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Technical (In)Efficiency in the U.S. Manufacturing Sector, 1977-1982

by

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ABSTRACT

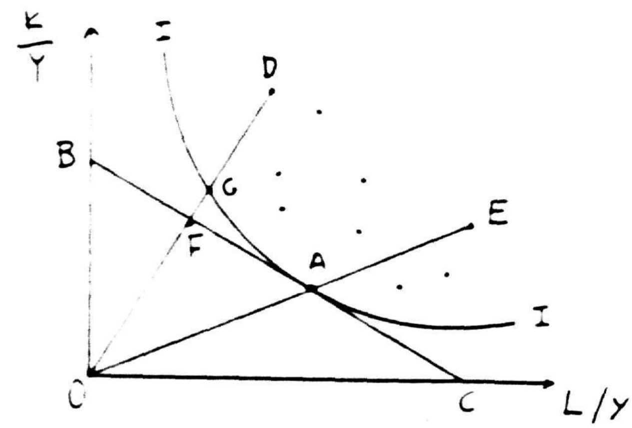
Although a big progress has recently taken place in both theory and empirical measurement of technical or productive efficiency, the topic has attracted relatively little attention by economists. This paper is a first attempt to measure the extent of technical (in)efficiency of the U.S. manufacturing sector at the industry level. The years 1977 and 1982 are examined within the theoretical framework of stochastic production frontiers, utilizing the translog form of the corresponding production function. The corrected OLS (COLS) estimates show that technical inefficiency was 7% on average for the whole manufacturing sector in 1977, when gross output is used, and 1.6%, when value added is used. There was a slight deterioration in 1982. These estimates compare with 60.5% and 23% of technical inefficiency according to a previous study at the establishment level for 1977. The differences between the two sets of obtained estimates may involve an index number problem.

1. INTRODUCTION

The definition of technical or productive inefficiency was first given by Farrell (1957). Until the late 1970's, its empirical application was very limited. Since 1977 that Aigner, Lovell, and Schmidt proposed the stochastic frontier production function, and Meeusen and Broeck considered the Cobb-Douglas production function with a composed multiplicative disturbance term, Farrell's conception became the tool for estimating technical (in)efficiency of various sectors and industries in a big number of developed and developing economies.[1] The theoretical assumptions and empirical measures used have gone through a tremendous improvement over the last ten years or so.

Farrell's inefficiency can be explained in terms of the following figure:

FIGURE 1



II is a unit isoquant of an economic activity X exhibiting constant returns to scale (CRTS). II is the locus of all minimum combinations of capital (K) and labor (L) per unit of output (Y) required to produce one unit of X's output, Y. Thus, II describes completely the

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[1] Among others, see the 1980, vol. 13, issue of the Annals of the Journal of Econometrics, Caves and Barton (1990), Caves (1992), the June 1992 issue of the Journal of Productivity Analysis, and Battese (1992).

technology of X. The relative prices of K and L are given by the line BC. The various points above II represent the various input-per-unit-of-output ratios, (K_i/Y, L_i/Y). A is the point of the least costly combination of inputs for producing the given quantity of output. The deviation of observed input-per-unit-of-output ratios from the unit isoquant, II, is considered to be associated with technical inefficiency of the firm involved.

If for example, the input combination was D instead of A, then DG/OG measures technical inefficiency which is defined as the proportional excess cost of inputs used over the feasible minimum cost G, using the input proportions indicated by OD. G is technically efficient, but it is not the least cost combination if factor prices are BC. The ratio GF/OF measures price inefficiency.[1] It indicates the proportional excess cost due to the use of inappropriate input proportions.

The overall or economic efficiency of firm D is given by the ratio OF/OD which is the product of technical and price efficiency. Thus, the economic efficiency of firm D is equivalent to the ratio of the average cost of production at A to the average cost of producing at D. (Notice that G is technically efficient but price inefficient, E is technically inefficient and price efficient.)

Figure 2 shows a more general presentation of Farrell's concept of the production function frontier.

The observed input-output values are below the production frontier. A measure of the technical efficiency of the firm which produces output Y_1 with inputs X_1 (point A) is given by the ratio Y_1/Y_1, where Y_1 is the frontier output associated with the level of inputs X_1. Firms in the interior of the production frontier may be either technically or price inefficient or both. If it is not known whether interior points are only price or only technically inefficient, then these interior points may be referred to as X-inefficient (Leibenstein, 1966).

