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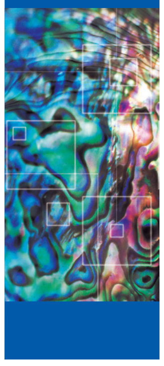

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Stochastic Frontier Analysis of New Zealand's Manufacturing Industries: Some Empirical Results

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ABSTRACT

This paper examines the sources of total factor productivity growth (TFP) in New Zealand's manufacturing industries over the period 1978-98 and over various sub-periods. Examination of the data adopts two stages using a stochastic frontier approach. The first stage involves the specification and estimation of the stochastic frontier production function and the prediction of technical efficiency effects. The second stage involves the specification of a regression model for the predicted technical efficiency effects. The sources of TFP growth have been decomposed into four components; i.e. technical progress, changes in technical efficiency, scale effects, and change in allocative efficiency. The empirical results show that productivity has been largely due to changes in technical progress, technical efficiency and resource allocation effect. The changes in technical progress and resource allocation have improved in the post-reform period, i.e. 1984-98, while technical efficiency has declined in the post-reform period. With respect to scale effect its contribution to productivity growth is quite small.

Key Words: New Zealand Manufacturing Sector, Total Productivity Growth, Technical Progress, Technical Efficiency, Scale Components, Allocative Efficiency.

JEL classification: D24, C23, O47

1. INTRODUCTION

The concept of Total Factor Productivity (TFP) has a history of being under scrutiny. The debate about how TFP should be measured and what it actually means is far from being closed.[1] An earlier criticism of TFP is that it measures "everything and anything" that is not accounted for by input growth (Abramovitz, 1956). Other criticisms are that TFP is not a perfect measure of technical progress, that TFP measurement is subject to methodological weakness, and that TFP is subject to problems associated with input and output measurement errors (Lipsey and Carlaw, 2003). While such criticisms are plausible, TFP is still useful and widely used to assess how efficiently an economy transforms its labour, capital, and raw materials into goods and services.

Given its usefulness TFP is often used with other indicators of economic activity '…to develop an idea of how well or poorly an economy is doing in terms of the return it is obtaining on its investments' (Mawson, *et al*., 2003, p.1). Moreover, productivity growth is found to be correlated with other measures that are linked to a country's economic performance, including per capita output growth, employment, economic policy and political and regulatory institutions.[2] Given that interest in the analysis of TFP growth is on its trend change rather than its magnitude change, '…there is little need to be overly concerned with obtaining the so-called accurate or "real" TFP growth rate' (Mahadevan, 2003, p.375). As such it is relevant to determine the sources of New Zealand's productivity growth.

To examine TFP growth in the case of New Zealand we need to decompose the sources of TFP growth first. So far the index number, growth accounting, non-frontier econometric approach and data envelopment analysis (DEA) have been used to study New Zealand's productivity growth.[3] The former three techniques estimate TFP growth as a residual of output growth after accounting for the growth of inputs. Quite often technical progress is considered to be the unique sources of TFP growth. On the other hand, even though the DEA approach can decompose the source of TFP growth into technical progress and technical efficiency components, it does not take into consideration the error term for the whole measure of TFP.

In this study we focus on the measurement and interpretation of TFP. A stochastic frontier model is used as it has the ability to gain information on the specified production technology and technical inefficiency component. This information will be used to decompose the sources of TFP growth into four components as follows: Technical Progress (TP), Technical Efficiency (TE), Scale Effect (SE), and Allocative Efficiency (AE). The result of TFP

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[1] See Lipsey and Carlaw (2001) for a thought provoking list of alternative interpretations of what TFP measures.

[2] Easterly and Levine (2002) found that most of the difference in cross-country per capita GDP growth is attributed to differences in multifactor productivity growth. Klein and Luu (2003) found that technical efficiency is positively correlated with policies supporting laissez-fair and political structures that promote policy stability. Becchetti et al. (2003) found that investment in information and communication technology improves firm efficiency.

[3] See Mawson et al (2003) for the list of the earlier studies on New Zealand's productivity growth.

growth estimation obtained using the stochastic frontier approach is compared with other approaches applied to New Zealand's TFP growth. Thus, we select New Zealand's manufacturing industry to measure various sources of TFP growth as this industry data is more accurate than other sectors.

The paper is organised as follows: Section 2 presents the decomposition of TFP using the stochastic frontier production function framework. Section 3 sets out the econometric specifications of the stochastic frontier production and the technical inefficiency functions, data and the relevant variables used in the estimation process. Section 4 presents the results for nine two-digit manufacturing industries, including the specification tests of various production functions. The analysis takes into consideration New Zealand's pre- and post- reform period. The final section presents the conclusion.

