THE JOURNAL OF THE KOREAN ECONOMY, Vol. 10, No. 2 (August 2009), 225-244

Productivity Growth Analysis in OECD Countries: Application of Metafrontier Functions[*]

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This paper adopts the metafrontier framework using the Malmquist Productivity Index (MPI) to measure and compare the productivity growth performance of countries in Organisation for Economic Cooperation and Development (OECD) under different technologies. This paper presents a number of useful decompositions of the metafrontier-MPI (MMPI) which can provide useful insights into the level of catch-up achieved by different groups of countries relative to the OECD frontier as a whole. This study uses a cross-country data set covering 26 countries in OECD for the period 1980-2008. These countries are grouped into three regions, namely, the Americas, Asia-Pacific, and Europe, in order to analyze the technological gap and catch-up of each of these regions with respect to the OECD technology. Using the DEAP software, we find that, the gap between the Asian-Pacific group frontier and the OECD metafrontier is decreasing, which posits that the Asian group is experiencing technological progress at a faster rate than the metafrontier which represents the OECD technology. On the other hand, the European technology has already achieved a certain level of progress in technology which is why the rate of growth is slower compared to the metafrontier. Meanwhile, the mean efficiency score for the Americas region is particularly low in 1985-1988 period, suggesting technology and knowledge diffusion within region might help to improve efficiency levels.

JEL Classification: B4, C6, O1, O3, O4
Keywords: technical efficiency, technological change, productivity growth, OECD, metafrontier, technology gap, DEA, MPI

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1. INTRODUCTION

Metafrontiers have been introduced to facilitate comparisons of performance of decision making units belonging to different firms, industries, countries or regions. The metaproduction function was first introduced by Hayami (1969) and Hayami and Ruttan (1970, 1971). As stated by Hayami and Ruttan (1971, p. 82), "The metaproduction function can be regarded as the envelope of commonly conceived neoclassical production functions". There are enough productivity studies to conclude that studies undertaken are generally represented by some form of frontier analysis. The two principal methods widely used are the nonparametric and the parametric approach. The common nonparametric approaches include the Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH). On the other hand, the common parametric approaches comprise of the Stochastic Frontier Approach (SFA), the Thick Frontier Approach (TFA) and the Distribution Free Approach (DFA). Data envelopment analysis (DEA) has been widely used in benchmarking studies over the last two decades. Typically such benchmarking studies make use of data on countries from a geographical region or decision making units belonging to a group.

Frontier methods have been used over the years in assessing the performance of firms or other decision making units whereby the efficiency scores and productivity index of firms are benchmarked against a cross-section of firms within the same industry. In recent years, frontier methods have also been used in assessing and comparing the performance of different regions and countries. Charnes *et al*. (1989) studied the economic performance of China's 28 cities in 1983 and 1984. In a similar study, Chang *et al*. (1995) used DEA and the Malmquist productivity index approach to study the economic performance of 23 regions in Taiwan from 1983 to 1990. Tong (1996, 1997) applied DEA to investigate the changes in production efficiency of 29 Chinese provinces meanwhile Bernard and Cantner (1997) calculated the efficiency of 21 French provinces from 1978-

1989. In a recent study, Maudos *et al*. (2000) analysed the relationship between efficiency and production structure in Spain from 1964 to 1993.

Countries in different regions face different production opportunities. Technically, they make choices from different sets of feasible input-output combinations. These so-called technology sets differ because of differences in available stocks of physical, human and financial capital (e.g., type of machinery, size and quality of the labour force, access to foreign exchange), economic infrastructure (e.g., number of ports, access to markets), resource endowments (e.g., quality of soils, climate, energy resources) and any other characteristics of the physical, social and economic environment in which production takes place. Due to such differences, it is imperative to estimate separate production frontiers for different groups of countries. Separate frontiers have been estimated for universities in Canada (McMillan and Chan, 2004), Australia (Worthington and Lee, 2005) and the United Kingdom (Glass, McKillop and Hyndman, 1995), and for bank branches in South Africa (O'Donnell and van der Westhuizen, 2002) and Spain (Lovell and Pastor, 1997). Pham *et al*. (2003) introduce new approach to test for sectoral technical gains even when aggregate growth accounting shows no gains. Their methodology is applied to data from Korea, Singapore, and Taiwan. Results suggest sector-specific technical progress may have been present in several episodes from 1972-1992.