Caves and Barton (1990) referred to a third efficiency measure, the "scale inefficiency" which may take place if the CRTS assumption is removed. Thus, scale inefficiency appears when production takes place at scales either too small, or too large to minimize costs of production.

Measuring technical efficiency helps identifying structural determinants of market equilibria and efficiency in the allocation of resources. Despite its significance, relatively little effort has been devoted to efficiency measurement, as well as to investigating its determining factors. This may be due to a probable belief that technical efficiency lies

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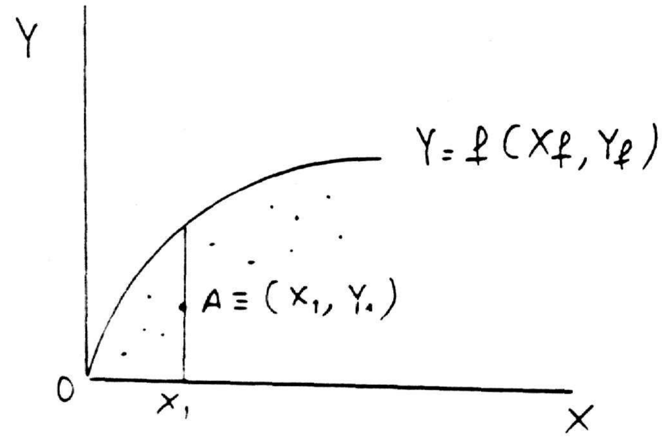
[1] This ratio has been called "allocative inefficiency" by later writers. Any divergence between price and marginal cost implies allocative inefficiency.

FIGURE 2



"outside the reach of analytically founded economic analysis", as Caves and Barton (1990, p.1) note.

There are two approaches to the construction of frontier production functions: The deterministic and the stochastic. The deterministic approach uses mathematical programming techniques. Seiford and Thrall (1990) discuss recent developments in this approach, which is also called "Data Envelopment Analysis" (DEA). The stochastic approach uses econometric techniques which are thoroughly reviewed by Bauer (1990). The stochastic approach has attracted more attention because mainly of its realism: the random character of the input-output relationship.

This paper measures the extent of technical (in)efficiency in the U.S. manufacturing sector at the four-digit SIC industry level. The stochastic paradigm framework is used. The main tool of this analysis is the "composed error" model, according to which the error term in a statistically fitted production function is composed of two components: the conventional normal distribution of random elements, and a one-sided distribution of non-random elements representing inefficiency. This theoretical structure is applied to the 450 four-digit SIC manufacturing industries for 1977 and 1982, both census-of-manufactures years. However, the final samples used are 431 and 437 for 1977, and 418 and 423 for 1982. Within the same theoretical framework, Caves and Barton (1990) estimated stochastic frontier production functions for a final sample of 162 industries at the establishment level in the year 1977. Thus, the results of this paper are compared with those obtained by Caves and Barton (1990).

This work has estimated technical inefficiency as 7% (or 1.6% when value added, instead of shipments, is used) for the year 1977 on average, and for all the manufacturing sector. Technical inefficiency is slightly increased (8% or 2.5%) for the year 1982. The comparison of this paper's estimates with those obtained by Caves and Barton (1990), C-B, for the year 1977 shows quite a difference between them. C-B estimate is 60.5% (or 23% when value added, instead of shipments, is used) on average for all the manufacturing sector.

This paper is organized as follows: Section 2 gives a brief overview of the existing theory. Section 3 discusses the data used and presents the empirical results. It also comments on the findings and compares them with those obtained from Caves and Barton (1990). Finally, the last section concludes the paper.

2. THEORY

The stochastic production frontier (SPF) is given by the following equation:

$$y = f(x)\exp(\varepsilon) \qquad \varepsilon = (v-u),\ u>0 \qquad (1)$$

where y is output, f(x) is the deterministic part of the frontier production function (FPF), v is a symmetrical random error (the conventional normal distribution of random elements, including measurement errors, minor omitted variables, and other exogenous factors beyond the plant's, firm's, or industry's control), and u is a one-sided error term $u \geq 0$, representing technical inefficiency. The elements of u indicate shortfalls of the industry's production units from the efficient frontier. Technical inefficiency is shown in the skewness of the residuals around the fitted production function. The economic logic behind the composed-error specification is that the production process is subject to two economically distinguishable random disturbances with different characteristics. The non-positive disturbance u reflects the fact that each firm's output must lie on or below its frontier f(x)exp(v). Any such deviation is the result of factors under the firm's control, such as technical and economic efficiency, the will and effort of the producer and his employees, or probably such factors as defective and damaged products. But the frontier itself can vary randomly across firms, or over time for the same firm. On this interpretation, the frontier is stochastic, with random disturbance $v \geq 0$ and $v \leq 0$, being the result of favorable or unfavorable external events, such as luck, climate, machine performance, topography, as well as errors of observation and measurement on y. Consequently, estimation of the variances of v and u, gives evidence on their relative sizes. This implies that the productive efficiency may be measured by the following ratio:

$$y/[f(x)\exp(v)] \qquad (2)$$

Given a parametric functional form for f(x) and distributional assumptions on u and v, the model (1) can be estimated either by maximum likelihood or by the corrected OLS (COLS) methods. For the asymptotic properties of the ml estimators, see Aigner et al. (1977) and Olson et al. (1980). The COLS was first proposed by Richmond (1974) and Forsund et al. (1980) have named it. Olson et al. (1980) showed that the COLS estimators have statistical properties at least as desirable as those of the ml estimators. The COLS may be briefly described as follows: Equation (1) can be written as,

$$\ln(y) = \ln[f(x)] + v - u = -\mu + \ln[f(x)] + (v - u + \mu) \tag{3}$$

where $\mu \equiv E(u) > 0$

It is assumed that u and v are independently and identically distributed and that the disturbances are also independent of x, so equation (3) satisfies all the assumptions for the traditional OLS model, except for the normality assumption of for $v-u+\mu$. Also, it is assumed that $\ln[f(x)]$ is linear in the parameters, so that the OLS would yield the BLUE of the parameters, except for the constant term, denoted as α_0, for which the bias will be $-\mu$. Thus, the OLS will give an unbiased estimator of $(\alpha_0-\mu)$.

The estimation of the SPF by the OLS leads to consistent estimators for all the parameters, μ included, if it is assumed that v is normally and u is half-normally distributed:

$$v \sim N(0, \sigma^2_v), \qquad u \sim |N(0, \sigma^2_u)| \tag{4}$$

In practice, both, half normal and exponential distributions have been employed for u. However, the available evidence suggests that these two assumptions lead to similar parameters (Caves and Barton, 1990, pp. 13-14, 18).

The distribution function of the sum of the symmetric normal random variable and the truncated normal random variable was first derived by Weinstein (1964):

$$f(\varepsilon) = (2/\sigma) f^*(\varepsilon/\sigma)[1-F^*(\varepsilon\lambda\sigma^{-1})] \qquad -\infty \le \varepsilon \le +\infty \tag{5}$$

where $\sigma^2 = \sigma^2_u + \sigma^2_v$, $\lambda = \sigma_u/\sigma_v$, $f^*(.)$ and $F^*(.)$ are the standard normal density and distribution functions respectively. This density function is asymmetric around zero, and its mean and variance are given by the following formulas:

$$E(\varepsilon) = E(-u) = -\mu = -\sigma_u(2/\pi)^{1/2} \tag{6}$$

$$Var(\varepsilon) = Var(u) + Var(v) = [(\pi-2)/\pi]\sigma^2_u + \sigma^2_v \tag{7}$$

Thus, a consistent estimator of μ can then be obtained if σ_u in equation (6) is replaced by its consistent estimator. (See Aigner, Lovell, and Schmidt, 1977, and Schmidt and Lovell, 1972.)

It can be shown that definitions of the second and third central moments of ε, denoted as $m_2(\varepsilon)$ and $m_3(\varepsilon)$, respectively, lead to the following system of equations:

$$\sigma^2_u = \{(\pi/2)\,[\pi/(\pi-4)]\,m_3(\varepsilon)\}^{2/3} \quad (8a)$$

$$\sigma^2_v = m_2(\varepsilon) - [(\pi-2)/\pi]\,\sigma^2_u \quad (8b)$$

$m_2(\varepsilon)$ and $m_3(\varepsilon)$ in equations (8) are replaced by their sample counterparts, $\hat{m}_2(\varepsilon)$ and $\hat{m}_3(\varepsilon)$, according to the following procedure:

Estimation of equation (3) by OLS gives the residuals e_i, $i = 1, 2, \ldots, N$. Then the second and third central moments of the residuals, $m_2(e)$ and $m_3(e)$, are calculated using the formulas (9):

$$\hat{m}_2 = 1/(N-k)\sum_{i=1}^{N} e_i^2, \quad \hat{m}_3 = (N-k-1)/[(N-k)(N-k-1)]\sum_{i=1}^{N} e_i^2 \quad (9)$$

where N is the sample size and k is the number of regressors, the constant term included.

