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 and technical efficiency change 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 efficiency change.

Technical change may be further decomposed into output and input biased of technical change. The biases indeed have impacts on factor income distribution and hence policy implications associated with them. It is therefore interesting to identify the technical change components of output and input bias and to measure them empirically.

In Färe, et. al. (1995), we investigate productivity in four of Taiwan's manufacturing industry groupings during 1978-89. In this paper, we explore the issues mentioned above for more disaggregated case of 18 Taiwan manufacturing industries at the 2-digit level grouping during the period 1978-92. To pursue our goal we apply the method initiated by Färe, et al. (1989) and used in Färe, et al. (1995), i.e., we decompose the Malmquist total factor productivity (TFP) index into two components: technical change and technical efficiency change. Here, however, we further decompose the technical change components, in particular we define: output bias, input bias and a magnitude term. In addition, we are able to identify the directions of the input biases.

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 data used here and presents our empirical results. Concluding remarks are made in Section IV.

II. THE PRODUCTIVITY MODEL

In this paper, as in our paper Färe, Grosskopf and Lee (1995), we use a Malmquist index to measure productivity. Here, however, we decompose the technical change component into a bias and a magnitude term, and we determine the direction of the bias, i.e., toward 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 or Färe 1988)

$$(2.1) \qquad D_o^t(x^t,y^t) = \inf\{\theta : (x^t,y^t/\theta)\in S^t\}.$$

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

$$(2.2) \qquad D_o^t(x^t,y^t) = y^t/F^t(x^t),$$

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

$$(2.3) \qquad F^t(x^t) = \max\{y^t : (x^t,y^t)\in S^t\}.$$

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

$$(2.4) \qquad D_o^t(x^t,y^t) \le 1 \text{ if and only if } (x^t,y^t)\in S^t,$$

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

$$(2.5) \qquad D_o^t(x^t,\theta y^t) = \theta D_o^t(x^t,y^t),\ \theta > 0.$$

Here we follow the tradition started by Färe, Grosskopf, Lindgren and Roos (1989) and define the Malmquist productivity index as the geometric mean of two Malmquist indexes as defined by Caves, Christensen and Diewert (1982), namely

$$(2.6) \qquad M_o(x^{t+1},y^{t+1},x^{t},y^{t}) = \left(\frac{D_o^{t}(x^{t+1},y^{t+1})}{D_o^{t}(x^{t},y^{t})} \; \frac{D_o^{t+1}(x^{t+1},y^{t+1})}{D_o^{t+1}(x^{t},y^{t})} \right)^{1/2}$$

This index employs distance functions from two different periods or technologies, $D_o^{t}(\cdot,\cdot)$, $D_o^{t+1}(\cdot,\cdot)$ and two pairs of input-output vectors namely (x^t,y^t) and (x^{t+1},y^{t+1}). The distance functions are defined for the input-output pairs as in (2.1).

Färe, Grosskopf, Lindgren and Roos (1989) showed that the Malmquist index (2.6) can be decomposed into two components, namely efficiency change (EFFCH) and technical change (TECH),

$$(2.7) \qquad EFFCH = \frac{D_o^{t+1}(x^{t+1},y^{t+1})}{D_o^{t}(x^{t},y^{t})},$$

$$(2.8) \qquad TECH = \left[\frac{D_o^{t}(x^{t+1},y^{t+1})}{D_o^{t+1}(x^{t+1},y^{t+1})} \; \frac{D_o^{t}(x^{t},y^{t})}{D_o^{t+1}(x^{t},y^{t})} \right]^{1/2}.$$

Given, as we do here, that constant returns to scale is imposed on the reference technologies S^t and S^{t+1}, EFFCH can be further decomposed. In particular, one may extract a scale efficiency component, see Färe, Grosskopf and Lovell (1994).[1] Here we do not pursue that decomposition,

