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Author(s): VICTORIA SHESTALOVA
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Sequential Malmquist Indices of Productivity Growth: An Application to OECD Industrial Activities

VICTORIA SHESTALOVA v.shestalova@kub.nl
Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands

Abstract

The paper applies both the standard DEA methodology with contemporaneous frontiers and DEA with sequential frontiers to study changes in productivity and efficiency in manufacturing for a sample of eleven OECD countries over a twenty-year period. It uses a decomposition of the industrial Malmquist productivity indices to locate the sources of productivity growth: 'technical progress' and 'catching up.' The alternative indices are interrelated in a unifying framework that provides an interpretation to their difference. We argue that for manufacturing industries, in which technological regress is unlikely to occur, DEA with sequential frontiers provides a more adequate measure for the contribution of technical changes than standard DEA.

JEL classification: C43, D24

Keywords: contemporaneous DEA, sequential DEA, TFP growth, Malmquist index

Since the fundamental paper by Solow (1957), in which he paid attention to the unexplained part of the growth of the economy, the so-called residual component, there were a lot of suggestions in the economic literature on measuring and explaining TFP growth. First, the growth of factors' productivity was viewed purely as a result of technical progress and the fact that an economy may be inefficient was simply neglected. However, later models incorporated efficiency into the analysis and distinguished between two sources of productivity growth: technical progress and catching up. These models construct a production frontier at each point of time and associate technical changes with shifts of the frontier. Changes of the position of observations relative to the frontier are classified as efficiency changes.

The inclusion of inefficiency in the analysis produces changes in the results for TFP growth (as, for example, Färe et al., 1994 have noticed). Moreover, different ways of incorporating inefficiency into the analysis may lead to different estimates for TFP growth or for the components in its decomposition to technical changes and efficiency changes. For example, Perelman (1995) compares the outcome of alternative approaches (parametric versus nonparametric) and reports that in his case the discrepancies between the estimates of TFP growth for different approaches are rather satisfactory, whilst the results for the decomposition of TFP growth differ significantly. To a large extent the differences in the results for parametric and nonparametric methods can be explained by differences in the construction of the frontier. Nonparametric methods assume that changes in technology may differ across countries and over time, while parametric methods deal with regular and common shifts of the frontier.

In the present paper we also compare two indices of TFP growth, resulting from alternative approaches. We consider two types of Data Envelopment Analysis (DEA) frontiers—contemporaneous and sequential—and analyze the difference between the corresponding indices of TFP growth and their decompositions. We propose to combine both indices in a common framework, which results in the further decomposition of the Malmquist indices into three components: technical progress, contemporaneous efficiency change and business cycle.

The analysis is applied to the evaluation of productivity performance in manufacturing industries in OECD countries. There already exist a few studies applying DEA to the international and interregional analysis of productivity performance at the level of industry or economy (Färe et al., 1994; Perelman, 1995; Gouette and Perelman, 1997; Taskin and Zaim, 1997; Weber and Domazlicky, 1999, etc.), but they operate with contemporaneous DEA, not with sequential DEA. The contemporaneous DEA assumes that the frontier in each period envelops the observations from this period only. Under such an assumption the technology of previous periods may become unfeasible in the following periods, that is, sometimes the frontier may move inward indicating some 'technical regress.' True, this has a reasonable explanation for industries like mining: the more we have extracted, the more effort and investment it takes to reach deeper layers. But for manufacturing a decline in productivity is usually a temporary phenomenon. Periods of deteriorations alternate with periods of improvement there, which implies that it is unlikely that temporary increases of inputs without increasing output are due to technology deterioration. Classifying these changes as a technological regress may be confusing. In contrast, DEA with sequential frontiers (see, e.g., Färe et al., 1985; Tulkens and Vanden Eeckaut, 1995) gives another interpretation to the productivity slowdown. It assumes that in each period of time all preceding technologies are also feasible. The frontier in a certain time envelops all data points observed up to this time, which eliminates the possibility of registering any regress by definition.[1] Another advantage of sequential DEA is practical. Sequential indices incorporate past information and are less sensitive than contemporaneous indices to the presence or not of a particular observation in the sample. We argue, therefore, that sequential DEA provides a more adequate measure of performance than the standard DEA does. It is more appropriate to use sequential frontiers while evaluating technical changes in manufacturing.

Both contemporaneous and sequential DEA have been applied to the data set covering 6 industries in 11 OECD countries in 1970–1990. We have found that both methods give us highly-correlated measures for the overall TFP growth, but (not surprisingly) less correlated measures for technological changes and for efficiency changes. The correlations between Malmquist indices computed by means of contemporaneous DEA and sequential DEA are above 0.97, whilst the correlations between the technical change components, as well as between efficiency change components, are much lower (ranging from 0.3 to 0.8 across industries).

By splitting the Malmquist indices into three components, we have shown that the discrepancy in the measures of TFP growth that they provide come from the component in their decompositions that represents changes of the position of the contemporaneous frontier relative to the sequential frontier. Two Malmquist indices coincide if the two frontiers move together, or if shifts of the contemporaneous frontier are Hicks neutral.

The paper is organized as follows. Section 1 describes the methodology, which will be used to measure the changes in productivity and efficiency. Section 2 presents data. Section 3 discusses empirical results on Malmquist indices and convergence of productivity, and Section 4 concludes.

1. Methodology

DEA is a nonparametric method that uses linear programming to construct a nonparametric piecewise frontier of the data. The frontier represents the best practice technology. Observations that belong to it are called efficient by default and the others are inefficient. The efficiency of each observation at a given point in time is measured by means of a distance function, which reflects the distance between the observation and the frontier. The methodology is described in detail in, for example, Färe and Grosskopf (1996).