Measures of Technical (In)Efficiency

The estimation of the SPF by COLS may fail to yield satisfactory estimates. The type I failure exists if the estimate of m_3 takes on a non-negative value so that σ^2_u cannot be defined. It is noted that m_3 must always be negative in the population under the assumptions (4). The smaller the σ^2_u, the greater is the probability of type I failure, because in this case the m_3 approaches to zero. But, a small value of σ^2_u implies that the gap $(\sigma\sqrt{2}\sqrt{\pi})$ between the average probability function and production frontier is also small. Thus, the chances are that type I failure may occur in relatively efficient industries. The type II failure occurs if the sample m_2 is so small relative to the estimate of σ^2_u that it results in a negative value of σ^2_v. This type of failure is rare and happens for relatively inefficient industries for which the estimate of σ^2_u takes on a relatively large value.

The existing measures of technical (in)efficiency are given by the following formulas

$$EFF = 2\exp(\sigma^2_u/2)\,[1-F(\sigma_u)] \quad (10)$$

$$\mathrm{ATI} = \overline{[(\sigma_u\sqrt{2}/\sqrt{\pi})/[(\ln(y) + (\sigma_u\sqrt{2}/\sqrt{\pi})]]} \tag{11}$$

$$\lambda = \sigma_u/\sigma_v \tag{12}$$

$$S = m_3(\varepsilon)/[m_2(\varepsilon)]^{3/2} \tag{13}$$

Measure (10) was proposed by Lee and Tyler (1978), who derived this formula as the "mean technical efficiency measure", $E(e^{-u})$ for the Cobb-Douglas $e^{u} = Y/AK^{\alpha}L^{\beta}e^{v}$, under the assumption that u is either truncated normal or exponentially distributed. F is the cdf of the standard normal distribution, and EFF stands for efficiency. EFF is the expected value of exp(-u), or the ratio of the actual output to the SPF. If EFF = 1, then the actual output is on the SPF.

Measure (11), ATI or average technical inefficiency, measures the gap between the average production function and the production frontier (the numerator), normalized by the mean of the production frontier measured on the y axis (the denominator). For the calculation of ATI, the mean of ln(y) is used in order to correct for the error that is made for negative values of ln(y). ATI was proposed by Caves and Barton (1990). This estimator is the ratio of the intercept shift of the frontier[7] to the average position of the production frontier.

If type I failure occurs, EFF = 1 and ATI = 0. Otherwise the two measures lie in the (0,1) interval.

Measure (12) gives information about the degree of asymmetry in the distribution of $\varepsilon = v - u$. λ implies whether the gap between y and f(x) comes from u or v, since it represents a measure of technical inefficiency, σ_u, normalized by the degree of variation in the SPF, σ_v.

Measure (13) is a measure of skewness in the distribution of ε, and is closely related to λ. According to Yoo (1992, p.128) λ and S have a negative relationship in the interval (-0.9968, 0). As the degree of negative skew increases with the level of technical inefficiency, S is used as a measure of technical efficiency. If type I failure occurs, $\lambda = 0$. In the case of type II failure, λ is not defined, while S always exists. Summarizing, EFF and S are measures of efficiency, while ATI and λ are measures of inefficiency.

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[7] When the half-normal distribution of σ_u is assumed, the production frontier shifts downward by $-\sigma_u\sqrt{2}/\sqrt{\pi}$.

The SPF has been criticized for its weakness in relation to the choice for the distribution of u and v which is usually made on an ad hoc basis. Until recently, there was a second weakness associated with the SPF: The difference between y and $f(x)$ could not be decomposed into u and v. So, only the average technical inefficiency could be calculated until the appearance of Jondrow et al. (1982), who derived the conditional density of u given ε for both distributional cases of u, the half-normal and exponential.