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[1]EFFCH can be further decomposed as follows to extract the effects of technology types and scale efficiency: EFFCH = VRSEFFCH x SCALECH, where VRSEFFCH is the efficiency change calculated under variable returns to scale, and SCALECH represents scale

but rather decompose TECH into input biased technical change (IBTECH) and Magnitude technical change (MATECH). Following Färe and Grosskopf (forthcoming), TECH in (2.8) can be written as

$$(2.9) \qquad \text{TECH} = \left[\frac{D_o^t(x^{t+1},y^{t+1})}{D_o^{t+1}(x^{t+1},y^{t+1})}\,\frac{D_o^{t+1}(x^{t+1},y^t)}{D_o^t(x^{t+1},y^t)}\right]^{1/2} \cdot \left[\frac{D_o^{t+1}(x^t,y^t)}{D_o^t(x^t,y^t)}\,\frac{D_o^t(x^{t+1},y^t)}{D_o^{t+1}(x^{t+1},y^t)}\right]^{1/2} \cdot \frac{D_o^t(x^t,y^t)}{D_o^{t+1}(x^t,y^t)}.$$

The first bracketed term denotes output biased technical change (OBTECH), the second measures input biased technical change (IBTECH), and the last ratio denotes the magnitude of technical change (MATECH). In this study, the technology produces only one output, thus OBTECH = 1, and we get

$$(2.10) \qquad \text{TECH} = \text{IBTECH} \cdot \text{MATECH}.$$

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

$$(2.11) \qquad \text{IBTECH} = \left(\frac{D_i^t(y^t,x^t)}{D_i^{t+1}(y^t,x^t)} \cdot \frac{D_i^{t+1}(y^t,x^{t+1})}{D_i^t(y^t,x^{t+1})}\right)^{1/2}.$$

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

$$(2.12) \qquad \text{IBTECH} = \left(\frac{D_i^t(1,x^t)}{D_i^{t+1}(1,x^t)}\,\frac{D_i^{t+1}(1,x^{t+1})}{D_i^t(1,x^{t+1})}\right)^{1/2}.$$

The magnitude component equals

$$(2.13) \qquad \text{MATECH} = D_o^t(x^t,1)/D_o^{t+1}(x^t,1).$$

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change.

Returning to the input bias term (2.11), we say that there is Hicks neutral technical change or no bias if IBTECH equals one, i.e., if

$$(2.14) \qquad \frac{D_i^t(1,x^t)}{D_i^{t+1}(1,x^t)} = \frac{D_i^t(1,x^{t+1})}{D_i^{t+1}(1,x^{t+1})}.$$

Now whenever only two inputs are used, we have

$$(2.15) \qquad \frac{D_i^t(1,x_1^t,x_2^t)}{D_i^{t+1}(1,x_1^t,x_2^t)} = \frac{D_i^t(1,x_1^{t+1},x_2^{t+1})}{D_i^{t+1}(1,x_1^{t+1},x_2^{t+1})}$$

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

$$(2.16) \qquad \frac{D_i^t(1,1,x_2^t/x_1^t)}{D_i^{t+1}(1,1,x_2^t/x_1^t)} = \frac{D_i^t(1,1,x_2^{t+1}/x_1^{t+1})}{D_i^{t+1}(1,1,x_2^{t+1}/x_1^{t+1})}.$$

The last expression may be used to measure the direction of bias. As we will illustrate, if there is an inequality in (2.16) 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 Figures 2.1 and 2.2. We assume $S^t \subseteq S^{t+1}$. 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]

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[2]Hick's 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

$$\frac{d}{dt}\text{MRTS} = \frac{d}{dt}\left(\frac{F_1^t}{F_2^t}\right) = -\frac{d}{dt}\frac{dx_2}{dx_1} = 0$$

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

First consider Figure 2.1, 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 (2.10) is as follows:

$$\text{(2.17)} \qquad \text{IBTECH} = \left(\frac{\dfrac{ox^t}{ob}}{\dfrac{ox^t}{oc}} \cdot \frac{\dfrac{ox^{t+1}}{oe_n}}{\dfrac{ox^{t+1}}{of}} \right)^{1/2}$$

$$= \left(\frac{oc}{ob} \cdot \frac{of}{oe_n} \right)^{1/2}$$

If (2.17) is equal to one, then

$$\text{(2.18)} \qquad \frac{ob}{oc} = \frac{of}{oe_n}$$

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 the unit isoquant, and thus (2.18) holds.[3] Therefore, it is possible to say if (2.16) holds, there is a Hicks neutral technical change.

