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Productivity and technical change: the case of Taiwan

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This paper analyses productivity growth in 16 of Taiwan's manufacturing industries during the period 1978–1992. The non-parametric Data Envelopment Analysis approach is used to compute Malmquist productivity indexes. These are decomposed into efficiency change and technical change. The latter is further decomposed into an output bias, an input bias and a magnitude component. In addition, the direction of input bias is identified. Empirical results indicate that the sector's TFP increased at a rate of 2.89% per annum, which could be ascribed to a technical progress (2.56%) and an efficiency improvement (0.33%).

I. INTRODUCTION

Productivity is of interest to economists and policymakers, because productivity growth is a major source of economic growth and welfare improvement. Technical advance (shift in production frontier) and technical efficiency change (movement towards or away from production frontier) are two key factors to productivity growth, which are associated with different sources, and so different policies may be required to address them. Therefore, it is important to decompose productivity growth into these two components: technical change and technical efficiency change.

Technical change may be neutral or biased in output and/or input dimensions. The biases indeed have impacts on factor income distribution and hence policy implications associated with them. It is therefore interesting to identify the directions of technical change biases and to measure them empirically.

Färe *et al*. (1995) investigated producitivity in four of Taiwan's manufacturing industry groupings during 1978–1989. This paper explores the issues mentioned above for a more disaggregated case of 16 manufacturing industries at the 2-digit level grouping during the period 1978–1992. To pursue the goal the method initiated by Färe *et al*. (1989) and used in Färe *et al*. (1995) is applied, i.e. the Malmquist total factor productivity (TFP) index is decomposed into two components: technical change and technical efficiency change. Here, however, the technical change components are further decomposed, in particular defining output bias, input bias and a magnitude term. In addition, identifying the directions of the input biases.

The Malmquist TFP index used is a geometric mean of two Malmquist indexes introduced by Caves *et al*. (1982).[1] Unlike Caves *et al*., this Malmquist TFP index allows for technical efficiency change. The component distance functions of the Malmquist index were calculated using non-parametric DEA (Data Envelopment Analysis, Charnes *et al*. 1978) approach. The techniques construct a 'grand' frontier based on the data from all of the industries in the sample. Each industry is compared to that frontier. How much closer an industry gets to the grand frontier is called 'technical efficiency', how much the grand frontier shifts at each industry's observed input mix is called 'technical change'.

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[1] The Malmquist index introduced by Caves *et al*. is equivalent, under certain conditions, to the Törnqvist index. These conditions include that technology is translog, second-order terms are constant over time, and firms are cost-minimizers and revenue-maximizers. The Malmquist TFP index is more general than the Tornqvist index, since it allows for inefficient performance, does not presume an underlying functional form for technology and does not require data on prices or factor shares. The merits have made Malmquist index more popular in recent years.

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The paper is organized as follows. Section II highlights the decomposition of the Malmquist TFP index into technical change and efficiency change, and the further decomposition of technical change into bias terms. Section III presents a brief description of the role of the manufacturing in the development of the Taiwan economy and the data used here. Section IV briefly discusses the estimation method. Section V presents the empirical results. Concluding remarks are made in Section VI.

II. THE PRODUCTIVITY MODEL

In this paper, as in Färe *et al.* (1995), a Malmquist index is used to measure productivity. Here, however, the technical change component is decomposed into an output bias, an input bias and a magnitude term, and the direction of the input bias is determined, i.e. towards which factor the bias operates.

Recall that the output distance function at time t can be defined on the technology $S^t = \{(x^t, y^t): x^t \text{ can produce } y^t\}$ as (Shephard, 1970; Färe, 1988)

$$D_0^t(x^t, y^t) = \inf\{\theta: (x^t, y^t/\theta) \in S^t\} \tag{1}$$

In the special case where a single output is produced we may write the output distance function as

$$D_0^t(x^t, y^t) = y^t/F^t(x^t) \tag{2}$$

where $F^t(x^t)$ is the production function defined by

$$F^t(x^t) = \max\{y^t: (x^t, y^t) \in S^t\} \tag{3}$$

If outputs are weakly disposable, i.e $(x^t, y^t) \in S^t$ and $0 \leqslant \theta \leqslant 1$, then $(x^t, \theta y^t) \in S^t$, then

$$D_0^t(x^t, y^t) \leqslant 1 \quad \text{if any only if } (x^t, y^t) \in S^t \tag{4}$$

in which case the output distance function completely characterizes the technology. It is also observed that the distance function is homogeneous of degree +1 in outputs, meaning that

$$D_0^t(x^t, \theta y^t) = \theta D_0^t(x^t, y^t), \theta > 0 \tag{5}$$

Here the tradition started by Färe *et al.* (1989) is followed and the Malmquist total factor productivity index is defined as the geometric mean of two Malmquist indexes as defined by Caves *et al.* (1982), namely

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D_0^t(x^{t+1}, y^{t+1}|CRS)}{D_0^t(x^t, y^t|CRS)} \frac{D_0^{t+1}(x^{t+1}, y^{t+1}|CRS)}{D_0^{t+1}(x^t, y^t|CRS)}\right]^{1/2} \tag{6}$$

This index employs distance functions from two different periods' constant returns to scale or technologies, $D_0^t(\cdot,\cdot)$, $D_0^{t+1}(\cdot,\cdot)$ and two pairs of input-output vectors, namely (x^t, y^t) and (x^{t+1}, y^{t+1}). This index also involves two mixed period distance functions. In particular, $D_0^{t+1}(x^t, y^t) = \inf\{\theta: (x^t, y^t/\theta) \in S^{t+1}\}$.

Färe *et al.* (1989) showed that the Malmquist index Equation 6 can be decomposed into two components, namely efficiency change (EFFCH) and technical change (TECH)

$$\text{EFFCH} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1}|CRS)}{D_0^t(x^t, y^t|CRS)} \tag{7}$$

$$\text{TECH} = \left[\frac{D_0^t(x^{t+1}, y^{t+1}|CRS)}{D_0^{t+1}(x^{t+1}, y^{t+1}|CRS)} \frac{D_0^t(x^t, y^t|CRS)}{D_0^{t+1}(x^t, y^t|CRS)}\right]^{1/2} \tag{8}$$

Productivity advance occurs if $M(\cdot) > 1$. Similarly, improvements in efficiency occur if EFFCH > 1, and technical advance occurs if TECH > 1.

Färe and Grosskopf (forthcoming, Proposition 3.2.7) showed that the CRS is necessary and sufficient for the Malmquist productivity index to be a true productivity index when productivity index is defined as the ratio of two average products for two periods in a one-input and one-output case. Nevertheless, the CRS Malmquist index in Equation 6 can accommodate nonconstant returns. Using an enhanced decomposition developed in Färe *et al.* (1994), the EFFCH component can be rewritten as the product of two components: an efficiency change component relative to the variable returns to scale technology (VRSEFFCH), and a scale efficiency component (SCALECH) capturing changes in the deviation between the VRS frontier and the CRS frontier. The two components are given by

$$\text{VRSEFFCH} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1}|VRS)}{D_0^t(x^t, y^t|VRS)} \tag{9}$$

$$\text{SCALECH} = \frac{D_0^t(x^t, y^t|VRS)/D_0^t(x^t, y^t|CRS)}{D_0^{t+1}(x^{t+1}, y^{t+1}|VRS)/D_0^{t+1}(x^{t+1}, y^{t+1}|CRS)} \tag{10}$$

