Microeconomic Reform and Technical Efficiency in Australian Manufacturing

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Abstract

The technical efficiency dividend reaped by Australian manufacturing industries following the implementation of microeconomic reforms over the past three decades is analysed empirically in this paper. The technical efficiency scores have been estimated for manufacturing industries using a combined stochastic production-frontier inefficiency model that is free of simultaneity bias. The model parameters have been estimated using maximum likelihood techniques using a panel data set covering a cross-section of 8 industries spanning a time-series of 26 years (1969-1995). The empirical results shed light on how technical inefficiency in manufacturing has been whittled down by the microeconomic reform induced trade liberalisation and technology diffusion processes. Generalised likelihood ratio tests reject the null hypotheses that trade liberalisation and technology transfer had no significant impact on the reduction of technical inefficiency. The reduction of effective rate of assistance and technical efficiency and technology proxies such as intra-industry trade and capital deepening are negatively correlated during the study period. These findings give credence to the predictions of endogenous growth theories that openness of the economy provides a conduit for accessing new technology that promotes innovation and technical efficiency. The increase in technical efficiency of manufacturing industries is the unsung hero behind the emergence of the 'new economy' or the spectacular pick-up of productivity growth observed for Australia during the 1990s.
The error-correction modelling reported at the outset confirms that this productivity pick-up is not an artefact of a cyclical upturn. It is attributable to the microeconomic reforms and the technology transfer that has followed it. The paper concludes on the need for further research , first, to shed light on the constituents of total factor productivity such as technical change and technical progress and second, to design policy to address the challenging issues of equity-efficiency trade-off lest it degenerates into a back-lash that could nullify the whole reform agenda.

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Microeconomic reforms. Trade liberalisation. Technology diffusion. Manufacturing Industries . Productivity. Technical inefficiency. Stochastic production frontier. Panel data. Translog function.

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I. INTRODUCTION

Australia inherited a protectionist yoke dubbed the 'Federation Tri-fecta' from the days of Federation (1901) according to Henderson (1990). The Tri-fecta comprised of: first, strong tariff protection to shelter domestic manufacturing industries from foreign competition; second, centralised wage-fixing and third, the white Australia immigration policy. The protectionist Tri-fecta policies nurtured high cost manufacturing industries catering for a small domestic market. It also sowed the seeds of Australia's downward slide on the OECD per capita income league. Protectionist Australia's fall from its top perch as the "lucky country" occurred at the same time when the export-oriented East-Asian economies were reporting miracle growth rates and catching-up with Australia in the per capita income stakes. Partly as an anti-dote to Australia's lack-lustre growth performance, a reversal from the Tri-fecta was ordained beginning with the across-the-board 25% tariff-cut in 1973. The microeconomic reform policies spearheaded by trade liberalisation encompassed a gamut of other initiatives such as financial deregulation, relaxing centralised wage-fixing, corporatisation and privatisation of state enterprises, tax reform and the floating of the exchange rate. These microeconomic reforms removed institutional and regulatory barriers that impeded the functioning of free markets. In the free market environment manufacturing industries had either to shape up to the challenges from global competition by adopting 'best practice' technology or go to the wall.

After thirty years of microeconomic reforms analysts are still hotly debating the pros and cons of reforms. Some have argued that the reforms have deindustrialized Australia and the globalisation process has marginalized large segments of the population. Critics claim that the much hyped productivity gains from the reforms are miniscule as of the observed productivity growth rates of 0.33% per annum it would take at least another century for Australia to reach the frontier predicted by growth theory (Quiggin,1998).

The proponents of microeconomic reform, e.g. the Productivity Commission, on the other hand contend that productivity growth has dramatically increased in the 1990s when compared to the previous decade causing the emergence of a 'new economy' (Parham, 1999). Independent empirical estimates based on dynamic econometric modelling undertaken in this study lends support to the proponents of the 'new economy".

Dynamic error correction (ECM) modelling based on the general-to-specific methodology (Hendry and Juregen, 1996) linked labour productivity (output per worker, y_t) to capital intensity (capital per worker ,k_t) for the study period (1969-95). The long-run static solution for Australian manufacturing industries was obtained as:

$$\Delta y_t = 0.0338 + 0.0146\Delta k_t - 0.0007T_1 + 0.0068T_2 + 0.0161T_3 - 0.1169ECM_{t-1}$$

The coefficients of T_1 , T_2 ,T_3 captures the trend growth rate of total factor productivity (TFP) for the whole study period 1996-95, the sub-period 1980-95 and 1990-95 , respectively, after controlling for cyclical effects. The equation reveals that the trend growth of TFP declined over the whole sample period (1996-95), but turned positive growing at the rate 0.68% per year during the sub-period 1980-95 and increased in a spectacular fashion growing at the rate of 1.6% per year during the sub-period 1990-95. These empirical results lend support to the claims of the Productivity Commission that microeconomic reforms may have contributed to the emergence of 'new economy' in Australia in the 1990s (Parham, 1999).

The empirical analysis undertaken in this paper breaks new ground on a number of fronts. First, it tests empirically a key hypothesis of endogenous growth theory, namely, that trade liberalisation by enhancing international competition and cross-border technology diffusion, boosts technical efficiency of production in manufacturing industries. Second, the empirical analysis of technical efficiency in Australian manufacturing reported in the paper are based on a combined stochastic frontier - inefficiency model that is free from the simultaneity bias problem that impaired the results of earlier studies on the subject.

Third, the empirical analysis uses an updated panel dataset to analyse factors that impinge on technical inefficiency of manufacturing in manner that has not been undertaken in Australia hitherto.