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[3]The reason for (2.18) 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 $F^t(x_1,x_2) = A(t)x_1 f\left(\frac{x_2}{x_1}\right)$. 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 Figure 1, the coordinates of points b, c, f and e are $\left(\frac{1}{A(t)f(k_t)}, \frac{k_t}{A(t)f(k_t)}\right)$, $\left(\frac{1}{A(t+1)f(k_t)}, \frac{k_t}{A(t+1)f(k_t)}\right)$, $\left(\frac{1}{A(t)f(k_{t+1})}, \frac{k_{t+1}}{A(t)f(k_{t+1})}\right)$, 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.

Meanwhile, in Figure 2.1 if technical change shifts the isoquant to $L_1^{t+1}(1)$, then $\frac{ob}{oc} < \frac{of}{oe_1}$, 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 $L_2^t(1)$, then $\frac{ob}{oc} > \frac{of}{oe_1}$, which in turn implies IBTECH < 1. Therefore, we say if $\frac{x_2^{t+1}}{x_1^{t+1}} < \frac{x_2^t}{x_1^t}$ and IBTECH < 1, then there is a x_2-using bias.

In Figure 2.2, we have $x_2^{t+1}/x_1^{t+1} > x_2^t/x_1^t$. By the same token, we could infer: (1) IBTECH > 1 implies x_2-using bias, (2) IBTECH = 1 implies neutrality, and (3) IBTECH < 1 implies x_1-using bias. Table 2.1 concludes the conditions for the direction of bias of technical change.

Table 2.1 Technical Change Direction

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

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

Finally, we note that if there are output and input technical change neutrality, then

$$\text{(2.19)} \qquad \text{TECH} = \text{MATECH} = \frac{D_o^{t}(x^{t},y^{t})}{D_o^{t+1}(x^{t},y^{t})} = \frac{F^{t+1}(x^{t})}{F^{t}(x^{t})},$$

where the last measure is equivalent to the definition given by Diewert (1980, pp. 263-264).

III. DATA AND RESULT

DATA

We calculate productivity growth and its components for a sample of 18 manufacturing industries at the two-digit level grouping over the period 1979-92 using data from DGBAS (The Directorate-General of Budget, Accounting and Statistics, Executive Yuan, R.O.C.). The classification of 18 all industries (except one) is consistent with SIC code; the exception is the chemicals industry, which here include industrial chemicals, chemical products and plastic products. The reason for the exception is the lack of disaggregation of these 3 industries' output in the earlier stage of the time period investigated.

Our measure of industrial output is real GDP (gross domestic product), and the corresponding inputs are employed man-hours and real capital stocks. The procedures used to create the data set are discussed in some detail in "The Study on Statistical Measurement of Capital Productivity in Taiwan Area", both published by DGBAS. GDP and capital stocks are measured in 1986 prices. The benchmark extrapolation method is adopted to estimate the capital stock, with the benchmark-year being designated as those when each industrial and commercial census took place, and as 1988 when the national wealth census was conducted.

Our method constructs an across-industries best-practice grand frontier from the data in the sample. The technology in any given period is represented as an output distance function. Since we have only one output, an output distance function becomes equivalent to a production function.

We begin with a summary of average annual growth rates of output, capital, and labor for each industry in our sample.[4] As seen in Table 3.1, the chemical, electrical and electronic, fabricated metal, and machinery industries all had a more than 10% annual average growth in GDP (11.78%, 10.97%, 10.62% and 10.55%, respectively). However, the wood and bamboo, apparel, petroleum and coal, textile mill industries only had a GDP growth rate not exceeding 5% (1.04%, 3.23%, 4.34% and 4.87%, respectively). As for capital stock, 7 out of the 18 industries had a more than 10% annual average growth rate; however, 2 industries increased their capital not exceeding 5% annually. As for labor input, all the industries (except fabricated metal industry) had a growth rate not exceeding 5%, and the textile mill, and wood industries even decreased the employment level (-2.44% and -3.02%, respectively).

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[4]For a comprehensive discussion of Taiwan's earlier economic structural change, see Kuo (1983).

