in P(x^t) \right\} \\ &= \sup \left\{ \beta | (y^t(1+\beta), b^t(1+\beta)) \in P(x^t) \right\} \\ &= \sup \left\{ -1 + (1+\beta) | (y^t(1+\beta), b^t(1+\beta)) \in P(x^t) \right\} \end{aligned}$$

$$
\begin{aligned}
&= -1 + \sup\Big\{(1+\beta)|(y^t(1+\beta), b^t(1+\beta)) \in P(x^t)\Big\} \\
&= -1 + \frac{1}{D_0^t(x^t, y^t, b^t)}
\end{aligned}
$$

This can be rewritten as

$$
D_0^t(x^t, y^t, b^t) = \frac{1}{1 + \overrightarrow{D}_0^t(x^t, y^t, b^t; y^t, b^t)} \tag{15}
$$

Substituting this into the previous result gives the Malmquist-Luenberger productivity index defined as:

$$
\begin{aligned}
ML_0^{t,t+1} &= \left(\frac{1 + \overrightarrow{D}_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + \overrightarrow{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \frac{1 + \overrightarrow{D}_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + \overrightarrow{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right)^{1/2} \\
&= MLECH_t^{t+1} \cdot MLTCH_t^{t+1}
\end{aligned}
$$

where

$$
\begin{aligned}
MLECH_0^{t,t+1} &= \frac{1 + \overrightarrow{D}_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + \overrightarrow{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \\
MLTCH_0^{t,t+1} &= \left[\frac{1 + \overrightarrow{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 + \overrightarrow{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \frac{1 + \overrightarrow{D}_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + \overrightarrow{D}_0^t(x^t, y^t, b^t; y^t, -b^t)} \right]^{1/2}
\end{aligned}
$$

This can be estimated by solving the set of linear programming problems:

$$
\begin{aligned}
\widehat{\overrightarrow{D}}_0^t(x^{t+1}(k'), y^{t+1}(k'), b^{t+1}(k'); y^{t+1}(k'), -b^{t+1}(k')) &= Max\ \beta \qquad (16) \\
\text{Subject to} \qquad (1+\beta) y_m^{t+1}(k') &\leq \sum_{k=1}^{K} z^t(k) y_m^t(k) \quad m = 1, \ldots, M \\
\sum_{n=1}^{N} z^t(k) b_n^t(k) &= (1-\beta) b_n^{t+1}(k') \quad n = 1, \ldots, N \\
\sum_{l=1}^{L} z^t(k) x_l^t(k) &\leq x_l^{t+1}(k') \quad l = 1, \ldots, L \\
z^t(k) &\geq 0 \quad k = 1, \ldots, K
\end{aligned}
$$

These procedures provide us with index number approaches to point estimates of productivity growth and its decomposition. A reasonable criticism of this methodology, however applied, is that there is no inference possible since there is no economic model to provide us with information. In the next section we attempt to provide such a justification.

3 Bootstrapping the Productivity Index

The index numbers outlined above provide us with point estimates of productivity growth rates and the decompositions into their technical and efficiency components. Clearly, there is sampling variability and thus statistical uncertainty about these estimates. We address this issue by turning to standard economic theory (Debreu, 1951). We follow neoclassical theory and assume a data generating process (DGP) wherein firms randomly deviate from the underlying true frontier. Random deviations from the contemporaneous frontier at time t is measured by the distance function. The Simar and Wilson (2000) bootstrapping method can be used to provide a statistical interpretation to the Malmquist/ Malmquist-Luenberger index which has been used by Boyd et. al. (1999)

The following assumptions used by Kneip, Simar, and Wilson (2001) serve to characterize the data generating process (DGP).

(A1) $\{(x_i, y_i, b_i),\ i = 1, ..., n\}$ are i.i.d. random variables on the convex production set, R_+^{p+q}, where p and q are the numbers of inputs and outputs.

(A2) Outputs y and b posses a density $f(\cdot)$ whose bounded support $D \subseteq R_+^q$ is compact.

(A3) For all (x, y, b), there exist constants $\epsilon_1 > 0$ and $\epsilon_2 > 0$ such that $f(\overrightarrow{D}_0(x, y, b; y, -b)|x, y, b) \geq \epsilon_1$ for all $\overrightarrow{D}_0 \in [0, \epsilon_2]$.

(A4) For all (x_i, y_i, b_i), $\overrightarrow{D}_0(x, y, b; y, -b)$ has a conditional probability density function $f(\overrightarrow{D}_0|x, y, b)$.

(A5) The distance function $\overrightarrow{D}_0$ is differentiable in its argument.

Under the those assumptions, Kneip et. al. (2001) proved that for the fixed point (x, y, b), $\widehat{\overrightarrow{D}}_0 - \overrightarrow{D}_0 = O_P(n^{-\frac{2}{p+q+1}})$ where $\widehat{\overrightarrow{D}}_0$ is a consistent estimator of $\overrightarrow{D}_0$. For our empirical analysis, p and q equal to 3 and 2 and thus the rate of convergence is 1/3 instead of the typical rate of 1/2. In order to implement the boostrapping methods we first draw a random sample $\chi = \{(x_i, y_i, b_i),\ i = 1, ..., n\}$ obtained by the DGP defined by (A1)-(A4) and bootstrapping involves replicating this DGP. It generates an appropriately large number B of pseudo samples $\chi^* = \{(x_i^*, y_i^*, b_i^*),\ i = 1, ..., B\}$ and applies the original estimators to these pseudo samples. For each bootstrap replication $b = 1, ..., B$, we measure the distance from each observation in the original sample χ to the frontiers estimated for either period from the pseudo data in χ^*. Let $\overrightarrow{D}_0^{t,t+1} = \overrightarrow{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1})$. The distance function based on pseudo data can be estimated by solving

$$\begin{aligned}
\widehat{\overrightarrow{D}}_0^{t^*}(x^{t+1}(k'), y^{t+1}(k'), b^{t+1}(k'); y^{t+1}(k'), -b^{t+1}(k')) &= Max\ \beta \\
(1+\beta) y_m^{t+1}(k') &\leq \sum_{k=1}^{K} z^t(k) y_m^{t*}(k) \quad m = 1, ..., M \\
\sum_{n=1}^{N} z^t(k) b_n^{t*}(k) &= (1-\beta) b_n^{t+1}(k') \quad n = 1, ..., N \\
\sum_{l=1}^{L} z^t(k) x_l^{t*}(k) &\leq x_l^{t+1}(k') \quad l = 1, ..., L \\
z^t(k) &\geq 0 \quad k = 1, ..., K
\end{aligned} \tag{17}$$