Fourth, it sets the stage for undertaking the decomposition of growth of total factor productivity into its components of technical change and technical progress in order to analyse the role of technology in the emergent 'new economy' in the new century.

Fifth, the empirical findings highlight the counterproductive nature of the single-minded pursuit of a policy agenda based on first-best efficiency criteria in a second-best world where equity-efficiency tradeoffs are the order of the day.

The rest of the paper is structured as follows: Section II surveys the theoretical literature postulating links between trade related microeconomic reforms and the increase in productivity in manufacturing industries. This section also reviews past Australian studies on the analysis of productivity of manufacturing industries. Section III presents an algebraic exposition of the combined stochastic frontier - inefficiency model used for the empirical analysis of technical efficiency of manufacturing industries. The procedures used for the maximum likelihood estimation of model parameters and the likelihood ratio tests of various null hypotheses are also explained in this section. Section IV describes the panel database, variables and the data sources that have been used for the empirical validation of the stochastic frontier-inefficiency model. Section V presents the empirical results in three parts. First, the maximum likelihood estimates and tests of model parameters are discussed. Second, test results on null hypotheses on reform and technology transfer processes are presented. Third, the significance of the time-varying technical efficiency scores for different manufacturing industries are reviewed. Section VI concludes by underscoring two important policy considerations to avoid counterproductive reforms. First, the need to decompose total factor productivity growth into its components of technical change and technical progress so to avoid flawed policy prescriptions. Second, the need to design adjustment policies to address the equity-efficiency trade offs that arise from the microeconomic reform agenda.

II. BACKGROUND

Theoretical perspectives

The analysis of technical efficiency in production has a pedigree that can be traced to the seminal work of Farrell (1957) which defines technical efficiency as the production of more output with a given set of fixed factor inputs.

The concept of efficiency is also linked to the concept of 'x-efficiency' or the increase in output through better organisation and management (Leibenstein 1966). The literature relating to trade focussed microeconomic reforms and efficiency gains can be discussed under three headings: Neoclassical trade perspective, political economy of protection and endogenous or new growth theories.

The conventional or neoclassical trade theory postulates that trade liberalisation by exposing manufacturing industries to the fresh winds of competition and by enlarging markets delivers gains in productivity and efficiency. These gains arise from specialising according to the principle of comparative advantage for the global market. The production for an enlarged global market generates increasing returns to scale and other dynamic benefits resulting in sizeable cost reductions due to technical efficiencies in production. Although some critics doubt the role of trade to act as an engine of growth , empirical studies both for Australia and other countries vindicate the role of trade as a propeller of growth. These studies support the conventional wisdom that free trade is first best in that it promotes efficiency and growth and maximises national and global welfare (Karunaratne 1997).

The political economy perspective on protection of manufacturing industries contends that it leads to a massive waste of resources to fund lobbying activities to perpetuate rent yielding protection. Lobbyist fund the re-election maximising strategies of politicians who pay-back the lobbies by maintaining tariff and non-tariff barriers. These measures inflict inflationary costs on the unorganised and free riding consumer and therefore harm national welfare. The microeconomic reform strategies implemented in Australia over the past three decades represent a sea change as there was a switch from protectionist policies nurtured under the Federation tri-fecta to the free trade ethos favoured by the neoclassical paradigm.

Endogenous or new growth theories contend that the opening an economy to freer trade facilitates the diffusion of new technologies through intra-industry trade by promoting horizontal differentiation of inputs and the scaling up of the product 'quality ladder' (Keller 2000). New growth theories contend that the exposure to international competition triggers endogenous research and development (R&D) and innovation. Therefore technological progress is not exogenous as assumed in neoclassical (Solow) growth theory but springs from the inner wells of industry (Romer 1990, Aghion and Howitt 1998, Grossman and Helpman 1991). Moreover trade acts as the conduit for the transfer of new technology that increases efficiency and growth (Barro and Sala-i-Martin 1995).

The new technology activates 'learning-by-doing' spillover effects (Lucas 1988, Young 1991) and accelerates the process of catch-up with best practice or efficient technology as confirmed by studies on manufacturing industries (Tybout et al. 1991).

To recap, endogenous growth theory foreshadows that microeconomic reforms liberalising trade facilitate the transfer of new technology through intra-industry trade (IT) and promotes domestic innovation and capital deepening bolstering productivity and technical efficiency in production.

Despite the cogent theoretical case and copious empirical evidence, there are misgivings about the existence of a positive links between trade liberalisation and productivity growth. Empirical evidence from developing countries is tendered to cast aspersions on the positive trade - growth nexus by Rodrik (1992). Productivity growth in Australia, after adjusting for cyclical factors during the study period increased only by a meagre 0.3 per cent per year, requiring 100 years to reach the upper bound postulated by growth theory according to Quiggin (1998:97). Nonetheless, the theoretical possibility for microeconomic reforms spearheaded by trade reforms in generating positive externalities or 'standing over the shoulders of giants' spillover effects that could far outweigh the negative externalities or 'stepping over toes' spillover effects

(Mankiw 2000) leading to a strong positive trade growth link cannot be gainsaid. Some observers have claimed that Australia has recently caught the wave of the 'new economy' due to microeconomic reforms. The need to illuminate the debate by empirical analysis motivates this paper.

Australian studies

An important survey by Dawkins and Rogers (1998) of productivity studies of over thirty manufacturing industries undertaken over the past two decades, hereafter referred to as the Survey , classifies the findings under three broad headings: micro, meso and macro studies. The micro level case studies examined productivity differentials between domestic and foreign firms e.g. in the manufacture of photographic paper and water heaters and the like. The meso or industry level studies used a variety of techniques such as shift-share analysis, econometrics, production frontiers to analyse and identify factors that retarded productivity and efficiency in domestic manufacturing. Regression methods revealed that existence of positive links between factor biased (labour augmenting) technical change and productivity (Whiteman 1991).