Table 3.1 Average Annual Growth Rates: Real GDP, Real Capital Stock and Labor

Evidence concerning the capital-labor mix in these industries is summarized in Table 3.2. We can see all the industries increased capital-labor ratio almost all the time. However, capital-labor ratio are quite different among industries. The petroleum and coal industry had the highest ratio (29.44 in 1992), the beverage and tobacco ranked second (7.38 in 1992), the primary metal came to the third (6.75 in 1992), and the miscellaneous industry had the lowest (0.59 in 1992).

Table 3.2 Capital-Labor Ratios: Selected Years

PRODUCTION FRONTIER AND TECHNICAL EFFICIENCY

Since the basic component of the Malmquist index is related to measures of technical efficiency, we first report technical efficiency for the industries in our sample for selected years in Table 3.3. 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 4 selected years (1978, 1983, 1988 and 1992), the beverage and tobacco, petroleum and coal products, and miscellaneous industries were on the frontiers in all of these years, while the textile, woods and bamboo products, nonmetalic mineral, and primary metal industries were far below the frontiers, i.e., they were less efficient. Observing the capital-labor ratios of the 3 industries on the frontiers, we find that the production frontiers were constructed by the two highest capital-labor ratio industries and the lowest capital-labor ratio industry.

Table 3.3 Technical Efficiency: Selected Years (constant returns to scale)

TOTAL FACTOR PRODUCTIVITIES OF INDUSTRIES AS A WHOLE

Next we calculate Malmquist productivity indexes as well as the efficiency change, technical change, and scale change components for each industry in our sample for average performance.

Instead of presenting the disaggregated results for each industry and year, we turn to a summary description of the average performance of all industries over the entire time period. Recall 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.[5] Also recall that these measures capture performance relative to the best practice in the relevant performance relative to the best practice in the sample. Looking first at the bottom of Table 3.4, we see that, on average, TFP decreased slightly over the entire 1978-1992 period for the industries in our sample: the average change in the Malmquist productivity index was -0.5%. On average, that deterioration was ascribed to technical regress (-1.14%) outweighing efficiency improvement (0.64%). Then observing the magnitudes of the 18 industries' productivities, we see they were quite close, ranging from 0.9699 (wood and bamboo industry) to 1.0330 (chemical industry).

Table 3.4 Decomposition of TFP with Scale Effects: Average Annual Change

TOTAL FACTOR PRODUCTIVITIES OF INDIVIDUAL INDUSTRIES

Next we turn to the industry-by-industry results. Although it is difficult to summarize the disaggregated results, we include some general remarks. First, the chemicals and chemical products industry had the highest average productivity growth at an annual average rate of

[5]Subtracting from the number reported in Table 3.4 gives average increase or decrease per annum for the relevant time period and relevant performance measure.

3.30%, the electrical and electronic equipment industry followed next with an annual rate of 2.83%, then the transportation equipment industry came after with an annual rate of 1.4%. For these three industries, their productivity improvement was completely due to efficiency improvement, since they even encountered technical regress. On average, all industries except the leather and fur industry faced technical regress, see the later analysis for details.

The above finding concerning productivity deterioration and technical regress seemed contrary to the general idea: manufacturing had been doing well, although some industries did not thrive. Indeed, we need to carefully to interpret the changes in the Malmquist TFP index. Recall that TFP growth is computed for two adjacent years' relative productivity performance. Thus as TFP growth is volatile, the mean of TFP growth over several periods may be close to zero since the ups and downs may be countervailed. Thus we provide the cumulated Malmquist index as well as the cumulated changes of its components in Table 3.5 to give more perspective on the growth pattern of productivity and its components. They are calculated as the sequential multiplicative sums of the annual indexes, since the index itself is multiplicative.

Since 1984, Taiwan has officially shifted her economic management policy from a fairly manipulative one to one of liberalization. Therefore, we report two cumulated TFP indexes benchmarked by 1984. In Table 3.5, when cumulated up to 1984, 13 out of 18 industries had productivity decreases; and when cumulated up to 1992, 12 out of 18 industries had productivity decreases. Further comparing the two cumulated TFP, we find that 14 industries lowered the performances after 1984. However, the machinery, electrical, and transportation equipment industries had their productivity improved after 1984. It is surprising that these three thriving industries are typical exporting ones.