1.1. DEA with Contemporaneous Frontiers

Let us start with notation. Denote the input and output vectors for one country at time t by $x^t \in \Re_+^n$ and $y^t \in \Re_+^m$, respectively. Let K be the number of countries in our sample. Then $X^t \in \Re_+^{nK}$ and $Y^t \in \Re_+^{mK}$ contain the observations on input and output for all countries in the sample at time t.

Technology in each period t is represented by the output sets $P^t(x) = \{y : x \text{ can produce } y\}$. We assume that sets $P^t(x)$ satisfy strong disposability of inputs and constant returns to scale. In the *contemporaneous* setting we also assume that $P^t(x)$ are determined by the observations on inputs and outputs corresponding to period t, that is,

$$P^t(x) = \{y : y \leq Y^t\lambda,\ x \geq X^t\lambda,\ \lambda \geq 0\}, \tag{1}$$

where $\lambda \in \Re_+^K$. For any pair of vectors (x, y) we define the output distance function at time t as

$$D_o^t(x, y) = \inf\{\theta : y/\theta \in P^t(x)\}. \tag{2}$$

The output distance function corresponds to the maximum possible proportional expansion of all outputs given inputs.[2] To compute the distance for some observation (x, y) we have to solve the following linear program.

$$\begin{aligned} &\inf_{\theta,\lambda\geq 0} \theta \\ \text{s.t.}\quad &-y/\theta + Y^t\lambda \geq 0 \\ &x - X^t\lambda \geq 0. \end{aligned} \tag{3}$$

The value θ, which we obtain from (3) will serve as a measure of overall technical efficiency for observation (x, y).

Note that for each observation the distance function reflects the gap between this observation and the frontier, that is, the gap between the observation and the leaders. Closing the gap between leaders and followers implies convergence in total factor productivity. Thus, contemporaneous efficiency introduced above provides us with a natural framework to study the convergence phenomena.

1.2. Contemporaneous Measure for TFP Growth

Färe et al. (1989) suggested using the geometric mean of two CCD-type[3] Malmquist indices to measure TFP growth and to locate its sources. In this paper we follow the same methodology and consider

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)\left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2}. \quad (4)$$

Rearranging the terms in formula (4), following Färe et al. (1989), we obtain the subsequent formula

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \sqrt{\left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right)} = EFFCH \times TECH. \quad (5)$$

The first factor in equation (5) is called efficiency change and shows the change of the relative position of an observation and the frontier. Movements of the observation towards the frontier are associated with values of *EFFCH* greater than one and are interpreted as efficiency improvements (or 'catching up'). The second factor, the square root term, represents technical change. It corresponds to the shift of the frontier. In particular, outward shifts of the frontier reflect 'technical progress.' An increase in productivity yields a value of the Malmquist index greater than unity and a deterioration leads to a less than unity value. The same holds for each component in the decomposition (5) above: any improvement in efficiency or technical progress yields a greater than unity value of the corresponding factor.

Notice that according to the definition, for any time t the contemporaneous frontier envelops the data points of time t and does not depend on data of the previous periods. Under such circumstances the production frontier may shift either inward or outward between t and $t + 1$. For manufacturing industries inward shifts of the contemporaneous best practice frontier are usually temporary. Soon the frontier shifts forward, offsetting a deterioration observed earlier. We suggest that shifts of this kind should not qualify as technical change, but as a change of efficiency of the current leaders.

The contribution of technical change can be estimated by means of DEA with sequential frontiers described in detail in Tulkens and Vanden Eeckaut (1995).

1.3. DEA with Sequential Frontiers

Assume that in any period t the technology of the previous period, $t-1$, is still feasible. Consequently, all preceding technologies are feasible as well. Then the production possibility set expands (or remains constant) from one period to the next, the technology can only improve in the course of time, and deteriorations in productivity performance are ascribed to reductions in efficiency.

Generally speaking, the feasibility of the previous period technology would have changed the definition of the output set at time t as follows,

$$\bar{P}^t(x) = \{y : y \leq \bar{Y}^t\lambda, x \geq \bar{X}^t\lambda, \lambda \geq 0\}, \tag{6}$$

where $\bar{X}^t = (\ldots, X^{t_0}, \ldots, X^{t-1}, X^t) = (\bar{X}^{t-1}, X^t)$, $\bar{Y}^t = (\ldots, Y^{t_0}, \ldots, Y^{t-1}, Y^t) = (\bar{Y}^{t-1}, Y^t)$ and t_0 is the first period, for which observations on inputs and outputs are available. However, the construction of the last set would require information on inputs and outputs before any time t_0. Since this information is missing, we have to truncate set $\bar{P}^t(x)$ at some t_0 and define

$$\begin{aligned}&\bar{P}^t(x \mid \bar{X}^{t_0} = X^{t_0}, \bar{Y}^{t_0} = Y^{t_0})\\ &\quad = \{y : y \leq (Y^{t_0}, Y^{t_0+1}, \ldots, Y^t)\cdot\lambda, x \geq (X^{t_0}, X^{t_0+1}, \ldots, X^t)\cdot\lambda, \lambda \geq 0\}.\end{aligned} \tag{7}$$