There is often considerable interest in measuring the performance of countries across geographical boundaries. The caveat is that such comparisons are only meaningful in the limiting special case where frontiers for different countries are identical. As a general rule, efficiency levels measured relative to one frontier (e.g., the Malaysian frontier) cannot be compared with efficiency levels measured relative to another frontier (the Taiwanese frontier). Therefore, the results from cross-country studies of productivity growth are not strictly comparable as each country is benchmarked against the frontier for that region as a whole. If the frontiers of the two regions or two countries are identical or very similar, then there is no real problem. In practice, however, it is rare that the frontiers estimated for two different regions or countries are likely to be similar enough to facilitate the use of a single frontier. In empirical work, one tends to reject the null hypothesis of constancy of the production frontier across different regions. Therefore, it is in these instances that it is imperative to construct metafrontiers for comparison of performance of different countries.

The metafrontier envelops the group frontiers. Thus, efficiencies measured relative to the metafrontier can be decomposed into two components: a component that measures the distance from an input-output point to the group frontier (the common measure of technical efficiency); and a component that measures the distance between the group frontier and the metafrontier (representing the restrictive nature of the production environment). The advantages of the metafrontier technique are that it is able to separate technological change from efficiency change and is also parsimonious in terms of data requirements. Specifically, the implementation of the metafrontier technique requires data only on output, capital stock and labour input. The technique involves constructing a global technology production frontier (or a metafrontier) and then separating the countries in the sample into relatively homogeneous groups and estimating group-specific frontiers. In the metafrontier framework, two measures of efficiency are obtained for each country each year: one vis-à-vis the group frontier and the other vis-à-vis the metafrontier. The ratio of the efficiencies, known as the metafrontier ratio (MFR), provides a measurement of the technology gap between a country and the metafrontier. Countries of a higher MFR are closer to the metafrontier and, hence, technologically more advanced. As a result, countries of a positive growth rate of the MFR are catching-up technologically. Some econometric advantages of applying the metaproduction function are discussed by Lau and Yotopoulos (1989), but the lack of comparable data and the presence of inherent differences across groups are the major limitations of the approach.

Maudos *et al*. (1999) analyzed the total factor productivity evolution in OECD countries by breaking down productivity gains into technical change and efficiency change. In this study, the authors noted the importance of human capital in the measurement of TFP growth in the OECD, highlighting the importance of efficiency as a source of variation in TFP other than technical progress. In this context, it would be interesting to investigate how the different regions within the OECD membership perform with respect to the OECD technological frontier.

Recent work by Battese and Rao (2002), further developed by Battese *et al.* (2004), and O'Donnell *et al.* (2005), introduced the idea of *metafrontiers*. The metafrontier technique entails the estimation of a metatechnology and the frontiers of relatively homogenous groups. These estimated frontiers give an empirical representation of the world and the group specific technologies respectively. The estimation of a metafrontier, group frontiers, and the relative efficiency levels with respect to both, allows the construction of a measure of the technology gap between countries with efficiency effects removed to give a clearer picture of the relative rates of technology differences between production entities. Battese and Rao (2002) give a more extensive literature review and proposed a stochastic metafrontier model that assumes a different data generation mechanism for the metafrontier than for the different group frontiers.

Battese *et al.* (2004) applied the metafrontier model to estimate technical efficiencies of Indonesian garment firms in five different regions, using panel data on medium- and large-scale garment firms over the period 1990 to 1995. The authors also used the model to estimate technology gaps for firms operating under different technologies relative to the potential technology available to the industry as a whole. On the other hand, O'Donnell *et al*. (2005) presents an empirical application on the concept of a metafrontier using cross-country agricultural sector data.

The models used by Battese *et al*. (2004) and by O'Donnell *et al*. (2005) are essentially static in nature and suitable for the measurement and analysis of the efficiency of firms at a given point of time. This paper extends their work on metafrontiers to a temporal context involving the measurement of productivity growth over time in OECD countries.