Table 3.5 Cumulated TFP: 1978-1984, 1978-1992

EFFICIENCY CHANGE

As for efficiency change (shown in Table 3.5), when cumulated up to 1984, 12 out of 18 industries improved their efficiency, 3 had the same efficiency level, and the others worsened. If cumulated up to 1992, 10 out of 18 improved their efficiency, 3 remained the same and the others got worse. The industries with overall declining efficiency were the leather, wood and bamboo products, rubber products, fabricated metal, and precision equipment industries. On the other hand, the machinery, electrical, and transportation equipment industries gained significant efficiency improvement after 1984.

TECHNICAL CHANGE AND TECHNICAL CHANGE BIAS

Finally, returning to technical change, we report the mean estimates in Table 3.6. Recall that if the capital-labor ratio increases, then IBTECH > 1 implies capital-using bias, and IBTECH < 1 implies labor-using bias. On the other hand, if the capital-labor ratio decreases, then IBTECH > 1 implies labor-using bias, and IBTECH < 1 implies capital-using bias. Our data show that 205 out of the 252 annual-industry capital-labor ratios increased. That is, most of the industries increased their capital-labor ratios in most of the time periods. Note that if the capital-labor ratios increase consistently, then cumulated technical bias can be calculated as the multiplicative sums of the series of technical change biases over time. However, if the capital-labor ratios move up and down, then the multiplicative sums do not represent the cumulated change bias.

Table 3.6 Decomposition of Technical Change: Mean Result

We already observed that on average all the industries experienced technical regress, except for leather industry which exhibited slight technical progress at a 0.7% annual rate. The reason for the almost industry-wide technical regress may be due to the recent moving-out wave

of industries, especially in labor-intensive industries or polluting industries. The wave was due to the deterioration of domestic investment climate in wage soaring, labor dispute, and pollution abatement regulation. As for the biases of technical change, the estimates indicate the following observations:

(1) None of the industries showed any consistent technical biases over time, i.e., some years were labor-using, and some years were capital-using.

(2) Roughly speaking, except for the beverage and tobacco, petroleum and coal products, primary metal, and miscellaneous industries which had significant technical change biases, the other 14 industries had technical change which was almost neutral.

(3) On average, capital-labor ratios for each industry increased almost all of the time, although not always. Based on this reason, the mean result in Table 3.7 may be able to be used to determine the trend directions of technical change biases. The beverage and tobacco, petroleum and coal products, primary metal, and miscellaneous industries had a 2.6%, 2.8%, 0.5% and 1.8% annual rate of capital-using bias, respectively, while other industries were just characterized with neutral technical changes.

(4) Indeed, since 1988, there was a slight industry-wide technology change toward capital-using bias.

To substantiate the effect of technical change biases, we present the cumulated technical change up to 1984 and 1992 in Table 3.7. Also, we include Figures 3.1 - 3.6 to present the cumulated trends of TFP, EFFCH and TECH for some selected industries: beverage and tobacco (on the frontiers, high capital-labor ratio), leather and fur (most significant technical change),

chemical (highest GDP growth, highest efficiency change) petroleum and coal products (highest capital-labor ratio, on the frontiers), electrical and electronic equipment (major export, high efficiency change), and miscellaneous (lowest capital-labor ratio, on the frontiers).

Table 3.7 Cumulated Technical Change: 1978-1984, 1978-1992

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

COMPARISON WITH THE DGBAS STUDY

Finally, we turn to comparison of our estimates to the result of DGBAS (1992b). The DGBAS calculated Törnqvist growth-accounting TFP indexes for 18 industries (as we classify here) over the period 1979-1990, see Table 3.8. The results showed on average the manufacturing as a whole had a 2.39% of annual TFP growth rate during 1979-1982, and had a 2.46% of 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 estimating Translog production function for each industry to measure technical change, and concluded a 2.62% of annual technical progress in 1979-1982, and 2.24% growth rate in 1983-1990.