For two time periods, this yields bootstrap estimates $\left\{\widehat{\overrightarrow{D}}_0^{t^*,t}, \widehat{\overrightarrow{D}}_0^{t^*,t+1}, \widehat{\overrightarrow{D}}_0^{t+1^*,t}, \widehat{\overrightarrow{D}}_0^{t+1^*,t+1}\right\}$ for each country. These estimates can then be used to construct bootstrap estimates $\widehat{ML}_0(b)$, $\widehat{MLECH}_0(b)$ and $\widehat{MLTCH}_0(b)$. The bootstrap method is based on the idea that if the $\widehat{DGP}$ is a consistent estimator of DGP and $\partial Q\left(\widehat{f}^*, \widehat{f}\right)/\partial \widehat{f}^{*\prime}$ exists continuously for $\left(\widehat{f}^*, \widehat{f}\right)$ in an open neighborhood of (f, f) then the bootstrap distribution of $\sqrt{n}Q\left(\widehat{\overrightarrow{D}}_0^*, \widehat{\overrightarrow{D}}_0\right)$ given $\widehat{\overrightarrow{D}}_0$ is asymptotically equivalent to the sampling distribution of $\sqrt{n}Q\left(\widehat{\overrightarrow{D}}_0, \overrightarrow{D}_0\right)$ given the true probability distribution $\overrightarrow{D}_0$ (Efron, 1979, pp22-23 Remark G). The confidence interval of the estimator then can be estimated by noting that the bootstrap approximates the unknown distribution of $\left(\widehat{ML}_0^{t,t+1} - ML_0^{t,t+1}\right)$ by the distribution of $\left(\widehat{ML}_0^{t,t+1}(b) - \widehat{ML}_0^{t,t+1}\right)$ conditioned on the original data set where b denotes the index based on bootstrap data. Therefore, we can find critical values of the distribution, $c_{\alpha/2}, c_{100-\alpha/2}$ by simply sorting the value $\left(\widehat{ML}_0^{t,t+1}(b) - \widehat{ML}_0^{t,t+1}\right)$ $b = 1, ..., B$ and then finding the $(\frac{\alpha}{2})$percentile and $(100 - \frac{\alpha}{2})$ percentile values. This critical value provides us with the following confidence interval:

$$c_{\alpha/2} < \widehat{ML}_0^{t,t+1} - ML_0^{t,t+1} < c_{100-\alpha/2}$$

$$\widehat{ML}_0^{t,t+1} - c_{100-\alpha/2} < ML_0^{t,t+1} < \widehat{ML}_0^{t,t+1} - c_{\alpha/2}$$

If this interval covers 1, i.e., no productivity change, then we cannot reject no productivity growth hypothesis. We can also correct finite-sample bias of the estimators using the bootstrap estimates. The bootstrap bias estimate for the estimator $\widehat{ML}_0^{t,t+1}$ is

$$\widehat{bias}_B\left[\widehat{ML}_0^{t,t+1}\right] = \frac{1}{B}\sum_{b=1}^{B} \widehat{ML}_0^{t,t+1}(b) - \widehat{ML}_0^{t,t+1} \tag{18}$$

The bias corrected estimator of ML_t^{t+1} will be

$$\begin{aligned} \widehat{\widehat{ML}}_0^{t,t+1} &= \widehat{ML}_0^{t,t+1} - \widehat{bias}_B\left[\widehat{ML}_0^{t,t+1}\right] \\ &= 2\widehat{ML}_0^{t,t+1} - \frac{1}{B}\sum_{b=1}^{B} \widehat{ML}_0^{t,t+1}(b) \end{aligned} \tag{19}$$

The variance of bias corrected estimator in (19) will be $4Var\left(\widehat{ML}_0^{t,t+1}\right)$ as $B \to \infty$. According to Efron and Tibshirani (1993), the bias corrected estimator can have higher mean square error than the original estimator $\widehat{ML}_0^{t,t+1}$. To obtain minimum mean square error estimator, we compare the mean squared error of $\widehat{\widehat{ML}}_0^{t,t+1}$, $4Var\left(\widehat{ML}_0^{t,t+1}\right)$, with the mean squared error of the original estimator $\widehat{ML}_0^{t,t+1}, var\left(\widehat{\widehat{ML}}_0^{t,t+1}\right) + \left(\widehat{bias}_B\left[\widehat{ML}_0^{t,t+1}\right]\right)^2$. The variance of $\widehat{ML}_0^{t,t+1}$ can be estimated using bootstrapped data, i.e., the sample variance of the bootstrap estimators $\left\{\widehat{ML}_0^{t,t+1}(b)\right\}_{b=1}^{B}$. The bias corrected estimator will have higher mean squared error if $var\left\{\widehat{ML}_0^{t,t+1}(b)\right\} > \frac{1}{3}\left(\widehat{bias}_B\left[\widehat{ML}_0^{t,t+1}\right]\right)^2$.

Simar and Wilson (2000) suggest following an 11 step bootstrapping algorithm.

[1] From the original data set $\chi(x^t, y^t, b^t)$, estimate $\widehat{\overrightarrow{D}}_i^{t,t}$, the first superscript is the technology base year and the second is the individual country's data year, for all countries i .

[2] Form the augmented matrix C .

From $(n\times1)$ matrix $A = \left[\widehat{\overrightarrow{D}}_1^{t,t}, ..., \widehat{\overrightarrow{D}}_n^{t,t}\right]'$, $B = \left[\widehat{\overrightarrow{D}}_1^{t+1,t+1}, ..., \widehat{\overrightarrow{D}}_n^{t+1,t+1}\right]'$ where n is the number of country, construct augmented $(4n \times 2)$ matrix C by reflection since the values in A and B are bounded from above at zero.

$$C = \begin{bmatrix} A & B \\ -A & B \\ A & -B \\ -A & -B \end{bmatrix}$$

where C contains 4n pairs of values corresponding to the two time periods.

[3] Compute the estimated covariance matrix $\widehat{\Sigma}$ from the original data $[A, B]$.

$$\widehat{\Sigma}_1 = \begin{bmatrix} \widehat{\sigma}_1^2 & \widehat{\sigma}_{12} \\ \widehat{\sigma}_{12} & \widehat{\sigma}_2^2 \end{bmatrix}$$

This is also the estimated covariance matrix of the reflected data $[-A, -B]$, Moreover,

$$\widehat{\Sigma}_2 = \begin{bmatrix} \widehat{\sigma}_1^2 & -\widehat{\sigma}_{12} \\ -\widehat{\sigma}_{12} & \widehat{\sigma}_2^2 \end{bmatrix}$$

must be the corresponding estimate of the covariance matrix of $[-A, B]$ and $[A, -B]$.