2. DECOMPOSITION OF TFP USING STOCHASTIC FRONTIER PRODUCTION

The stochastic frontier production approaches proposed by Aiger *et al*., (1977) and Meeusen and van den Broeck (1977) have been extensively used as a research technique in productivity analysis.[4] The fundamental difference between the frontier and non-frontier approaches lies in the assumption of utilisation of existing technology by the firm. The frontier approach assumes that firms do not fully utilise the existing technology because of various non-prices and organisational factors. This implies the existence of technical inefficiency effect that causes a firm to produce below its potential output or a set of output in the production frontier. Since this assumption is ignored in the non-frontier approach, this estimation in this study utilises the stochastic frontier production approach. The generic form of this frontier production function is defined by:[5]

$$Y_{it} = Y^{d}(X_{it}, \beta, t)\exp(V_{it} - U_{it}) \qquad (1)$$

Where i=1,…I indexes firms or industries; t=1,… T indexes the observations overtime; and variables and parameters are:

Y_{it}	denotes output level of industry i at time t;
X_{it}	is a vector of inputs of industry i at time t;
β	is vector of unknown parameters to be estimated;
V_{it}	is a symmetric random error term, independently and identically distributed as $N(0,\sigma_v^2)$, intended to capture random variation in output level due to external shocks;
U_{it}	is intended to capture technical inefficiency of industry i at time t. A higher value for U implies an increase in technical inefficiency of industry i. A value of U closes to zero implies that industry i is perfectly technical efficient.

---

[4] More detailed reviews on the stochastic production frontier literature are explained by Forsund, *et al*., (1980), Schmidt (1986), Bauer (1990), Battese (1992), Lovell (1993), Greene (1993), and Kumbhakar and Lovell (2000).

[5] For the graphic demonstration of the basic framework of the stochastic frontier production function see Figure A1 in Appendix 1.

Taking logs and totally differentiating equation (1) with respect to time gives the growth rate of output at time *t* for industry *i* as follows:

$$\frac{\dot{Y}_{it}}{Y_{it}} = \frac{\partial \ln Y^{d}}{\partial t} + \sum_{k} \varepsilon_{k} \frac{\dot{X}_{it}}{X_{it}} - \frac{\partial U_{it}}{\partial t} + \frac{\partial V_{it}}{\partial t} \qquad (2)$$

Where $\varepsilon_k = \frac{\partial Y^d}{\partial X_k} \frac{X_k}{Y^d}$ is output elasticity with respect to input *k*.

Accordingly the Solow residual, i.e. residual growth rate of output not explained by the growth in inputs, is defined by:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \frac{\dot{Y}_{it}}{Y_{it}} - \sum_{k} s_{k} \frac{\dot{X}_{it}}{X_{it}} \qquad (3)$$

Where $s_k = \frac{w_k X_k}{\sum_{n=1}^{k} w_n X_n}$ is input *k*'s share in production costs.

The technical inefficiency of industry *i* at time *t* defined in equation (1) relates to its technical efficiency level by:

$$Te_{it} = \frac{E\left(Y_{it} \middle| U_{it,} X_{it}\right)}{E\left(Y_{it} \middle| U_{it} = 0, X_{it}\right)} = \exp(-U_{it}) \qquad (4)$$

Taking logs and differentiating equation (4) with respect to time yields the growth rate of technical efficiency as follows:

$$\frac{\dot{Te}_{it}}{Te_{it}} = -\frac{\partial U_{it}}{\partial t} \qquad (5)$$

Combining equations (2) and (5) and substituting the growth rate of industry *i's* output into equation (3) yields:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \frac{\partial \ln Y^{d}}{\partial t} + \sum_{k} \varepsilon_{k} \frac{\dot{X}_{it}}{X_{it}} + \frac{\dot{Te}_{it}}{Te_{it}} + \frac{\partial V_{it}}{\partial t} - \sum_{k} s_{k} \frac{\dot{X}_{it}}{X_{it}} \qquad (6)$$

Following the decomposition method proposed by Kumbhakar (2000), equation (6) can be rearranged as follows:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \frac{\partial \ln Y^{d}}{\partial t} + \frac{\dot{Te}_{it}}{Te_{it}} + (RTS-1)\sum_{k} \lambda_{k} \frac{\dot{X}_{it}}{X_{it}} + \sum_{k} (\lambda_{k} - s_{k}) \frac{\dot{X}_{it}}{X_{it}} + \frac{\partial V_{it}}{\partial t} \qquad (7)$$

Where $RTS = \sum_k \varepsilon_k$ is a return to scale coefficient, and $\lambda_k = \dfrac{\varepsilon_k}{\sum_k \varepsilon_k}$

Equation (7) shows that TFP growth is decomposed into five components. The first component is the change in technical progress (TP). It measures the shift in the production function over time. The second component is the change in technical efficiency (TE). It measures the shift in production towards the known frontier production function. The third component measures the effect of scale economies (SE). A firm can benefit from economies of scale through access to a larger market. The more it can produce the lesser is the cost per unit of fixed input. The fourth component measures the effect of resource allocation efficiency (AE) subject to the deviations of factor input prices from the values of their marginal products. The last term captures the measurement error and could be equal to zero if the variation in the stochastic output is not different from the variation in deterministic output. If the error term equals to zero then Equation (7) is equivalent to the decomposition method as proposed by Kumbhakar (2000).

While the above interpretations of the SE and AE components are quite straight forward, the TP and TE components have various definitions that one should take some cautions when interpreting the change in TP and TE components. Some of these issues are noted here.

The TP component is sometimes identified as disembodied technical change that associates with the knowledge-creating activities of research, invention and development, the diffusion of knowledge, and the spillover effects from capital and labour (Mahadevan, 2003, p.367; Schreyer and Pilat, 2001, pp.157-58). This view has been noted as early as the study by Jorgenson and Grilliches (1967). They associated the shift in production frontier with the ‘free lunches’ of externalities reflecting the ‘part of any alteration in the pattern of productive activity that is ‘cost less’ from the point of view of market transactions’ (see Jorgenson, 1995, p.54). For example, the investment in information and communication technology (ICT) could help firms to get extra benefits arising from transaction cost savings from business to consumers and from business to business e-commerce (OECD, 2000). For this reason, the expected return on ICT investment could be well above the opportunity cost of its investment.