A point to note is that all these studies derived their decompositions under the assumption that all the countries in a group operated under a common technology. This paper extends previous study by considering groups of OECD countries which operate under different technologies thus relaxing the common technology assumption, as well as explicitly accounting for temporal effects, which measures productivity and efficiency changes over the period 1980-2008.

In most empirical applications of the metafrontiers, grouping of countries is implicit in the problem under consideration. There are no *a priori* theoretical prescriptions on how countries should be allocated to regions or groups when estimating frontiers. O'Donnell, Rao, and Battese (2005) grouped countries by geographical regions, while Iyer *et al*. (2006) grouped countries by income levels.

Since all the member countries of OECD, with exceptions to Mexico (which falls under the upper middle income group) belong under the high income group, we decided to group the countries according to geographical regions to gauge the extent of a country's emphasis on technology catching-up. We assume that countries that are in the same region share the same technology.

The main objective of this study is to empirically measure the level of catch-up in productivity growth achieved by different group of OECD member countries over the period of 1980-2008. This paper provides the metafrontier framework to measure and compare the productivity growth performance of countries under different technologies in OECD countries. There is no study, to the best of our knowledge, commissioned to investigate the technological gap and catch-up in productivity in OECD countries. In addition, this study extends the period of study until year 2008 as compared to the previous studies, thus taking into effect the latest technological change and how it affects the countries' performance of the OECD countries.

Analyses of technical efficiency of countries within the same regional level are important and challenging. From a policy point of view, it is of interest to distinguish the regional differences in mean efficiency levels and to determine whether the regions share some common characteristics.

The rest of the paper is organized as follows: section 2 details the definitions of group and meta-frontiers as well as technology gap ratios (TGRs) and presents the empirical model to be used in this study. Section 3 describes the data and section 4 presents results. Finally, policy implications and the conclusion of this study are detailed in section 5.

2. BASIC CONCEPTS AND THEORETICAL FRAMEWORK

Consider the case where countries are grouped in *K* (>1) regions, each operating under group specific technologies. From the general definition of a technology set, we define the *k*th group technology set, which satisfies the relevant axioms

$$Tk = \{x,\ y) : x \in Lk(y),\ y \in Pk(x), x \text{ can producey}\}. \tag{1}$$

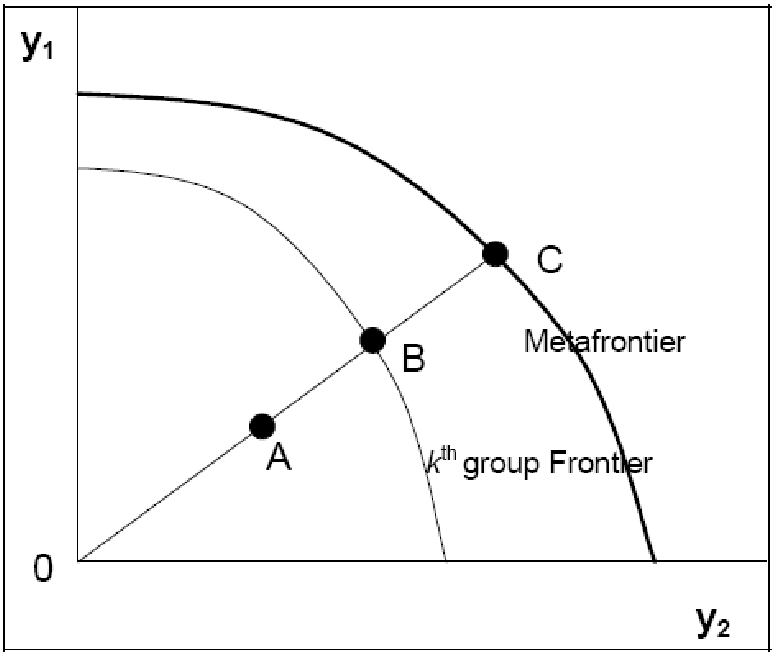
As all the group-specific technology sets (termed as *g*) are sub-sets of the metatechnology set, then for the *g-th* region (*g*=1, 2, …., *G*), the output distance function (termed as *D*) in time period *t* with respect to the group frontier is greater than or equal to the output distance function in time period *t* with respect to the metafrontier (termed as *A*)

$$D_t^g(x_t,\ y_t) \geq D_t^A(x_t,\ y_t) \text{ for any } g = 1,\ 2,\ \ldots,\ G. \tag{2}$$