Stochastic frontier production analysis demonstrated that productivity in manufacturing was positively linked to R&D and regional concentration (Caves, 1982). Macro level studies based on vintage capital models elucidate that labour augmenting technical progress occurred when the growth rate of labour productivity exceeded the positive growth rate differential between wages and rental capital (Bloch and Madden 1994).

Studies on labour market institutions demonstrated that the corporatist Accord was less conducive to higher labour productivity than the more decentralised wage-fixing options (Dowrick 1993). International comparisons of manufacturing productivity disclosed that lagged behind the frontrunners like the USA by more than 50% (Pilat et al. 1993). The Survey despite its wide coverage had some glaring omissions. For example, it failed to review the path-breaking computer general equilibrium (CGE) policy studies pioneered by Dixon et al. (1983), the numerous input-output studies (Karunaratne 1989) and the visionary information economy studies initiated by Don Lamberton (see Jussawalla et al. 1988). The Survey made three important recommendations to upgrade productivity analysis in Australian manufacturing. First, use of modern databases beyond 1977-78. Second, analysis at a more disaggregated cross-section time series to shed better light on the efficiency dynamics in the post-reform period. Third, the use of more robust techniques to unravel the complex links between reform policy and productivity. The empirical analysis undertaken in this paper attempts to addresses the important recommendations made by the Survey.

III. THE STOCHSASTIC FRONTIER-INEFFICIENCY MODEL

The stochastic production frontier model was formulated independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977) based on the theoretical insights of Farrell (1957) and others. Surveys reveal that the production frontier has been applied to analyse technical efficiency in agriculture, health, education, business, military, banking and many other areas (Lovell 1993,Green 1997). It should be noted that stochastic frontier modelling of technical efficiency differs from Data Envelopment Analysis (DEA) - the deterministic approach to productivity analysis based on linear programming .

Conceptually technical efficiency describes the shortfalls in production from the maximum capacity output level or the output on the production frontier. Movements of the production frontier over time describes the concept of technical progress.

Both technical efficiency and technical progress combine to explain total factor productivity growth. The methodology of stochastic production frontier applied in this paper focuses mainly on the analysis of technical efficiency. A noteworthy feature of the combined stochastic frontier -inefficiency model used in the empirical analysis in this paper is that it is free of the simultaneity bias that vitiated estimates of technical efficiency used in earlier studies. For example, the two-stage method used by Pitt and Lee (1981) and Kalirajan (1981) was deficient as the technical efficiency estimates were afflicted by simultaneous equation bias. The bias free methodology for the simultaneous estimation of the stochastic production frontier and the inefficiency effects model used in the empirical analysis reported in this paper is based on the exposition by Coelli et al. (1998). The methodology has been applied using panel data to analyse technical efficiency in a developing country agriculture by Battese and Coelli (1995) and in a developing country manufacturing by Lundwall and Battese (2000). In this paper, the results of the first application of the combined stochastic frontier production frontier - inefficiency model to analyse technical efficiency of Australian manufacturing industries using a comprehensive panel dataset is presented.

The empirical validation of the combined stochastic production frontier-inefficiency model required the implementation of a number of steps. First, tests had to be performed to determine whether the stochastic frontier model was really an advancement over the average response function or a deterministic model with no technical inefficiency.

Second, the appropriate functional form for the stochastic frontier model had to be determined from specifications such as the Cobb-Douglas (CD) function with constant returns to scale and the Translog (TL) with variable elasticity of factor input substitution. Third, numerous null hypotheses relating to significance of subsets of parameters had to be tested to establish whether it was trade reforms or technology that was making a dent on the reduction of technical inefficiency.

The above null hypotheses were tested using the generalised likelihood ratio (LR) test $LR_{cal} = -2[\ln L(H_0) - \ln L(H_1)]$, which was distributed as chi-squared distribution with the degrees of freedom determined by the number of parameter restrictions. Therefore the critical values (CVs) to test the null hypotheses were read off the chi-squared table and has been presented as LR_{tab} in Table 3.

The stochastic production frontier model could be defined as :

$$Y_{NTx1} = X_{NTxK}\, \beta_{Kx1} + \varepsilon_{NTx1} \qquad (1)$$

Y_{NTx1} : Value-added at constant prices of a panel of NTx1.

where NT=208, given N=8 industries (cross-section), T=26 years (time-series).

X_{NTxK} : NTxK =208x 3. K=Factor inputs: capital (K) , labour (L) and time (T).

β_{Kx1} : Maximum likelihood estimates of the K parameters.

$\varepsilon_{NTx1} = V_{NTx1} + U_{NTx1}$ (composite error term) relating to vector of NT=208 observations, where V_{NTx1} refers to stochastic errors and U_{NTx1} to the technical inefficiency effects with distributions as specified below.

$V_{NTx1} \sim$ iid $N(0, \sigma^2_v)$ NT stochastic errors (independently distributed of U_{NTx1})

$U_{NTz1} \sim$ iid $N(\mu, \sigma^2_u)$ NT technical inefficiency effects distributed truncated normal.

The distribution has mean $\mu_{NTx1} = Z_{NTxQ}'\delta_{Qx1}$, where the vector Z_{NTxQ} represents proxy variables explaining the technical inefficiency effects U_{NTx1} . The associated parameters δ_{Qx1} are estimated simultaneously with the stochastic production frontier model thus expunging simultaneity bias.