In order to clarify the above measure indexes, consider Fig. 1, which illustrates construction of reference technology for scalar input and output for period t. There are four observations of industries A, B, C and D. Under strong disposability of inputs and outputs, non-parametric DEA approach yields the following reference (or frontier) technologies in period t. The CRS technology is a cone with vertex at 0; the NIRS (non-increasing returns to scale) technology is bounded by OAB and the horizontal extension from B; the VRS technology is bounded by $x_D^t DAB$ and the horizontal extension from B. In Fig. 1, for observation (x_c^t, y_c^t), $D_0^t(x_c^t, y_c^t|CRS) = od/of$, and

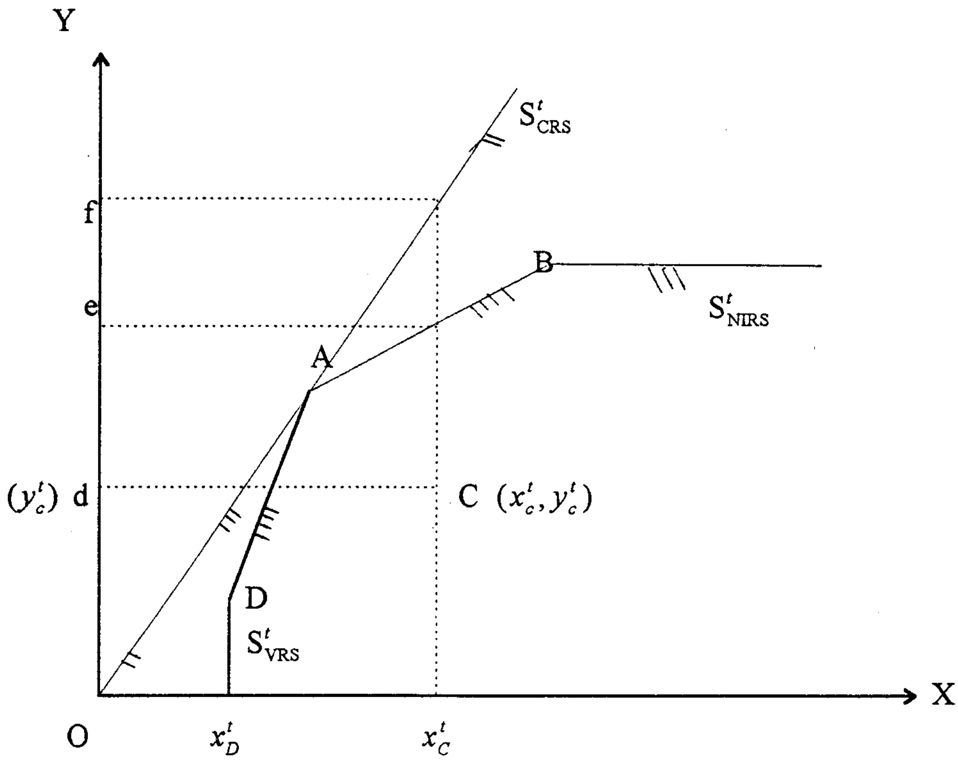

Fig. 1. *Construction of reference technology*

$D_0^t(x_c^t, y_c^t|VRS) = od/oe$. Thus Farrell's technical efficiency relative to CRS is of/od, technical efficiency relative to VRS is oe/od, and the scale efficiency is of/oe. It is also noted that the technical efficiency change (EFFCH or VRSEFFCH) would be the ratio of technical efficiency in period t and $t+1$, the scale efficiency change (SCALECH) would be the ratio of scale efficiency in period t and $t+1$. Furthermore, with the estimates of mixed distance functions, it could calculate the Malmquist productivity index ($M_0(\cdot)$) and technical change (TECH).

Following Färe and Grosskopf (forthcoming), TECH in Equation 8 can be written as (henceforward suppressing CRS for notational simplicity)

$$\text{TECH} = \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \frac{D_0^{t+1}(x^{t+1}, y^t)}{D_0^t(x^{t+1}, y^t)}\right]^{1/2} \times \left[\frac{D_0^{t+1}(x^t, y^t)}{D_0^t(x^t, y^t)} \frac{D_0^t(x^{t+1}, y^t)}{D_0^{t+1}(x^{t+1}, y^t)}\right]^{1/2} \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \quad (11)$$

The first bracketed term denotes output biased technical change (OBTECH), the second term measures input biased technical change (IBTECH), and the last ratio denotes the magnitude of technical change (MATECH).

To see how these terms capture bias, consider the input bias term. The first ratio in IBTECH measures the shift in technology between period t and $t+1$ evaluated at the input-output vector observed in period t. The second ratio in IBTECH also measures the shift in technology between period t and $t+1$ but does so at the input level observed in period $t+1$. Note, however, that output does not change – it is at the level observed in period t. Thus the only thing that changes is the input vector. If there is technical change (i.e. technology shifts), that change will be input biased if the product of these two terms does not equal unity.

In this study, the technology produces only one output, thus OBTECH $= 1$. This conclusion follows from the property that the output distance function is homogeneous of degree $+1$ in outputs. Thus, we get

$$\text{TECH} = \text{IBTECH} \cdot \text{MATECH} \quad (12)$$

Under constant returns to scale, the input and output distance functions are reciprocal, hence IBTECH may be written as

$$\text{IBTECH} = \left[\frac{D_i^t(y^t, x^t)}{D^{t+1}(y^t, x^t)} \cdot \frac{D_i^{t+1}(y^t, x^{t+1})}{D_i^t(y^t, x^{t+1})}\right]^{1/2} \quad (13)$$

Furthermore for the single output case, under constant returns to scale, IBTECH is independent of outputs, i.e.

$$\text{IBTECH} = \left[\frac{D_i^t(1, x^t)}{D_i^{t+1}(1, x^t)} \frac{D^{t+1}(1, x^{t+1})}{D_i^t(1, x^{t+1})}\right]^{1/2} \quad (14)$$

The magnitude component equals

$$\text{MATECH} = \frac{D_0^t(x^t, 1)}{D_0^{t+1}(x^t, 1)} \tag{15}$$

Returning to the input bias term Equation 14, it is said that there is Hicks neutral technical change or no bias if IBTECH equals one, i.e. if

$$\frac{D_i^t(1, x^t)}{D_i^{t+1}(1, x^t)} = \frac{D_i^t(1, x^{t+1})}{D_i^{t+1}(1, x^{t+1})} \tag{16}$$

Now whenever only two inputs are used

$$\frac{D_i^t(1, x_1^t, x_2^t)}{D_i^{t+1}(1, x_1^t, x_2^t)} = \frac{D_i^t(1, x_1^{t+1}, x_2^{t+1})}{D_i^{t+1}(1, x_1^{t+1}, x_2^{t+1})} \tag{17}$$

or since the input distance function is homogeneous of degree +1 in inputs,

$$\frac{D_i^t(1, 1, x_2^t/x_1^t)}{D_i^{t+1}(1, 1, x_2^t/x_1^t)} = \frac{D_i^t(1, 1, x_2^{t+1}/x_1^{t+1})}{D_i^{t+1}(1, 1, x_2^{t+1}/x_1^{t+1})} \tag{18}$$

The last expression may be used to measure the direction of bias. As illustrated, if there is an inequality in Equation 18 such that the left-hand side is larger than the right-hand side, one can say the bias is Hicks x_1-using when $x_2^{t+1}/x_1^{t+1} < x_2^t/x_1^t$, and x_2-using when $x_2^{t+1}/x_1^{t+1} > x_2^t/x_1^t$. On the other hand, if the left-hand side is less than the right-hand side, then the bias is x_1-using when $x_2^{t+1}/x_1^{t+1} > x_2^t/x_1^t$, and x_2-using when $x_2^{t+1}/x_1^{t+1} < x_2^t/x_1^t$.

