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Industrial Policy for Promoting Automation: An Econometric Analysis of Major Industries in Singapore*

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Based upon data collected on the manufacturing and industrial servicing sectors in Singapore by the Economic Development Board for the period between 1984 and 1988, the relevant production indices were estimated and compared with figures obtained by studies in other countries. Although Singapore is considered as successful in its economic development, its industries did not perform better than other developing countries. The estimated production indices will provide policy makers with valuable information to evaluate the performance of the industries and to identify target industries to promote automation as a way to enhance competitiveness and stimulate growth.

I. Introduction

Considerable work has been done in the past two decades to quantitatively analyse the production and growth experience of many developing and developed countries. In particular, the relative efficiency of manufacturing firms in developing countries has been a major topic of interest in economic development. Together with Korea, Taiwan and Hong Kong, Singapore is considered as one of the prime examples of countries with successful economic development. Much of the success of the nation was attributed to its vibrant manufacturing sector. How well did the Singapore manufacturing performed compared to the other developng countries? Unfortunately, relatively little research has been done in empirically evaluating the performance of the Singapore's industrial sector.

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This analysis will provide estimates of the key production indices of eleven major manufacturing and industrial servicing sectors of Singapore. The indices analysed include the average technical efficiency of firms, capital intensities, capital and labour elasticities and the marginal rate of technical substitution between labour and capital. These estimates will provide policy makers in Singapore with valuable information to evaluate the performance of the industries and to formulate strategic plans to lead the economy to higher economic growth. The estimates will also serves as a useful source of comparison for the other newly industrialised nations and developing countries.

An immediate problem facing Singapore and many other smaller nations is the shortage of labour supply. As stated in the Singapore Economic Development Board and National Automatic Master Plan Report (1988), automation is the key technology to improving labour productivity, flexibility, enhancing competitiveness and stimulating growth in the future. It is therefore critical that guidance is provided to policy makers on the potential contribution of capital investment and the technical and economic relationships between labour and capital inputs in the production process.

The methodology employed in this analysis will be presented in the next section followed by a discussion on the data. Section 4 presents the estimation results and analysis. Several popular hypotheses were tested and reported in section 5. The final section summarises the findings and offers some concluding remarks.

II. Methodology

In economic theory, the production function describes the maximum level of output that can be produced for each specific combination of inputs. Conversely, it indicates the minimum amount of resources that is required to produce a given quantity of output. The latter interpretation is commonly graphed as an isoquant as shown in figure 1. Points above the isoquant indicate inefficient production since the same amount of output can be produced with fewer resources. Therefore, estimating the production frontier will enable us to estimate the production efficiency of firms in the industry. This approach was first proposed by Farrell (1957) and later developed by Aigner, Lovell and Schmidt (ALS; 1977).

The most widely assumed production frontier is the Cobb-Douglas production function which has a mathematical form given by

(1) $Q = A\ L^{\alpha}K^{\beta}$

where Q is the amount of output, L is the amount of labour employed, K is the amount of capital used, and A, α, β are constants.

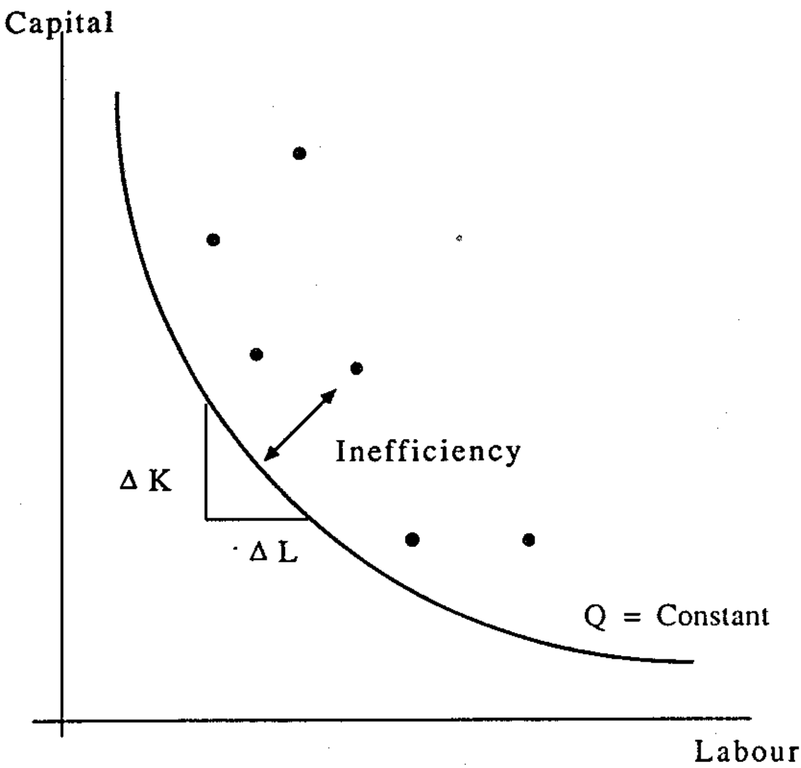
This production frontier yields an isoquant shown in figure 1. The slope of the isoquant indicates how the quantity of one input (capital) and be traded off against the quantity of the other input (labour), while keeping output constant. The absolute value of the slope is known as the marginal rate of technical substitution (MRTS) of capital for labour. Mathematically, the MRTS can be expressed as