The corresponding production set will be the set $\{(x, y) : y \leq (Y^{t_0}, Y^{t_0+1}, \ldots, Y^t)\cdot\lambda$, $x \geq (X^{t_0}, X^{t_0+1}, \ldots, X^t)\cdot\lambda, \lambda \geq 0\}$. Therefore, the linear program that defines the distance function relative to the sequential frontier becomes

$$\begin{aligned}&\inf_{\theta,\lambda\geq 0} \theta\\ \text{s.t.}\quad & -y/\theta + (Y^{t_0}, Y^{t_0+1}, \ldots, Y^t)\cdot\lambda \geq 0\\ & x - (X^{t_0}, X^{t_0+1}, \ldots, X^t)\cdot\lambda \geq 0.\end{aligned}$$

The outcome of the latter linear program can be used in (4) and (5) to compute the sequential Malmquist index and its decomposition. The component *TECH* thus obtained shows pure technical progress and never indicates regress. All deteriorations in performance are attributed to the efficiency change component.[4] Since sequential DEA uses past information to construct the frontier, the results of the sequential method are less sensitive to data attrition than the results of the contemporaneous method.

1.4. Synthesis of the Two Approaches

Let us consider an example. There are two countries A and B using the same quantity of input in year t and year $t+1$ (that is $x_A^t = x_A^{t+1} = x_B^t = x_B^{t+1}$) to produce a single output y. Country A produces 1 unit of output in each year t and $t+1$ ($y_A^t = y_A^{t+1} = 1$), while country B reduces its production from 3 units of output in year t to 2 units in year $t+1$ ($y_B^t = 3$, $y_B^{t+1} = 2$). Since country B produces more output given the amount of input, it determines the production frontier in both years.

Now let us compute the Malmquist productivity indices for both countries in this example. Country A's production has not changed between two years, therefore, $M^A(t, t+1) = 1$

for both contemporaneous and sequential methods. However, despite the fact that the two Malmquist indices are equal, their decompositions to technical change and efficiency change are different. It appears that in the case of contemporaneous frontiers efficiency improvement is offset by a negative shift of the technology: $M^A(t, t+1) = 1 = TECH \times EFFCH = \frac{2}{3} \times \frac{3}{2}$, while in the case of sequential frontiers both components show no change: $M^A(t, t+1) = 1 = 1 \times 1$. For country B the story is similar. $M^A(t, t+1) = \frac{2}{3}$ for both methods. However, depending on the choice of the reference frontier—contemporaneous or sequential—it is decomposed as $\frac{2}{3} \times 1$ and $1 \times \frac{2}{3}$, which means that the productivity change is interpreted as a pure technical change in the case of the contemporaneous Malmquist index and as a pure efficiency change in the case of the sequential index.

Note that in our example the contribution of a shift of the contemporaneous frontier relative to the sequential frontier is $\frac{2}{3}$. In the case of contemporaneous frontiers this shift is allocated to the technical change component, while in the case of sequential frontiers it belongs to the efficiency change. And this is exactly what causes the differences between the two decompositions. If we separate this factor and consider the combination of three shifts, shift of the sequential frontier, shift of the contemporaneous frontier relative to the sequential frontier and shift of an observation relative the contemporaneous frontier, we obtain that $M^A(t, t+1) = 1 = 1 \times \frac{2}{3} \times \frac{3}{2}$ and $M^B(t, t+1) = \frac{2}{3} = 1 \times \frac{2}{3} \times 1$. Or, more generally $M = TECH_S \times \frac{2}{3} \times EFFCH_C$.

Consequently, the formulae for the decompositions of the Malmquist indices can be rewritten as

$$M_C = TECH_S \times \frac{TECH_C}{TECH_S} \times EFFCH_C \tag{8}$$

$$M_S = TECH_S \times \frac{EFFCH_S}{EFFCH_C} \times EFFCH_C. \tag{9}$$

Here and below the subscript C refers to the contemporaneous frontier and the subscript S refers to the sequential frontier. Consequently, the contemporaneous efficiency will be denoted as θ_C, while for the sequential measure we will use the notation θ_S.

It has been explained that the first factor in either of the above decompositions—the technical change component computed using sequential frontiers—reflects pure improvements of the technology ('technical progress'). The third one—contemporaneous efficiency change—shows changes of the gap between the leaders and the followers ('catch up').

The second factors in (8) and (9) correspond to shifts of the contemporaneous frontier relative to the sequential frontier or, in other words, changes of the position of the contemporaneous best practice relative to the best practice frontier ever achieved so far. This component measures productivity change attributable to the 'business cycle' via capacity utilization and labor hoarding.

Note that the two decompositions (8) and (9) are equivalent if and only if $\frac{TECH_C}{TECH_S} = \frac{EFFCH_S}{EFFCH_C}$, that is, when the measure of shifts of the contemporaneous frontier relative to the sequential frontier in (8) is the same as that in (9).

Obviously this component drops out if contemporaneous productivity sets are expanding (or at lest not shrinking) 'everywhere' over time. Then contemporaneous frontiers coincide with the corresponding sequential ones, and both decompositions (8) and (9) lead to the same result.

PROPOSITION 1 *If for all $t, t = t_0, t_0 + 1, \ldots, T$, the output sets satisfy $\{(x, y) : y \leq Y^t\lambda, x \geq X^t\lambda, \lambda \geq 0\} \subseteq \{(x, y) : y \leq Y^{t+1}\lambda, x \geq X^{t+1}\lambda, \lambda \geq 0\}$, then $M_C = M_S = TECH_S \times EFFCH_C$ for all $t, t = t_0, t_0 + 1, \ldots, T$.*

Hicks-neutrality[5] provides another (sufficient) condition for the two indices to coincide.