Later, Battese and Coelli (1988) criticized Jondrow et al. (1982) for having considered the $E(u/\varepsilon)$ instead of the correct $E[\exp(u)/\varepsilon]$ for the multiplicative production frontier model. Consequently, by correcting this mistake, Battese and Coelli (1988) derived the conditional expectation of $\exp(-u_i)$ given sample values of ε. Their predictor of technical efficiency of the ith sample unit is the following:

$$TE_i = \{1-F[\sigma_* - (M^*_i/\sigma_*)]\}/[1-F(-M^*_i/\sigma_*)]\}\exp[-M^*_i + (\sigma^2_*/2)] \qquad (14)$$

where $F(.)$ denotes the distribution function of the standard normal random variable.

$$M^* \equiv (-\sigma^2_u\varepsilon)(\sigma^2_u + \sigma^2_v)^{-1}, \quad \sigma^2_* \equiv \sigma^2_u\sigma^2_v(\sigma^2_u + \sigma^2_v)^{-1}$$

Equation (14) is the minimum squared error predictor for $\exp(-u_i)$, given ε_i, and is consistent.

Furthermore, Waldman (1984) proposed two alternative linear estimators for predicting the ith sample unit technical (in)efficiency. The first is his "linear unbiased estimator", $-\varepsilon_i$, denoted as: $e = -\varepsilon_i$ (15)

Measure (15) is justified by $E(-\varepsilon) = E(-v+u) = E(u)$. Waldman (1984, p.355) explains it as "A more important reason for considering this estimator is that often the random disturbance (v) is ignored and a "full" frontier is fit to the data. In the production function case this means that no observation may lie above the frontier. One method of obtaining firm-specific measures of inefficiency is to estimate by least squares and subtract the largest (positive) residual from each residual in the sample" as in Greene (1980).

The second linear estimator that Waldman (1984) proposed is his "best linear predictor", denoted as: $blp = \alpha + \beta\varepsilon_i$

$$\beta = -Var(u)/[Var(u) + Var(v)], \ \alpha = E(u)-\beta E(\varepsilon) = E(u)(1+\beta) \qquad (16)$$

Despite the theoretical superiority of the conditional expectation predictor over these two linear estimation predictors, Waldman (1984) finds very little empirical gain.

In the next section, the data used are discussed and all six (in)efficiency measures given by formulas (10)-(16) are estimated.

3. EMPIRICAL ESTIMATES

The Data

Following Caves and Barton (1990), this paper uses the translog functional form to approximate production frontiers. In using the translog function, it is not necessary to impose any strong a priori assumption about the Allen partial elasticity of substitution or separability, or else homotheticity (Christensen et al., 1973). This paper is also confined to the use of a single-equation approach to the measurement of technical efficiency alone. Research is underway for the derivation of input demand frontiers so that to test for price inefficiency as well.

The adopted functional form is the following:

$$
\begin{aligned}
\ln(GO/L) = {} & a_0 + a_1 \ln(K/L) + a_2 \ln(M/L) + a_3 \ln N + a_4 [\ln(K/L)]^2 + \\
& + a_5 [\ln(M/L)]^2 + a_6 (\ln N)^2 + a_7 [\ln(K/L)][\ln(M/L)] + \\
& + a_8 [\ln(K/L)](\ln N) + a_9 [\ln(M/L)](\ln N) + aX + v\text{-}u \qquad (17)
\end{aligned}
$$

GO is a measure of industry output. In this paper, but also in Caves and Barton (1990), GO is a sales measure of output and represents value of shipments, not adjusted for changes in inventories. M is purchased materials, including energy spending, N is total number of employees, L is number of production worker hours, and K is capital stock. X denotes other exogenous variables used to control for the possible effects of other sources of heterogeneity among the four-digit SIC industries. Four such X's have been used in this paper:

(1) X_1, the ratio of production workers to total employment,
(2) X_2, the ratio of non-production workers to total employment,
(3) X_3, the ratio of energy spending to total cost of materials, and
(4) X_4, the ratio of production workers' payment to total payroll.

All the variables come from the Gray (1989) Productivity File at the NBER. It contains annual output and input measures for 450 four-digit SIC industries since 1958. This file is an updated version of the PEN-SRI Database created at the Census Bureau in the late 1970's. It is described in Griliches and Lichtenberg (1984).

Equation (17) is estimated by the COLS. In the place of the GO two measures of output have been used, value of shipments and value added. In total 52 equations have been estimated, 26 for 1977 and 26 for 1982. These categories refer to total manufacturing and 12 industry groupings, presented in Table 1.