When our result is compared with the DGBAS result, it seems that there are differences more than similarities. Both study in common found that a quite big portion of the industries did lower productivity growth in the latter years. Our study found a technical regress, and the DGBAS found a positive but slow down technical change. Why are the results different? The difference may be in part due to different time domain investigated, and largely due to different technique applied. The two approaches yield comparable results in a world in which there is no

inefficiency, see Caves, Christensen and Diewert (1982). Thus, any technical inefficiency would result in a discrepancy between the two productivity growth estimates.

There is another reason why the two studies may yield different estimates of TFP growth and technical change. In DGBAS (1992b) each industry's Törnqvist TFP index or technical change is constructed only referring to itself in two adjacent years. However, in our 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.

IV. CONCLUSION

In this paper, we first decompose the Malmquist TFP index into technical efficiency and technical change components. Then we decompose technical change into input bias and magnitude components, and further identify the directions of technical change biases.

Our empirical estimates on Taiwan manufacturing productivity performance yield several results that seem very striking. The manufacturing as a whole enhanced its technical efficiency but worsened its technology; thus overall productivity stagnated. We thought that technical regress might be due to the recent moving-out waves in some labor intensive industries and more polluting industries due to the worsening investment climates in Taiwan area. The production frontiers were constructed by two highest capital-labor ratio industries and one lowest capital-labor industry. As for the biases of technical change, none of the industries showed any consistent technical bias over time, 14 out of the 18 industries had technical change which was almost neutral. However, since 1988, there was a slight industry-wide technology change toward capital-using bias.

Table 3.1 Average Annual Growth Rates:
Real GDP, Real Capital Stock and Labor: 1978-1992

Industry	GDP	Capital	Labor
Food and kindred products	0.0634	0.0755	0.0038
Beverage and tobacco	0.0661	0.0952	0.0256
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, nonmetallic 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
Petroleum and coal products	0.0434	0.1005	0.0354
Rubber products	0.0729	0.1147	0.0047
Nonmetallic 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	0.0611	0.1063	0.0382
Miscellaneous	0.0549	0.0682	0.0187

Table 3.2 Capital-Labor Ratios: Selected Years
Unit: N.T. Million/man-hours

Industry	1978	1983	1988	1992
Food and kindred products	1.0868	1.7118	2.5970	2.8263
Beverage and tobacco	2.8360	5.3876	8.0599	7.3827
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, nonmetallic furnitures	0.5430	0.6595	0.8852	1.6797
Paper, paper products, printing and publishing	1.0069	1.1407	1.7581	1.9443
Chemicals and chemical products	1.2401	1.3426	2.1211	3.3121
Petroleum and coal products	12.2712	16.0907	24.9291	29.4407
Rubber products	0.4169	0.7344	1.2612	1.7974
Nonmetallic 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

Table 3.3 Technical Efficiency: Selected Years
(Constant Returns to Scale)

Industry	1978	1983	1988	1992
Food and kindred products	4.0560	3.7023	2.8372	3.3698
Beverage and tobacco	1.0000	1.0000	1.0000	1.0000
Textile mill products	5.6267	4.9019	3.8120	4.4057
Apparel and other textile products	1.9310	1.2703	1.2679	1.5288
Leather, fur and related products	1.3553	1.4919	1.6873	1.7896
Wood and bamboo products, nonmetallic furnitures	4.0905	4.9171	3.1052	5.1739
Paper, paper products, printing and publishing	3.2559	3.0821	2.7261	3.1281
Chemicals and chemical products	6.1073	3.4424	2.4955	3.0772
Petroleum and coal products	1.0000	1.0000	1.0000	1.0000
Rubber products	2.8345	2.6555	2.9807	3.4507
Nonmetallic mineral products	4.1817	3.8724	3.6893	4.1763
Primary metal products	4.5460	5.3725	3.7776	3.8478
Fabricated metal products	2.8945	2.9021	2.7725	3.2638
Machinery except electrical equipment	3.1393	3.0650	2.4961	2.6872
Electrical and electronic equipment	2.1802	1.9574	1.2908	1.3232
Transportation equipment	2.0722	1.8780	1.3887	1.3624
Precision equipment	1.1714	1.1977	1.5261	1.5777
Miscellaneous	1.0000	1.0000	1.0000	1.0000