To illustrate the direction of technical change, consider Figs. 2 and 3. It is assumed that $S^t \subseteq S^{t+1}$. In each figure there are four input sets $L^t(1), L_n^{t+1}(1), L_1^{t+1}(1)$, and $L_2^{t+1}(1)$, all producing at least one unit of output. The latter three sets reflect different types of technical change; $L_n^{t+1}(1)$ is drawn with a Hicks neutral technical change, $L_1^{t+1}(1)$ is associated with x_1-using, and $L_2^{t+1}(1)$ is associated with x_2-using technical change.[2]

First consider Fig. 2, where x_2/x_1 ratio decreases, i.e. $x_2^{t+1}/x_1^{t+1} < x_2^t/x_1^t$. When $L_n^{t+1}(1)$ and $L^t(1)$ are compared, x^t and x^{t+1} imply that IBTECH in Equation 13 is as follows

$$\text{IBTECH} = \left[\frac{\dfrac{ox^t}{ob}}{\dfrac{ox^t}{oc}} \cdot \frac{\dfrac{ox^{t+1}}{oe_n}}{\dfrac{ox^{t+1}}{of}}\right] = \left[\frac{oc}{ob} \cdot \frac{of}{oe_n}\right]^{1/2} \tag{19}$$

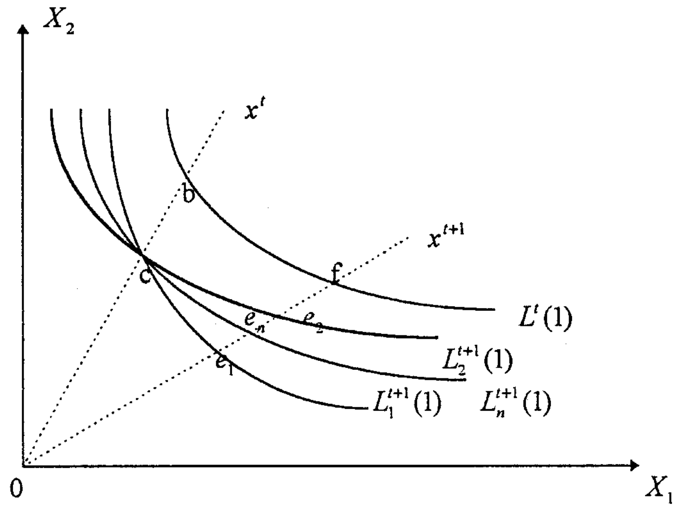

Fig. 2. *Technical change (I)*

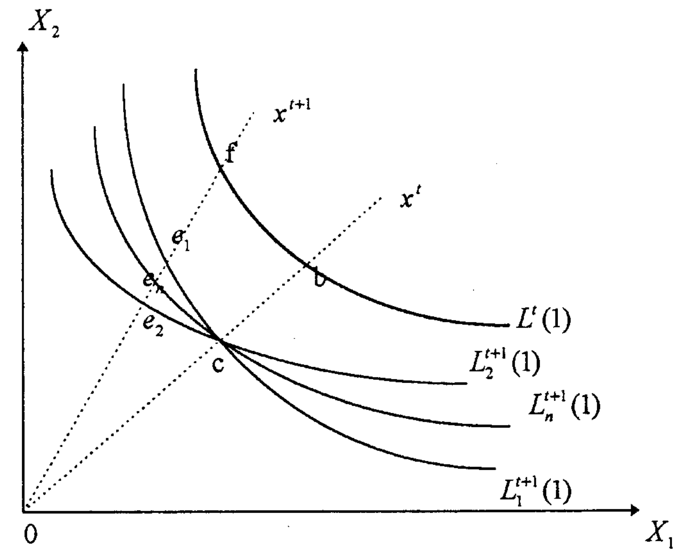

Fig. 3. *Technical change (II)*

If Equation 19 is equal to one, then

$$\frac{ob}{oc} = \frac{of}{oe_n} \tag{20}$$

i.e. the line through points c and e_n is parallel to the line through points b and f. Now on the other hand, Hicks neutrality implies a 'homothetic' inward shift of unit isoquant, and thus Equation 20 holds. Therefore, it is possible

[2] Hicks' definition is as follows (see Binswanger, 1974): technical change is said to be neutral, x_1-using or x_2-using depending on whether, at a constant x_2/x_1 ratio, the marginal rate of technical substitution (MRTS) stays constant, increases or decreases. Mathematically neutrality can be written as

$$\frac{d}{dt}MRTS = \frac{d}{dt}\left[\frac{F_1^t}{F_2^t}\right] = -\frac{d}{dt}\frac{dx_2}{dx_1} = 0$$

where F_1^t and F_2^t stand for the marginal products and x_2/x_1 ratio is held constant. Neutrality implies, therefore, a homothetic inward shift of the unit isoquant.

Table 1. *Technical change direction*

	IBTECH < 1	IBTECH = 1	IBTECH > 1
$\dfrac{x_2^{t+1}/x_1^{t+1}}{x_2^t/x_1^t} < 1$	x_2-using	Neutral	x_1-using
$\dfrac{x_2^{t+1}/x_1^{t+1}}{x_2^t/x_1^t} > 1$	x_1-using	Neutral	x_2-using

to say if Equation 18 holds,[3] there is a Hicks neutral technical change.

Meanwhile, in Fig. 2 if technical change shifts the isoquant to $L_1^{t+1}(1)$, then $ob/oc < of/oe_1$, which in turn implies IBTECH > 1. Therefore, we say if $x_2^{t+1}/x_1^{t+1} < x_2^t/x_1^t$ and IBTECH > 1, then there is a x_1-using biased technical change. On the other hand, if technical change shifts the isoquant to $L_2^{t+1}(1)$, then $ob/oc > of/oe_2$, which in turn implies IBTECH < 1. Therefore, it is said if $x_2^{t+1}/x_1^{t+1} < x_2^t/x_1^t$ and IBTECH < 1, then there is a x_2-using bias.

Figure 3 has $x_2^{t+1}/x_1^{t+1} > x_2^t/x_1^t$. By the same token, we could infer: (i) IBTECH > 1 implies x_2-using bias; (ii) IBTECH $= 1$ implies neutrality, and (iii) IBTECH < 1 implies x_1-using bias. Table 1 concludes the conditions for the direction of technical change bias.

Note that if $x_2^{t+1}/x_1^{t+1} = x_2^t/x_1^t$, then IBTECH $= 1$. In this case, one is unable to draw any conclusion about the type of technical change.

Finally, it is noted that if there are output and input technical change neutrality, then

$$\text{TECH} = \text{MATECH} = \frac{D_0^t(x^t, t^t)}{D_0^{t+1}(x^t, y^t)} = \frac{F^{t+1}(x^t)}{F^t(x^t)} \qquad (21)$$

where the last measure is equivalent to the definition given by Diewert (1980: 263–4).

III. THE BACKGROUND AND DATA

Background

The development of the Taiwanese economy over the past four decades was characterized by rapid economic growth, low unemployment, stable prices, and high dependence on international trade.[4] The economy moved from an agricultural to an industrial orientation. The share of agriculture on GDP dropped from 32% in 1952 to 4% in 1990, while the share of the industrial sector rose from 20% to 42% over the same period. The rapid expansion of the industrial sector prior to 1971 was caused primarily by the rapid growth of three manufacturing industries: food processing, textiles, and electrical machinery. After 1971, however, this tendency changed. The share of food and textiles decreased. Instead, a relative increase was observed for more capital- and skill-intensive industries, such as petrochemicals, metals, electronics, and machinery.