TABLE 1
Total Manufacturing by two-digit Industry Branches
and SIC Groupings

	SIC	SIC Groupings
20	Food and kindred products	1. 20, 21
21	Tobacco products	2. 22, 23
22	Textile mill products	3. 24, 25
23	Apparel and other textile products	4. 26, 27
24	Lumber and wood products	5. 28, 29
25	Furniture and fixtures	6. 30, 31
26	Paper and allied products	7. 32
27	Printing and publishing	8. 33, 34
28	Chemicals and allied products	9. 35
29	Petroleum and coal products	10. 36
30	Rubber and misc. plastics products	11. 37
31	Leather and leather products	12. 38, 39
32	Stone, clay, and glass products	
33	Primary metal industries	
34	Fabricated metal products	
35	Industrial machinery and equipment	
36	Electronic and other electric equipment	
37	Transportation equipment	
38	Instruments and related products	
39	Miscellaneous manufacturing industries	

The Estimates

Table 2 presents the four (in)efficiency measures based on equations (10)-(13) for 1977 and 1982. These are average (in)efficiency measures. Table 3 presents the correlation coefficients of these measures.

TABLE 2

Measures of Average Technical Efficiency
at the two-digit SIC, 1977

OBS	SIC	EFF	ATI	λ	S
Based on COLS of Value of Shipments					
1.	20-39	0.9799	0.0054	0.2930	-0.0052
2.	20	0.9621	0.0104	0.8484	-0.0940
3.	22	0.9855	0.0039	0.5386	-0.0293
4.	24	0.9746	0.0069	1.3070	-0.2359
5.	26	0.9892	0.0029	0.5216	-0.0269
6.	28	0.9588	0.0113	0.9770	-0.1301
7.	30	0.9814	0.0050	4.8358	-0.8423
8.	33	0.9788	0.0057	0.5164	-0.0261
9.	35	0.9558	0.0122	2.6426	-0.6047
10.	36	0.9624	0.0103	1.6964	-0.3638
11.	37	0.9770	0.0063	1.7121	-0.3687
12.	38	0.9632	0.0101	1.6105	-0.3364
Based on COLS of Value Added					
13.	20-39	0.9032	0.0341	0.6748	-0.0532
14.	20	0.8143	0.0685	1.6398	-0.3458
15.	22	0.9484	0.0178	0.6910	-0.0566
16.	24	0.9472	0.0182	1.0651	-0.1569
17.	26	0.8961	0.0368	2.1468	-0.4931
18.	28	0.9147	0.0299	1.3373	-0.2460
19.	30	0.9287	0.0248	1.0220	-0.1436
20.	32	0.9393	0.0210	1.1227	-0.1752
21.	35	0.9006	0.0351	1.5576	-0.3192
22.	36	0.8815	0.0422	1.3969	-0.2660
23.	37	0.9605	0.0135	1.2227	-0.2079
24.	38	0.9693	0.0105	0.5244	-0.0273

TABLE 2 (Continued)

Measures of Average Technical Efficiency
at the two-digit SIC, 1977

1982					
OBS	SIC	EFF	ATI	λ	S
Based on COLS of Value of Shipments					
1.	20-39	0.9699	0.0073	0.4648	-0.0195
2.	20	0.9586	0.0101	0.6550	-0.0493
3.	22	0.9767	0.0056	0.5544	-0.0317
4.	24	0.9755	0.0059	0.8281	-0.0887
5.	26	0.9628	0.0091	1.1530	-0.1850
6.	28	0.9438	0.0139	3.0928	-0.6811
7.	30	0.9802	0.0048	0.9562	-0.1240
8.	32	0.9446	0.0137	1.2072	-0.2027
9.	33	0.9699	0.0073	1.0653	-0.1570
10.	35	0.9372	0.0156	2.3741	-0.5482
11.	36	0.9725	0.0067	1.1684	-0.1900
12.	37	0.9682	0.0078	0.7153	-0.0618
13.	38	0.9437	0.0139	2.0242	-0.4605
Based on COLS of Value Added					
14.	20-39	0.9048	0.0295	0.5955	-0.0384
15.	20	0.8324	0.0540	1.2600	-0.2202
16.	22	0.8484	0.0484	2.9863	-0.6649
17.	24	0.9498	0.0152	0.7859	-0.0781
18.	26	0.9756	0.0073	0.4035	-0.0131
19.	28	0.9476	0.0159	0.5595	-0.0325
20.	30	0.9331	0.0204	1.7596	-0.3834
21.	33	0.8673	0.0420	1.5368	-0.3124
22.	32	0.9496	0.0152	0.6474	-0.0478
23.	35	0.8986	0.0315	0.3102	-0.2370
24.	36	0.8768	0.0387	2.2428	-0.5172
25.	37	0.9504	0.0150	0.6449	-0.0474
26.	38	0.9033	0.0300	1.4407	-0.2806