Next obtain the lower triangular matrices L_1 and L_2 such that $\widehat{\Sigma}_1 = L_1 L_1'$ and $\widehat{\Sigma}_2 = L_2\ L_2'$ via Cholesky decomposition.

[4] Choose an appropriate band width h of bivariate kernel density estimator. We use Silverman's (1986) suggestion for bivariate data, and set $h = \left(\frac{4}{5N}\right)^{1/6}$.

[5] Draw n rows randomly with replacement from C and denote the result by the $(n \times 2)$ matrix C^*. Then compute $\overline{C^*}$, which is the (1×2) row vector containing the means of each column of C^*.

[6] Use a random number generator to generate an $(n \times 2)$ i.i.d matrix ϵ^* with i^{th} row

$$\epsilon^*_{i,.} = \epsilon_{i,.} L_k' \quad k = 1 \ or \ 2$$

so that $\epsilon^*_{i,.} \sim N_2(0, \widehat{\Sigma}_1 \text{ or } \widehat{\Sigma}_2)$ if the ith row of C^* was drawn from rows 1,....,n or 3n+1,....,4n, then the covariance matrix is $\widehat{\Sigma}_1$ otherwise $\widehat{\Sigma}_2$.

[7] Compute the $(n \times 2)$ matrix,

$$\Gamma = (1 + h^2)^{-0.5}(M \cdot C^* + h\epsilon^*) + i_n \otimes \overline{C^*}$$

where $M = I_n - \frac{1}{n} i_n i_n'$ and i_n is a $(n \times 1)$ unit vector. Random deviates needed for the bootstrap are provided by the Γ function (Silverman, 1986).

[8] Define the $(n \times 2)$ matrix of bootstrap pseudo data Γ^*

$$\gamma^*_{i,j} = \begin{cases} \gamma_{i,j} & \text{if } \gamma_{i,j} \geq 0 \\ -\gamma_{i,j} & \text{Otherwise} \end{cases}$$

[9] Construct the pseudo sample $\chi^* = \{(x^*_{it}, y^*_{it}, b^*_{it}),\ i = 1, ...n\}$ by setting $y^*_{it} = y_{it}$, $b^*_{it} = b_{it}$ and $x^*_{it} = \gamma^*_{i,j}\left(\frac{x_{it}}{\widehat{\overrightarrow{D}}_i^{t,t}}\right)$, where $\left(\frac{x_{it}}{\widehat{\overrightarrow{D}}_i^{t,t}}\right)$ represents the production frontier of the original sample.

[10] Compute $\widehat{\overrightarrow{D}}_i^{t^*|t}(b)$, $\widehat{\overrightarrow{D}}_i^{t+1^*|t}(b)$, $\widehat{\overrightarrow{D}}_i^{t^*|t+1}(b)$, $\widehat{\overrightarrow{D}}_i^{t+1^*|t+1}(b)$. This can be obtained by solving the programming problem in (15) under the pseudo technology consisting of the pseudo sample χ^* in step [9]. For observations where this results in infeasible solutions, repeat steps [5]-[10].

[11] Repeat steps [5]-[10] B times to get a set of bootstrap estimates $\left\{\left(\widehat{\overrightarrow{D}}_i^{t^*|t}(b), \widehat{\overrightarrow{D}}_i^{t+1^*|t}(b), \widehat{\overrightarrow{D}}_i^{t^*|t+1}(b), \widehat{\overrightarrow{D}}_i^{t+1^*|t+1}(b)\right) \mid b = 1, ..., B\right\}$ for all i. We can then compute the Malmquist-Luenberger productivity index for $b = 1, ..., B$, confidence interval, and the bias of the estimator.

We next turn to how these econometric developments may affect our comfort in and use of productivity forecasts for growth in the U. S., OECD, and in Asia in the international debate on trade-offs between growth and environmental protection.

4 Analysis of Productivity Growth Controlling for CO2 Emission

We calculate productivity growth and its components from a sample of 17 OECD countries during the period 1980-1990 using the data from the Penn World Tables (Mark 5.6) and the U. S. Energy Information Administration. We then examine similar measures for a sample of 11 Asian countries during the period 1980-1995. We next focus attention on the affect that pollution reduction would have on Chinese growth possibilities through the period 2020. Our measure of aggregate outputs are gross domestic product (GDP) as the desirable output and carbon dioxide (CO_2) emission from the combustion of energy as the undesirable output. Capital stock, employment and energy are aggregate input proxies. GDP and capital stock are measured in 1985 international prices. Employment is calculated from real GDP per worker and capital is obtained from capital stock per worker. CO_2 emission accounts for only the combustion of energy. Although the Kyoto accords suggested establishment of a market in CO_2 emission credits for OECD countries, it exempted developing countries such as those in Asia, in particular China.

4.1 OECD Country Results

We estimate three types of Malmquist productivity indices and the Malmquist-Luenberger index. Using the terminology of Boyd et al. (1999), the first, which is labeled Standard, ignores carbon dioxide completely. This is the traditional index calculated in the productivity growth literature.

The second, which is labeled More Outputs, recognizes the jointness of the aggregate production frontier in output and in carbon dioxide but does nothing to account for the deleterious aspect of CO_2 production. The third, which we label as More Goods, holds CO_2 emissions constant between the two periods of comparison and allows the level of good outputs to increase. The fourth, which is Malmquist-Luenberger index, reduces CO_2 emissions between the two periods by the same proportion that GDP is allowed to increase. Table 1 lists the output and input growth rates for the OECD countries. A summary of productivity changes for each of the seventeen countries, based on the four scenarios for treating environmental factors in the growth accounting exercise, are tabulated in Tables 2, 3, and 4. The results suggest that there has been improvement in productivity due largely to technical change.

CO_2 emissions account for over 80% of total greenhouse gas emissions. When we account for the effect of CO_2 emissions on productivity growth (More goods) we find marginally higher productivity growth rates. On average, the productivity growth of OECD countries changes from 1.13% per year to 1.62% per year, suggesting an underestimate of almost 0.5% per year in OECD countries' productivity growth rates when CO_2 emission is constrained not to increase in the calculation of each year's productivity growth (Table 2).

The Malmquist-Luenberger productivity index imposes a more strict restriction on CO_2 output consistent with concerns with global warming. We can allow for an expansion of goods and a reduction of bads using the directional distance function. When we use the Malmquist-Luenberger productivity index, the index on average slightly increases from 1.13% per year to 1.16% per year. This result is consistent with the findings of Ball et al. (1998) and Boyd et al.(1999). Table 5 reports the trends in each member country's carbon intensities during the sample period and shows significant improvement made by the OECD during the 1980's. This result may be explained in part by environmental regulations in place in the member countries which are intended to reduce sulfur dioxide and nitrogen dioxide emissions because of public health concerns. Policies that reduce sulfur dioxide or nitrogen dioxide play a complementary role in reducing carbon dioxide emission.