(2) $MRTS = -(\beta/\alpha)\ (K/L)$

The sum of the constants, $\alpha + \beta$, measures the return to scale of the

Figure 1

A Typical Isoquant



production process. If it is greater than unity, then the process is said to exhibit increasing returns to scale which implies that if we increase the inputs, we will obtain more than proportionate increase in the output. Conversely, if $\alpha + \beta$ is less than one, then the process will exhibit decreasing returns to scale.

In reality, we do not know the exact form of the production function and have to rely on statistical procedures to estimate the frontier. The most widely used empirical specification is the Cobb-Douglas production function discussed above. As proposed by ALS (1977), we include two random terms, μ and ν. The random term, ν, is incorporated to capture the measurement errors and random shocks such as weather which are beyond the control of the firm. These disturbances are assumed to have a normal distribution. The other random term, μ, measures the deviations from the desired frontier due to controllable factors such as poor management, damaged materials and other sources of inefficiencies in the firm. This term is assumed to have a truncated-normal distribution since it should take only non-positive values. The stochastic production frontier obtained is described by

(3) $$Q = A\ L^{\alpha} K^{\beta} \exp(\mu - \nu)$$

where exp is the exponential function. This production function is generally transformed into its logarithmic form given by

$$\ln Q = \ln A + \alpha \ln L + \beta \ln K + \mu - \nu$$

(4) $$\ln Q = \ln A + \alpha \ln L + \beta \ln K + \varepsilon$$

where $\varepsilon = \mu - \nu$

$\mu \sim |N(0, \sigma_{\mu}^2)|$

$\nu \sim N(0, \sigma_{\nu}^2)$

$\ln A$, α and β are parameters to be estimated

In this formulation, the coefficients, α and β, are the elasticities of output with respect to labour and capital. α (β) measures the percentage increase in output arising from a percentage increase in labour (capital). Weinstein (1964) showed that ε has a distribution given by

(5) $$g(\varepsilon) = (2/\sigma) f(\varepsilon/\sigma)(1 - F(\varepsilon\lambda/\sigma))$$

where f and F are the standard normal pdf and cdf

$$\sigma^2 = \sigma_\mu^2 + \sigma_v^2$$

$$\lambda = \sigma_\mu / \sigma_v$$

$$E(\varepsilon) = -\sigma_\mu \sqrt{2\pi}$$

$$V(\varepsilon) = ((\pi-2)/\pi)\ \sigma_\mu^2 + \sigma_v^2$$

ALS (1977) claimed that all coefficients except the intercept of the model given by (4) can be estimated unbiasedly and consistently by the least squares procedure. In addition, Richmond (1974) showed that a correction term equal to the estimated mean of ε can be added to the constant term to obtain the unbiased estimate of the intercept. Moreover, σ_μ and σ_v can be consistently estimated using higher moments of the residuals. In particular, the variance of the random term capturing the inefficiency can be estimated using

$$\text{(6)} \qquad \sigma_\mu^2 = ((\pi \sqrt{2\pi}) / (2\pi-8))((1/N) \sum_{i=1}^{N} \varepsilon_i^{3})^{2/3})$$

Having estimated the production frontier, an appropriate measure of technical efficiency can be obtained as the ratio of the actual production to the maximum output which is indicated by the production frontier. This ratio is given by the random term, μ, incorporated to capture the inefficiency. Lee and Tyler (1978) showed that the average technical efficiency of the industry can be estimated by the mean value of this term.

$$ATE = E(\varepsilon^\mu)$$

$$\text{(7)} \qquad ATE = 2(1-F(\sigma_\mu)\ \exp(\sigma_\mu^2/2)$$

Finally, the level of automation prevailing in an industry can be approximated using the average capital investment or fixed assets per worker of the particular industry.