From the measures of technical efficiency with respect to the group-specific frontier and the metafrontier, we can formally define the output-orientated Technology Gap Ratio (*TGR*) at time *t* as the ratio of the two technical efficiencies as follows

$$TGR_t^g(x_t,\ y_t) = \frac{D_t^A(x_t,\ y_t)}{D_t^g(x_t,\ y_t)} = \frac{TE_t^A(x_t,\ y_t)}{TE_t^g(x_t,\ y_t)}. \tag{3}$$

Figure 1 Meta- and Group-Frontiers



The metafrontier envelops the group frontiers, therefore from (2) $TE_t^A(x_t, y_t) \le TE_t^g(x_t, y_t)$ and thus $TGR_t^g(x_t, y_t) \le 1$.

The growth index of the *TGR* can be interpreted as the relative technological progress or regress of the country (or a firm) in group *g* with respect to shifts in the metatechnology or Asian technology change. If the gap between the group frontier and the metafrontier is decreasing (i.e. the specific group is experiencing technological progress at a faster rate than the metafrontier which represents the Asian technology), then the growth index of the *TGR* will be less than 1.

Consider the following illustration in figure 1 where the *k-th* group frontier and the metafrontier are depicted.

The technological change (*TC*) for a region relative to the metafrontier is equal to the product of the technical change relative to the group frontier and the geometric mean of the inverse of the technology gap growth index evaluated at (x_t, y_t) with respect to period t+1 technology and at (x_{t+1}, y_{t+1}) with respect to period t technology. This term can be interpreted as the inverse of the relative improvement in the technology gap of a specific region from t to t+1.

It is important to examine if all the regions share the same technology. If all the country-level data were generated from a single production frontier and the same underlying technology, there would be no good reason for estimating the efficiency levels of countries relative to a metafrontier production function.

Malmquist productivity index (MPI) has been commonly used as a productivity index. The MPI measures productivity change from period t to period t+1 and is defined with respect to a reference period technology. The MPI can be constructed with the ratio of two distance corrections between period t and t+1, which is given in equation 4 as follows

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \right)^{1/2}. \tag{4}$$

The index thus employs distance functions from two different periods or technologies, $D_0^t(., .)$ and $D_0^{t+1}(., .)$, and two pairs of input-output vectors, (x^t, y^t) and (x^{t+1}, y^{t+1}). A value greater than unity will indicate positive total factor productivity growth, whereas a value of lesser than unity will indicate productivity retrogress.

As has been demonstrated by Fare *et al.* (1989), the Malmquist index as shown in equation (4) can be decomposed into two components, namely technical efficiency change (EFFCH) and technological change (TECHCH), defined as equation (5) as follows

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right)^{1/2}. \tag{5}$$

where the ratio outside the square bracket measures the change in relative efficiency (i.e., the change in how far observed production is from maximum potential production) between years t and t+1. The geometric mean of the two ratios inside the square bracket captures the shift in technology between the two periods evaluated at x^t, and x^{t+1} that is shown in equations (6) and (7) as follows

$$\text{Technical efficiency change} = \text{EFFCH} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}, \quad (6)$$

$$\text{Technological change} = \text{TECHCH} = \left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right)^{1/2}. \quad (7)$$

Hence, Malmquist total factor productivity growth is the product of technical efficiency change and technological change, as shown in equation (8) as follows

$$\text{Malmquist Productivity Index} = \text{EFFCH} * \text{TECHCH}. \quad (8)$$

The metafrontier approach leads to two types of MPI's, one defined with respect to group specific technology/frontier (*GMPI*) and another defined with respect to the metatechnology/metafrontier (*MMPI*).