The mean inefficiency effects model for the panel , where W_{NTx1} is the stochastic error can be defined as:

$$\mu_{NT\xi 1} = Z_{NxQ}\delta_{QxT} + W_{NxT} \qquad (2)$$

The log-likelihood function of the stochastic frontier model (1) yields asymptotically efficient maximum likelihood estimates (Coelli et al. 1998) :

$$\ln L\ (\beta, \gamma, \sigma^2) = -N/2[\ln (\pi/2) - N/2\log (\sigma^2) + \Sigma_{i=1}^{N} \ln[(1-\Phi(\zeta_i)] - + \Sigma_{i=1}^{N} \ln[(y_i-x_i\beta)^2] \qquad (3)$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$; $\zeta_i = [(\ln y_i - x_i\beta)/\sigma][\gamma/(1-\gamma)]^{1/2}$ and $\Phi(.)$ represent the standard normal distribution function. The first order conditions from the likelihood function (3) from the combined frontier and inefficiency models (1) and (2) provide the maximum likelihood estimates of the parameters:

$\theta = (\beta, \delta, \sigma^2, \gamma)$. The total error variance of the combined model defined by $\sigma^2 = (\sigma^2_u + \sigma^2_v)$ consists of the sum of the variance due to inefficiency effects (σ^2_u) and the stochastic error (σ^2_v). The proportion of the total error variance explained by inefficiency effects is defined by ratio γ (gamma) which lies in the range $0 \le \gamma \le 1$. If γ is near unity a high proportion of the error variance is explained by technical inefficiency effects.

$$\gamma = \sigma^2_u / \sigma^2 \qquad (4)$$

The technical efficiency (TE) is measured by the non-negative random error vector U_{NTx1} which is distributed iid (independently, identically distributed) normally and truncated at zero with mathematical expectation or population mean μ and variance σ^2_{u}.. The average TE is estimated by the mathematical expectation of the exponential distribution given below:

$$TE_{NTx1} = \exp(-U_{NTx1}) \qquad (5)$$

The maximum likelihood estimates of the time-varying industry specific technical inefficiencies are estimated from the conditional expectation of inefficiency effects defined in equation (6) below, where E refers to the expectations operator and exp to the exponential (Coelli et al. 1998: 190)

$$E[\exp(-u_i \mid e_i] = [1-\phi(\sigma_A + \gamma e_i/\sigma_A)\exp(\gamma e_i + \sigma^2_A/2)]/[1-\phi(\gamma e_i/\sigma_A)] \qquad (6)$$

The maximum likelihood estimates of the β–parameters of the stochastic frontier model and δ–parameters of the inefficiency model were estimated simultaneously to obtain estimates that were free simultaneous equation bias.

IV. THE DATABASE AND MODEL VARIABLES

A comprehensive panel dataset covering a cross-section of 8 industries over a time-series of 26 years (1969-1995) was used to validate the combined frontier-inefficiency model. The aggregation for the cross-section of the 8 industries is based on a modified two-digit Australia New Zealand Standard Industrial Classification (ANZSIC) code (ABS, 1993) . The classification and industry codes are reported in Table 1.

Table 1 Manufacturing Industry ANZSIC Classification used in the study.

Industry	ANZSCC ode	Australia New Zealand Standard Industry Classification (ANZSIC)	Industry code
1	21	Food beverages and tobacco	FBT
2	22	Textiles, clothing, footwear and leather	TCF
3	24	Printing, publishing and recorded media	PPR
4	25	Petroleum, coal, chemicals and associated products	PCC
5	271,2,3	Basic metal products	BMP
6	274,5,6	Structural and sheet metal products	SMP
7	281,2	Transport equipment	TEQ
8	23,26,284, 5,6.29	Other manufacturing	OMF

Source: IC (1997)

Variables in the stochastic frontier model ($\beta-$ parameters)

The stochastic frontier model explains value added (Y) in terms of factor inputs capital (K) and labour (L) and time (T). The latter variable T purports to capture Hicks neutral technical change. The combined models specified in equations (1) and (3) have been empirically validated using the IC (1997) panel dataset for a cross-section of N=8 industries over time-series T=26 for over NTx1 observations.

Y_{NTx1}: Value-added is measured in terms of unassisted prices, thereby providing a distortion free measure (IC 1997:28). Value-added is gross output minus intermediate inputs. All values are measured using unassisted constant 1989/90 prices. An index of the size of assistance measured the benefits due to tariff, quotas, subsidies accruing to the assisted industries. The index was used to deflate market prices in order to derive a measure of unassisted value-added, that was free of distortion.

K_{NTx1} : Capital stock is the stock of physical capital and has been estimated as weighted average of the capital stock of machinery and equipment plus vehicles, non-residential dwellings and other buildings. The value of capital stock has been estimated using the perpetual inventory method (PIM) and other techniques (IC, 1997).

L_{NTx1} : Labour inputs is estimated by the number of workers employed by each of the N industries over the T years.. The data has been obtained from Australian Bureau of Statistics Labour Force Survey.

T_{NTx1}: The time variables aim to capture Hicks neutral technological progress for the N industries over T years as done in growth accounting studies.

The variables of the inefficiency model (δ–parameters)

The technical efficiency effects model given by equation (2) has reform and technology variables. Subsets of the variables with coefficients or the δ–parameter measure whether they explain in a significant manner the inefficiency scores of the N industries over the T years.

ER_{NTx1} : Effective rate of assistance or assistance on value-added which is conceptually analogous to the measure of effective rate of protection. Measures for ER were obtained from the Industry Commission database . The ER measure takes account of the value-added by giving assistance (tariffs, quotas, subsidies etc.) on both outputs and intermediate inputs of each of the N industries over T years.