III. Data

Data for this analysis is provided by the Research and Statistical Unit of the Economic Development Board of Singapore which conducts annual census of industrial production for the manufacturing and industrial servicing sectors. The census collects information on the total employment, total renumeration, materials used, total input, gross output, value added, sales, capital expenditure, net value of fixed assets, and other facets of the production according to the International Standard Industrial

Classification of All Economic Activities (1986 Revision) of the United Nations.

The basic unit of analysis is the individual firms of 11 major industries categorised according to the three digits Standard Industrial Classification codes. Some sectors have to be combined or ignored due to their small sample sizes. Firm-level or micro data is used because aggregated data disguises inefficiencies and yields upward biased estimates which will lead policy makers to believe that the industries are performing better than they actually are. Value added of the individual firms is chosen to represent output. This measure is a better indicator of output though sales is commonly used due to lack of data on value added. Labour input is measured by the number of workers employed and net value of fixed assets is used as a proxy of capital input. Although a better measure of labour would be man-hour used, number of workers employed is widely used in numerous studies due to the lack of data on man hours.

Table 1 provides some descriptive statistics of these variables for each sector. Only the industrial chemcials and non-electrical machinery sector had experienced continued growth in the number of firms. Most of the other sectors were hit by the local recession in 1985 which saw a reduction in the size of the industries. The average size of firms, measured by the average number of workers per firm, did not exhibit any consistent trend over the five year period analysed although fluctuations are small. These patterns in industry size may be attributed to a the presence of several dominant multinational corporations with many small and medium sized companies in most sectors.

Omitting 1985, the value added per firm of most sectors registered consistent growth over the period from 1984 to 1988. One exception is the machinery industry whose value added recorded gradual decreases until 1988. The only two industies that registered continued expansion in the net fixed assets per firm were the printing and publishing and the electronics sectors. Ideally, the value added per firm should be highly correlated with the net fixed assets per firm since increases in capital expenditure should lead to higher output. Aside from the electronic industry, the other sectors did not exhibit this relationship. This anomaly suggested that larger per capita investment did not generate higher value added per firm.

IV. Results

In general, the model fits very well with R-squares ranging from

Table 1

MEAN VALUES OF KEY VARIABLES

	1984	1985	1986	1987	1988
Food					
No. of Firms	301	284	288	284	272
Value-Added*	1,263	1,395	1,417	1,599	1,928
No. of workers	34.15	34.11	33.41	35.85	38.24
Net Fixed Assets*	1,869	1,865	1,853	1,807	2,068
Textile / Apparel					
No. of Firms	466	431	435	436	437
Value-Added	958	946	1,010	1,298	1,483
No. of workers	63.63	63.84	63.16	70.27	74.89
Net Fixed Assets	686	721	665	723	854
Printing / Publishing					
No. of Firms	327	306	317	320	316
Value-Added	1,624	1,695	1,692	1,894	2,229
No. of workers	43.52	43.24	41.47	41.00	45.47
Net Fixed Assets	1,210	1,328	1,336	1,374	1,553
Industrial Chemicals					
No. of Firms	56	56	58	62	65
Value-Added	4,582	6,371	9,891	14,759	21,176
No. of workers	57.43	57.98	54.53	53.40	57.17
Net Fixed Assets	30,462	33,118	30,848	28,001	25,353
Other Chemicals					
No. of Firms	90	90	88	86	87
Value-Added	7,155	5,965	7,935	9,457	10,060
No. of workers	51.13	50.54	48.47	51.13	52.56
Net Fixed Assets	4,441	3,617	3,515	3,458	3,599
Plastic					
No. of Firms	224	221	210	229	273
Value-Added	1,018	1,019	1,082	1,267	1,472
No. of workers	38.23	38.33	37.31	42.30	43.62
Net Fixed Assets	1,588	1,648	1,153	1,303	1,369
Fabricated Metals					
No. of Firms	437	437	415	427	449
Value-Added	1,741	1,517	1,689	1,937	2,373
No. of workers	48.05	45.02	44.64	49.05	57.37
Net Fixed Assets	2,229	1,995	1,994	2,064	2,193

Table 1 (Continued)