PROPOSITION 2 *If the technology exhibits CRS and there exists an output set $\hat{P}(x)$ that all output sets $P^t(x), t = t_0, t_0 + 1, \ldots, T$, satisfy the condition*

$$P^t(x) = A_t\hat{P}(x), \tag{10}$$

in which $A_t \in \Re_+$, then $\frac{TECH_C}{TECH_S} = \frac{EFFCH_S}{EFFCH_C}$ and $M_C = M_S$.

Proof. If condition (10) holds, then the distance functions computed relative to the contemporaneous frontiers satisfy the condition $D_o^t(x, y) = \hat{D}_o(x, y)/A_t$. Therefore the formula for the contemporaneous Malmquist index can be rewritten as follows:

$$\begin{aligned} &M_o(x^{t+1}, y^{t+1}, x^t, y^t) \\ &= \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)\left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2} \\ &= \left[\left(\frac{\hat{D}_o(x^{t+1}, y^{t+1})}{A_t}\frac{A_t}{\hat{D}_o(x^t, y^t)}\right)\left(\frac{\hat{D}_o(x^{t+1}, y^{t+1})}{A_{t+1}}\frac{A_{t+1}}{\hat{D}_o(x^t, y^t)}\right)\right]^{1/2} = \frac{\hat{D}_o(x^{t+1}, y^{t+1})}{\hat{D}_o(x^t, y^t)}. \end{aligned}$$

Condition (10) implies that the sequential output sets satisfy $\bar{P}^t(x) = \max_{t_0 \leq s \leq t} A_s \cdot \hat{P}(x) = B_t \cdot \hat{P}(x)$, where $B_t = \max_{t_0 \leq s \leq t} A_s$, and consequently, distance functions based on sequential frontiers have to satisfy $\bar{D}_o^t(x, y) = \hat{D}_o(x, y)/B_t$. Therefore, the formula for the sequential index can be reduced the same way as above, which completes the proof. ■

Let us now turn to the empirical part. The next two sections present the data and the results.

2. Data

The data used in this study come from the International Sectoral Data Base (ISDB) constructed by the OECD statistical division. The ISDB contains a number of data series on sectoral outputs and primary factor inputs in 14 OECD countries (G7 and seven other countries, namely Australia, Netherlands, Belgium, Denmark, Norway, Sweden and Finland). The data are reported with annual frequency. The longest time series in ISDB cover the period between 1960 and 1995. However, for some countries the observation of the first ten years as well as the last few years are missing, which prompted the truncation of the time period in the analysis to 1970–1990. Moreover, three countries (Australia, The Netherlands and Norway) had to be dropped, because the data were missing for some years and industries.

The study covers the following manufacturing sectors:

- FOD—Food, beverages, tobacco;
- TEX—Textiles, wearing apparel and leather industries;
- CHE—Chemicals and chemical petroleum, coal, rubber and plastic products;
- MNM—Non-metallic mineral products except products of petroleum and coal;
- BMI—Basic metal industries;
- MEQ—Fabricated metal products, machinery and transport equipment.

Three categories of data are required: data on output, capital, and labor. Industrial value added[6] (series 'GDPD' in the ISDB classification) is taken as output, gross capital stock ('KTVD') as capital and total employment ('ET') as labor. Industrial value added presented in the ISDB is computed on the base of national accounts. Gross capital stock is estimated by means of a perpetual inventory model. Both data on output and capital are given in constant prices and in US dollars corresponding to 1990 purchasing power parities.

3. Empirical Results

In this section we present the empirical findings. Subsection 4.1 summarizes the results on sequential and contemporaneous indices and their decompositions. In 4.2 we study the evolution of average efficiency in different sectors and identify the leaders in productivity. We also provide some evidence on the issue of convergence in TFP on sectoral level.

3.1. Analysis of the Results on Malmquist Indices

First, we compare the Malmquist indices based on the two alternative DEA models. Figure 1 shows the evolution of average Malmquist indices in each industry. Here and below the average is computed by means of weighted geometric means. The solid line corresponds to contemporaneous frontiers and the dotted line to sequential frontiers. We can see that the two lines almost coincide, which indicates that the two measures of TFP growth produce very close results. However, this is not the case for the components in the decompositions of the Malmquist indices. Figure 2 demonstrates that the technical change components associated with the alternative approaches behave differently. The contemporaneous measure $TECH_C$ shows much more volatility than the sequential one. This is because it classifies each change in productivity of countries that belong to the frontier as technical change. On the contrary, $TECH_S$ registers only those changes that lead to the expansion of the production possibility set. For example two oil crises of 1973 and of 1979, which caused overall fall in productivity, appear as declines in $TECH_C$, however have no impact on $TECH_S$.

Table 1. Summary of correlations between the alternative Malmquist indices and their components.