The indices are point estimates and an innovation of this paper is to provide a statistical interpretation to the index number measures. In order to bound them with a confidence interval we turn to the bootstrapping procedures discussed above. According to the bootstrap results, the bias corrected estimator has higher mean squared error

$$var\left\{\widehat{ML}_0^{t,t+1}(b)\right\} > \frac{1}{3}\left(\widehat{bias}_B\left[\widehat{ML}_0^{t,t+1}\right]\right)^2$$

Therefore, we use the original estimator in constructing the confidence interval of the true index. Based on the Malmquist-Luenberger index, in the 1980's (Table 6) confidence intervals derived from the bootstrap show that there is significant aggregate productivity change for most countries. However, we cannot tell whether efficiency change or technological change drives this productivity change. The disaggregated indices do not show statistically significant change (Tables 7 and 8).

4.2 Asian Results with a Particular Focus on China

We next turn to our analysis of Asia. Of particular importance is China which we analyze in more depth to assess the proper evaluation of carbon dioxide. The major energy source for China is coal, one of the highest carbon dioxide emitting fossil fuels. We estimate China's productivity growth along with 10 other Asian countries for the period 1980-1995. The other countries are: Japan, Korea, Taiwan, Hong Kong, Singapore, India, Thailand, Indonesia, Malaysia, and the Philippines. Aggregate country data are from the Penn World Tables (Mark 5.6) and International Financial Statistics of IMF while CO_2 emission data come from the U. S. Energy Information Administration.

Table 9 shows the output and input growth rates for the sample of Asian countries. Tables 10, 11, and 12 provide results analogous to those contained in Tables 2,3, and 4 for the OECD countries. If carbon dioxide emissions are ignored, China does not show productivity growth during the sample period. For the other Asian countries, productivity growth can be found only in Japan, Korea, Taiwan, Singapore and Hong Kong. This is consistent with the finding of Young (1995) who pointed out that the bulk of post-WWII growth in Asian countries was due to input growth and not TFP growth.

When we apply the directional distance function methods Japan is the only country that shows positive productivity growth over the entire sample period. China shows TFP growth but only in the 1990's. No productivity growth now can be found for Korea, Taiwan, Singapore and Hong Kong, countries that showed positive TFP growth without the consideration of CO_2. This may indicate that measured TFP growth in these countries was distorted by a failure to properly account for the growth in environmental bads.

The developing countries are arguably less interested in and well-equipped to handle waste by-products in pursuing their economic policy. Confidence intervals derived from the bootstrap show that there is also significant aggregate productivity change for most Asian countries (Table 13). However, we cannot tell whether efficiency change or technological change drives this productivity change. The disaggregated indices do not show statistically significant change (Tables 14 and 15).

Historically, China does not appear to have the flexibility to pay for its by-product emissions by residual TFP growth. Since its most cost-effective energy source, without regard to its production of substantial waste by-products, is coal any divergence of resources to mitigate waste by-product production such as CO_2 will have a significant marginal impact on China's growth prospects, and hence the growth in its energy needs.

Table 16 shows the 95% confidence interval of the index from bootstrap. China does show significant productivity growth for the period 1990-1991 and 1991-1992 when using the Malmquist-Luenberger index. At the beginning of the 1990's China appeared to attain its growth in a more environmentally safe way than in the 1980's.

Table 17 shows each country's efficient production combination in 1995, the end of the Asian sample. This is obtained using the Malmquist-Luenberger distance function and scaling radially its actual outputs to their frontier efficient levels. If the largest polluting country in Asia, China, could operate at her frontier, she could increase GDP and decrease carbon dioxide emission by

38% and attain a 0.146 Ton/$1000 carbon intensity. This is in line with the least polluting countries in the OECD (Table 5).

4.2.1 Assessing the Impact of Environmental Targets on China's Growth and Energy Demand

Our estimates can be put to use to examine the impact that moderating CO_2 emission would have on China's its growth prospects and energy demands in the new millennium. We assume that the future population growth rate of China is 1% per annum and construct three GDP growth rate scenarios, low(5.5%), standard(6.5%) and high(7.5%) growth respectively. The standard growth rate comes from China's average GDP growth rate over the last 15 years.

Results of this exercise are in Table 18. Using the directional distance function approach, China's estimated total factor productivity growth rate (1990-1995) falls from 2.63% to 1.47% when we control for carbon dioxide emission. This implies that the GDP growth rate would fall by 1.16% were carbon dioxide emissions controlled. Assuming that this most recent epoch is representative of China's growth prospects in the first two decades of the new millennium, then under the standard scenario China's forecasted GDP of 3.4 trillion (US$) in 2000 would grow to 9.5 trillion (US$) in 2020 (1985 international prices). This is 80.3% of the level of the GDP if CO_2 emissions were ignored. One measure of the cost of carbon dioxide emission control during the period 2000-2020 is in terms of lost GDP. This amounts to about 17.6 trillion (US$) which is almost twice China's forecasted GDP in 2020. In order to forecast China's energy demand we use the relation between energy intensity (=Energy consumption/GDP) and per capita GDP[1]. Given China's population growth, we compute per capita GDP and then estimate energy intensity at this income level. Finally, the energy demand can be forecasted using GDP and energy intensity. Under the standard scenario, by controlling carbon dioxide emission China's energy demand would be 10,615.1 quadrillion Btu instead of 13,014.8 quadrillion Btu by 2020. On average, the control of carbon dioxide emission will cause a 0.86% decrease in the annual growth rate of total energy. Since China's energy consumption accounts for almost 10% of world consumption and coal, the most carbon dioxide emitting energy source, is her major energy source, reductions of these magnitudes will have a major impact on global CO_2 emissions. These findings point to the enormous benefits of proper environmental accounting as well as to potential difficulties ahead for developing countries such as China were they to meet the CO_2 emissions criteria suggested for developed countries in recent world forums on the environment.

[1] The following equation is estimated

$$\ln(EI_t) = \underset{(0.2982)}{2.3821} + \underset{(0.0416)}{-0.2556} \ln(PCG_t)$$

using the China's data from 1980 to 1995.

PCG and EI denote for per capita GDP and energy intensity respectively. The numbers in parenthesis are standard errors.