The group specific Malmquist productivity index (GMPI) for a country belonging to the *g-th* group with observed input-output combinations (x_t, y_t) and (x_{t+1}, y_{t+1}) in periods t and t+1 respectively can be defined using a formula similar to that defined in equation (5).

All the distances involved in equation (5) are computed using data on entities belonging to group g. The Metafrontier MPI (*MMPI*) can be similarly defined using the metafrontier denoted by (A). *MMPI* can also be decomposed into technical efficiency change and technical change components.

The following equations (equation (9) and (10)) indicate that the MMPI can be expressed as the product of two components, viz., group specific productivity index (*GMPI*); and inverse group catch-up from *t to t*+1. The $catch\text{-}up_{t,\,t+1}$ term is greater than unity when the group shows catch-up with the OECD technology over the period *t* to *t*+1.

$$M_{t,\,t+1} = M^{g}_{t,\,t+1} \times (catch\text{-}up_{t,\,t+1})^{-1}, \qquad (9)$$

where

$$catch\text{-}up_{t,\,t+1} = \frac{M^{g}_{t,\,t+1}}{M^{A}_{t,\,t+1}} = \frac{GMPI_{t,\,t+1}}{MMPI_{t,\,t+1}}. \qquad (10)$$

In this paper, Data Envelopment Analysis (*DEA*) is utilized to compute the distance functions of Malmquist Productivity Index (*MPI*). Hence, all of the Malmquist indices on the country's data were derived using the program DEAP Version 2.1 developed by Coelli (1996). It is a computer program, which has been written to conduct data envelopment analysis for the purpose of calculating efficiencies in production. Three principal options are available in the computer program and the application of Malmquist *DEA* option is applied in this paper. This application uses panel data to calculate indices of total factor productivity change, technological change and technical efficiency change. Fare *et al.* (1994) have provided a detailed discussion of this decomposition.

For the purpose of the present study, the OECD countries are grouped into three regions, namely the Americas, Asia-Pacific, and Europe. By performing the *DEA* frontier analysis separately at the regional levels, the study permits the parameters of the empirical model to be different for these three regions. The regional-level analyzes are believed to be desirable because it is likely that the countries in the different regions are operating under different technologies. The estimation of a metafrontier production function for OECD countries enables a comparison of the technical efficiencies of countries in different regions, together with an analysis of the technology gaps of countries in particular regions, relative to the technology available to the OECD as a whole.

3. DATA

The data used for this study comprises of annual time series data for real gross domestic product (GDP), real capital, and labour force. Real GDP and real capital are in US dollar at 2005 prices. The sample period for this study spans from 1980-2008, a total of 29 years. Data for real GDP, real capital, and labour force are made available from EIU database. The data used were a complete panel of annual observations on 26 OECD countries and for the purpose of the technology gap and catch-up analyses, these countries are grouped into three regions, namely, the Americas, Asia-Pacific, and Europe (see Appendix for details). Czech Republic, Poland, Slovak Republic, and Turkey are not included in our sample because of missing observations for certain variables. Since DEA analysis requires a balanced panel data, these countries are excluded from the study.

The output for the DEA analysis comprises of real GDP, whereas the inputs comprise of real capital and labour force. The total number of countries involved in the three regions is 26 and the total number of observations for all countries is 754.

4. EMPIRICAL RESULTS

Table 1 presents a summary of the decompositions of *MMPI* and *GMPI* described in the previous section. The annual values of productivity growth have been averaged over four yearly intervals for the purpose of presentation. The last column of table 1 is the computed catch-up/lag effect for each group of countries presented at four year intervals.