	1984	1985	1986	1987	1988
Machinery					
No. of Firms	349	349	353	369	381
Value-Added	2,547	2,332	2,136	2,060	2,538
No. of workers	61.34	56.43	50.17	51.61	54.59
Net Fixed Assets	1,989	2,029	1,882	2,047	2,283
Electrical					
No. of Firms	113	118	110	112	133
Value-Added	4,854	4,358	4,954	5,904	5,885
No. of workers	145.16	140.77	146.96	167.24	165.54
Net Fixed Assets	4,009	4,238	4,684	5,111	4,905
Electronics					
No. of Firms	209	202	187	229	239
Value-Added	13,797	14,169	19,834	22,069	26,516
No. of workers	346.32	325.70	370.76	374.36	471.84
Net Fixed Assets	6,607	7,615	9,517	10,458	12,418
Transport					
No. of Firms	253	221	198	184	216
Value-Added	4,013	4,699	5,112	6,016	6,109
No. of workers	98.58	99.08	86.25	94.73	93.45
Net Fixed Assets	4,858	4,964	4,851	5,048	4,874

0.6084 to 0.8918 as shown in table 2. Most of the R-squares fell between 0.75 and 0.85 with an average of 0.7988. Since the framework adopted is appropriate for analyzing cross-section data, separate analyses are conducted for each year. This scheme also traces the trends in the different industries over the period and enable the collation of movements between technical efficiency and four factors that are popularly believed to have some effect on efficiency.

The estimated average technical efficiencies of the manufacturing and industrial servicing sectors of Singapore range from 45.3% to 73.5% as shown in table 3. Most of the industries have realised efficiencies between 50% and 60% which are comparable to estimates obtained in other developing countries such as Indonesia, India, Thailand, Egypt and Philippines. In particular, Lee and Tyler (1978) estimated the average technical efficiency of industrial firms in Brazil to be approximately 62.5%.

Table 2

ESTIMATION RESULTS

	1984	1985	1986	1987	1988
Food					
R-Square	0.7540	0.6380	0.7501	0.7833	0.7531
Capital Intensity	38,088	40,845	40,663	38,467	42,879
Capital Elasticity	0.1977	0.2269	0.1887	0.2189	0.2209
Labour Elasticity	0.9431	0.8448	1.0447	0.9576	0.9299
MRTS	7,985	10,969	7,346	8,795	10,189
Technical Efficiency	0.5842	0.2888	0.4115	0.5221	0.4571
Textile and Apparel					
R-Square	0.7891	0.8416	0.8603	0.8439	0.8549
Capital Intensity	10,008	11,078	10,796	10,798	11,453
Capital Elasticity	0.1704	0.1766	0.1867	0.1956	0.2044
Labour Elasticity	0.8867	0.8197	0.8314	0.8627	0.8702
MRTS	1,923	2,386	2,425	2,448	2,690
Technical Efficiency	0.4570	0.6613	0.6580	0.5144	0.7447
Printing & Publishing					
R-Square	0.8002	0.8560	0.8659	0.8541	0.8387
Capital Intensity	19,086	20,041	19,691	21,712	24,514
Capital Elasticity	0.1263	0.0823	0.0442	0.1118	0.1541
Labour Elasticity	1.0212	1.1127	1.1799	1.1053	0.9955
MRTS	2,361	1,482	737	2,197	3,796
Technical Efficiency	0,6992	0.7607	0.6919	0.8291	0.6989
Industrial Chemicals					
R-Square	0.7489	0.6572	0.8061	0.7872	0.7905
Capital Intensity	194,046	225,822	206,339	273,032	256,532
Capital Elasticity	0.1100	0.2351	0.4109	0.4683	0.6243
Labour Elasticity	0.9829	0.9386	0.6652	0.6349	0.3378
MRTS	21,722	56,554	127,457	201,306	474,143
Technical Efficiency	0.7404	0.2983	0.4696	0.4393	0.4876
Other Chemicals					
R-Square	0.8252	0.7694	0.7721	0.7898	0.7510
Capital Intensity	63,498	54,815	57,268	57,081	53,803
Capital Elasticity	0.4443	0.3313	0.3383	0.4501	0.3165
Labour Elasticity	0.8562	1.0001	1.0313	0.9073	0.9471
MRTS	32,951	18,162	18,479	28,319	17,981
Technical Efficiency	0.5564	0.5614	0.6116	0.6034	0.5216

Table 2 (Continued)