The above interpretations however are not entirely correct for many reasons. As Hulten (2000, p.9) argues that the shift in production frontier ‘…captures only costless improvements in the way an economy’s resources of labor and capital are transformed into real GDP (the proverbial ‘Manna from Heaven’). As such, ‘technical change that results from R&D spending [which is likely to be costly] will not be captured by the shift in production frontier’ (ibid, p.9.). Carlaw and Lipsey (2003, pp. 468-69) also argue that an extra return on investment above its opportunity cost may not always arise from investment in new technology but also from ‘a reward facing the high degree of uncertainty’ associated with the development of new technology. These are not free lunches (ibid, p.469). Other factors may also cause the shift in production frontier; including *inter alia* terms of trade (Ten Raa and Mohnen, 2002), adjustment costs, cyclical effects (Schreyer and Pilat, 2001, p.158) shifts in social attitudes, fluctuations in demand, changes in factor shares, and other unwanted factors (i.e. measurement errors, omitted variables, aggregation bias, and model misspecification) (Hulten, 2002, p.11 and p.61).

The TE component on the other hand identified as embodied technical change that 'captures the effects of learning by doing (experience), and advances in applied technology (Mahadevan, 2003, p.366). It also captures the 'improvements made in using a given technology – even when this technology is outdated by international standards (Schreyer and Pilat, 2001, pp. 160-61). With such improvements, more output is obtained with a given quantity of inputs or the same output can be produced with lesser input at the same cost. Therefore given the technology the TE component captures the firms' ability to operate on the production frontier through "best practice" technique. Other factors such as institutional support can affect the efficiency through its influence on transaction costs, work efforts, and investment incentives (Klein and Luu, 2003). Nevertheless, some issues that could cause confusion in the interpretation of TE are related to the measurement of the quality of factor inputs (Mahadevan, 2003). We discuss this issue more in the next sections.

3. ECONOMETRIC SPECIFICATIONS AND DATA

To compute the sources of TFP growth identified in equation (7), the stochastic frontier production and the technical inefficiency functions are specified below. We employ the model developed by Battese and Coelli (1995), as the stochastic frontier production and the technical inefficiency functions can be estimated simultaneously.[6] The stochastic frontier production function to be estimated here takes the translog form as follows:

$$\begin{aligned}\ln Y_{it} &= \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \frac{1}{2}\beta_3 (\ln L_{it})^2 + \frac{1}{2}\beta_4 (\ln K_{it})^2 + \beta_5 \ln L_{it} \ln K_{it} \\ &+ \beta_6 T + \beta_7 T^2 + \beta_8 T \ln L_{it} + \beta_9 T \ln K_{it} - U_{it} + V_{it} \qquad (8)\end{aligned}$$

Where the technical inefficiency function is assumed to be defined by:

$$U_{it} = \delta_0 + \delta_1 LQ_{it} + \delta_2 KL_{it} + \delta_3 .T + W_{it} \qquad (9)$$

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[6] Either two-stage approach or simultaneous approach can be used to estimate the parameters of stochastic frontier production and technical inefficiency functions. The former involves with the estimations, in which the parameters of the stochastic frontier production function and the prediction of technical efficiency component are estimated in the first stage. Then, the parameters of the technical inefficiency function can be estimated in the second stage. However, the two-stage approach is unlikely to provide estimates which are as efficient as the simultaneous approach (Coelli, 1996. p.5).

Where ln denotes the natural logarithm, i=1,…, 9 indexes the 9 manufacturing industries, t=1,…, 21 indexes the annual observations over the period 1978-98, and the variables are:

Y_{it}	is the value added for industry i at time t,
K_{it}	is capital input for industry i at time t,
L_{it}	is labour input for industry i at time t,
T	is time trend
LQ_{it},	is the quality index of labour input developed by Ho and Jorgenson (1999). It is defined as the ratio of volume of labour input to hour worked.
KL_{it}	is stock of physical capital per unit of person employed
V_{it}	is assumed to be iid $N(0,\sigma_v^2)$
W_{it}	is random error term, distributed as $N(0,\sigma^2)$, truncated at $-(\delta_0+\delta_1 LQ_{it}+\delta_2 KL_{it}+\delta_3 T)$, which ensures that $U_{it}\geq 0$
U_{it}	is obtained by truncation of the $N(\delta_0+\delta_1 LQ_{it}+\delta_2 KL_{it}+\delta_3 T,\sigma^2)$

In this study, we model the technical inefficiency component as a function of the quality of labour and the capital-labour intensity. This is because we do not make any adjustments for quality change in inputs used to estimate equation (8).[7] Based on the model specification identified in equations (8) and (9), the technical progress component of the ith industry in the tth period is defined by:

$$TP_{it} = \frac{\partial \ln Y_t}{\partial t} = \beta_6 + \beta_7 T + \beta_8 \ln L_{it} + \beta_9 \ln K_{it} \qquad (10)$$

Where β_6 and β_7 are "Hicksian" parameter and β_8 and β_9 are "factor-augment" parameter.