The general environment of the Taiwanese economy changed significantly since the 1973 oil crisis, and is expected to intensify in the 1990s. Challenges come from various domestic and international aspects, such as the expansion of international protectionism, keen competition from newcomers, sharp appreciation of the N.T. dollar, shortage in domestic infrastructure, rising wages, environmental and sanitary awareness, etc. Under such unfavourable situations for investments, the Taiwan authorities have adopted decisive polices or measures[5] to quicken the paces of industrialization, market liberalization, production upgrading, infrastructure construction and balancing regional development. It is expected to observe these

[3] The reason for Equation 20 to be true for Hicks neutrality under constant returns to scale is as follows. Suppose the production function is $F^t(x_1, x_2) = A(t)f(x_1, x_2)$. Since $f(\cdot)$ is homogeneous of degree +1, thus $F^t(x_1, x_2) = A(t)x_1 f(x_2/x_1)$. Let x^t determine an x_2/x_1 ratio, say k_t, and x^{t+1} determine another one, say k_{t+1}. Then in Fig. 2, the coordinates of points b, c, f and e_n are

$$\left(\frac{1}{A(t)f(k_t)}, \frac{k_t}{A(t)f(k_t)}\right), \left(\frac{1}{A(t+1)f(k_t)}, \frac{k_t}{A(t+1)f(k_t)}\right), \left(\frac{1}{A(t)f(k_{t+1})}, \frac{k_{k+1}}{A(t)f(k_{t+1})}\right)$$

and

$$\left(\frac{1}{A(t+1)f(k_{t+1})}, \frac{k_{t+1}}{A(t+1)f(k_{t+1})}\right)$$

respectively. Therefore, it is easy to see

$$\frac{ob}{oc} = \frac{of}{oe_n} = \frac{A(t+1)}{A(t)}$$

Here we also note that under constant returns to scale, the last expression implies that

$$\frac{D_i^{t+1}(x, y)}{D_i^t(x, y)} = \frac{A(t+1)}{A(t)}$$

for Hicks neutrality.

[4] For a comprehensive discussion of the earlier Taiwanese economic development, see Kuo (1983).

[5] For a detailed discussion of how Taiwan has carried out a series of economic plans to meet the needs of different stages of economic development, see Li (1988).

measures affecting the economy in general, and the manufacturing in particular. Indeed, under this kind of challenging and somewhat perverse environment, some manufacturing industries did not thrive, e.g. some labour-intensive industries lost their comparative advantages and then have been forced to move their facilities abroad, mainly to Thailand, Malaysia, Indonesia, Hong Kong and mainland China, where Taiwanese foreign direct investment[6] has been significantly amplifying since 1987. However, it is alleged that the sector in general has been doing well.

Recently, several studies (e.g. DGBAS, 1992; Kim and Lau, 1994; Liang, 1995; Young, 1995; Chuang, 1996) related to Taiwan manufacturing performance provide different results. The differences may stem from different techniques applied, industry breakdown or aggregation, or different time domain investigated. This paper uses a Malmquist index to measure the two-digit manufacturing industries' productivity growth and the associated issues of efficiency change, technical change and the direction of technical change bias are investigated. It is hoped that the results can lend greater insight into the sources of industrial productivity growth, and help to enhance the resource allocation and to improve income distribution in the future.

Data

Productivity growth and its components were calculated for a sample of 16 pure or almost pure private manufacturing industries[7] at the two-digit level grouping over the period 1979–1992 using data from DGBAS (The Directorate-General of Budget, Accounting and Statistics, Executive Yuan, ROC). The classification of the 16 industries (except one) is consistent with SIC code; the exception is the chemicals industry, which here includes industrial chemicals, chemical products and plastic products. The reason for the exception is the lack of disaggregation of these three industries' output in the earlier stage of the time period investigated.

The measure of industrial output is real GDP (gross domestic product), and the corresponding inputs are work-hours and utilized real capital stocks. Work-hours are dedicated by the employment population which includes employees, employers, own-account workers, and unpaid workers. GDP and capital stocks are measured in 1986 prices. The benchmark extrapolation method (see the Appendix for exposition) is adopted to estimate the capital stock. The benchmark years are designated when industrial and commercial censuses took place, and when the national wealth census was conducted in 1988. Utilized real capital stock is calculated as the product of real capital stock and equipment utilization rate.

IV. ESTIMATION

Non-parametric DEA[8] was used to construct a cross-industries best-practice grand frontier from the data in the sample. In principle, the 16 industries are quite different in nature. Therefore, it is assumed their technologies are different in factor intensities, but they share the same production frontier, i.e. they operate on very different parts of the same production function. The CRS technology is assumed to calculate the Malmquist productivity index, since it is necessary and sufficient for the Malmquist index to be the true TFP index if the productivity index is defined as the ratio of average products for two periods. Of course, as discussed above, a returns to scale or scale efficiency component can be extracted in our productivity measure. The technology in any given period is represented as an output distance function. Since only one output is present, an output distance function becomes equivalent to a production function.

V. EMPIRICAL RESULT

Output and input growth

Beginning with a descriptive summary of average annual growth rates of output, capital and labour for each industry in the sample. As seen in Table 2, the chemical, electrical and electronic, fabricated metal and machinery industries all had a more than 10% annual average growth in GDP. However, the wood and bamboo, apparel and textile mill product only had a GDP growth rate not exceeding 5%. As for capital stock, 6 out of the 16 industries had a more than 10%

[6] Since 1987, Taiwanese foreign direct investments (FDI) have dramatically increased, e.g. officially approved FDI increased from US$ 102.8 million in 1987 to $1656 million in 1991. The majority of FDI includes electronic, chemicals, primary metal, rubber and plastic, textile mill, food, apparel and wood. FDI could be defensive or expansionary. The increases in Taiwanese FDI were harmful to the growth of the manufacturing industries which use labour intensively (Lin *et al.* 1994).

[7] The analysis excludes the beverage, tobacco, petroleum and coal industries, which are pure or almost pure monopolies. The reason for this exclusion is as follows. The output values of the monopolies are inflated by monopoly profits and tax revenue and this exaggerates the relative productivity of the monopoly. As a result, the best-practice technology would be inappropriately identified if without the exclusion. The study is greatly indebted to one of the referees for bringing this to its attention. When two industries were included, the resulting estimate was peculiar: technology regressed, which contrasts with the alleged view that the manufacturing in general has been doing well, although some labour-intensive industries did not thrive.

[8] The DEA expression was coined by Charnes *et al.* (1978) in their use of the activity analysis for efficiency gauging.