Table 3.4 Decomposition of TFP With Scale Effects:
Average Annual Changes

Industry	MALMQ	EFFCH	TECHCH	VRSEFFCH	SCALECH
Food and kindred products	0.9952	1.0146	0.9809	1.0064	1.0082
Beverage and tobacco	0.9922	1.0000	0.9922	1.0000	1.0000
Textile mill products	1.0008	1.0182	0.9829	0.9760	1.0433
Apparel and other textile products	1.0068	1.0147	0.9929	0.9966	1.0182
Leather, fur and related products	0.9779	0.9707	1.0074	0.9732	0.9974
Wood and bamboo products, nonmetallic furnitures	0.9699	0.9786	0.9911	0.9578	1.0217
Paper, paper products, printing and publishing	0.9893	1.0061	0.9833	1.0006	1.0055
Chemicals and chemical products	1.0330	1.0504	0.9835	1.0245	1.0253
Petroleum and coal products	0.9852	1.0000	0.9852	1.0000	1.0000
Rubber products	0.9772	0.9880	0.9891	0.9907	0.9972
Nonmetallic mineral products	0.9821	1.0019	0.9803	1.0041	0.9978
Primary metal products	0.9953	1.0146	0.9810	1.0399	0.9756
Fabricated metal products	0.9916	0.9958	0.9958	0.9951	1.0007
Machinery except electrical equipment	1.0025	1.0166	0.9861	1.0171	0.9996
Electrical and electronic equipment	1.0283	1.0372	0.9914	1.0151	1.0218
Transportation equipment	1.0140	1.0333	0.9814	1.0158	1.0172
Precision equipment	0.9730	0.9781	0.9949	1.0000	0.9781
Miscellaneous	0.9957	1.0000	0.9957	1.0000	1.0000
Mean:	0.9949	1.0064	0.9886	1.0005	1.0059

Table 3.5 Cumulated TFP: 1978-1984, 1978-1992

Industry	MALMQ		EFFCH		TECHCH		VRSEFFCH		SCALECH	
	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92
Food and kindred products	0.9971	0.9354	1.1432	1.2252	0.8722	0.7635	1.1935	1.0927	0.9578	1.1213
Beverage and tobacco	0.9623	0.8956	1.0000	1.0000	0.9623	0.8956	1.0000	1.0000	1.0000	1.0000
Textile mill products	1.0215	1.0111	1.1609	1.2870	0.8799	0.7856	0.8867	0.7113	1.3091	1.8093
Apparel and other textile products	1.5559	1.0997	1.6129	1.2269	0.9647	0.8964	1.4651	0.9532	1.1009	1.2872
Leather, fur and related products	0.9794	0.7310	0.8753	0.6591	1.1188	1.1091	0.7486	0.6832	1.1693	0.9647
Wood and bamboo products, nonmetallic furnitures	0.8531	0.6522	0.9100	0.7386	0.9375	0.8830	0.8061	0.5467	1.1288	1.3511
Paper, paper products, printing and publishing	0.9394	0.8600	1.0568	1.0892	0.8889	0.7896	1.0501	1.0087	1.0064	1.0798
Chemicals and chemical products	1.7067	1.5759	1.9529	1.9896	0.8739	0.7921	1.4028	1.4028	1.3921	1.4183
Petroleum and coal products	0.9330	0.8120	1.0000	1.0000	0.9330	0.8120	1.0000	1.0000	1.0000	1.0000
Rubber products	0.8864	0.7244	0.9400	0.8440	0.9430	0.8583	0.9383	0.8777	1.0017	0.9616
Nonmetallic mineral products	0.8870	0.7768	1.0300	1.0269	0.8612	0.7564	1.0928	1.0597	0.9425	0.9691

Table 3.5 (continued)