It should be noted that when technical progress is non-neutral the change in TP may vary for different input vectors. To avoid such a problem, Coelli *et al*., (1998, p. 234) suggest that the geometric mean between the adjacent periods be used to estimate the TP component. The geometric mean between time t and t+1 is defined by:[8]

$$TP_{it} = \left\{\left[1+\frac{\partial \ln Y_t}{\partial t}\right].\left[1+\frac{\partial \ln Y_{t+1}}{\partial (t+1)}\right]\right\}^{0.5} \qquad (9)$$

---

[7] When the measurement of factor inputs are adjusted for quality changes, all embodied technical change (TE), which is the inverse function of technical inefficiency component, is to be counted as inputs. As such, the changes in the quality of inputs are translated into output growth directly. Thus the change in TFP is confined to the change in disembodied technical change (TP) (see for example, Mahadevan, 2003, pp.367-370).

[8] It is likely that the variation of parameters of the production function over time could affect the change in TP measurement over the long period. If there are enough observations, one needs to estimate a separate frontier production function for each time period in order to avoid such a problem. However, Coelli *et al*., (1998) note that the partial derivative of the production function with respect to time is a good approximation for the measurement of TP change over time.

The estimates of (Te_{it}) are obtained through maximum likelihood procedure, where the maximum likelihood function is based on a joint density function for the composite error term ($V_{it}+U_{it}$). As such, technical efficiency can be calculated for each firm per year by:

$$Te_{it} = E\left[\exp(-U_i) : V_i + U_i\right] = \frac{1-\Phi(\alpha_a + \gamma(V_i + U_i)/\sigma_a}{1-\Phi(\gamma(V_i + U_i)/\sigma_a)} \exp\left[\gamma(V_i + U_i) + \sigma_a^2/2\right] \quad (10)$$

Where $\sigma_a = \sqrt{\gamma(1-\gamma)\sigma^2}$, $\sigma^2 \equiv \sigma_u^2 + \sigma_v^2, \gamma \equiv \sigma_u^2/\sigma^2$ and $\phi(.)$ the density function of a standard normal random variable (Battese and Coelli, 1988). Gamma is the unknown parameter to be estimated.

The data used in this study are the panel data of nine two-digit manufacturing industries for the period 1978-98. It was drawn from Diewert and Lawrence (1999), which is the fixed-weighted series in 1992 constant price. The value added measure of output is given by gross product at production that accounts after deducting the intermediate input of goods and services used by the industry. The capital input is measured by net capital stock, whereas employment data is by hour worked.

4. EMPIRICAL RESULTS

The empirical results are reported in this section. First, the tests for the specifications of stochastic production and technical inefficient functions are presented. Second, the results of TFP growth in New Zealand's manufacturing industry are compared to studies of Diewert and Lawrence's (1999) and Fare *et al.*, (2003). The results for the decomposition analysis of technological progress, technological efficiency, scale effect, and allocative effect are presented next.

4.1 Empirical results and tests for the specifications of the stochastic production and technical inefficiency functions

The coefficients reported in Table 1 are estimated using the computer program FRONTIER 4.1 (Coelli, 1996). The panel 1 of Table 1 reports the estimated coefficients for the stochastic frontier production function. Based on this production function the marginal product of capital and labour is 0.283 and 0.815, respectively.[9] The estimated value of the return-to-scale parameter is 1.097.[10] The result of the return-to-scale parameter in this study is similar to that obtained by Szeto (2001).

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[9] Marginal products of capital $= \frac{\partial Y}{\partial K} = \beta_1 + \beta_3 \ln \overline{K} + \beta_5 \ln \overline{L} + \beta_8 \overline{T}$ and the Marginal products of labour $= \frac{\partial Y}{\partial L} = \beta_2 + \beta_4 \ln \overline{L} + \beta_5 \ln \overline{K} + \beta_9 \overline{T}$

[10] The return-to-scale parameter $= \frac{\partial Y}{\partial K} + \frac{\partial Y}{\partial L}$

The results of the estimated stochastic frontier function show that only half of the estimated coefficients are statistically significant. This could be because of the presence of the squared and interactive term in the translog function that creates a high level of multicollinearity. Thus, the t-statistic is not appropriate for the test of individual statistical significance but the likelihood ratio (LR) tests are implemented to further assess the validity of those coefficients. These tests are discussed in Table 2.

Table 1: Empirical Results for Frontier Production Function and Inefficiency Model

Variables	Parameters	Parameter estimates
Panel 1: Stochastic frontier production model		
Constant	β_0	4.719 (0.993)***
ln(K)	β_1	0.164 (0.257)
ln(L)	β_2	-0.736 (0.329)**
$[\ln(K)]^2$	β_3	-0.316 (0.130)**
$[\ln(L)]^2$	β_4	-0.027 (0.111)
ln(K).ln(L)	β_5	0.241 (0.117)**
T	β_6	0.005 (0.021)
T^2	β_7	0.003 (0.001)***
T.ln(K)	β_8	0.005 (0.006)
T.ln(L)	β_9	-0.005(0.006)
Panel 2: Inefficiency model		
Constant	δ_0	3.832 (0.776)***
LQ	δ_1	-0.530 (0.086)***
KL	δ_2	-0.245 (0.109)***
T	δ_3	0.055 (0.011)***
Panel 3: Variance Parameters		
	σ^2	0.008(0.001)***
	γ	0.587 (0.121)***

The panel 2 of Table 1 reports the estimated coefficients for the technical inefficient function. All coefficients are statistically significant implies that much of output variation from the production function is due to the presence of technical inefficiency effect.[11] Both the estimated δ_1 and δ_2 values are negative and statistically significant which imply that an increase in labour quality and the ratio of capital to labour will lower the technical inefficiency effects. The estimated value of δ_3 is positive and statistically significant, indicating that inefficiency has varied and increased over time.