ID_{NTx1} : The intra-industry trade index for trade in transport equipment and other manufactures was used to estimate the Grubel-Lloyd intra-industry trade index (IT) as defined below. It has been used to measure international transfer of technology through trade.

$$IT_{it} = \Sigma_i [(X_{it} + M_{it}) - |(X_{it} + M_{it})|] / [\Sigma_i X_{it} + \Sigma_i M_{it}]$$

where X_{it} refers to exports and M_{it} refers to imports of capital goods by the i-th industry in the t-th year .

KD_{NTx1} : Capital deepening or the application of more capital per unit of labour has been estimated by dividing the capital stock for each industry by labour input or by using (K_{NTx1}/L_{NTx1}) where K_{NTx1} and L_{NTx1} are as defined before. Capital deepening can be labour saving or biased and could occur due to technological change or due to substitution of capital for labour in response to changes in the labour market.

D_{NTx1}: Time dummies represent time-varying Hicks neutral technical progress for industries. They capture the shifts of the production function over time (i.e. technical progress) assuming fixed coefficients of parameters relating factor inputs.

Table 2 presents a summary of the key variables and data sources used to empirically validate the combined stochastic frontier-inefficiency model for Australian manufacturing industries.

Table 2. Key variables and Data Sources

Variables ***Stochastic Frontier Model***	**Description**	**Data sources**
Y_{NTx1}: Value-added	Value of gross product at 1989-90 constant unassisted prices.	ABS (1997) Cat. 5204.0, 5221.0 IC (1997)
K_{NTx1}: Capital stock	Value of capital stock at capacity estimated by perpetual inventory methods (PIM).	ABS (1997)Cat. 5234.0,5625.0, 5233.0 and IC (1997).
L_{NTx1}: Labour	Total number of workers per industry per year.	ABS (1997) Cat. 6203.0 Labour Force Surveys
T_{NTx1}: Time	Cyclical and Hicks neutral tech-progress	
Inefficiency Model	Description	Data sources
ER_{NTx1}: Effective Rate of Assistance	Assistance as a percentage of value-added by each manufacturing industry.	IC (1997)
IT_{NTx1}: Intra-industry index	Intra-industry trade (IT) machinery & equipment. $IT_{it}=\Sigma_{i=1}^{N} (X_i + M_I - \|X_I + M_i\|) / (\Sigma_{i=1}^{N} X_I+\Sigma_{i=1}^{N} M_I)$ X_i, M_i:exports, imports of capital goods	Grubel -Lloyd index Chand et al. (1998)
KD_{NT}: Capital deepening	Capital stock per worker.= [K_{it}/L_{it}]	
T_{NTx1}: (Year)	Time-varying inefficiency effect	

Notes: IC (1977) Industry Commission, Productivity Growth and Australian Manufacturing Industry, Staff Research Paper by Gretton and Fisher (1997).
ABS: Australian Bureau of Statistics

V. EMPIRICAL RESULTS

The unbiased asymptotically efficient MLE (maximum likelihood estimates) of the parameters of the combined stochastic frontier–inefficiency model were estimated using the FRONTIER 4.1 software of Coelli (1994) based on the Davidson-Fletcher-Powell (DFP) iterative algorithm.

The empirical results are discussed in three parts. First, the model selection and parameter tests are briefly reviewed. Second, the tests on null hypotheses of subsets of reform and technology proxies are discussed . Third the significance of the relationship of time-varying technical efficiency (TE) and the symbiotic effects of policy variables are reviewed.

Model selection tests

The MLEs of the β–parameters for the stochastic frontier model and the δ–parameters for the inefficiency model and their asymptotic t-statistics are reported for both the Translog (TL) and Cobb-Douglas (CD) stochastic production frontiers in Table 3 . The null hypothesis that the (OLS) average response function where production is at full capacity or on the frontier with zero inefficiency effects is tested by the null hypothesis that H_0: $\gamma = 0$. This implies that the proportion of total error variance explained by stochastic inefficiency error is zero against the alternative that is is non-zero H_0: $\gamma \neq 0$. The generalised one-sided LR statistic LR_{cal} = 16.7 and exceeded the critical value at 5% LR_{cal}= 2.71 from the asymptotically distributed mixed chi-squared distribution ($\frac{1}{2}\chi^2_0 + \frac{1}{2}\chi^2_1$) . Therefore the null is rejected in favour of the stochastic production frontier alternative (see Table 3 row from bottom).

The proportion of total variance in the model error explained by the stochastic inefficiency effects is estimated by γ–parameter and it is 37% and 077 % for the Translog (TL) and Cobb-Douglas stochastic frontier models respectively.

Table 3 Maximum Likelihood Estimates (MLE)
Cobb-Douglas (CD) and Translog (TL) Stochastic Production Frontier Models