Industry	cor (M_C, M_S)	cor ($EFFCH_C$, $EFFCH_S$)	cor ($TECH_C$, $TECH_S$)
FOD	0.971	0.807	0.756
TEX	0.979	0.899	0.712
CHE	0.989	0.444	0.336
MNM	0.991	0.657	0.556
BMI	0.985	0.727	0.470
MEQ	0.984	0.561	0.522

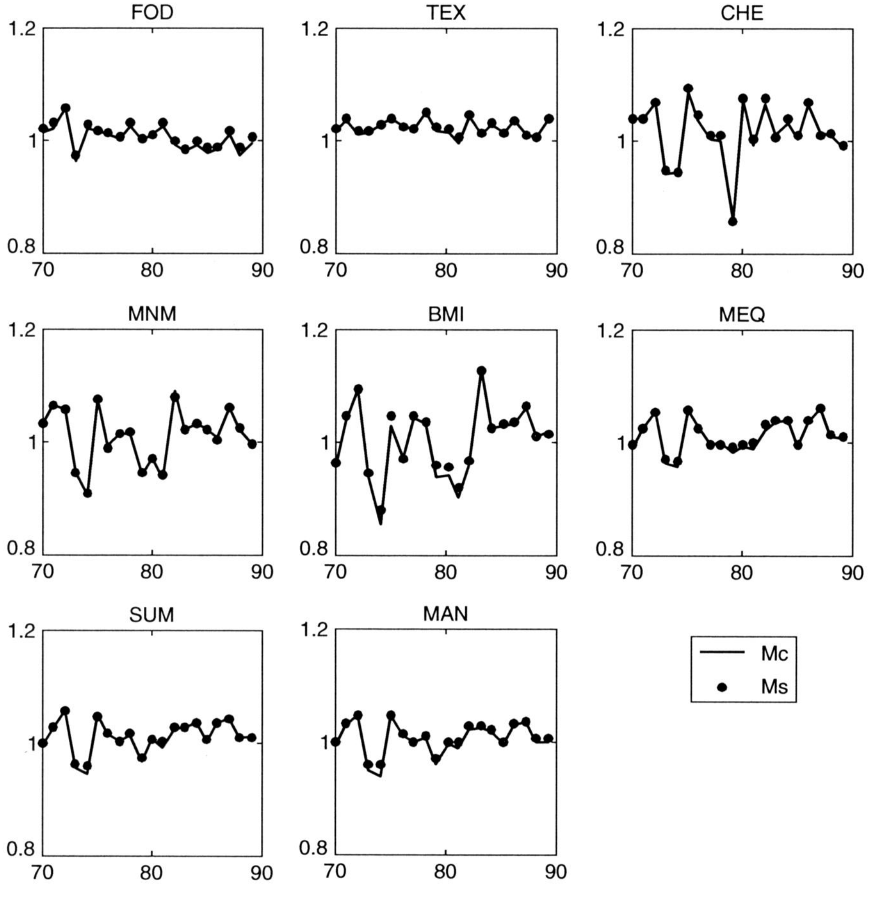

Figure 1. Evolution of the contemporaneous and sequential Malmquist indices. (*Note:* The graph for 'MAN' presents the results for total manufacturing. 'SUM' is used for the sum of the six studied industries.)

Table 1 summarizes the correlations between the Malmquist indices and between their components. The first column shows correlations between the Malmquist indices: all numbers there are above 0.97. The next two columns correspond to efficiency change and technical change and give much smaller values than those in the first column. We observe

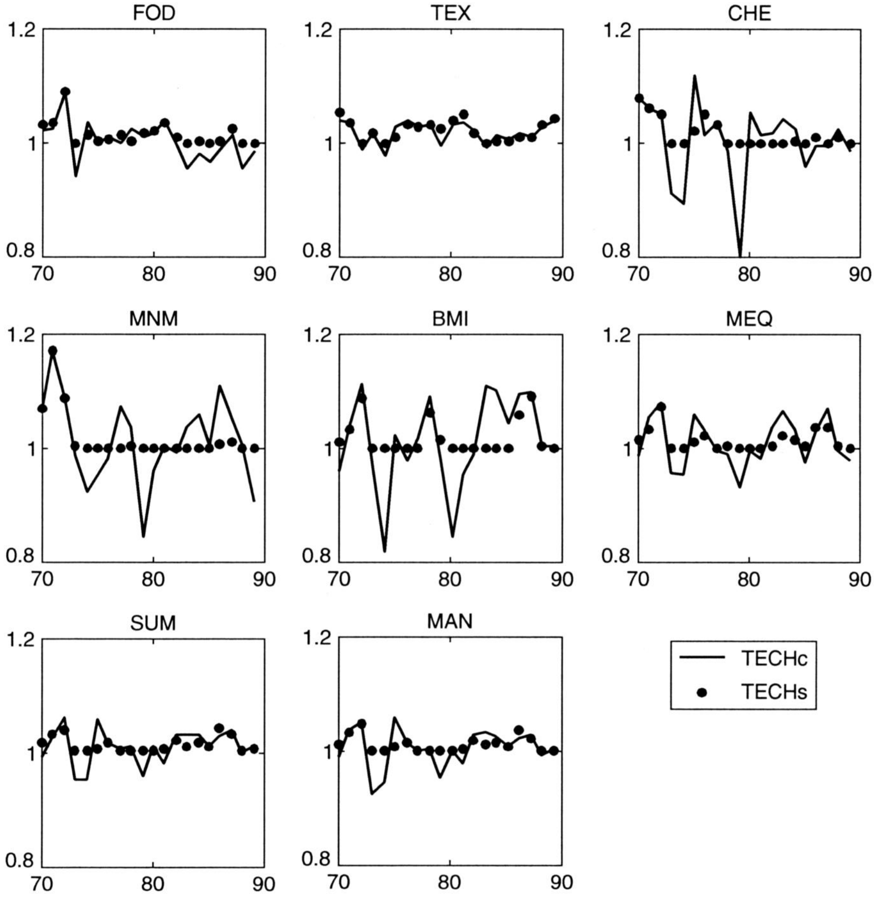

Figure 2. Indices of technical changes (*TECH*) measured as shifts of the contemporaneous and the sequential frontiers correspondingly. (*Note:* The graph for 'MAN' presents the results for total manufacturing. 'SUM' is used for the sum of the six studied industries.)

that although the correlation between Malmquist indices is very high, the components show much less correlation. Thus, there is little discrepancy between the two Malmquist indices while there are significant differences in their decompositions. This agrees with our earlier finding from the analysis of Figures 1 and 2: the indices of TFP growth are very close, however their decompositions provide different interpretations to the sources of productivity growth. This is because contemporaneous indices, $TECH_C$, classify each change in productivity of the frontier countries as technical change. Thus they cover both forward and backward shifts of the frontier. In contrast, sequential indices, $TECH_S$, register only those changes that lead to the expansion of the production possibility set. The other changes are attributed to catch-up and reflected in $EFFCH_S$.