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[11] If the variance parameters are not significantly different from zero it implies that stochastic production function is not required and that the production function can be consistently estimated using ordinary least squares (Coelli, 1996, p.5).

The panel 3 of Table1 reports the estimates of variance parameters (i.e., δ^2 and γ) that test for the validity of technical inefficiency effect. Both the estimated coefficients are statistically significant, this result confirms the presence of technical inefficiency effect in the output residual, as indicated in the panel 2. This implies that TFP estimation using non-frontier approach is invalid.[12] The estimated coefficient of gamma (γ) equals 0.587, which is by far less than one.[13] This implies that output variation is associated with random errors. Thus, stochastic frontier model and the deterministic frontier model (i.e. DEA model) are different. In other words, the assumption of the DEA model that there are no measurement errors is not correct.

In the next step we perform the joint tests using the likelihood ratio (LR) tests. The null hypotheses relate to three tests of the production specifications. The results are presented in Table 2. The first null hypothesis test whether the Cobb-Douglas production function is adequate to explain the underlying technology of New Zealand's manufacturing industry. The second hypothesis tests whether there is no technical progress effect, and the third hypothesis tests whether technical change is neutral. The test results presented in Table 2 show that all three null hypotheses are rejected thus indicating that a trans-log production function is accepted and is applicable here.

Table 2: Statistics for Tests of Hypothesis: Stochastic Production Function

Null hypothesis	**Test statistics λ=-2[L(H_0)-L(H_1)]**	**Critical value at 1% level**	**Decision**
1. Data can be explained by Cobb-Douglass production specification. H_0: $\beta_3 = \beta_4 = \beta_5 = \beta_7 = \beta_8 = \beta_9 = 0$	250.8	16.81	Reject H_0
2. There is no technical progress effect. H_0: $\beta_6 = \beta_7 = \beta_8 = \beta_9 = 0$	141.2	13.28	Reject H_0
3. Technical change is neutral. H_0: $\beta_8 = \beta_9 = 0$	141.4	9.21	Reject H_0

Note: Critical value is obtained from Table 1 of Kodde and Palm (1986, p.1246).

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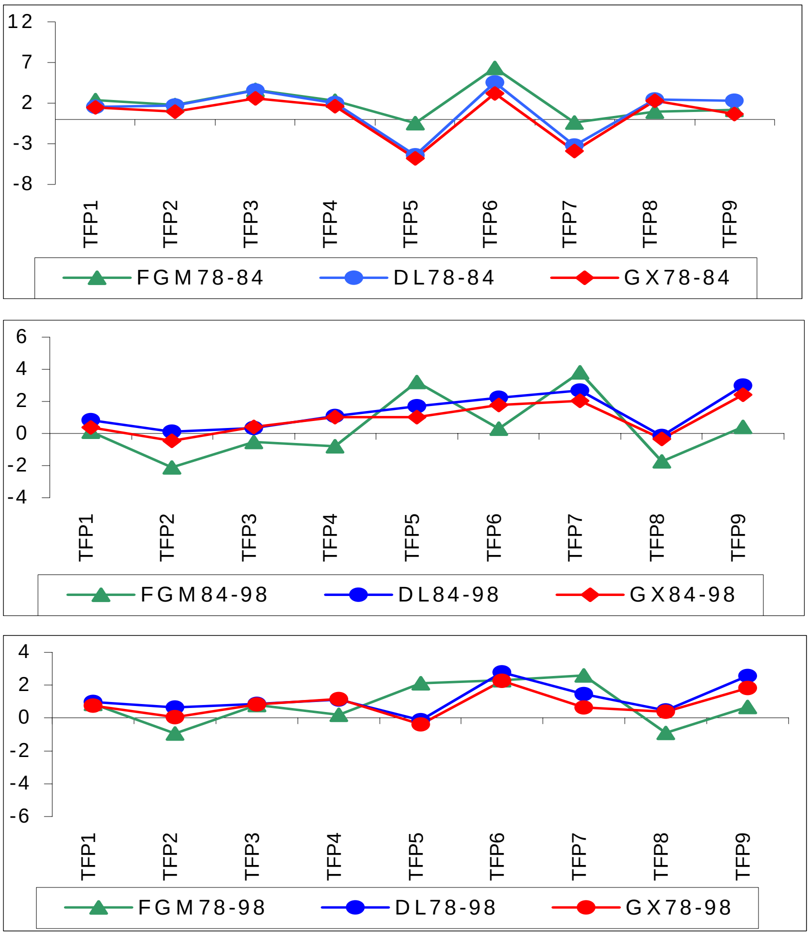
[12] The non-frontier approach does not measure the technical inefficiency effect and assumes that a firm operates at its full capacity. Thus, TFP can be measured only as shifts in the production function.

[13] The estimated value of gamma (γ) must be between zero and one. If it is closed one, the random error term (V_{it}) is closed to zero, then the stochastic frontier model may not be significantly different from the deterministic model (Coelli, *et al.*, 1998, p.215).