	1984	1985	1986	1987	1988
Plastic					
R-Square	0.8050	0.6261	0.6084	0.8179	0.7560
Capital Intensity	28,129	30,883	28,328	32,720	29,739
Capital Elasticity	0.1967	0.2444	0.2058	0.2513	0.2254
Labour Elasticity	0.9113	0.7405	0.8204	0.7779	0.8330
MRTS	6,073	10,191	7,109	10,569	8,047
Technical Efficiency	0,7604	0.3308	0.3269	0.8872	0.5792
Fabricated Metal					
R-Square	0.8069	0.7964	0.8221	0.8363	0.8181
Capital Intensity	33,608	35,134	32,944	33,858	30,887
Capital Elasticity	0.1604	0.1732	0.1437	0.1765	0.1782
Labour Elasticity	0.9613	0.8916	1.0038	0.9252	0.8869
MRTS	5,606	6,824	4,734	6,458	6,205
Technical Efficiency	0.5590	0.5656	0.5151	0.5774	0.5353
Machinery					
R-Square	0.7370	0.7707	0.7399	0.7768	0.7267
Capital Intensity	33,467	343,348	36,129	33,714	38,836
Capital Elasticity	0.1343	0.0943	0.1479	0.1574	0.1795
Labour Elasticity	0.9689	1.0579	0.8988	0.9157	0.8120
MRTS	4,637	3,060	5,947	5,795	8,585
Technical Efficiency	0.4949	0.6026	0.7377	0.5390	0.6097
Electrical					
R-Square	0.7078	0.8701	0.8719	0.8803	0.8612
Capital Intensity	29,105	25,461	29,945	29,129	26,298
Capital Elasticity	0.1731	0.1693	0.2135	0.2633	0.2990
Labour Elasticity	0.8458	0.8659	0.7727	0.7417	0.7181
MRTS	5,956	4,979	8,274	10,340	8,385
Technical Efficiency	0.2648	0.6576	0.5572	0.5026	0.5465
Electronics					
R-Square	0.8413	0.8296	0.8618	0.8534	0.8918
Capital Intensity	31,344	25,687	31,612	34,051	26,597
Capital Elasticity	0.2492	0.1901	0.2871	0.3653	0.3353
Labour Elasticity	0.8594	0.9964	0.8841	0.7939	0.7838
MRTS	9,088	4,901	10,268	15,677	11,376
Technical Efficiency	0.4885	0.4424	0.4848	0.4372	0.5732
Transport					
R-Square	0.8232	0.8387	0.8475	0.8574	0.8035

Table 2 (Continued)

	1984	1985	1986	1987	1988
Capital Intensity	23,527	29,663	26,374	25,946	23,559
Capital Elasticity	0.1874	0.2072	0.1401	0.1996	0.2449
Labour Elasticity	0.8153	0.7752	0.9177	0.8503	0.6928
MRTS	5,407	7,928	4,026	6,090	8,328
Technical Efficiency	0.5604	0.5667	0.6040	0.5894	0.7248

Table 3

ESTIMATED PRODUCTION INDICES

Efficiency	1984	1985	1986	1987	1988	Average
Print/Publish	0.6962	0.7607	0.6919	0.8291	0.5969	0.7354
Transport	0.5604	0.5667	0.6064	0.5894	0.7248	0.6091
Text/Apparel	0.4570	0.6613	0.6580	0.5144	0.7447	0.6071
Machinery	0.4949	0.6026	0.7377	0.5390	0.6097	0.5968
Plastic	0.7604	0.3308	0.3269	0.8872	0.5792	0.5769
Other Chem	0.5564	0.5614	0.6116	0.6034	0.5216	0.5769
Fab Metal	0.5590	0.5656	0.5151	0.5774	0.5353	0.5505
Electrical	0.2648	0.6576	0.5572	0.5026	0.5465	0.5057
Ind Chem	0.7404	0.2983	0.4696	0.4393	0.4876	0.4870
Electronic	0.4885	0.4424	0.4848	0.4372	0.5732	0.4852
Food	0.5842	0.2888	0.4115	0.5221	0.4330	0.4527

Capital Inten	1984	1985	1986	1987	1988	Average
Ind Chem	194,046	225,822	206,339	273,032	256,532	235,154
Other Chem	63,498	54,815	57,268	57,081	53,803	57,293
Food	38,088	40,845	40,663	38,467	42,879	40,188
Machinery	33,467	34,348	36,129	33,714	38,836	35,299
Fab Metal	33,608	35,134	32,944	33,858	30,887	33,286
Plastic	28,129	30,883	28,328	32,720	29,739	29,959
Electronic	31,344	25,687	31,612	34,051	26,597	29,858
Electrical	29,105	25,461	29,945	29,129	26,298	27,988
Transport	23,527	29,663	26,374	25,946	23,559	25,814
Print/Publish	19,086	20,041	19,691	21,712	24,514	21,009
Text/Apparel	10,008	11,078	10,796	10,798	11,453	10,827