In Table 2 we compare the Malmquist indices and the corresponding technical change and efficiency change components for two subperiods: 1970–1980 and 1980–1990. According

Table 2. Comparison of the Malmquist indices and their components for subperiods 1970–1980 and 1980–1990.

Industry	M_C	M_S	$TECH_C$	$TECH_S$	$EFFCH_C$	$EFFCH_S$
1970–1980						
FOD	1.013	1.018	1.015	1.021	0.998	0.997
TEX	1.026	1.029	1.019	1.024	1.007	1.005
CHE	0.993	0.999	0.984	1.027	1.010	0.973
MNM	1.000	1.001	1.004	1.029	0.996	0.972
BMI	0.984	0.995	0.992	1.020	0.992	0.975
MEQ	1.004	1.007	0.999	1.014	1.005	0.992
1980–1990						
FOD	0.995	1.002	0.991	1.011	1.004	0.992
TEX	1.020	1.023	1.018	1.022	1.002	1.001
CHE	1.008	1.012	0.991	1.002	1.018	1.010
MNM	1.007	1.008	0.993	1.001	1.015	1.006
BMI	0.999	1.006	1.013	1.015	0.986	0.991
MEQ	1.016	1.021	1.007	1.011	1.009	1.009

to both indices, textile industry experienced the highest TFP growth over the whole period. Although the technical change component was especially high in the first subperiod, four out of six industries showed a better performance in the eighties. This later subperiod is characterized by somewhat higher catch up than the first subperiod. Notice also that in a half of the cases we obtain $TECH_C$ less than one, indicating the average decline of productivity of the leaders in the corresponding industries.

Table 3 presents the numerical results of the decomposition of TFP growth indices outlined in (8) and (9) over the period of 20 years. The average numbers are computed by means of weighted geometric means over the period. The last column in the table is given for the

Table 3. Decomposition of the Malmquist indices.

Industry	M_C	$EFFCH_C$	$\frac{TECH_C}{TECH_S}$	$TECH_S$	$TECH_C$
FOD	1.003	1.002	0.986	1.015	1.001
TEX	1.023	1.003	0.997	1.023	1.020
CHE	1.010	1.012	0.985	1.013	0.998
MNM	1.007	1.000	0.992	1.015	1.007
BMI	0.995	0.991	0.987	1.017	1.004
MEQ	1.012	1.005	0.995	1.013	1.008
Industry	M_S	$EFFCH_C$	$\frac{EFFCH_S}{EFFCH_C}$	$TECH_S$	$EFFCH_S$
FOD	1.009	1.002	0.993	1.015	0.994
TEX	1.026	1.003	1.000	1.023	1.003
CHE	1.015	1.012	0.990	1.013	1.002
MNM	1.008	1.000	0.993	1.015	0.993
BMI	1.002	0.991	0.994	1.017	0.985
MEQ	1.016	1.005	0.998	1.013	1.003

reader's convenience, to facilitate the comparison between the three-term decomposition of the Malmquist indices and their two-term decomposition (5). The highest TFP growth was observed in textile, machinery and chemical industries, and the lowest in basic metal products. Most of TFP growth is attributed to technical progress, the contribution was about 1.5–2% in all industries. The contribution of catching up was modest in most sectors, and even negative in the case of basic metal industry. Only in chemicals have we found a strong effect of catching up (1.3%). Therefore, for the average of OECD countries, the productivity gains in manufacturing are due to technical progress. The contribution of the business cycle component appeared to be negative in most cases. The factor $\frac{TECH_C}{TECH_S}$ was always less than $\frac{EFFCH_S}{EFFCH_C}$, which implies that M_S was above M_C.

As we explained in Section 2, changes in the position of the current productivity leaders relative to the sequential frontier are not necessarily changes in technology. More likely they are attributed to the cyclical processes in the economies. The corresponding component has been dubbed as 'business cycle' to emphasize its cyclical nature. Separating effects of technical changes from cyclical behavior is desirable for the correct interpretation of productivity changes, as well as for the correct measuring of technical progress.

Cycles are closely related to variations in capacity utilization, and so does our 'business cycle' component. The contemporaneous frontier shifts inward when the utilization of capacity in the best-practice countries decreases, and moves back, when it restores. We recognize, however, that the effect of capacity utilization on TFP is much more complex. In particular, changes in capacity utilization contribute to the efficiency change component as well.[7]

3.2. *Evolution of Efficiency*

In this section we apply the DEA model considered above to analyze the evolution of efficiency in the selected sectors. Table 4 summarizes the results for average efficiency θ_C in each sector for four periods: 1970–1975, 1976–1980, 1981–1985 and 1986–1990. From these results we can identify technological leaders. They are listed in Table 5 on the next page. The table shows that in most cases the leaders keep their leading position over the whole 20-year period.