TABLE 3

Correlation Matrix of Technical Efficiency Measures

(obs = 24)	EFF	ATI	λ	S	OBS
EFF	1.0000				
ATI	-0.9995	1.0000			
λ	-0.0728	0.0743	1.0000		
S	0.1625	-0.1632	-0.9700	1.0000	
OBS	-0.0341	0.0328	-0.3123	0.3330	1.0000
			1982		
(obs = 26)	EFF	ATI	λ	S	OBS
EFF	1.0000				
ATI	-0.9997	1.0000			
λ	-0.4966	0.4920	1.0000		
S	0.5067	-0.5017	-0.9964	1.0000	
OBS	-0.0114	0.0092	-0.2584	0.2510	1.0000

The next step is, by utilizing equation (14), to get individual (in)efficiency measures for the 437 and 431 industries, using value of shipments and value added respectively, for the year 1977. The corresponding numbers of individual industries for the year 1982 are 418 and 423. The difference between these numbers and the total number of industries, 450, represents type I failures. Table 4 shows summary statistics of these estimates classified by the two-digit SIC level, since the individual estimates for all 1709 cases are not reported here.

Table 4 is based on Battese and Coelli (1988), B-C, conditional distribution. Table 5reports individual (in)efficiency estimates based on Waldman's (W) (1984) linear estimation predictors.

TABLE 4

Summary Statistics of B-C Technical Efficiency Measure,
TE in Formula (14), by two-digit SIC, 1977

(v denotes measure based on value added)

Variable	Obs	Mean	Std. Dev.	Min	Max
20-39	437	0.9805	0.0025	0.9724	0.9879
20-39v	431	0.9152	0.0225	0.8209	0.9611
20	41	0.9690	0.0100	0.9401	0.9826
20v	41	0.8802	0.0542	0.7525	0.9523
22	51	0.9868	0.0030	0.9791	0.9920
22v	59	0.9552	0.0122	0.9214	0.9755
24	29	0.9825	0.0076	0.9649	0.9934
24v	28	0.9600	0.0148	0.9311	0.9801
26	28	0.9901	0.0022	0.9853	0.9936
26v	33	0.9433	0.0338	0.8295	0.9872
28	29	0.9679	0.0120	0.9264	0.9853
28v	27	0.9411	0.0252	0.8807	0.9752
30	15	0.9960	0.0134	0.9777	1.0384
30v	17	0.9453	0.0217	0.8744	0.9760
33	60	0.9806	0.0042	0.9701	0.9878
32v	21	0.9550	0.0175	0.9155	0.9777
35	40	0.9788	0.0152	0.9329	0.9963
35v	44	0.9359	0.0322	0.8421	0.9822
36	36	0.9771	0.0117	0.9464	0.9928
36v	39	0.9192	0.0367	0.8085	0.9692
37	17	0.9863	0.0075	0.9629	0.9955
37v	15	0.9720	0.0112	0.9522	0.9862
38	32	0.9770	0.0117	0.9475	0.9934
38v	26	0.9720	0.0061	0.9605	0.9816

TABLE 4 (Continued)