Table 2. *Average annual growth rates: real GDP, real capital stock and labour: 1978–1992*

Industry	GDP	Capital	Labour
Food and kindred products	0.0634	0.0755	0.0038
Textile mill products	0.0487	0.0553	−0.0244
Apparel and other textile products	0.0323	0.0290	0.0099
Leather, fur and related products	0.0691	0.1201	0.0146
Wood and bamboo products, non-metallic furnitures	0.0104	0.0479	−0.0302
Paper, paper products, printing and publishing	0.0742	0.0929	0.0418
Chemicals and chemical products	0.1178	0.0912	0.0180
Rubber products	0.0729	0.1147	0.0047
Non-metallic mineral products	0.0637	0.0896	0.0121
Primary metal products	0.0966	0.1113	0.0345
Fabricated metal products	0.1062	0.1329	0.0590
Machinery except electrical equipment	0.1055	0.1110	0.0384
Electrical and electronic equipment	0.1097	0.0882	0.0352
Transportation equipment	0.0750	0.0612	0.0351
Precision equipment	0.0661	0.1063	0.0382
Miscellaneous	0.0549	0.0682	0.0187

Table 3. *Capital–labour ratios: selected years, Unit: million NT$/thousand work-hour*

Industry	1978	1983	1988	1992
Food and kindred products	1.0868	1.7118	2.5970	2.8263
Textile mill products	0.9382	1.3005	2.1319	2.8375
Apparel and other textile products	0.5739	0.5354	0.5847	0.7657
Leather, fur and related products	0.2149	0.2865	0.5621	0.8701
Wood and bamboo products, non-metallic furnitures	0.5430	0.6595	0.8852	1.6797
Paper, paper products, printing and publishing	1.0096	1.1407	1.7581	1.9443
Chemicals and chemical products	1.2404	1.3426	2.1211	3.3121
Rubber products	0.4169	0.7344	1.2612	1.1974
Non-metallic mineral products	1.1541	1.5663	2.6397	3.2400
Primary metal products	2.5097	4.6267	6.2717	6.7544
Fabricated metal products	0.4057	0.4980	0.8806	1.0493
Machinery except electrical equipment	0.5610	0.8907	1.4104	1.4557
Electrical and electronic equipment	0.4885	0.6412	0.6755	1.0503
Transportation equipment	0.9703	1.2260	1.2844	1.4049
Precision equipment	0.4175	0.5549	0.7518	1.0355
Miscellaneous	0.2878	0.2497	0.3179	0.5894

annual average growth rate; however, two industries increased their capital not exceeding 5% annually. As for labour input, all the industries (except fabricated metal industry) had a growth rate not exceeding 5%, but the textile mill, and wood industries even decreased the employment level.

Evidence concerning the capital–labour ratios is summarized in Table 3. It can be seen that all the industries increased capital–labour ratio almost all the time. However, capital–labour ratios were quite different among industries. The primary metal industries had the highest ratio (6.75 in 1992), the chemicals ranked second (3.31 in 1992), the non-metallic mineral came to the third (3.24 in 1992), and the miscellaneous industry had the lowest ratio (0.59 in 1992).

Production frontier and technical efficiency

Since the basic component of the Malmquist index is related to measures of technical efficiency, technical efficiency is reported first for the industries for selected years in Table 4. Here the output distance function used is the reciprocal of the output-based Farrell measure of technical efficiency,[9] and following Färe *et al.* (1985) the Farrell technical efficiency is computed using linear programming for each observation. Values of unity imply that the industry is on the industry-wide frontier in the associated year. Values exceeding unity imply that the industry is below the frontier or technically inefficient. As reported for the four selected years (1979, 1983, 1987 and 1992), the apparel, primary metal, transportation, precision

[9] Precisely, the Farrell output-based measure of technical efficiency is defined as $F_0(x, y) = \max\{\theta: \theta y \in P(x)\}$, where $P(x)$ is the output set obtainable from x.

Table 4. *The Farrell technical efficiency: selected years*

Industry	1979	1983	1987	1992
Food and kindred products	1.7741	1.7277	1.3156	1.5483
Textile mill products	2.7715	2.5115	1.9807	2.0249
Apparel and other textile products	1.3128	1.0000	1.0192	1.3814
Leather, fur and related products	1.3553	1.3730	1.3062	1.5583
Wood and bamboo products, non-metallic furnitures	2.8906	3.6379	2.2622	3.7695
Paper, paper products, printing and publishing	1.5215	1.6063	1.5225	1.8390
Chemicals and chemical products	2.3854	1.9528	1.3110	1.3032
Rubber products	2.4210	1.8858	1.9726	2.2437
Non-metallic mineral products	1.7369	1.7995	1.6503	1.7795
Primary metal products	1.0000	1.0000	1.0000	1.0000
Fabricated metal products	2.4990	2.4483	2.0147	2.6338
Machinery except electrical equipment	2.1683	2.0807	1.7065	1.9493
Electrical and electronic equipment	1.6608	1.5532	1.0877	1.0857
Transportation equipment	1.0000	1.0000	1.0000	1.0000
Precision equipment	1.0000	1.0731	1.1852	1.3207
Miscellaneous	1.0000	1.0000	1.0000	1.0000
Mean	1.8331	1.7284	1.4584	1.7148
Standard Deviation	0.6285	0.6940	0.4104	0.7041

equipment, and miscellaneous industries were on or very near the frontier in all of these years, while the textile mill, wood and bamboo products, rubber, machinery, and fabricated metal industries were far below the frontiers, i.e. they were less efficient.

In general, there were large differences in efficiency among industries. It might just reflect the different nature of industries, the market stability and general competitiveness of individual industries. However, it is interesting to find that relative efficiency among industries was converging over 1978 to 1990, reflected by almost continuous decreases in the means and variations of the Farrell efficiency indexes for all industries over the period. Why did the convergence occur? The convergence is consistent with the conjecture that the markets during this period were rather stable and became more competitive, induced mainly by the economic liberalization and internationalization. However, the discrepancy of efficiency among industries did widen significantly after 1990. Why? It is conjectured that it should be related to the dramatic appreciation of exchange rate, and the worsening investment climate in the 1990s as mentioned above, which in turn affect the market stability and the relative advantages of individual industries.

Total factor productivities of industries as a whole

Next Malmquist productivity indexes were calculated as well as the efficiency change, technical change and scale change components for each industry in the sample.

Instead of presenting the disaggregated results for each industry and year, a summary description of the average performance of all industries over the entire period was utilized. Note that if the value of Malmquist index or any of its components is less than 1, that denotes regress or deterioration in performance between any two adjacent years, whereas values greater than 1 denote improvements in the relevant performance.[10] Also note that these measures capture performance relative to the best practice in the sample. Looking first at the bottom of Table 5, it is seen that TFP increased with an average rate of 2.89% per annum over the entire 1978–1992 period for the manufacturing as a whole. On average, that improvement was ascribed to a technical progress (2.56%) and a slight efficiency improvement (0.33%).

As for the source of the overall technical efficiency improvement, it can be seen that it totally came from scale efficiency improvement (0.92% annually), since there was an efficiency deterioration (−0.59%) based on the VRS technology. In other words, production scale change did result in productivity improvement, although not exceeding 1% per annum for the sample period.

Total factor productivities of individual industries

Although it is difficult to summarize the disaggregated results, some general observations are presentable. First, except precision equipment, all other industries did have positive productivity growth. The chemicals had the highest average productivity growth at an annual rate of

[10] Subtracting one from the number reported in Table 5 gives average increase or decrease per annum for the relevant time period and relevant performance measure.