Variable Description in natural logs	**Parameter**	**Translog (TL)**	**Asymptotic |t-statistic|**	**Cobb-Douglas (CD)**	**Aysmptotic |t-statistic|**
Constant	β_0	65.62**	9.46	2.04**	3.80
K_t : Capital	β_1	– 9.63**	7.95	0.18**	3.74
L_t : Labour	β_2	6.05**	4.60	0.75**	14.59
T_t : Time	β_3	– 0.02	0.94	0.04**	13.31
K_t^2 : $(Capital)^2$	β_4	0.45**	8.02	–	–
L_t^2 : $(Labour)^2$	β_5	0.87**	11.54	–	–
T_t^2 : $(Time)^2$	β_6	– 0.00**	4.01	–	–
K_tL_t : (Capital x Labour)	β_7	– 0.89**	7.17	–	–
K_tT_t : (Capital x Time)	β_8	0.00	1.53	–	–
L_tT_t : (Labour x Time)	β_9	0.00	0.39	–	–
Constant	δ_0	4.73**	2.31	–30.05**	4.79
ER_t : (Effective rate of assistance)	δ_1	5.83**	11.17	.60**	2.55
IT_t : (Intra-Industry Trade)	δ_2	3.50**	3.89	1.96**	2.02
KD_t : (Research & Development)	δ_3	2.70**	3.05	4.78**	4.49
ER^2 : $(Nominal\ rate\ of\ assistance)^2$	δ_4	- 0.19**	10.56	‾0	0.07
IT_t^2 : $(Intra\text{-}Industry\ Trade)^2$	δ_5	- 0.02	0.37	– 0.08	1.29
KD_t^2 : $(Capital\ Deepening)^2$	δ_6	0.24**	7.22	– 0.21**	4.19
ER_t x IT_t	δ_7	- 0.13**	2.48	– 0.08	1.40
ER_t x KD_t	δ_8	-.039**	9.38	– 0.12**	2.46
IT_t x KD_t	δ_9	- 0.03**	3.89	–0.10	1.29
T_t : (Time)	δ_{10}	0.02	1.30	0.03**	2.06
$\Sigma_{t=11}^{36} D_t$:(Time-specific dummies)	$\Sigma_{t=11}^{36}\delta_t$	Significant	t-stat none	Significant	t-stat none
Variance of u (TE)	σ_s^2	0.62**	7.99	0.12**	7.85
Tech efficiency / Total variance	γ	0.37**	5.52	0.77**	7.63
LL :Log-likelihood function	OLS =103.92	CD =188.96	OLS =193.92	TL =265.24	
Ho: Deterministic (ARF) adequate vs Stochastic Frontier Model	H_0: γ=0 H_1: $\gamma\neq$0	1-sided LR $\chi^2_{cal=16..79}$	$\chi^2_{df=1,2\alpha=2(.05)=2.71}$ α		Decision Rej Ho:
LR-test=χ^2_{cal}=- 2[LL(H_o) - LL H_1)]		TL vs OLS LR=χ^2_{cal} =142.6*4		CDvsOLS LR=χ^2_{cal} 170.08*	TL vs CD LR=χ^2_{cal} 152.56*
Critical value=$\chi^2_{df,\alpha}$ (KP):Kodde & Palm, 1986		$\chi^2_{37, 0.05 (KP)}$ = 51.62		$\chi^2_{37\ 0.05(KP)}$ = 51.62	$\chi^2_{42, 0.05}$ = 52.56
Decision: > (Reject Ho in favour of H_1)		CD> OLS Rej Ho vs H1		TL> OLS	TL> CD

Notes: OLS: Ordinary Least Squares; CD: Cobb-Douglas ; TL: Translog ; ARF: Average Response Function. ; LL: Log likelihood function. Ho: Null hypothesis; H_1: Alternative hypothesis.

* : Significant at 5 per cent level.

** : Significant at 1 per cent level.

The one-sided generalised LR tests report results on three separate null hypotheses tests. First, the average response function (OLS) null was tested was tested against the Cobb-Douglas (CD) alternative. The rejection of the null in favour of the alternative is reported as CD>OLS. Second, the average response function (OLS) null was tested against the Translog (TL) stochastic frontier alternative. The rejection of the null in favour of the alternative is reported as TL>OLS. Third, the Cobb-Douglas stochastic frontier

null was tested against the Translog stochastic frontier alternative. The rejection of the null in favour of the alternative is reported as TL>CD (see last three rows of Table 3). Therefore the generalised LR tests demonstrated that the stochastic frontier model with a Translog functional form was the best description of the data generation process underpinning the panel dataset for Australian manufacturing.

Inefficiency affects model tests

Model (2) explains technical inefficiency effects (-TE) in terms of explanatory variables in the vector:
Z_{NxQ}= (ER_{NxQ}, $IT_{NxQ,}$ KD_{NxQ}), where N=8 industries and Q=3 are the effects variables.
The effects variables define effective rate of assistance (ER), intra-industry trade (IT) and capital deepening (KD). Quadratics of the effects variables are included to capture increasing or decreasing effects over time while the cross-product terms capture interaction terms. LR tests are used to determine whether subsets of the effects are significant in explaining the symbiotic effects of these variables on reduction of technical inefficiency in manufacturing industries.

The null hypotheses that effective rate of assistance (ER) has no significant effect on technical inefficiency of manufacturing tested using the LR-test have been rejected (see row 1 Table 4).

The LR tests reveal that the null hypotheses that subsets containing effective rate of assistance (ER), intra-industry trade (IT), (KD) have no effect on technical inefficiency on manufacturing have been rejected (see row 2 and 3 Table 4). The null hypotheses that the effective rate of assistance (ER) and the technology proxies relating to intra-industry trade (IT) and capital deepening (KD) have no significant effects on the technical inefficiency on manufacturing industries is soundly rejected by the LR-tests (see last 3 rows of

Table 4). Overall the empirical results lend support to the tenets of the new growth theories that assert that trade liberalisation by promoting the transfer of new technology and innovation improves technical efficiency and productivity in manufacturing industries.