Table 1 GMPI and MMPI Decomposition into TEC and TC: Annual Average Growth Rates by Sub-Periods

Group	Period	TEC^A	TC^A	MMPI	TEC^G	TC^G	GMPI	TEC^A/TEC^G(TGR)	TC^A/TC^G	GMPI/MMPIcatch-up
Americas	1981-1984	1.060	0.968	1.023	1.050	0.976	1.024	1.009	0.992	1.001
	1985-1988	0.825	24.427	16.206	0.754	19.498	2.159	1.094	1.253	0.133
	1989-1992	5.950	1.575	0.992	3.634	1.458	0.806	1.637	1.080	0.812
	1993-1996	1.050	1.110	1.069	1.065	1.941	1.553	0.986	0.572	1.453
	1997-2000	1.012	1.059	0.989	1.018	0.960	0.977	0.995	1.103	0.987
	2001-2004	1.229	1.827	1.006	1.007	1.002	1.008	1.221	1.824	1.001
	2005-2008	1.855	1.880	1.095	2.175	2.383	1.085	0.853	0.789	0.991
Asia-Pacific	1981-1984	1.022	0.947	0.964	1.057	0.914	0.965	0.967	1.036	1.001
	1985-1988	0.750	9.799	1.010	0.984	1.030	1.013	0.762	9.513	1.003
	1989-1992	7.119	1.590	1.282	0.987	1.369	1.293	7.214	1.161	1.009
	1993-1996	1.052	1.073	0.982	1.004	1.003	1.006	1.048	1.070	1.024
	1997-2000	1.041	1.094	1.075	1.041	1.129	1.057	1.000	0.970	0.984
	2001-2004	1.249	1.912	1.123	1.258	2.208	1.058	0.993	0.866	0.942
	2005-2008	1.846	1.808	1.013	1.058	1.008	1.008	1.745	1.793	0.995
Europe	1981-1984	1.030	0.982	1.008	1.017	0.994	1.008	1.012	0.988	1.000
	1985-1988	0.739	8.468	1.002	0.999	0.995	0.993	0.740	8.509	0.991
	1989-1992	6.883	1.884	1.020	0.986	1.029	1.013	6.984	1.831	0.993
	1993-1996	1.030	1.029	1.010	1.001	1.002	1.001	1.029	1.027	0.990
	1997-2000	1.010	1.035	0.998	1.004	0.979	0.982	1.007	1.057	0.984
	2001-2004	1.317	1.905	1.017	1.000	1.012	1.011	1.317	1.882	0.994
	2005-2008	2.013	1.960	1.011	1.005	0.991	0.995	2.004	1.977	0.984
OECD Group	1981-1984	1.029	0.974	1.001	1.041	0.961	0.999	0.988	1.013	0.998
	1985-1988	0.741	9.055	1.058	0.913	7.175	1.388	0.812	1.262	1.312
	1989-1992	6.146	1.727	1.001	1.869	1.285	1.037	3.289	1.344	1.037
	1993-1996	1.024	1.029	1.007	1.023	1.315	1.187	1.001	0.782	1.179
	1997-2000	1.008	1.040	1.005	1.021	1.023	1.005	0.987	1.017	1.000
	2001-2004	1.268	1.828	1.020	1.088	1.407	1.026	1.165	1.299	1.005
	2005-2008	1.861	1.857	1.011	1.413	1.461	1.029	1.318	1.271	1.018

Notes: TEC: technical efficiency change. TC: technological change. TEC^A is calculated based on the average of the countries over the 4-year average by running the DEA analysis for almquist option for all the countries in the sample. So, the measures are in comparison to the OECD frontier as a whole. On the other hand, TEC^G is obtained by running the analysis for the sub-sample and the results is averaged over 4-year period; so the measures are in comparison to the sub-sample's frontier.

As can be seen from table 1, the gap between the Asia-Pacific group frontier and the OECD metafrontier is decreasing, which posits that the Asian-Pacific group is experiencing technological progress at a faster rate than the metafrontier which represents the OECD technology. This is shown as the growth index of the technology gap ratio (i.e., TEC^A/TEC^G) for the Asia-Pacific group being less than 1 for sub-periods 1981-1984, 1985-1988, and 2001-2004.

On the other hand, for the Europe group, it can be noted that the technology gap ratio is less than 1 only for one sub-period, i.e., 1985-1988. For the other four sub-periods, it shows a value of more than 1, which means that this group is experiencing technological progress at a slower rate than the metafrontier. This shows that the European technology has already achieved a certain level of progress in technology which is why the rate of growth is slower compared to the metafrontier.