5 Conclusions

In this paper we have analyzed the productivity growth of OECD and Asian countries, taking explicit account of environmental waste by-products such as CO_2 which account for over 80% of total green house gas emissions. The Malmquist-Luenberger productivity index is estimated to account for CO_2 and is compared with a reference Malmquist index that does not account CO_2 emissions. When we include carbon dioxide as a bad output of the economies, average growth rates in total factor productivity for OECD countries show a marginal increase. This is consistent with the findings of Ball et al. (1998) and Boyd et al. (1999). Such higher rates also are found when we only constrain levels of CO_2 to remain at sample levels (the More Goods case). The Asian economies on average show little apparent impact of such environmental accounting on their total factor productivity growth rates.

The confidence intervals derived by bootstrapping methods indicate that significant aggregate productivity growth in the Malmquist-Luenberger sense has taken place in the last decade in OECD. Asian countries showed significant negative productivity growth except Japan. This is consistent with the finding of Young (1995) who pointed out that the bulk of post-WWII growth in Asian countries was due to input growth and not TFP growth. But we cannot determine with nominal statistical confidence whether it is due to catching up (efficiency change) or innovation (technology change). China shows significant productivity growth only in the 1990s.

Using the relation between energy intensity and per capita GDP, we also have forecasted China's energy demand up to 2020. The evaluation of CO_2 emission drops the energy demand growth rate from 5.23% to 4.38%. Considering China's energy consumption level and high dependency on coal, the proper evaluation of CO_2 emissions in China is clearly an important international issue and should play a central role in framing international agreements ongoing in the global warming debates.

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[Table 1] Average growth rate of inputs and outputs(%)(1980-1990)

	GDP	Carbon Dioxide	Capital	Labor	Energy
Australia	2.96	3.18	3.91	1.88	3.01
Austria	2.12	0.45	3.93	0.83	0.79
Belgium	1.89	-0.90	2.12	0.54	-0.05
Canada	2.97	0.15	5.17	1.14	1.34
Denmark	2.10	-1.84	2.21	0.58	-0.60
Finland	3.05	-0.45	3.91	0.73	1.52
France	2.22	-2.69	3.01	0.96	0.35
Germany	2.14	-0.94	2.73	1.34	0.18
Greece	1.87	4.01	2.21	0.53	3.29
Ireland	3.43	1.21	2.83	0.69	1.46
Italy	2.14	1.01	2.99	0.75	1.28
Japan	4.17	0.51	5.99	0.80	1.75
Norway	2.43	0.22	2.52	0.92	1.66
Spain	3.05	0.51	4.44	0.95	1.76
Sweden	2.01	-4.71	3.89	0.68	0.38
U.K.	2.85	0.03	3.01	0.51	0.72
U.S.A.	2.64	0.43	3.49	1.13	1.05

[Table 2] Comparison of average annual productivity growth, 1980-1990

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs*	More Goods**	Standard***
Australia	1.0078	1.0048	n.a	n.a
Austria	1.0104	1.0051	1.0147	1.0067
Belgium	1.0142	1.0061	1.0136	1.0127
Canada	1.0181	1.0155	1.0203	1.0157
Denmark	1.0212	0.9970	1.0153	n.a
Finland	1.0207	1.0137	1.0244	1.0202
France	1.0133	1.0133	1.0216	1.0148
Germany	1.0100	1.0061	1.0079	1.0087
Greece	0.9946	1.0092	1.0099	0.9950
Ireland	1.0086	1.0029	1.0060	1.0060
Italy	1.0069	1.0053	1.0062	1.0072
Japan	1.0238	1.0096	1.0330	1.0181
Norway	1.0154	1.0154	1.0207	1.0136
Spain	0.9988	0.9975	0.9979	1.0078
Sweden	1.0135	1.0135	1.0347	1.0247
U.K.	1.0065	1.0095	n.a	n.a
U.S.A.	1.0080	0.9907	n.a	n.a
Average	1.0113****	1.0068	1.0162	1.0116

* USA for 1980-1987, 1988-1990

** Belgium for 1980-1981, 1982-1990, Denmark for 1988-1990, Greece for 1980-1983, 1985-1986.

*** Ireland for 1980-1987, Italy for 1983-1990, Spain for 1982-1990

**** 1.0014 for the countries which corresponds to the Malmquist-Luenberger indices.

[Table 3] Comparison of average annual efficiency change growth, 1980-1990

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs*	More Goods**	Standard***
Australia	0.9946	1.0000	n.a	n.a
Austria	0.9993	0.9989	0.9994	0.9965
Belgium	1.0003	0.9986	0.9934	1.0005
Canada	1.0031	1.0031	1.0040	1.0033
Denmark	1.0097	1.0000	1.0000	n.a
Finland	1.0075	1.0022	1.0097	1.0082
France	1.0001	1.0001	1.0027	1.0024
Germany	0.9964	0.9963	0.9950	0.9955
Greece	0.9883	1.0017	0.9923	0.9901
Ireland	1.0080	1.0000	1.0001	1.0118
Italy	1.0000	1.0000	1.0000	1.0000
Japan	1.0152	1.0036	1.0152	1.0096
Norway	0.9996	0.9996	1.0009	0.9985
Spain	0.9965	0.9961	0.9974	1.0023
Sweden	0.9997	0.9997	1.0104	1.0090
U.K.	1.0000	1.0256	n.a	1.0000
U.S.A.	1.0000	1.0000	n.a	1.0000
Average	1.0011	1.0015	1.0015	1.0021

* USA for 1980-1987, 1988-1990

** Belgium for 1980-1981, 1982-1990, Denmark for 1988-1990, Greece for 1980-1983, 1985-1986.

*** Ireland for 1980-1987, Italy for 1983-1990, Spain for 1982-1990

[Table 4] Comparison of average annual technical change growth, 1980-1990

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs*	More Goods**	Standard***
Australia	1.0132	1.0048	n.a	n.a
Austria	1.0111	1.0063	1.0153	1.0102
Belgium	1.0140	1.0075	1.0203	1.0122
Canada	1.0150	1.0123	1.0162	1.0124
Denmark	1.0113	0.9970	1.0153	n.a
Finland	1.0131	1.0115	1.0145	1.0119
France	1.0133	1.0133	1.0188	1.0124
Germany	1.0137	1.0098	1.0130	1.0132
Greece	1.0064	1.0075	1.0178	1.0049
Ireland	1.0006	1.0029	1.0059	0.9943
Italy	1.0069	1.0053	1.0062	1.0072
Japan	1.0085	1.0060	1.0175	1.0083
Norway	1.0158	1.0158	1.0198	1.0151
Spain	1.0023	1.0014	1.0005	1.0054
Sweden	1.0138	1.0138	1.0241	1.0156
U.K.	1.0065	0.9843	n.a	n.a
U.S.A.	1.0080	0.9907	n.a	n.a
Average	1.0102	1.0053	1.0146	1.0095