4.2 New Zealand's manufacturing industry: comparison and decomposition analysis of TFP growth

To further assess the validity of stochastic frontier approach, the rates of TFP growth is computed using the information from the results reported in Table 1 and the TFP decomposition identified in equation (7). We then compare our estimation of the growth rate of TFP with those estimated by Diewert and Lawrence (1999) and Fare *et al.*, (2003). The comparative results are shown in Figure 1.

Figure 1: Comparison of Various Studies



Notes: FGM, DL and GX series were taken from Fare et al (2003), Diewert and Lawrence (1999) and this study, respectively. For more detail see Table A.1.

Overall, Diewert and Lawrence's (1999) TFP growth series seem quite similar to our results in the sense that the mean TFP growths of nine industries for different sub-periods move in the same direction. The only difference in the present study is that the estimated values of the growth of TFP are lower. On the other hand, Fare *et al.*,'s (2003) TFP growth series do not move in the same direction with our TFP estimation series, except for the period 1978-84. This is due to the presence of measurement errors in the DEA approach, as indicated in Section 4.1. The difference could also be due to the number of industries used in Fare *et al.*, (2003) study and this study, where twenty industries were used in the former study while only nine industries were used in the latter.

Table 3 reports the change in technical progress, change in technical efficiency, economic scale effect and allocation efficiency effect for the period 1978 to 1998, and the pre- and post-reform period.[14] See also Appendix Table A.2 that reports the results of the sources of TFP taking into consideration the post-reform period as 1987 to give a larger time lag effect. The results do not indicate any significant change for the estimated components. The unweighted (weighted) mean value of TP is estimated to be 2.18 percent (2.15) for the overall period, 1978-98. Its contribution to TFP growth has increased from 0.13 (0.07) percent in the pre-reform period, 1978-84, to 2.92 (2.89) percent in the post-reform period, 1984-98. The unweighted (weighted) mean value of TE on the other hand is estimated at –0.68 (-0.85) percent for the whole period, 1978-98. Its contribution to TFP growth has declined from 1.73 (1.93) percent in the pre-reform period, 1978-84, to –1.53 (-1.85) percent in the post-reform period, 1984-98. Overall, the changes in TP have been increased, whereas it has declined for TE. This result is similar to the findings of Fare *et al.*, (1996, 2003).

The increase in TP can be supported with the view that the post-reform period has led to more competition through improved technology and opening of the New Zealand markets.[15] The Australian study by Mahadevan (2002) finds that TP has increased in the manufacturing industry due to the reduction in the effective rate of assistance given by the Australian government to the firms. Thus, firms have been urged to be open and be more competitive by adopting new technology (2002, p.1020).

Modelling the technical inefficiency component we note that the decline in TE, in New Zealand's case, is in the post-reform period. This could be due to the lack of firm's ability in catching-up new technological adoptions. From the empirical results reported Table 1 it can be said that technical inefficiency is correlated with labour quality and capital to labour ratio. As these two variables are the main factors that drive labour productivity, the results support that decline in TE is attributed to decline in labour productivity. In the Australian case, while there is no empirical evidence, however Mahadevan suggests that the decline in TE is due to lack of technological know-how or learning-by-doing gains to accommodate a better improvement in adopted technology.

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[14] See Table A.1 in Appendix 1 for the estimation result of the source of TFP Growth in different sub-period.

[15] It should be noted that an increase in TP may not only be due to technical spillover but also could be due to other factors as explained in section 2. Thus, the change in TP may be an overestimated here, see Shapiro (2003).

Table 3: Sources of TFP Growth of New Zealand's Manufacturing Industries: Decomposition Analysis for the Pre- and Post-Reform Periods (%)

		1978-84	**1984-98**	**1978-98**
	Technical Progress (TP)			
1	Food, beverages, tobacco	0.19	2.94	2.22
2	Textiles	-0.21	2.53	1.81
3	Wood & Wood Products	-0.03	2.74	2.01
4	Paper & Paper Products	0.29	3.00	2.28
5	Chemicals	0.24	3.28	2.47
6	Non-metallic minerals	0.20	3.00	2.26
7	Basic metals	0.58	3.46	2.70
8	Machinery	-0.16	2.59	1.86
9	Other manufacturing	0.04	2.74	2.03
	Unweighted mean	*0.13*	*2.92*	*2.18*
	Weighted mean	*0.07*	*2.89*	*2.15*
	Technical Efficiency (TE)			
1	Food, beverages, tobacco	2.09	-1.67	-0.69
2	Textiles	1.11	-2.39	-1.34
3	Wood & Wood Products	2.80	-2.39	-1.21
4	Paper & Paper Products	1.73	-1.33	-0.52
5	Chemicals	0.76	-1.07	-0.66
6	Non-metallic minerals	3.68	-0.81	0.45
7	Basic metals	0.20	-0.16	-0.05
8	Machinery	2.38	-3.11	-1.68
9	Other manufacturing	0.84	-0.81	-0.46
	Unweighted mean	*1.73*	*-1.53*	*-0.68*
	Weighted mean	*1.93*	*-1.85*	*-0.85*
	Scale Effect (SE)			
1	Food, beverages, tobacco	0.23	-0.04	0.08
2	Textiles	-0.05	-0.49	-0.36
3	Wood & Wood Products	-0.11	0.17	0.12
4	Paper & Paper Products	0.01	0.06	0.03
5	Chemicals	0.40	-0.02	0.11
6	Non-metallic minerals	-0.03	0.04	0.02
7	Basic metals	-0.23	0.03	-0.02
8	Machinery	-0.09	0.17	0.15
9	Other manufacturing	0.01	0.10	0.07
	Unweighted mean	*0.02*	*0.00*	*0.02*
	Weighted mean	*0.07*	*0.01*	*0.06*
	Allocation Effect (AE)			
1	Food, beverages, tobacco	-1.06	-0.86	-0.845
2	Textiles	0.13	-0.08	-0.041
3	Wood & Wood Products	-0.06	-0.12	-0.094
4	Paper & Paper Products	-0.36	-0.71	-0.627
5	Chemicals	-6.22	-1.18	-2.299
6	Non-metallic minerals	-0.63	-0.47	-0.452
7	Basic metals	-4.48	-1.28	-1.972
8	Machinery	0.13	0.02	0.049
9	Other manufacturing	-0.27	0.38	0.180
	Unweighted mean	*-1.42*	*-0.48*	*-0.68*
	Weighted mean	*-1.08*	*-0.56*	*-0.64*