Table 5. *Decomposition of TFP with scale effects: average annual changes*

Industry	MALMQ	EFFCH	TECH	VRSEFFCH	SCALECH
Food and kindred products	1.0484	1.0101	1.0371	0.9915	1.0196
Textile mill products	1.0574	1.0233	1.0334	0.9711	1.0537
Apparel and other textile products	1.0113	0.9935	1.0180	0.9850	1.0086
Leather, fur and related products	1.0007	0.9798	1.0213	0.9732	1.0068
Wood and bamboo products, non-metallic furnitures	1.0012	0.9825	1.0190	0.9690	1.0139
Paper, paper products, printing and publishing	1.0172	0.9882	1.0293	0.9905	0.9977
Chemicals and chemical products	1.0849	1.0461	1.0371	1.0092	1.0365
Rubber products	1.0313	1.0090	1.0221	1.0231	0.9862
Non-metallic mineral products	1.0380	1.0011	1.0369	1.0015	0.9997
Primary metal products	1.0528	1.0000	1.0528	1.0000	1.0000
Fabricated metal products	1.0141	0.9988	1.0153	0.9853	1.0137
Machinery except electrical equipment	1.0374	1.0113	1.0258	1.0085	1.0028
Electrical and electronic equipment	1.0468	1.0311	1.0152	1.0000	1.0311
Transportation equipment	1.0300	1.0000	1.0300	1.0000	1.0000
Precision equipment	0.9934	0.9799	1.0137	1.0000	0.9799
Miscellaneous	1.0027	1.0000	1.0027	1.0000	1.0000
Mean	1.0289	1.0033	1.0256	0.9941	1.0092

8.49%, then followed by the textile mill, primary metal, food and electrical and electronic equipment with annual rates of 5.74%, 5.28%, 4.84% and 4.68%, respectively. Second, all industries experienced technical progress. Third, some industries gained efficiency improvement, while some ones did worsen their efficiency. Fourth, the TFP improvement was almost totally attributed to technical progress.

The above finding concerning productivity improvement and technical progress seems consistent with the alleged view: manufacturing had been doing well, although some industries did not thrive. The cumulated Malmquist indexes in Table 6 are provided to give more perspective on the growth pattern of productivity. The table also shows the cumulated changes of the TFP components. They are calculated as the sequential multiplicative sums of the annual indexes, since the index itself is multiplicative. Note that while the cumulated index has the long-run indication, it has the indication of the short-run change when two adjacent indexes are compared.

Two cumulated TFP indexes benchmarked by 1984 are reported, when Taiwan announced officially to shift her economic management policy from a fairly manipulative one to one of liberalization.[11] Table 6 shows, when cumulated up to 1984, 14 industries had productivity increases; when cumulated up to 1992, 15 industries had productivity improvement, and the precision equipment is the only exception. Further, comparing the series of the two cumulated TFP indexes, it is found that 14 industries had higher cumulated TFP up to 1992 than that up to 1984. This reconfirms the hypothesis that the manufacturing in general has been doing well.

Naturally, one may wonder which period had higher productivity growth. Since the cumulated TFP index is the sequential multiplicative sums of the annual indexes, that the square root of the cumulated TFP up to 1992 is greater (less) than the cumulated TFP up to 1984 implies the second period has a higher (lower) productivity growth. Based on this reasoning, it was found that only 10 industries experienced higher productivity advance in the latter period than in the earlier period.

Efficiency change

Table 5 has already observed that the manufacturing as a whole experienced a negligible efficiency improvement. However, some industries had a 2–5% efficiency improvement per annum, such as chemicals, electrical and electronic, and textile mill, while some labour-intensive industries did worsen their efficiency, such as leather, wood, and precision equipment.

The efficiency issue is further examined by looking at the cumulated changes (shown in Table 6). When cumulated up to 1984, 9 out of 16 industries improved their efficiency, three had the same efficiency level, and the others worsened. If cumulated up to 1992, seven industries improved their efficiency, three remained the same, and the others got worse. Comparing the series of the two cumulated EFFCH indexes, it is found the apparel, leather, wood, paper, rubber, and precision equipment lowered their efficiency substantially.

[11] Broadly speaking, economic liberalization includes deregulation, internalization, and systemization in industry, trade, financial market and foreign exchange market. Trade liberalization has progressed most actively.

Table 6. *Cumulated TFP: 1978–1984, 1978–1992*

Industry	MALMQ		EFFCH		TECH		VRSEFFCH		SCALECH	
	1978–1984	1978–1992	1978–1984	1978–1992	1978–1984	1978–1992	1978–1984	1978–1992	1978–1984	1978–1992
Food and kindred products	1.5313	1.9375	1.2210	1.1633	1.2541	1.6655	1.0561	0.8870	1.1562	1.3116
Textile mill products	1.3888	2.1846	1.1674	1.3799	1.1896	1.5832	0.7560	0.6636	1.5441	2.0794
Apparel and other textile products	1.4819	1.1710	1.3128	0.9123	1.1288	1.2836	1.1541	0.8088	1.1375	1.1280
Leather, fur and related products	1.0414	1.0101	0.9481	0.7515	1.0985	1.3441	0.7486	0.6832	1.2664	1.0999
Wood and bamboo products, non-metallic furnitures	0.9492	1.0164	0.8805	0.7805	1.0780	1.3022	0.6983	0.6433	1.2610	1.2132
Paper, paper products, printing and publishing	1.0247	1.2689	0.8952	0.8472	1.1447	1.4978	0.9207	0.8747	0.9723	0.9685
Chemicals and chemical products	1.8372	3.1282	1.4748	1.8786	1.2457	1.6652	1.1374	1.1374	1.2967	1.6517
Rubber products	1.3216	1.5392	1.2577	1.1330	1.0508	1.3585	1.2459	1.3768	1.0095	0.8229
Non-metallic mineral products	1.2530	1.6867	1.0053	1.0161	1.2464	1.6599	1.0170	1.0209	0.9885	0.9953
Primary metal products	1.3937	2.0545	1.0000	1.0000	1.3937	2.0545	1.0000	1.0000	1.0000	1.0000
Fabricated metal products	1.0822	1.2162	1.0349	0.9833	1.0456	1.2369	0.9480	0.8124	1.0917	1.2103
Machinery except electrical equipment	1.2130	1.6715	1.1126	1.1706	1.0903	1.4278	1.0549	1.1253	1.0546	1.0403
Electrical and electronic equipment	1.2953	1.8964	1.2281	1.5347	1.0548	1.2357	1.0000	1.0000	1.2281	1.5347
Transportation equipment	1.1723	1.5119	1.0000	1.0000	1.1723	1.5119	1.0000	1.0000	1.0000	1.0000
Precision equipment	0.9003	0.9114	0.8728	0.7530	1.0315	1.2103	1.0000	1.0000	0.8728	0.7536
Miscellaneous	1.1142	1.0387	1.0000	1.0000	1.1142	1.0387	1.0000	1.0000	1.0000	1.0000

Table 7. *Decomposition of technical change: mean result*

Industry	TECH	IBTECH	MATECH
Food and kindred products	1.0371	1.0027	1.0343
Textile mill products	1.0334	1.0046	1.0286
Apparel and other textile products	1.0180	1.0017	1.0163
Leather, fur and related products	1.0213	0.9984	1.0230
Wood and bamboo products, non-metallic furnitures	1.0190	1.0003	1.0188
Paper, paper products, printing and publishing	1.0293	1.0006	1.0286
Chemicals and chemical products	1.0371	0.9997	1.0374
Rubber products	1.0221	1.0025	1.0195
Non-metallic mineral products	1.0369	0.9995	1.0374
Primary metal products	1.0528	1.0095	1.0429
Fabricated metal products	1.0153	1.0003	1.0150
Machinery except electrical equipment	1.0258	0.9992	1.0266
Electrical and electronic equipment	1.0152	1.0000	1.0152
Transportation equipment	1.0300	1.0113	1.0185
Precision equipment	1.0137	1.0025	1.0112
Miscellaneous	1.0027	1.0301	0.9734