Table 4. Test of null hypotheses on reform and technology proxies

Translog function	Ho: Null hypothesis	χ^2_{cal}	$\chi^2_{tab,df,\alpha=.05}$	Decision
Null: No ER-effects	$\delta_1=\delta_5=\delta_7=\delta_8=0$	192.86*	$\chi^2_{32,.05}$=45.91	Reject
Null: No IT-effects	$\delta_2=\delta_5=\delta_7=\delta_9=0$	125.58*	$\chi^2_{32,.05}$=45.91	Reject
Null: No KD-effects	$\delta_3=\delta_6=\delta_8=\delta_9=0$	86.13*	$\chi^2_{32,.05}$=45.91	Reject
Null: No IT & KD effects	$\delta_2=\delta_3=\delta_5=\delta_6=\delta_7=\delta_8=\delta_9=0$	75.78*	$\chi^2_{28,.05}$=41.31	Reject
Null: No ER & KD effects	$\delta_1=\delta_3=\delta_4=\delta_6=\delta_7=\delta_8=\delta_9=0$	68.34*	$\chi^2_{28..05}$=41.31	Reject
Null: No ER & IT effects	$\delta_1=\delta_2=\delta_4=\delta_5=\delta_7=\delta_8=\delta_9=0$	51.14*	$\chi^2_{28,.05}$=41.31	Reject

Time-varying technical efficiency effects

Based on the panel dataset the parameters of the combined stochastic frontier -efficiency model (4) with a translog functional form was estimated by maximum likelihood methods using the FRONTIER 4.1software (Coelli, 1994). For the 8 manufacturing industries over the study period of 26 years, the average technical efficiency (TE) score was 81% implying that manufacturing industries were operating 19% below capacity. During the study period the lowest average technical efficiency (TE) scores of 45%, 65% and 69% were recorded for the industries TCF , PPR, OMF which were also the recipients of the highest levels of average effective rate of assistance (ER) of approximately 127%, 24%, 25%.respectively. Therefore, the industries that were heavily assisted exhibited the lowest levels of technical efficiency. These findings support both neoclassical and protectionist theories which contend that assistance or protection breeds inefficiency by sheltering manufacturing industries from the fresh winds of international competition.

The industries with the high average technical efficiency (TE) scores greater than 97% were the resource intensive FBT, PCC and BMP industries which were subjected to low effective rate of assistance of 11%, 17% and 14% respectively. Incidentally these were resource intensive industries in which Australia exhibited a comparative advantage (see Table 5).

Table 5 Effective Rates of Assistance(ER) and Technical Efficiency (TE)

TE	FBT	TCF	PPR	PCC	BMP	SMP	TEQ	OMF	AVG	SD	CV
AVG	0.98	0.45	0.65	0.98	0.97	0.83	0.94	0.69	0.81	0.21	26.02
SD	0.01	0.12	0.22	0.01	0.03	0.03	0.05	0.15	0.07	0.06	9.00
CV	1.43	27.27	33.33	1.44	3.29	4.05	5.43	22.09	8.15	27.84	34.58
ER	FBT	TCF	PPR	PCC	BMP	SMP	TEQ	OMF	AVG	SD	CV
AVG	10.56	126.96	24.48	17.07	13.52	31.89	48.63	25.71	37.35	38.85	104.61
SD	6.18	53.46	15.40	8.66	8.60	15.31	12.73	5.37	10.04	18.92	38.22
CV	58.54	42.11	62.91	50.69	63.63	48.02	26.19	20.89	26.89	48.69	36.54

Notes. Industry codes are as in Table 1. TE: Technical Efficiency. ER: Effective rate of Assistance. AVG: Average. SD: Standard deviation. CV: Coefficient of variation in percentage terms

The average technical TE of manufacturing industries increased from 72% to 92% when average effective rate of assistance (ER) declined from 14% to about 9% during the study period. Therefore the efficiency gains could be regarded as spillover effects from trade liberalisation associated with micro-economic reforms. It is noteworthy, that the reform process incubated for nearly a decade before finally kicking-in around the mid-1980s when the TE score raced past the industry TE average score of 81%. With the reduction in the effective rate of assistance (ER) and trade liberalisation both the intra-industry (IT) trade and capital deepening (KD) increased by more than 7 -fold and 2-fold respectively. During the study period high negative correlation coefficients were observed between effective rate of assistance and the technical efficiency coefficients (*er.te*), inter intra-industry trade (*er.it*) and capital deepening (*er.kd*) e (see bottom rows of Table 6). The negative correlation coefficients confirm that the trade reforms reducing effective rate of assistance (ER) increased technology transfer from overseas via intra-industry trade (IT) and facilitated capital deepening (KD) as hypothesised by the endogenous growth paradigm.

The time-varying technical efficiency scores indicated that the highly protected Textile Clothing and Footwear (TCF) and the Printing , Publishing and Recorded media (PPM) ranked last in terms of average technical efficiency (TE) with scores of 45% and 65% respectively.

Furthermore these two most inefficient industries, TCF and PPM had the highest coefficients of variation (CV) of 26% and 33%. The highest average TE scores of over 97% were reported by the industries FBT, PCC and BMP- industries in which Australia had a resource based comparative advantage.

Table 6 Technical efficiency (TE), Reform & Technology Processes

Year	AVG TE	AVG ER	AVG IT	*AVG KD*
1969	0.72	14.03	7.37	*27698.36*
1985	0.82	7.91	46.93	*47627.44*
1995	0.92	3.91	30.21	*61436.42*
AVG	0.81	8.70	34.66	*43437.70*
cor	er.te=-0.94	er.it=-0.69	er.kd=-0.94	
cor	*te.it = 0.60*	*te.kd=0.94*	*it.kd=0.60*	

Notes: AVG : Average . TE: Technical Efficiency. ER: Effective Rate of Assistance. IT: Intra-industry Trade.KD: Capital deepening. Cor: correlation.