With respect to SE, its contribution to TFP growth is very small. This could be due to the small size of New Zealand's domestic market coupled with its geographic distance from the larger markets. The unweighted (weighted) mean values of the SE is estimated at the range of 0.00 (0.01) to 0.02 (0.07) percent. The results show that in the post-reform period the scale effect for some of the industries have become positive. Overall it can be said that the industries have benefited from scale economies. This may be because of New Zealand's trade liberalization associated with the falling transport costs that has led to an increase in market excess of New Zealand's manufacturing firms.

The unweighted (weighted) mean values of AE on the other hand is estimated at –0.68 (-0.64) percent for the period 1978-98. The negative values of AE indicate the existence of allocative inefficiency. However, this negative effect on TFP growth has declined from -1.42 (-1.08) percent from the pre-reform period, 1978-84, to –0.48 (-0.56) percent in the post-reform period, 1984-98. This implies that deregulation in the post-reform period has reduced price distortions. Thus, it can be said that factor inputs have been paid closer to the values of their marginal products.

From the decomposition analysis presented above it is obvious that changes in TP, TE and AE have been the main factors dominating the TFP growth in New Zealand. Therefore, understanding what determines source of TFP growth is important for the policy formulation to raise TFP and economic growth.

5. CONCLUSION

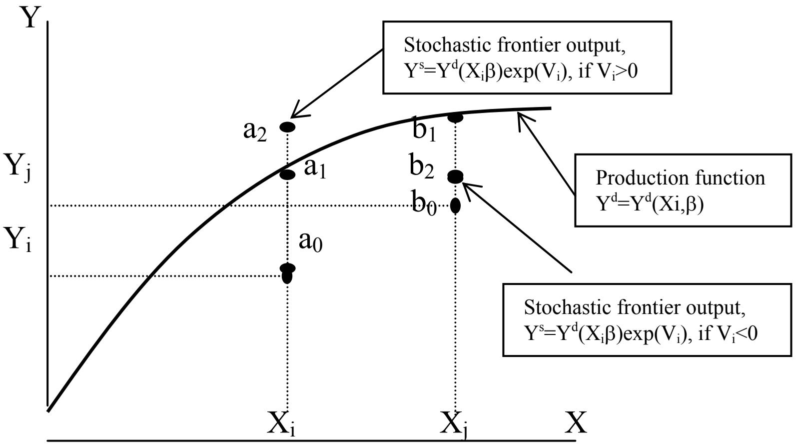
This paper examines the sources of TFP growth in New Zealand's manufacturing industry for the period 1978 to 1998 utilising the stochastic frontier approach. This methodology involves decomposition of the sources of TFP growth into four components, i.e. technical progress, technical efficiency, scale effect, and allocative efficiency.

The main findings of the decomposition analysis show that TFP growth is largely due to changes in technical progress, technical efficiency and resource allocation effect. The changes in technical progress and resource allocation have improved in the post-reform period, i.e. 1984-98, while technical efficiency has declined in the post-reform period. With respect to scale effect its contribution to total factor productivity growth is very small. However, it shows that in the post-reform period the scale effects for some of the industries have become positive. Overall it can be said that the industries have benefited from scale economies. The allocative efficiency component indicates that resource allocation has improved in the post-reform period. This implies that deregulation in the post-reform period has reduced price distortion. Since the interpretation of change in technical progress and technical efficiency components is more complicated, further examination is needed to understand what drives these two components at the firm level.

APPENDIX 1:

This basic framework is illustrated in input and output space in Figure A1. The inputs are represented on the horizontal axis and the output on the vertical axis. The observed input and output of two firms *i* and *j* are represented by a_0 and b_0, respectively. The stochastic frontier outputs (i.e. $Y^s=Y^d(X_i,\beta)\exp(V_i)$) vary about the deterministic frontier output or the best practice production frontier (i.e. $Y^d=Y^d(X_i, \beta)$). In this case, firms *i* and *j* produce below the best practice production frontier. The level of output that firms *i* and *j* should have gained if they were more efficient are represented by a_0a_1 and b_0b_1, respectively. These distances also represent the inefficient measurement (*U*) for the firms.