Table 8. *Cumulated technical change: 1978–1984, 1978–1992*

	TECH		IBTECH		MATECH	
Industry	1978–1984	1978–1992	1978–1984	1978–1992	1978–1984	1978–1992
Food and kindred products	1.2542	1.6656	1.0362	1.0384	1.2103	1.6037
Textile mill products	1.1896	1.5831	1.0666	1.0661	1.1153	1.4849
Apparel and other textile products	1.1287	1.2838	1.0217	1.0235	1.1049	1.2542
Leather, fur and related products	1.0984	1.3440	0.9912	0.9775	1.1083	1.3749
Wood and bamboo products, non-metallic furnitures	1.0781	1.3023	0.9986	1.0037	1.0795	1.2974
Paper, paper products, printing and publishing	1.1447	1.4977	0.9987	1.0089	1.1462	1.4847
Chemicals and chemical products	1.2456	1.6650	0.9960	0.9958	1.2509	1.6724
Rubber products	1.0509	1.3587	1.0085	1.0363	1.0419	1.3107
Non-metallic mineral products	1.2464	1.6598	0.9881	0.9924	1.2612	1.6728
Primary metal products	1.3938	2.0547	1.0309	1.1410	1.3520	1.8002
Fabricated metal products	1.0457	1.2370	1.0027	1.0041	1.0430	1.2319
Machinery except electrical equipment	1.0903	1.4278	0.9852	0.9886	1.1065	1.4441
Electrical and electronic equipment	1.0547	1.2358	0.9987	1.0004	1.0561	1.2349
Transportation equipment	1.1723	1.5118	1.0931	1.1698	1.0725	1.2924
Precision equipment	1.0315	1.2104	1.0329	1.0360	0.9986	1.1685
Miscellaneous	1.1142	1.0388	1.0869	1.5143	1.0250	0.6859

Technical change and technical change bias

Finally, returning to technical change, it is reported that the mean and cumulated estimates in Table 7 and Table 8. Recall that if the capital-labour ratio increases, then IBTECH > 1 implies capital-using bias, and IBTECH $<$ 1 implies labour-using bias. On the other hand, if the capital–labour ratio decreases, then IBTECH > 1 implies labour using bias, the IBTECH < 1 implies capital-using bias. The data show that 198 out of 224 annual-industry capital–labour ratios increased. That is, most of the industries increased their capital–labour ratios in most of the time periods.

It is already observed that on average the manufacturing experienced a significant technical progress. Among individuals, the primary metal, chemicals, non-metallic mineral, food and textile mill products are most remarkable. How and/or why did the technical progress be so significant in general? In the pace of industrialization, the Taiwanese authorities had undertaken many projects, policies and measures with tax incentives to upgrade production and restructure the configuration of the industries. Indeed, the manufacturing has been considerably increasing R & D activities, which should render beneficial effect on technical change. For example, the percentage of the firms with less than 1% R & D intensity, computed as the ratio of the R & D expenditures to sales revenue, was 64% in 1986, but dropped to 30% in 1989; on the other hand, the percentage of the firms with greater than 4% R & D intensity was 4% in 1986, but increased to 23% in 1989 (see Lee, 1991).

As for the baises of technical change, the estimates indicate the following observations.

(i) None of the industries showed any consistent technical biases over time, i.e. some years were labour-using, and some years were capital-using.
(ii) Roughly speaking, based on the means shown in Table 7, except for the transportation equipment, and miscellaneous industries which had moderate capital-biased technical change, the others had almost neutral technical change.
(iii) However, based on the cumulated aspect, there was a different picture to some extent. On average, capital–labour ratios for each industry increased almost all the time, although not always. Thus, the cumulated results in Table 8 may be able to be used to determine the trend directions of technical change biases. It is found that the textile mill, primary metal, transportation equipment, and miscellaneous industries had 6.6%, 14.1%, 17.0% and 51.4% cumulated rates of capital-using bias over the sample period, respectively, while other industries were just characterized with moderate capital-biased or almost neutral technical change.
(iv) Indeed, since 1985, there was a slight industry-wide technology change toward capital-using bias.

As for the meaning of the magnitude technical change, once IBTECH is defined, it is self-evident.

Finally, to substantiate the exposition of TFP growth, efficiency change and technical change, we include Figs 4–9 to present the cumulated trends of TFP, EFFCH and TECH for some selected industries: food (high productivity growth, high efficiency change), textile mill (high productivity growth, high efficiency improvement), leather and fur (low capital–labour ratio, efficiency deterioration), chemical (highest GDP growth, highest productivity growth, highest efficiency improvement), primary metal (highest capital–labour ratio, high productivity growth, on frontiers), electrical and electronic equipment (high productivity growth, high efficiency improvement).

Comparison with some recent studies

Finally, comparison of the estimates were compared to the results of some recent studies concerning the Taiwanese