* USA for 1980-1987, 1988-1990

** Belgium for 1980-1981, 1982-1990, Denmark for 1988-1990, Greece for 1980-1983, 1985-1986.

*** Ireland for 1980-1987, Italy for 1983-1990, Spain for 1982-1990

[Table 5] The trend of carbon intensity(Ton/1985 Thou.$)

	1980	1985	1990	AAGR(%)
Australia	0.2950	0.2868	0.3014	0.2
Austria	0.2084	0.1898	0.1767	-1.6
Belgium	0.3422	0.2884	0.2593	-2.7
Canada	0.3683	0.3026	0.2790	-2.7
Denmark	0.3179	0.2672	0.2146	-3.9
Finland	0.3013	0.2231	0.2131	-3.4
France	0.2138	0.1602	0.1307	-4.8
Germany	0.2831	0.2463	0.2084	-3.0
Greece	0.2650	0.2791	0.3260	2.1
Ireland	0.2655	0.2181	0.2140	-2.1
Italy	0.1758	0.1663	0.1573	-1.1
Japan	0.2214	0.1723	0.1548	-3.5
Norway	0.1864	0.1501	0.1497	-2.2
Spain	0.2136	0.2051	0.1664	-2.5
Sweden	0.2329	0.1557	0.1179	-6.6
U.K.	0.2929	0.2527	0.2217	-2.7
U.S.A.	0.3705	0.3146	0.2981	-2.2

Note: AAGR means average annual growth rate(%).

[Table 6] Changes in Malmquist-Luenberger productivity index(CRS)

	’80-’81	’81-’82	’82-’83	’83-’84	’84-’85	’85-’86	’86-’87	’87-’88	’88-’89	’89
Austria	0.9931	1.0351*	1.0312*	0.9685*	1.0094*	0.9852*	1.0126	1.0167	1.0192*	0.9
Belgium	0.9756*	1.0187*	1.0123	1.0116*	0.9970	1.0091*	1.0193*	1.0431*	1.0220*	1.0
Canada	1.0340*	0.9644	1.0225*	1.0388*	1.0244*	1.0308*	1.0217*	1.0177	1.0081	0.9
Finland	1.0082	1.0435*	1.0297*	1.0229*	0.9929*	1.0070*	1.0246*	1.0454*	1.0450*	0.9
France	1.0093	1.0174*	1.0014	1.0131*	1.0062*	1.0397*	1.0139*	1.0449*	0.9984	1.0
Germany	0.9829*	0.9759*	1.0198*	1.0241*	1.0036	1.0131*	1.0140*	1.0294*	0.9960	1.0
Greece	1.0022	1.0205	0.9753*	0.9963	0.9874*	0.9957	0.9704	0.9988	1.0162*	0.9
Ireland	1.0035	0.9940	0.9719*	1.0386	0.9677*	0.9603*	1.1144*	n.a	n.a	n
Italy	n.a	n.a	n.a	0.9867*	1.0022	1.0078	1.0080*	0.9820	1.0207	1.0
Japan	1.0262*	1.0509*	1.0283*	0.9834*	1.0335*	1.0273*	1.0140*	0.9994	1.0079*	1.0
Norway	1.0527*	1.0291*	1.0168*	1.0213*	1.0101	1.0085	0.9890*	1.0139	0.9802*	1.0
Spain	n.a	n.a	0.9936	1.0012	1.0105	1.0159*	1.0293*	1.0172*	0.9800*	1.0
Sweden	1.0119	1.0606*	1.0395*	1.0386*	0.9866*	1.0156*	1.0159*	1.0173*	1.0446*	1.0

Note: Single asterisks(*) denotes significant differences from unity at 0.05

[Table 7] Changes in efficiency(CRS)

	'80-'81	'81-'82	'82-'83	'83-'84	'84-'85	'85-'86	'86-'87	'87-'88	'88-'89	'89-'
Austria	0.9982	1.0239	1.0170	0.9546*	1.0102	0.9539*	1.0140	0.9772	1.0266	0.99
Belgium	0.9687	1.0290	1.0001	0.9883	0.9823	0.9914	1.0092	1.0179	1.0065	1.01
Canada	1.0228	0.9762	1.0073	1.0031	1.0067	1.0153	1.0156	1.0019	0.9920	0.99
Finland	1.0161	1.0357*	1.0196	1.0077	0.9874	0.9862	1.0140	1.0129	1.0296*	0.974
France	1.0162	1.0078	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.00
Germany	0.9761	0.9997	1.0020	0.9942	0.9882	0.9938	1.0023	1.0010	0.9805	1.01
Greece	1.0079	1.0110	0.9628*	0.9869	0.9879	0.9765	0.9779	0.9801	1.0219	0.99
Ireland	1.0298	0.9967	0.9684	1.0484	0.9545*	0.9476*	1.1515*	n.a	n.a	n.a
Italy	n.a	n.a	n.a	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.00
Japan	1.0316	1.0388*	1.0126	0.9719	1.0340	1.0016	1.0207	0.9735	1.0157	0.99
Norway	1.0291	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9884	0.9654*	1.00
Spain	n.a	n.a	0.9865	0.9900	1.0088	1.0019	1.0334	0.9938	0.9869	1.01
Sweden	1.0177	1.0513*	1.0224	1.0000	1.0000	0.9838	1.0019	0.9740	1.0415	1.00

[Table 8] Changes in technology(CRS)

	'80-'81	'81-'82	'82-'83	'83-'84	'84-'85	'85-'86	'86-'87	'87-'88	'88-'89	'89-'90
Austria	0.9949	1.0109	1.0139	1.0145	0.9991	1.0328*	0.9986	1.0405	0.9928	1.0056
Belgium	1.0071	0.9900	1.0122	1.0236	1.0150	1.0179	1.0101	1.0247	1.0155	1.0067
Canada	1.0109	0.9879	1.0151	1.0356	1.0176	1.0153	1.0060	1.0158	1.0162	1.0041
Finland	0.9923	1.0075	1.0099	1.0150	1.0056	1.0211	1.0104	1.0321*	1.0150	1.0109
France	0.9933	1.0095	1.0014	1.0131	1.0062	1.0397*	1.0139	1.0449	0.9984	1.0044
Germany	1.0069	0.9762	1.0177	1.0301	1.0155	1.0194	1.0117	1.0284	1.0158	1.0114
Greece	0.9944	1.0094	1.0130	1.0095	0.9995	1.0196	0.9923	1.0191	0.9945	0.9981
Ireland	0.9744	0.9973	1.0037	0.9906	1.0138	1.0134	0.9677*	n.a	n.a	n.a
Italy	n.a	n.a	n.a	0.9867	1.0022	1.0078	1.0080	0.9820	1.0207	1.0446
Japan	0.9948	1.0117	1.0154	1.0119	0.9995	1.0257*	0.9935	1.0265	0.9924	1.0128
Norway	1.0230	1.0291	1.0168	1.0213	1.0101	1.0085	0.9890	1.0258	1.0153	1.0128
Spain	n.a	n.a	1.0072	1.0113	1.0018	1.0140	0.9961	1.0235	0.9930	0.9970
Sweden	0.9944	1.0089	1.0166	1.0386*	0.9866	1.0323*	1.0140	1.0444	1.0029	1.0186