Table 6 shows the average efficiency level of the industries for both methods. The second column gives lower numbers indicating that the contemporaneous frontier was sometimes shifting back in each industry. The gap between the two efficiency measures is very small for the textile industry (less than 1%), but rather high in chemicals, basic metal products, and in non-metallic mineral products (about 10%), suggesting more backward shifts of the contemporaneous frontier in the latter three industries comparing with the others.

As we have noted in Section 2.1 contemporaneous efficiency provides us with a natural framework for studying convergence. (For more on convergence see, e.g., Abramovitz, 1986; Barro and Sala-i-Martin, 1991; Wolff, 1993, etc.) Convergence means that observations move towards the frontier in the course of time. The distance function reflects the distance between observations and the frontier. If there is convergence in TFP, then the mean efficiency[8] in the industry should approach to one with time, while the coefficient

Table 4. Contemporaneous efficiency.

Industry	Bel	Can	Den	Fin	Fra	WG	Ita	Jap	Swe	GB	US
FOD											
1970–1975	0.738	0.969	0.364	0.476	0.783	0.785	0.726	1.000	0.713	0.652	1.000
1976–1980	0.782	0.953	0.404	0.436	0.806	0.794	0.768	1.000	0.646	0.638	1.000
1981–1985	0.821	0.856	0.442	0.447	0.731	0.777	0.773	1.000	0.664	0.663	1.000
1986–1990	0.901	0.992	0.510	0.481	0.735	0.858	0.838	1.000	0.744	0.778	1.000
TEX											
1970–1975	0.654	0.963	0.728	0.595	1.000	0.807	0.824	0.503	0.964	0.934	0.777
1976–1980	0.722	1.000	0.838	0.592	0.993	0.885	0.944	0.474	0.846	0.786	0.895
1981–1985	0.782	1.000	0.917	0.651	1.000	0.803	0.912	0.512	0.725	0.801	0.908
1986–1990	0.868	1.000	0.759	0.658	0.999	0.862	0.970	0.443	0.762	0.793	1.000
CHE											
1970–1975	0.192	0.404	0.490	0.397	0.643	0.916	0.290	1.000	0.711	0.712	0.722
1976–1980	0.313	0.451	0.627	0.421	0.764	0.997	0.465	1.000	0.713	0.800	0.684
1981–1985	0.593	0.485	0.663	0.487	0.866	1.000	0.627	1.000	0.741	0.736	0.766
1986–1990	0.755	0.545	0.629	0.541	0.880	1.000	0.825	1.000	0.751	0.836	0.925
MNM											
1970–1975	0.628	1.000	0.744	0.609	0.778	0.781	0.638	0.792	0.753	1.000	0.818
1976–1980	0.698	0.985	0.719	0.602	0.887	0.876	0.837	0.657	0.710	1.000	0.809
1981–1985	0.939	0.943	0.713	0.748	1.000	0.950	0.836	0.788	0.828	1.000	0.817
1986–1990	0.964	0.995	0.576	0.702	1.000	0.884	0.806	0.720	0.780	1.000	0.842
BMI											
1970–1975	0.507	0.574	0.364	0.339	0.487	0.750	0.589	0.884	0.336	1.000	1.000
1976–1980	0.652	0.573	0.309	0.385	0.516	0.885	0.526	0.970	0.343	0.978	0.922
1981–1985	0.788	0.554	0.396	0.494	0.531	1.000	0.643	0.957	0.420	1.000	0.846
1986–1990	0.786	0.499	0.390	0.447	0.476	1.000	0.571	0.788	0.393	1.000	0.657
MEQ											
1970–1975	0.865	0.974	0.775	0.544	0.860	0.945	0.597	0.606	0.732	0.914	1.000
1976–1980	0.936	1.000	0.742	0.552	0.916	0.976	0.707	0.607	0.676	0.750	1.000
1981–1985	0.998	0.990	0.780	0.645	0.907	0.938	0.759	0.795	0.758	0.687	1.000
1986–1990	0.932	1.000	0.658	0.746	0.909	0.920	0.808	0.873	0.742	0.747	1.000

Table 5. The leaders.

Industry	The Leading Countries[a]
FOD	US, Japan, Canada*
TEX	Canada, France, US*
CHE	Japan, West Germany*
MNM	GB, Canada, France*
BMI	GB, West Germany*, US*
MEQ	US, Canada, Belgium*

[a] A star next to a country name indicates that the country was leading not over the whole 20-year period.

Table 6. Average contemporaneous efficiency.

Industry	Contemporaneous	Sequential
FOD	0.888	0.851
TEX	0.843	0.834
CHE	0.820	0.707
MNM	0.826	0.737
BMI	0.831	0.733
MEQ	0.898	0.865

of variation should decline (the so-called σ-convergence). Figure 3 shows the evolution of the average efficiency and the corresponding coefficient of variation in each industry. Strong convergence of TFP levels is observed in chemicals. There are also some indications of convergence in food industry and machinery. The last two graphs labelled by 'SUM'