Table 3 (Continued)

MRTS	1984	1985	1986	1987	1988	Average
Ind Chem	21,722	56,554	127,479	201,306	474,143	176,236
Other Chem	32,951	18,162	18,479	28,319	17,981	23,178
Electronic	9,088	4,901	10,268	15,677	11,376	10,262
Food	7,985	10,969	7,346	8,795	11,718	9,057
Plastic	6,673	10,191	7,109	10,569	8,047	8,398
Electrical	5,956	4,797	8,274	10,340	8,385	7,587
Transport	5,407	7,928	4,026	6,090	8,328	6,356
Fab Metal	5,606	6,824	4,734	6,458	6,205	5,965
Machinery	4,637	3,060	5,947	5,795	8,585	5,605
Text/Apparel	1,923	2,386	2,425	2,448	2,690	2,374
Print/Publish	2,361	1,482	737	2,197	6,717	2,115

Capital Elas.	1984	1985	1986	1987	1988	Average
Other Chem	0.4443	0.3313	0.3383	0.4501	0.3165	0.3761
Ind Chem	0.1100	0.2351	0.4109	0.4682	0.6243	0.3697
Electronic	0.2492	0.1901	0.2871	0.3653	0.3353	0.2854
Plastic	0.1967	0.2444	0.2058	0.2513	0.2254	0.2247
Food	0.1977	0.2269	0.1887	0.2189	0.2646	0.2106
Electrical	0.1731	0.1693	0.2135	0.2633	0.2290	0.2096
Transport	0.1874	0.2072	0.1401	0.1996	0.2449	0.1958
Text/Apparel	0.1704	0.1766	0.1867	0.1956	0.2044	0.1867
Fab Metal	0.1604	0.1732	0.1437	0.1765	0.1782	0.1664
Machinery	0.1343	0.0943	0.1479	0.1574	0.1795	0.1427
Print/Publish	0.1263	0.0823	0.0442	0.1118	0.1984	0.1037

Labour Elas	1984	1985	1986	1987	1988	Average
Print/Publish	1.0212	1.1127	1.1799	1.1053	0.9085	1.0655
Other Chem	0.8562	1.0001	1.0313	0.9073	0.9471	0.9484
Fab Metal	0.9613	0.8916	1.0038	0.9252	0.8869	0.9338
Machinery	0.9689	1.0579	0.8988	0.9157	0.8120	0.9307
Food	0.9431	0.8448	1.0447	0.9576	0.8569	0.9294
Electrónic	0.8594	0.9964	0.8841	0.7939	0.7838	0.8635
Text/Apparel	0.8867	0.8197	0.8314	0.8627	0.8702	0.8541
Plastic	0.9113	0.7405	0.8204	0.7779	0.8330	0.8166
Transport	0.8153	0.7752	0.9177	0.8503	0.6928	0.8103
Electrical	0.8458	0.8659	0.7727	0.7417	0.7181	0.7888
Ind Chem	0.9829	0.9386	0.6652	0.6349	0.3378	0.7119

Table 3 (Continued)

RetScale	1984	1985	1986	1987	1988	Average
Other Chem	1.3005	1.3314	1.3696	1.3574	1.2636	1.3245
Print/Publish	1.1475	1.195	1.2241	1.2171	1.1069	1.1781
Electronic	1.1086	1.1865	1.1712	1.1592	1.1191	1.1489
Food	1.1408	1.0717	1.2334	1.1765	1.1215	1.1488
Fab Metal	1.1217	1.0648	1.1475	1.1017	1.0651	1.1002
Ind Chem	1.0929	1.1737	1.0761	1.1031	0.9621	1.0816
Machinery	1.1032	1.1522	1.0467	1.0731	0.9915	1.0733
Plastic	1.108	0.9849	1.0262	1.0292	1.0584	1.0413
Text/Apparel	1.0571	0.9963	1.0181	1.0583	1.0746	1.0409
Transport	1.0027	0.9824	1.0578	1.0499	0.9377	1.0061
Electrical	1.0189	1.0352	0.9862	1.005	0.9471	0.9985

The most efficient industry was the printing and publishing firms with an average technical efficiency of 73.5%, followed by the transport equipment and the textile and apparel sectors which attained efficiencies of about 60%. These sectors are highly competitive industries with large number of firms and relatively little barriers to entry or exit. Higher levels of economic competition yield higher levels of production efficiency. Conversely, the least efficiently managed productions were the food, electronics and industrial chemicals industries which recorded efficiencies of less than 50%. The latter markets have very high capital investment and relatively few firms which reduce economic competition. These industries also face less regional competition than the top performers.