The Asia-Pacific region shows a catch-up term greater than 1 which indicates that the group shows catch-up with the OECD technology for the beginning period of study, which is from 1981-1996. Subsequently, from 1997-2008, the region lagged from the OECD frontier technology. The mean efficiency score for the Americas region is particularly low in 1985-1988 period, suggesting technology and knowledge diffusion within region might help to improve efficiency levels. Countries in the European region generally lead in terms of technology gap ratio and have a large variation of TGR.

The Europe region has the lowest average TGR ratio during 1985-1988, hence, its average efficiency is reduced from 99% when compared relative to the European frontier to 74% when compared to the metafrontier. It is interesting to note that in Asia-Pacific, the regional frontier is tangent to the metafrontier, in which the maximum value for the technology gap ratio, namely one, was obtained for the Asia-Pacific region from 1997-2000.

Countries in Europe achieved the lowest mean technical efficiencies relative to the metafrontier. Similarly, for the other regions, the technical efficiencies calculated relative to the metafrontier function were substantially smaller than those calculated from the regional frontiers.

The study of the reasons for the wide variations in the TGRs and the technical efficiencies in the different regions for both the regional stochastic frontiers and the metafrontier is worthy of further investigation.

5. CONCLUSION AND POLICY IMPLICATIONS

In several empirical applications of the metafrontiers, grouping of countries is implicit in the problem under consideration. There are no *a priori* theoretical prescriptions on how countries should be allocated to regions or groups when estimating frontiers. O'Donnell, Rao, and Battese (2005) grouped countries by geographical regions, while Iyer *et al*. (2006) grouped countries by income levels. This study grouped the countries according to geographical regions to gauge the extent of a country's emphasis on technology catching-up. We assume that countries that are in the same region share the same technology.

The models used by Battese *et al*. (2004) and by O'Donnell *et al*. (2005) are essentially static in nature and suitable for the measurement and analysis of the efficiency of firms at a given point of time. This study extends their work on metafrontiers to a temporal context involving the measurement of productivity growth over time in OECD countries.

This paper modifies previous study by considering groups of OECD countries which operate under different technologies thus relaxing the common technology assumption, as well as explicitly accounting for temporal effects, which measures productivity and efficiency changes over the period 1980-2008.

Our paper provides the metafrontier framework to measure and compare the productivity growth performance of countries under different technologies in OECD. There is no study, to the best of our knowledge, commissioned to investigate the technological gap and catch-up in productivity for the selected OECD member countries. In addition, this study extends the period of study until year 2008 as compared to the previous studies, thus taking into effect the latest technological change and how it affects the countries' performance in OECD.

Different levels of economic development may induce disparities in information transmission, technology adoption, and even institutions. In addition, the technology diffusion may follow a geographic contiguous pattern. Therefore, the often observed disparity in economic development across the three regions motivates us to evaluate the difference in the technologies, i.e., whether they have distinctive production frontiers from each other, and hence this should be accommodated when measuring production efficiencies.

APPENDIX

Table A1 List of OECD Countries

No	Countries	No	Countries
1	Australia	14	Japan
2	Austria	15	Korea
3	Belgium	16	Luxembourg
4	Canada	17	Mexico
5	Denmark	18	Netherlands
6	Finland	19	New Zealand
7	France	20	Norway
8	Germany	21	Portugal
9	Greece	22	Spain
10	Hungary	23	Sweden
11	Iceland	24	Switzerland
12	Ireland	25	U.K.
13	Italy	26	U.S.

Table A2 Countries and Groupings According to Geographical Region

OECD Member Countries	Americas	Asia-Pacific	Europe
Australia	Canada	Australia	Austria
Austria	Mexico	Japan	Belgium
Belgium	United States	Korea	Denmark
Canada		New Zealand	Finland
Denmark			France
Finland			Germany
France			Greece
Germany			Hungary
Greece			Iceland
Hungary			Ireland
Iceland			Italy
Ireland			Luxembourg
Italy			Netherlands
Japan			Norway
Korea			Portugal
Luxembourg			Spain
Mexico			Sweden
Netherlands			Switzerland
New Zealand			United Kingdom
Norway			
Portugal			
Spain			
Sweden			
Switzerland			
United Kingdom			
United States			

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