[Table 9] Average growth rate of inputs and outputs, 1980-1995

	GDP	Carbon Dioxide	Capital	Labor	Energy
China	6.50	4.79	7.64	2.06	5.11
Hong Kong	6.40	5.27	7.89	1.72	5.89
India	5.64	6.90	5.58	1.84	6.77
Indonesia	6.36	6.21	10.67	2.29	7.59
Japan	3.31	0.50	5.12	0.65	2.09
Korea	8.70	7.41	11.99	2.03	9.23
Malaysia	6.71	8.04	9.74	2.96	8.79
Philippines	1.94	2.51	3.96	2.64	3.40
Singapore	7.45	6.05	8.58	2.25	6.80
Taiwan	7.61	5.71	7.52	1.89	6.49
Thailand	7.33	10.21	9.79	2.00	10.33

[Table 10] Comparison of average annual productivity growth, 1980-1995

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs	More Goods*	Standard**
China	0.9952***	0.9875	n.a	1.0079
Hongkong	1.0147	1.0083	1.1099	n.a
India	0.9998	1.0020	0.9996	n.a
Indonesia	0.9736	0.9759	0.9701	0.9847
Japan	1.0254	1.0246	1.0268	1.0259
Korea	1.0048	0.9808	0.9897	0.9921
Malaysia	0.9749	0.9922	0.9778	0.9964
Philippines	0.9819	0.9823	0.9874	0.9934
Singapore	1.0446	1.0146	n.a	n.a
Taiwan	1.0046	0.9965	0.9960	0.9957
Thailand	0.9759	0.9785	0.9785	0.9744
Average	0.9996****	0.9948	1.0040	0.9963

* Korea for 1980-1981, 1983-1995, Hong Kong for 1980-1982.

** China for 1989-1995, Korea for 1980-1984 and 1985-1995, Taiwan for 1980-1994, Thailand for 1981-1982 and 1983-1995, Indonesia for 1983-1995.

*** 1.0087 for 1989-1995, which corresponds to the period of Malmquist-Luenberger

**** 0.9937 for eight countries which corresponds to the Malmquist-Luenberger indices.

[Table 11] Comparison of average annual efficiency change growth, 1980-1995

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs	More Goods*	Standard**
China	1.0046	1.0000	n.a	1.0146
Hongkong	1.0000	1.0000	1.0000	n.a
India	1.0116	1.0048	1.0097	n.a
Indonesia	0.9882	0.9926	0.9937	0.9963
Japan	0.9894	0.9894	0.9906	0.9913
Korea	1.0005	0.9908	0.9939	0.9970
Malaysia	0.9865	0.9991	0.9824	0.9916
Philippines	0.9934	0.9934	0.9964	0.9986
Singapore	1.0000	1.0000	n.a	n.a
Taiwan	1.0147	1.0039	1.0057	1.0124
Thailand	0.9881	0.9960	0.9885	0.9906
Average	0.9979	0.9973	0.9957	0.9991

* Korea for 1980-1981, 1983-1995, Hong Kong for 1980-1982.

** China for 1989-1995, Korea for 1980-1984 and 1985-1995, Taiwan for 1980-1994, Thailand for 1981-1982 and 1983-1995, Indonesia for 1983-1995.

[Table 12] Comparison of average annual technical change growth, 1980-1995

	Malmquist			Malmquist-Luenberger
Country	Standard	More Outputs	More Goods*	Standard**
China	0.9907	0.9875	n.a	0.9935
Hongkong	1.0147	1.0083	1.1099	n.a
India	0.9884	0.9972	0.9900	n.a
Indonesia	0.9852	0.9832	0.9762	0.9884
Japan	1.0363	1.0356	1.0365	1.0352
Korea	1.0043	0.9899	0.9958	0.9968
Malaysia	0.9883	0.9931	0.9953	1.0048
Philippines	0.9884	0.9888	0.9909	0.9950
Singapore	1.0446	1.0146	n.a	n.a
Taiwan	0.9900	0.9927	0.9903	0.9837
Thailand	0.9877	0.9825	0.9898	0.9841
Average	1.0016	0.9976	1.0083	0.9977

* Korea for 1980-1981, 1983-1995, Hong Kong for 1980-1982.

** China for 1989-1995, Korea for 1980-1984 and 1985-1995, Taiwan for 1980-1994, Thailand for 1981-1982 and 1983-1995, Indonesia for 1983-1995.

[Table 13] Changes in Malmquist-Luenberger productivity index(CRS)

	China	Indonesia	Japan	Korea	Malaysia	Philippines	Taiwan	Thailand
’80-’81	n.a	n.a	1.0443*	0.9441*	0.9984	1.0322*	0.8703*	n.a
’81-’82	n.a	n.a	1.0248*	0.9518	1.0043	1.0187*	0.9780*	1.0203*
’82-’83	n.a	n.a	1.0190*	0.9531*	0.9419*	0.9915	0.9934*	n.a
’83-’84	n.a	0.9309*	1.0248*	0.9722*	0.9744	0.9887	0.9967*	0.9150*
’84-’85	n.a	0.9355*	1.0426*	n.a	0.9623	1.0012	0.8828*	0.9119*
’85-’86	n.a	1.0212*	1.0174*	1.0031	0.9603*	0.9995	1.1614*	1.0114*
’86-’87	n.a	0.9681*	1.0345*	1.0358*	1.0319*	0.9585*	1.0639*	1.0046
’87-’88	n.a	0.9968	1.0472*	1.0018	1.0454*	1.0073*	0.9861*	0.9852*
’88-’89	n.a	0.9785*	1.0386*	1.0204*	1.0038	0.9719*	1.0047*	0.9670*
’89-’90	0.9749	1.0250*	1.0416*	1.0095	0.9655*	1.0044*	0.9341*	0.9780*
’90-’91	1.0001*	1.0025	1.0407*	0.9840*	1.0151	0.9836*	1.0866*	0.9686*
’91-’92	1.0186*	0.9690*	1.0014*	1.0006	1.0082*	0.9647*	0.9733*	0.9830
’92-’93	1.0224	0.9681*	1.0073*	0.9319*	0.9743*	0.9628*	1.0662*	0.9756*
’93-’94	1.0173	1.0303*	0.9905	1.0323*	1.0224*	1.0106*	0.9425*	1.0014
’94-’95	1.0151	0.9905	1.0144*	1.0488*	1.0371*	1.0054*	n.a	0.9449*