Figure A1 The Stochastic Frontier Production Function



Source: Coelli *et al.,* (1998, p.186). Some symbols have been added and some notations for the production function have been modified to make it consistent with the notation used in this study.

Table A.1 Comparative New Zealand Studies of Productivity Growth

		Fare et al (2003)	Diewert and Lawrence (1999)	This study (Gounder & Xayavong)
	1978-84			
1	Food, beverages, tobacco	2.39	1.56	1.45
2	Textiles	1.80	1.67	0.97
3	Wood & Wood Products	3.61	3.57	2.62
4	Paper & Paper Products	2.33	2.04	1.66
5	Chemicals	-0.47	-4.41	-4.82
6	Non-metallic minerals	6.35	4.55	3.22
7	Basic metals	-0.40	-3.22	-3.93
8	Machinery	0.97	2.42	2.27
9	Other manufacturing	1.15	2.31	0.62
	Unweighted mean	*1.97*	*1.17*	*0.45*
	Weighted mean		*1.51*	*1.05*
	1984-98			
1	Food, beverages, tobacco	0.12	0.84	0.37
2	Textiles	-2.11	0.12	-0.43
3	Wood & Wood Products	-0.54	0.35	0.40
4	Paper & Paper Products	-0.80	1.09	1.01
5	Chemicals	3.20	1.69	1.01
6	Non-metallic minerals	0.30	2.22	1.76
7	Basic metals	3.83	2.69	2.04
8	Machinery	-1.72	-0.15	-0.33
9	Other manufacturing	0.42	3.00	2.40
	Unweighted mean	*0.30*	*1.32*	*0.91*
	Weighted mean		*0.87*	*0.50*
	1978-98			
1	Food, beverages, tobacco	0.87	0.96	0.76
2	Textiles	-0.93	0.62	0.06
3	Wood & Wood Products	0.80	0.87	0.84
4	Paper & Paper Products	0.19	1.12	1.17
5	Chemicals	2.11	-0.13	-0.39
6	Non-metallic minerals	2.29	2.78	2.28
7	Basic metals	2.58	1.45	0.66
8	Machinery	-0.91	0.46	0.38
9	Other manufacturing	0.68	2.57	1.83
	Unweighted mean	*0.85*	*1.19*	*0.84*
	Weighted mean		*0.96*	*0.71*

Table A.2 Sources of TFP Growth of New Zealand's Manufacturing Industries: Decomposition Analysis for the Pre- and Post-Reform Periods (%)

		1978-87	**1987-98**	**1978-98**
	Technical Progress (TP)			
1	Food, beverages, tobacco	0.63	3.52	2.22
2	Textiles	0.21	3.12	1.81
3	Wood & Wood Products	0.42	3.32	2.01
4	Paper & Paper Products	0.70	3.58	2.28
5	Chemicals	0.78	3.84	2.47
6	Non-metallic minerals	0.64	3.59	2.26
7	Basic metals	1.09	4.01	2.70
8	Machinery	0.27	3.16	1.86
9	Other manufacturing	0.44	3.33	2.03
	Unweighted mean	***0.58***	***3.50***	***2.18***
	Weighted mean	***0.53***	*3.47*	***2.15***
	Technical Efficiency (TE)			
1	Food, beverages, tobacco	1.18	-2.22	-0.69
2	Textiles	-0.08	-2.38	-1.34
3	Wood & Wood Products	1.98	-3.81	-1.21
4	Paper & Paper Products	0.77	-1.57	-0.52
5	Chemicals	0.68	-1.76	-0.66
6	Non-metallic minerals	2.12	-0.92	0.45
7	Basic metals	0.21	-0.25	-0.05
8	Machinery	0.62	-3.56	-1.68
9	Other manufacturing	0.55	-1.28	-0.46
	Unweighted mean	***0.89***	***-1.97***	***-0.68***
	Weighted mean	***0.55***	***-1.28***	***-0.85***
	Scale Effect (SE)			
1	Food, beverages, tobacco	0.37	-0.16	0.08
2	Textiles	0.12	-0.76	-0.36
3	Wood & Wood Products	-0.02	0.24	0.12
4	Paper & Paper Products	0.26	-0.15	0.03
5	Chemicals	0.31	-0.06	0.11
6	Non-metallic minerals	-0.03	0.06	0.02
7	Basic metals	-0.06	0.00	-0.02
8	Machinery	0.16	0.14	0.15
9	Other manufacturing	-0.06	0.18	0.07
	Unweighted mean	***0.12***	***-0.06***	***0.02***
	Weighted mean	***-0.06***	***0.18***	***0.06***
	Allocation Effect (AE)			
1	Food, beverages, tobacco	-0.60	-1.04	-0.845
2	Textiles	0.03	-0.10	-0.041
3	Wood & Wood Products	-0.10	-0.09	-0.094
4	Paper & Paper Products	-0.09	-1.07	-0.627
5	Chemicals	-4.57	-0.44	-2.299
6	Non-metallic minerals	-0.27	-0.60	-0.452
7	Basic metals	-5.47	0.89	-1.972
8	Machinery	0.09	0.01	0.049
9	Other manufacturing	-0.41	0.67	0.180
	Unweighted mean	***-1.27***	***-0.20***	***-0.68***
	Weighted mean	***-0.81***	***-0.51***	***-0.64***

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