Industry	MALMQ		EFFCH		TECHCH		VRSEFFCH		SCALECH	
	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92
Primary metal products	0.8317	0.9360	0.9285	1.2243	0.8957	0.7646	1.4236	1.7300	0.6523	0.7077
Fabricated metal products	0.9907	0.8887	0.9909	0.9429	0.9998	0.9426	1.1049	0.9331	0.8969	1.0105
Machinery except electrical equipment	0.9092	1.0362	0.9771	1.2600	0.9305	0.8224	1.0531	1.2673	0.9278	0.9942
Electrical and electronic equipment	1.2399	1.4785	1.3105	1.6676	0.9461	0.8866	1.2334	1.2334	1.0625	1.3520
Transportation equipment	0.9999	1.2157	1.1329	1.5816	0.8826	0.7686	1.0917	1.2449	1.0377	1.2704
Precision equipment	0.8219	0.6821	0.8289	0.7332	0.9916	0.9303	1.0000	1.0000	0.8289	0.7332
Miscellaneous	1.1286	0.9420	1.0000	1.0000	1.1286	0.9420	1.0000	1.0000	1.0000	1.0000
Mean:	1.0357	0.9061	1.1028	1.1387	0.9450	0.8555	1.0828	1.0414	1.0230	1.1128

Table 3.6 Decomposition of Technical Change:
Mean Result

Industry	TECH	IBTECH	MATECH
Food and kindred products	0.9809	0.9993	0.9816
Beverage and tobacco	0.9922	1.0261	0.9669
Textile mill products	0.9829	0.9993	0.9836
Apparel and other textile products	0.9922	1.0005	0.9917
Leather, fur and related products	1.0074	0.9992	1.0082
Wood and bamboo products, nonmetallic furnitures	0.9911	1.0002	0.9909
Paper, paper products, printing and publishing	0.9833	0.9995	0.9837
Chemicals and chemical products	0.9835	0.9997	0.9838
Petroleum and coal products	0.9852	1.0284	0.9581
Rubber products	0.9891	0.9991	0.9900
Nonmetallic mineral products	0.9803	0.9994	0.9808
Primary metal products	0.9810	1.0054	0.9757
Fabricated metal products	0.9958	0.9986	0.9972
Machinery except electrical equipment	0.9861	0.9989	0.9872
Electrical and electronic equipment	0.9914	1.0001	0.9913
Transportation equipment	0.9814	0.9997	0.9817
Precision equipment	0.9949	0.9999	0.9949
Miscellaneous	0.9957	1.0176	0.9785

Table 3.7 Cumulated Technical Change:
1978-1984, 1978-1992

Industry	TECH		IBTECH		MATECH	
	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92
Food and kindred products	0.8722	0.7635	0.9949	0.9907	0.8767	0.7707
Beverage and tobacco	0.9623	0.8956	1.2007	1.4342	0.8014	0.6245
Textile mill products	0.8799	0.7856	0.9927	0.9899	0.8864	0.7936
Apparel and other textile products	0.9647	0.8964	1.0029	1.0077	0.9618	0.8895
Leather, fur and related products	1.1189	1.1091	0.9923	0.9892	1.1274	1.1211
Wood and bamboo products, nonmetallic furnitures	0.9375	0.8830	0.9948	1.0034	0.9424	0.8800
Paper, paper products, printing and publishing	0.8889	0.7896	0.9977	0.9936	0.8910	0.7947
Chemicals and chemical products	0.8739	0.7921	0.9974	0.9952	0.8762	0.7959
Petroleum and coal products	0.9330	0.8120	1.2642	1.4794	0.7380	0.5489
Rubber products	0.9430	0.8583	0.9873	0.9875	0.9552	0.8691
Nonmetallic mineral products	0.8612	0.7564	0.9957	0.9919	0.8650	0.7626
Primary metal products	0.8957	0.7646	1.0806	1.0791	0.8289	0.7085
Fabricated metal products	0.9998	0.9426	0.9889	0.9800	1.0110	0.9618
Machinery except electrical equipment	0.9305	0.8224	0.9909	0.9846	0.9399	0.8353
Electrical and electronic equipment	0.9461	0.8866	0.9946	1.0013	0.9513	0.8854
Transportation equipment	0.8826	0.7686	0.9943	0.9960	0.8877	0.7717

Table 3.7 (continued)

Industry	TECH		IBTECH		MATECH	
	1978-84	1978-92	1978-84	1978-92	1978-84	1978-92
Precision equipment	0.9916	0.9303	0.9977	0.9991	0.9939	0.9311
Miscellaneous	1.1286	0.9420	1.0320	1.2761	1.0937	0.7382

Table 3.8 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, nonmetallic 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
Nonmetallic 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.

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