A distinguishing feature of the top performers, as indicated in table 2, is that these sectors are relatively adept in weathering the recession in 1985. Incidentally, these sectors have the lowest capital investment per worker. On the other hand, most of the low performers suffered a significant drop in efficiencies during the recession and had relatively high capital investment per worker. One possible explanation may be the high cost of carrying excess capacity during a recession.

Capital elasticity measures the percentage increase in value added arising from a percent increase in the capital investment. As shown in table 3, the highest potential returns from capital investment is in the chemical industries, followed by the electronics and plastic productions. It is lower in the more traditional sectors such as printing and publishing, machinery, fabricated metals and textile and apparel. Ignoring the labour-capital trade-offs or holding employment constant, investments in automation should be channelled into those industries with the highest potential returns.

The amount of capital investment required to replace a worker without affecting the output is measured by the industry's marginal rate of technical substitution. The estimates displayed in table 3 indicate that workers in the chemical industries are the most expensive to replace, followed by employees of the electronic industries. On the other hand, workers in the printing and publishing and the textile and apparel businesses are the least expensive to replace. To relieve labour shortage, policy makers responsible for the National Automation Program may wish to invest in the latter group of industries for maximum impact per dollar.

As reported in table 3, increasing labour input in the printing and publishing industries will bring about the highest percentage increase in value added. Conversely, a percentage increase in the labour force of the industrial chemical sector will produce the samllest percentage increase in value added. This result is somewhat surprising since the industrial chemicail sector has the highest capital investment per worker and the printing and publishing industry has one of the lowest capital intensity. This indicates that the optimal production process of the chemical industry is relatively more capital intensive than the printing and publishing industry.

V. Testing Hypotheses on Efficiency

Four hypotheses were proposed to explain the variation in average technical efficiencies across industries and years. Data was pooled together resulting in a sample size of 55. T-tests of the correlations between the average technical efficiencies and the number of firms in the industry, the average number of workers per firm, the average net fixed asset per worker and the average value added per worker were conducted and the results are presented in table 4. It should be pointed out that these test results are not as conclusive as those that test these relationships by sectors using individual firm's efficiencies. However, since this paper focuses on the overall performance of the economy, the individual firm's efficiencies were not estimated.

In general, the test results were not very encouraging. None of the proposed influences were found to be highly significant (95% confidence level) in explaining the variations in technical efficiencies. However, the number of firms in the industry was found to be positively correlated with the technical efficiency at the 90% confidence level. This result is consistent with the economic theory of market structure which posits that in-

Table 4

RESULTS OF HYPOTHESIS TESTS

Correlation with Technical Efficiency

Variables	Coefficients*	P-Values
Number of Firm	0.2324	0.10
Workers per Firm	−0.2481	0.18
Fixed Assets per Worker	−0.1795	0.16
Value Added per Worker	−0.3031	0.27

*values in 10^{-3}

creases in economic competition should lead to an increase in efficiency.

One tinsel result is lack of strong correlation between technical efficiency and capital intensity. This is not surprising since there is little theoretical justification in this much speculated hypothesis. Efficiency measures how well the given resources are utilised and not how good the resources are. Improving the quality of the resources will extend the production frontier leading to higher output but will not result in more efficient production which are nearer to the frontier.

The lack of correlation between technical efficiency and firm size, which is measured by the number of workers, is not surprising. Again there is little economic theory supporting this popular belief and there are conflicting views in management and organisational behaviour theories regarding this hypothesis. This lack of conclusive relationship between firm size and technical efficiency is also found in the Indian industries by Page (1984).

VI. Concluding Remarks

The manufacturing industries of Singapore performed fairly over the five year period from 1984 to 1988 with most sectors attaining mean technical efficiencies between 50% and 60%. These estimates are similiar to those obtained for other developing countries like India, Indonesia, Philippines, Thailand, Egypt and Brazil. The top performers were printing and publishing, transport and textile and apparel industries followed by the next group which included machinery, plastic, non-industrial chemicals and fabricated metals. At the lower end were electrical, industrial chemicals, electronics and food industries.