Note: Single asterisks(*) denotes significant differences from unity at 0.05

[Table 14] Changes in efficiency(CRS)

	China	Indonesia	Japan	Korea	Malaysia	Philippines	Taiwan	Thailand
'80-'81	n.a	n.a	1.0000	1.0052	0.9818	1.0221	0.9112*	n.a
'81-'82	n.a	n.a	1.0000	1.1144	1.0183	1.0022	1.0337*	1.0000
'82-'83	n.a	n.a	1.0000	0.9873*	0.9581*	0.9829	1.0102	n.a
'83-'84	n.a	0.9648	1.0000	0.9563	0.9674*	0.9989	0.9892	1.0000
'84-'85	n.a	0.9905	1.0000	n.a	0.9651	1.0185	1.0333*	1.0000
'85-'86	n.a	1.0082	1.0000	0.9208	0.9606	1.0000	1.0198	1.0000
'86-'87	n.a	0.9894	0.9882	1.0255*	1.0221*	0.9939	1.0040	1.0000
'87-'88	n.a	1.0009	0.9811	1.0067	1.0485*	1.0061	0.9865	1.0000
'88-'89	n.a	1.0099	1.0162	1.0222	1.0070	1.0000	1.0613	1.0000
'89-'90	0.9884	1.0378	1.0020	0.9784	0.9395*	1.0000	1.0072	1.0000
'90-'91	1.0209	1.0000	0.9919	0.9791	1.0112	1.0000	1.1171*	1.0000
'91-'92	1.0242	1.0000	0.9389*	0.9966	1.0067	1.0000	0.9878	0.9962
'92-'93	1.0235	0.9986	1.0005	0.9364*	0.9820	1.0000	1.0123	0.9961
'93-'94	1.0045	0.9750	0.9545	0.9962	0.9775	0.9587	1.0000	0.9479
'94-'95	1.0264	0.9806	0.9946	1.0334	1.0288	0.9955	n.a	0.9372

[Table 15] Changes in technology(CRS)

	China	Indonesia	Japan	Korea	Malaysia	Philippines	Taiwan	Thailand
'80-'81	n.a	n.a	1.0443	0.9393	1.0170	1.0099	0.9551	n.a
'81-'82	n.a	n.a	1.0248	0.8541	0.9862	1.0165	0.9462*	1.0203
'82-'83	n.a	n.a	1.0190	0.9654*	0.9830	1.0087	0.9834*	n.a
'83-'84	n.a	0.9649*	1.0248	1.0166	1.0072	0.9899	1.0076*	0.9150*
'84-'85	n.a	0.9445*	1.0426	n.a	0.9971	0.9830	0.8543*	0.9119*
'85-'86	n.a	1.0129	1.0174	1.0894	0.9996	0.9995	1.1388*	1.0114
'86-'87	n.a	0.9784	1.0469	1.0101	1.0095	0.9644*	1.0597*	1.0046
'87-'88	n.a	0.9959	1.0675*	0.9951	0.9970	1.0012	0.9996	0.9852
'88-'89	n.a	0.9690	1.0221	0.9983	0.9968	0.9719	0.9466	0.9670
'89-'90	0.9863	0.9876	1.0395	1.0318	1.0276	1.0044	0.9273*	0.9780
'90-'91	0.9797	1.0025	1.0492	1.0050	1.0039	0.9836	0.9727	0.9686
'91-'92	0.9945	0.9690	1.0655	1.0040	1.0015	0.9647*	0.9853	0.9868
'92-'93	0.9989	0.9695	1.0068	0.9952	0.9921	0.9628*	1.0532*	0.9795
'93-'94	1.0127	1.0567*	1.0377	1.0362	1.0460*	1.0542*	0.9425*	1.0565
'94-'95	0.9890	1.0101	1.0199	1.0149	1.0080	1.0100	n.a	1.0082

[Table 16] Bootstrap confidence interval(95%) for China

Time Period	Malmquist Luenberger	Efficiency Change	Technical Change
1989-1990	(0.9778, 1.2551)	(0.9135, 1.3232)	(0.5846, 1.1849)
1990-1991	(1.0161, 1.3175)	(0.8791, 1.2507)	(0.9150, 1.1935)
1991-1992	(1.0222, 1.0601)	(0.8530, 1.1597)	(0.8824, 1.1504)
1992-1993	(0.8611, 1.0268)	(0.8305, 1.1548)	(0.7792, 1.0709)
1993-1994	(0.9117, 1.0121)	(0.8239, 1.1028)	(0.8477, 1.1218)
1994-1995	(0.9359, 1.0073)	(0.9447, 1.1687)	(0.7784, 1.0205)

[Table 17] Malmquist Luenberger production frontier at 1995

Country	Actual value			Frontier		
	GDP	CO_2	Intensity	GDP	CO_2	Intensity
China	2452.2	792.3	0.323	3377.2	493.5	0.146
Hongkong	111.3	12.1	0.109	111.3	12.1	0.109
India	1380.8	223.6	0.162	1380.8	223.6	0.162
Indonesia	479.4	57.3	0.119	502.1	54.5	0.109
Japan	1916.8	280.8	0.146	2193.2	240.3	0.110
Korea	412.3	102.3	0.248	551.5	67.8	0.123
Malaysia	138.5	23.3	0.168	168.3	18.3	0.109
Philippines	121.2	14.5	0.120	127.0	13.8	0.109
Singapore	47.3	21.0	0.445	47.3	21.0	0.445
Taiwan	238.5	46.7	0.196	238.5	46.7	0.196
Thailand	293.8	42.1	0.143	333.3	36.5	0.109

[Table 18] China's long term energy demand projection($10^{13} Btu$)

	Without CO_2 Consideration			With CO_2 Consideration		
	Low	Standard	High	Low	Standard	High
1995	3634.6	3634.6	3634.6	3634.6	3634.6	3634.6
2000	4676.5	4843.6	6648.1	4487.9	4650.1	4816.6
2010	7145.9	7939.7	8813.0	6316.0	7025.8	7807.5
2020	10919.2	13014.8	15487.1	8888.6	10615.1	12655.7
AAGR	4.50	5.23	5.97	3.64	4.38	5.12