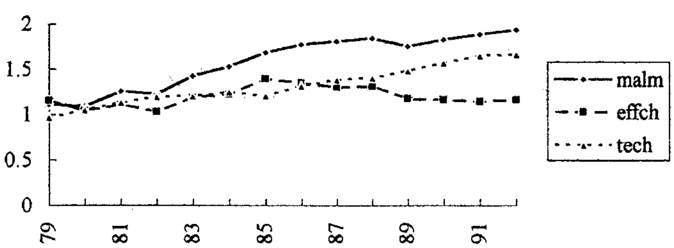

Fig. 4. *Cumulated results: food and kindred products*

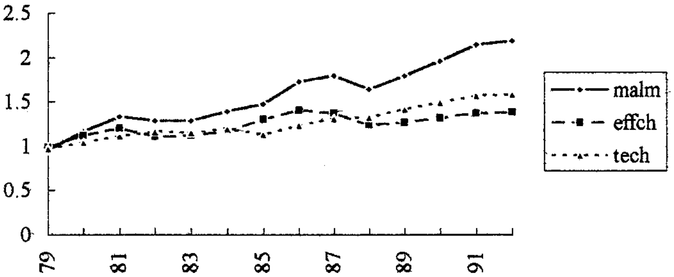

Fig. 5. *Cumulated results: textile mill products*

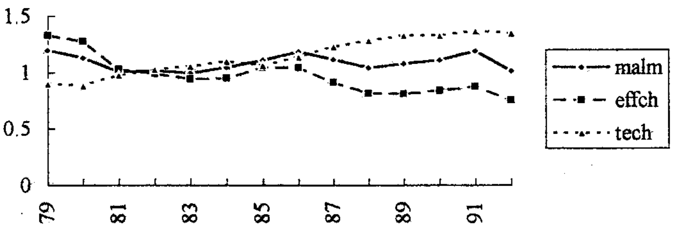

Fig. 6. *Cumulated results: leather, fur and related products*

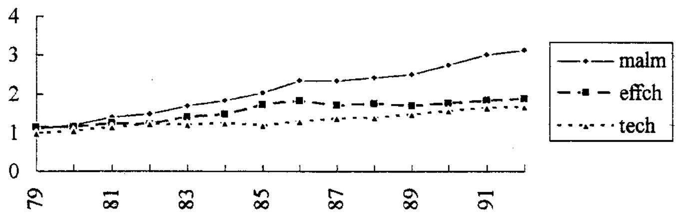

Fig. 7. *Cumulated results: chemicals and chemical products*

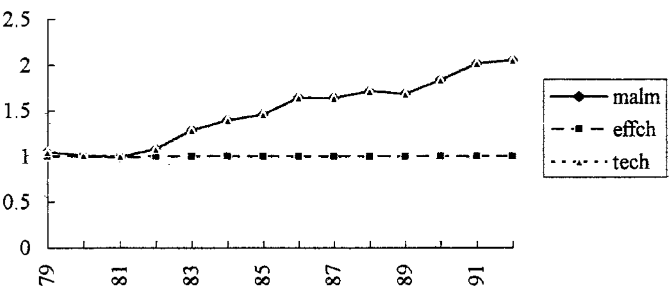

Fig. 8. *Cumulated results: primary metal products*

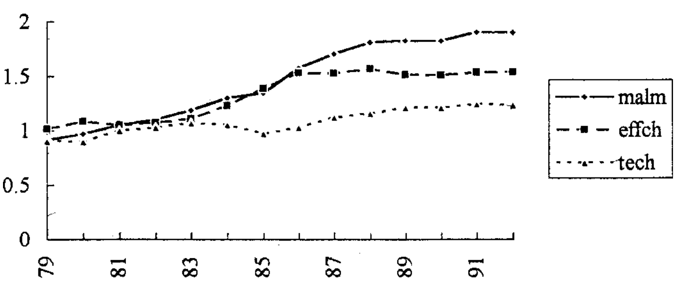

Fig. 9. *Cumulated results: electrical and electronic equipment*

Table 9. *Törnqvist TFP: 1979–1990*

Industry	1979–1982	1983–1990	1979–1990
Food and kindred products	3.63	1.93	2.50
Beverage and tobacco	3.01	0.08	1.06
Textile mill products	5.89	2.78	3.82
Apparel and other textile products	9.25	−1.04	2.39
Leather, fur and related products	3.78	2.20	2.73
Wood and bamboo products, non-metallic furnitures	−1.96	4.53	2.37
Paper, paper products, printing and publishing	2.17	0.20	0.86
Chemicals and chemical products	9.77	4.36	6.16
Petroleum and coal products	−4.92	−4.27	−4.48
Rubber products	7.16	1.12	3.13
Non-metallic mineral products	0.11	1.67	1.15
Primary metal products	−4.77	4.28	1.26
Fabricated metal products	1.50	1.23	1.32
Machinery except electrical equipment	3.54	4.20	3.98
Electrical and electronic equipment	1.87	6.86	5.20
Transportation equipment	3.40	3.08	3.19
Precision equipment	0.07	1.23	0.84
Miscellaneous	−0.01	3.74	2.49
Mean	2.39	2.46	2.44

Source: DGBAS (1992), Table 18.

economy and manufacturing in particular. The first study compared is officially done by DGBAS (1992). The DGBAS calculated Törnqvist growth-accounting TFP indexes[12] for 18 industries (as classified here, but excluded tobacco and petroleum) over the period 1979–1990, see Table 9. The results show that on average the manufacturing as a whole had a 2.39% annual TFP growth rate during 1979–1982, and had a 2.46% growth rate in 1983–1990. However, 10 out of the 18 industries had lower productivity growth rates in the second period. DGBAS also used econometric approach to estimate Translog production function for each industry to measure technical change, and concluded a 2.62% annual technical progress in 1979–1982, and a 2.24% growth rate in 1983–1990.

In addition, four other recent productivity studies are worthy of mention. Young (1995) had an estimate of 2.8% annual productivity growth for Taiwanese manufacturing over 1980–1990. Kim and Lau (1994) concluded that the high growth of the Taiwan economy over the postwar three decades had little to do with TFP growth. Liang (1995), taking account the heterogeneous characteristics of inputs, had an estimate of 3.84% TFP growth per annum over 1982–1993. Chuang (1996) found a 1.9% annual TFP growth for the manufacturing as a whole in the period 1975–1990.

When this result is compared with those of the above five studies, it seems that there are more differences than similarities. In particular, this finding is contrary to the Lau hypothesis that there has been no technical progress in NICs during the postwar period. Why are the results different? The difference may be in part due to different time and industrial domains investigated, and largely due to different estimation techniques applied. This approach allows for inefficiency, but the others do not.

There is another reason why our study yields different estimates of TFP growth and technical change from the DGBAS or other studies. In the DGBAS, each industry's Törnqvist TFP index or technical change is constructed only by referring to itself in two adjacent years. However, in this approach, Malmquist TFP index and its components are constructed by referring to the grand frontier, i.e. they do have a common benchmark for direct multilateral comparisons.

VI. CONCLUSION

This paper first decomposed the Malmquist TFP index into technical efficiency and technical change components. Then decomposed technical change into output bias, input bias and magnitude components, and further identified the directions of technical change biases.

[12] Törnqvist TFP growth in time $t+1$ is calculated as:

$$\ln TFP_{t+1} - \ln TFP_t = \ln y_0^{t+1} - \ln y_0^t - \sum_{n=1}^{N} \bar{h}_n^{t+1} (\ln x_n^{t+1} - \ln x_n^t)$$

where y_0^t is the observed output at time t, $\bar{h}_n^{t+1} = 1/2(h_n^{t+1} + h_n^t)$ and h_n^t represents the nth input's cost share at time t.

The empirical estimates on the Taiwanese manufacturing productivity performance yielded several results that seem very striking. The manufacturing as a whole enhanced its technology remarkably, and improved its efficiency slightly; overall productivity increased at 2.89% per annum. There were large differences in efficiency among industries. However, their relative efficiency was converging during 1978–1990, and then diverged. It was also found that scale change did slightly improve efficiency and productivity. It was thought that high technical progress was closely related to the industry-upgrading policies and the increases in R&D activities. However, some labour-intensive industries experienced technical regress and efficiency deterioration in the latter period, and the root cause for the deterioration was thought to be the worsening investment climates in the Taiwanese area. Therefore, it is conjectured that in order for the lower technical progress industries to catch up with the higher technical progress industries, a greater investment in R&D is needed. To maintain high efficiency, a stable and well-informed environment is called for.

As for the biases of technical change, none of the industries showed any consistent bias over time. For two adjacent years, most industries experienced netural technical change. However, some industries did have cumulated capital-bias to a great extent. Moreover, since 1985, there was a slight industry-wide technical change bias tendency toward capital-using. The finding of technical change bias may provide insight into understanding why income distribution in Taiwan area was getting unequal since 1981.[13] In addition, capital-biased technical progress in general implies that an industry with more capital stocks will benefit more from technical progress than an industry with lower capital stock, other things being equal. Therefore, it is conjectured that for improving income distribution, policy and/or strategy inducing labour-using technical change are helpful.

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APPENDIX

The benchmark extrapolation method uses the percentage wedge procedure to measure the capital stock for the interbenchmark years. Specifically, the original estimates for the interbenchmark years are multiplied by adjustment factors to obtain estimates adjusted to the new benchmark level. The adjustment factors for the interbenchmark years are determined by increasing or decreasing the adjustment

[13] In terms of income distribution by household, the ratios of highest fifth's income to lowest fifth's income were 4.18 in 1978, and 4.21, 4.29, 4.36, 4.40, 4.50, 4.60, 4.69, 4.85, 4.94, 5.18, 4.97, 5.24, and 5.42 for 1981–1993, respectively.

factors by a constant amount each year, so that the adjusted final year's estimate is equal to the new benchmark level. The wedge procedure can be expressed as the following three steps (for a detailed discussion see DGBAS, 1991).

Step 1 calculates the original capital estimate for year t:

$$K(t) = K(t-1) + I(t)$$

where $I(t)$ = gross fixed capital formation in t; $K(t-1)$ = fixed capital stock estimate for $t-1$; note that if year $t-1$ is the benchmark year, then $K(t-1)$ equals the benchmark level.

Step 2 determines the constant yearly adjustment factor:

$$d = (B - E)/(nE)$$

where B = new benchmark capital level; E = original capital estimate for the new benchmark year; n = number of years in the wedging period.

Step 3 calculates the adjusted capital estimate for a particular year in the wedging period as the product of the original estimate for this year (as calculated in Step 1) and an adjustment factor $(1 + Nd)$, where N is the number of years between the particular year and the original benchmark year.