The number of firms in the industry was found to have a positive effect on the mean technical efficiency but capital intensity, mean number of workers and average value added per firm were found to have little impact on efficiency. Some factors which are found in other studies that are significant in determining technical efficiency and productivity are the degree or existence of unionisation in the firm, the vintage of major production lines and the education level of the labour employed. Data on these variables should also be collected in future surveys to facilitate better research and provide more information to policy makers.

Although technical efficiency is a very important yardstick to measure the performance of our industries, there are other dimensions which policy makers have to consider. In addition to technical efficiency, producers should also strive to achieve economic efficiency. The latter encompasses both technical efficiency and optimal factor combination as dictated by the relative price of inputs. Technical efficiency traces the production frontier whereas economic efficiency defines a particular point on the frontier depending on the relative factor price. Another important consideration of performance is productivity which can be measured by either value added per worker, labour elasticity or marginal product of workers. It is important for policy makers to monitor and analyse the trend and determinants of productivity.

One statistic that is important to an open economy like Singapore is the export to sales ratio. Besides its balance of trade implications, this ratio also measures the diversity of the industry's outlet. An optimal balance should be achieved to minimise the impact of a local, regional or international recession. The poor performance of the plastic sector which is primarily a domestic industry in the local recession of 1985 illuminated the need to diversify its market.

The most capital intensive industries were the chemicals sectors followed by food, machinery and fabricated metals. Conversely, the least automated sectors were textile and apparel and printing and publishing. The highest potential returns from capital investment were in the chemicals and electronics industries. Workers in the printing and publishing and the textile and apparel industries were found to be the least expensive to replace with automation. Depending on the objectives, these two groups of industries are potential targets for promoting higher level of automation.

Since there are a vareity of different public investment schemes available for automation, one possible approach is to provide the low cost automation financing to the more traditional industries, training aids to industries with low technical efficiencies to improve their efficiencies and funds at market rates to industries with high capital elasticities. Industries like the printing and publishing and the textile and apparel have higher efficiencies and should be given the priviledge of low cost financing to encourage other industries to improve on their efficiencies. Owning to the low capital elasticities, these industries also have less incentives to invest in automation. In addition, these industries have low marginal rate of technical substitution which makes them prime target for automation to ease the labour shortage.

Conversely, the chemicals and electronics industries have low efficiencies, high capital elasticities and rate of substitution. The high capital elasticities will provide the requisite incentives for these industries to invest in automation without much assistance from the government. It is also more costly to substitute capital for labour in these industries and investment in automation will result in the least relieve to the labour crunch. Thus, it is not recommendated that the government should provide low cost financing to these industries but to ensure that these industries are able to obtain funds at market rates. However, training aids may be provided to these industries to enable them to improve their performances.

It should be noted that although the elasticities are very useful measures in decision making, they indicate a percentage change and are different for different industries due to the variations in the average level of the key variables across industries. For examples, a one percent increase in the value added of the industrial chemical sector averages about $11.4 million per firm per year whereas it is only about $1.14 million per firm per year for the textile and apparel industries and the corresponding figures for capital investment are $29.6 million and $0.73 million respectively. Depending on the criteria and type of decision making, policy makers have to select the appropriate statistics to utilise.

Another important qualification on the research is that the number of workers employed is used as the proxy for labour input instead of the man-hour used. Although this is commonly done in estimation, it has some statistical problems. This approximation may introduce some errors in estimation if the work hours vary drastically among firms. For example, if overtime work is quite prevalent in a particular industry but not the norm, then firms that do not have overtime will produce less output than firms that operate on overtime. Since these are not exceptions in the industry, firms that possess the same fixed assets and employ the same number of workers without overtime will be deemed as more inefficient than similar firms which allow overtime. Therefore, for the benefit of future research, it is recommended that the Economic Development

Board collect data on the man-hours used or the average working hours per worker in addition to the number of workers employed.

It is also recommended that further research be conducted to determine the technical efficiency of individual firms in each industry. This will enable policy makers to study the differences in production technology and managerial style between firms with different levels of efficiency. This analysis should provide valuable insight on ways to improve the industry. In addition, the individual firm estimates will present an improved method to test the relationship between technical efficiency and capital intensity. Over the years and across industries, the relationship between these key variables may not be significant or even be pervasive due to sectorial differences. A better test would be to determine these relationships within each industry and allocate capital investment to industries that exhibit a positive relationship between technical efficiency and capital intensity.

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