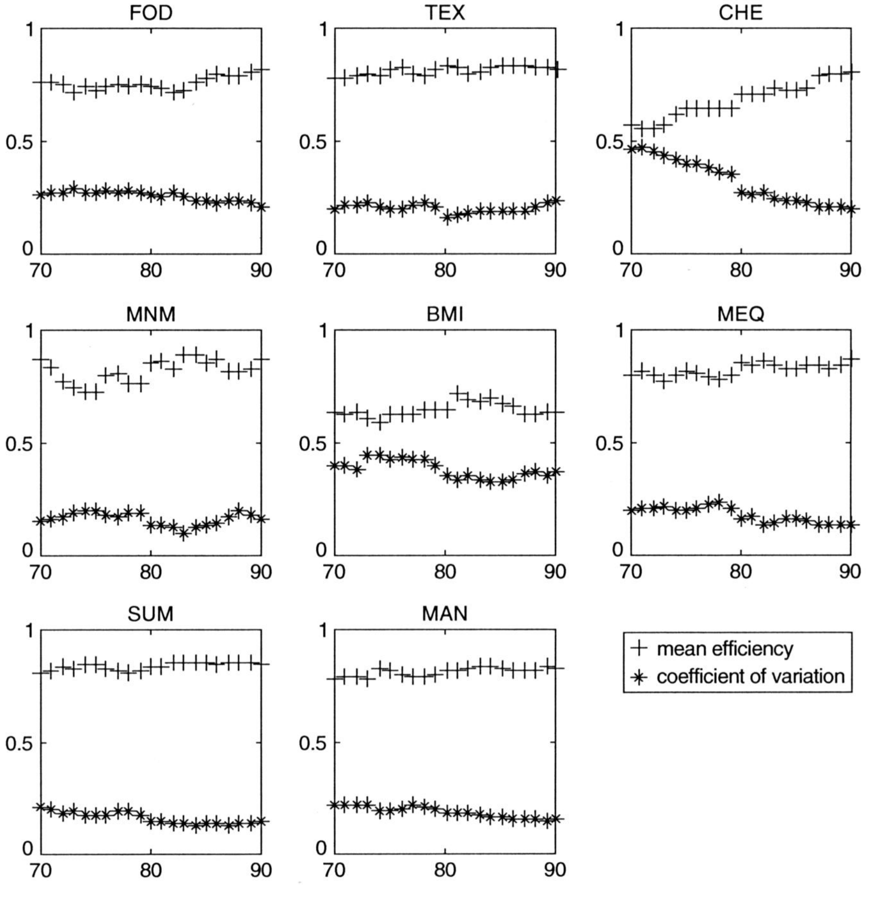

Figure 3. Evolution of the average efficiency and coefficient of variation in each industry. (*Note:* The graph for 'MAN' presents the results for total manufacturing. 'SUM' is used for the sum of the six studied industries.)

and 'MAN' present the results for the total of the six considered industries and for total manufacturing correspondingly. For this sample of eleven countries over the considered period signs of convergence of TFP are present on the aggregate level as well.

Another convergence hypothesis (β-convergence) asserts that a country with a lower initial TFP level should have a higher TFP growth. This implies that correlation between the initial efficiency and the subsequent indices of TFP growth should be negative. The correlation analysis has shown that this was the case in chemicals, food industry and for total manufacturing, in which the result was significant at 95% level. Combining this result with the former, we conclude that these industries exhibit both σ-convergence and β-convergence.

4. Conclusion

In this paper two approaches have been used to evaluate the TFP growth in manufacturing in eleven OECD countries, namely DEA with contemporaneous frontiers and DEA with sequential frontiers. It has been demonstrated that both methods produce highly correlated results for the total measure of TFP growth, but less correlated results for the decomposition into technical changes and efficiency changes. The sequential measure takes past information into account and reallocates temporary backwards shifts in the productivity of the best-practice countries to the efficiency change component, whilst the contemporaneous measure accounts for them as a technical regress. The former is more suitable for measuring technical changes in manufacturing and suggest a decomposition of Malmquist indices, which links the two measures of TFP growth with each other. The new decomposition distinguishes three sources of TFP growth: technical progress, catching up and business cycle.

The empirical analysis has shown that most productivity increase in manufacturing in the OECD countries during the period 1970–1990 can be ascribed to technical progress. Five out of the six considered manufacturing sectors showed little or no catching up. Only in chemicals efficiency changes were substantial. We have found the strongest convergence of TFP levels for this sector. The contribution of the business cycle component of TFP growth appeared to be negative in most cases.

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Notes

1. The two cases considered in the present paper—computations with contemporaneous and sequential frontiers—do not exhaust all possibilities. One can also consider a 'window' type of computations (Charnes et al., 1985), in which the frontier in time t is based on a few years of observations.
2. Alternatively we could use an input distance function, which shows the maximum possible proportional contraction of all inputs still to be able to produce the same amount of output. This would lead to the same measure of efficiency, because input and output distance functions are equivalent under the assumption of constant returns to scale (see Färe and Grosskopf, 1996).

3. CCD refers to Caves, Christensen and Diewert (1982), who introduced this type of productivity indices.
4. Notice, since the construction of the conditional (or sequential) output set at time t uses information on all time periods within the interval $[t_0, t]$, the indices computed starting from different periods will have different sized reference sets. In practice, however, as $t - t_0$ increases, the distinction vanishes.
5. Note, we assume CRS. Condition (10) is the condition of Joint Hicks Neutrality for the CRS technology discussed in Färe and Grosskopf (1996).
6. The ISDB gives value added in market prices. The rate of indirect taxes is also included in the ISDB, but it is missing in many cases. In this work no adjustment for indirect taxes has been introduced.
7. Recently De Borger and Kerstens (2000) suggested a way of incorporating of capacity utilization variations in the Malmquist index, by separating the variation in capacity utilization from the efficiency change component.
8. In this paragraph and in Figure 3 we refer to simple arithmetic means and the standard coefficient of variation, since they are commonly used in literature on convergence.

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