It is noteworthy that the highly protected TCF industries had a TE score of only 21% at the start of the study period and by the end of the study period due to the scaling down of effective rate of assistance, the TE score had risen to 64%. These results give legs to the predictions of endogenous growth theories and the claims of the proponents of the microeconomic reform agenda that the reforms have delivered in terms of enhance productivity and efficiency in production. But despite the noteworthy gains it needs to be noted that the TCF industries at the end of the study period were performing 36% below the 'best practice' or the maximum capacity level of production. The fact that TCF sector continues to heavily protected even to day could be blamed for this outcome (see Table 7)

Table 7 Technical Efficiency of Manufacturing in Australia (1969-95)
(selected years)

YR/IND	FBT	TCF	PPM	PCC	BMP	SMP	TEQ	OMF	AVG	SD	CV%
1969	1	0.21	0.47	0.99	0.99	0.75	0.91	0.43	0.72	0.3	42.8
1985	1	0.45	0.65	0.97	0.92	0.81	0.98	0.76	0.82	0.2	23.4
1995	1	0.64	0.99	0.98	0.99	0.86	0.99	0.94	0.92	0.1	13.4
AVG	1	0.45	0.65	0.98	0.97	0.83	0.94	0.69	0.81		
Rank	1	8	7	2	3	5	4	6			
SD	0	0.12	0.22	0.01	0.03	0.03	0.05	0.15			
CV	1.5	26.8	33.3	1.5	3.25	3.99	5.3	22			
RANK	7	2	1	8	6	5	4	3			

Notes. Average (AVG), Standard deviation (SD) , Coefficient of Variation (CV) refer to the whole year.

The implementation of microeconomic reform policies during the study period appears to have contributed to a monotonic improvement in the average technical efficiency in manufacturing industries. The average TE score rose from 72% to 92% over the 26-year study period. This rise was accompanied by a concomitant reduction in the coefficient of variation (CV) of the TE scores from an average of 43% to 13% during the same period. The reduction in coefficient of variation (CV) in TE improves the efficient

allocation of resources in the same way that reduction in the CV of protection improves the efficient allocation by reducing distortions in the price signal among trading nations (Corden 1971).

The average time varying TE scores for the manufacturing sector has increased from 72% to 92% during the study period. The TE scores accelerated during the mid-period when the micro-economic reforms started to kick-in. The increase in TE is no doubt the unsung hero in Australia's spectacular labour productivity pick-up observed in the 1990s. The observed northward trek of TE scores and the rejection of the null hypotheses that reform and technology proxies had no impact on manufacturing industry technical inefficiency lend unequivocal support to the predictions of endogenous growth theories and to the claims that microeconomic reforms have ushered a 'new economy' in Australia.

V. CONCLUSIONS

The validation of a simultaneity bias free stochastic production frontier-technical inefficiency model for the first time for manufacturing industries in Australia, using a comprehensive panel dataset, has provided invaluable insights on the performance of technical efficiency. The results of time-varying technical efficiency scores analysed over for a cross-section of 8 industries over a time span of 26 years clearly demonstrated that the scaling down of effective rate of assistance was followed closely by improvements in the technical efficiency in manufacturing industries. Furthermore, manufacturing industries appeared to have absorbed new technology through intra-industry trade as demonstrated by the increase in capital deepening - all bolstering the productivity pick up observed during the 1990s. These findings augur well both for the microeconomic reform agenda which has copped some flak recently on the grounds that the productivity and efficiency performance has not matched the hype of protagonists of microeconomic reforms nor the predictions of the high profile endogenous growth theories.

Nonetheless, the empirical research highlights the need for extending the research agenda embarked in this paper in two directions. First, the need to decompose the total factor productivity growth in manufacturing into change in technical efficiency and technical progress. Second, the need to address the equity-efficiency trade off that occurs in the relentless pursuit of the first-best micro economic reform policies narrowly focussed only on technical efficiency.

The analysis in the paper by default equates technical efficiency growth with total factor productivity or the growth of the Solow residual. However, total factor productivity growth consists of both changes in technical efficiency and technical progress. It is possible for declining technical progress to co-exist with increasing technical efficiency and if the former exceeds the latter we could have a productivity slowdown on our hands due to technical regress rather than a rise in technical inefficiency. The need to dichotomise total factor productivity into the components of technical efficiency and technical progress is imperative in order to avoid counterproductive policy prescriptions (Nishimizu and Page, 1982).

The research initiated in this paper aims to perform this decomposition using a version of the time-varying parameters methodology which has been applied to agriculture by Kalirajan and Obwana (1996) and others. It is recognised that the relentless pursuit of the first-best technical efficiency microeconomic reform policy agenda has serious limitations if it benignly neglects those marginalized by the reform process on the premise that the trickle down paradigm will convert those who are initial losers from reform policies to eventual winners. Properly designed microeconomic reform policies need to address at the outset issues relating the equity-efficiency tradeoffs that arise in a second-best world lest the backlash by those injured by reforms will put the whole reform agenda on the back burner or even send it up in smoke.

It is noteworthy that three types of policy options are advocated to cope with the equity-efficiency dilemma that arises from the single-minded pursuit of the efficiency-only reform policy agenda. The first, the statist option, recommends a reversal of the globalisation process by the re-imposition of protectionist barriers and regulatory distortions. The second, the neo-liberal option (*a la* Washington consensus) reposes a blind faith in the neoclassical trickle-down growth paradigm that losers will be magically transformed into winners during the penultimate stage of the reform process (Kasper, 1999). The third, the social smoothing option , ruminates that pre-emptive policy design should manipulate the tax -transfer and social safety net mechanisms to address the concerns of those injured by the reforms (Argy, 1998). The design of a reform policy agenda in order to tackle the efficiency-equity paradox, so as to avoid destructive policy back-flips, remains a formidable challenge that needs to be addressed by policymakers and their mentors.

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