(v denotes measure based on value added) 1982					
Variable	Obs	Mean	Std.Dev.	Min	Max
20-39	418	0.9720	0.0056	0.9553	0.9847
20-39v	423	0.9144	0.0210	0.8169	0.9686
20	37	0.9637	0.0098	0.9363	0.9800
20v	29	0.8779	0.0476	0.7845	0.9447
22	60	0.9789	0.0049	0.9656	0.9884
22v	60	0.9283	0.0555	0.7611	0.9837
24	29	0.9799	0.0065	0.9646	0.9895
24v	29	0.9579	0.0129	0.9246	0.9776
26	30	0.9728	0.0110	0.9474	0.9889
26v	28	0.9769	0.0040	0.9673	0.9833
28	27	0.9798	0.0334	0.9167	1.1221
28v	26	0.9525	0.0109	0.9234	0.9685
30	17	0.9845	0.0055	0.9720	0.9922
30v	16	0.9600	0.0211	0.9177	0.9874
32	26	0.9602	0.0162	0.9205	0.9829
32v	27	0.9135	0.0424	0.7913	0.9716
33	54	0.9773	0.0091	0.9404	0.9911
33v	51	0.9556	0.0118	0.9129	0.9763
35	43	0.9676	0.0208	0.8987	0.9922
35v	44	0.9291	0.0314	0.8278	0.9758
36	34	0.9801	0.0083	0.9547	0.9920
36v	35	0.9338	0.0399	0.8202	0.9851
37	17	0.9727	0.0079	0.9523	0.9847
37v	17	0.9564	0.0114	0.9267	0.9734
38	30	0.9687	0.0174	0.9229	0.9910
38v	31	0.9353	0.0282	0.8796	0.9734

TABLE 5

Summary Statistics of W Efficiency Measures,
e [formula (15)] and blp [formula (16)] by two-digit SIC, 1977

(v denotes measure based on value added)					
Variable	Obs	Mean	Std.Dev.	Min	Max
e 20-39	437	-0.2380	0.0886	-0.5929	-0.0000
blp20-39	437	0.0188	0.0070	-0.0000	0.0468
bl20-39v	431	0.0720	0.0658	-0.1208	0.2925
blp20	41	0.0227	0.0271	-0.0348	0.0707
blp20v	41	0.0592	0.1710	-0.2262	0.3746
blp22	51	0.0114	0.0081	-0.0052	0.0300
blp22v	59	0.0364	0.0342	-0.0361	0.1146
blp24	29	0.0096	0.0199	-0.0245	0.0556
blp24v	28	0.0258	0.0410	-0.0380	0.1001
blp26	28	0.0086	0.0059	-0.0023	0.0205
blp26v	33	0.0202	0.0889	-0.1684	0.2718
blp28	29	0.0218	0.0309	-0.0530	0.0925
blp28v	27	0.0328	0.0707	-0.0906	0.1729
blp30	15	0.0008	0.0145	-0.0218	0.0385
blp30v	17	0.0370	0.0556	-0.0955	0.1712
blp33	60	0.0170	0.0115	-0.0064	0.0425
blp32v	21	0.0282	0.0479	-0.0544	0.1122
blp35	40	0.0057	0.0358	-0.0639	0.1110
blp35v	44	0.0315	0.0844	-0.1411	0.2926
blp36	36	0.0100	0.0304	-0.0445	0.0811
blp36v	39	0.0443	0.1014	-0.1693	0.2729
blp37	17	0.0060	0.0184	-0.0317	0.0459
blp37v	15	0.0163	0.0311	-0.0273	0.0662
blp38	32	0.0105	0.0296	-0.0426	0.0919
blp38v	26	0.0246	0.0170	-0.0032	0.0576

TABLE 5 (Continued)

(v denotes measure based on value added) 1982					
Variable	Obs	Mean	Std.Dev.	Min	Max
e20-39	418	-0.2061	0.0862	-0.4954	-0.0000
blp20-39	418	0.0253	0.0153	-0.0113	0.0767
bl20-39v	423	0.0760	0.0603	-0.1220	0.3951
blp20	37	0.0300	0.0264	-0.0279	0.0928
blp20v	29	0.0749	0.1484	-0.1555	0.3689
blp22	60	0.0181	0.0133	-0.0106	0.0547
blp22v	61	0.0174	0.1341	-0.2579	0.5368
blp24	29	0.0148	0.0172	-0.0171	0.0508
blp24v	29	0.0323	0.0353	-0.0382	0.1080
blp26	30	0.0164	0.0289	-0.0344	0.0839
blp26v	28	0.0214	0.0111	-0.0013	0.0421
blp28	27	0.0056	0.0457	-0.0817	0.1205
blp28v	26	0.0417	0.0308	-0.0241	0.0970
blp30	17	0.0105	0.0146	-0.0150	0.0391
blp30v	16	0.0172	0.0554	-0.0666	0.1438
blp32	26	0.0236	0.0441	-0.0557	0.1155
blp32v	27	0.0442	0.1159	-0.1920	0.3415
blp33	54	0.0144	0.0229	-0.0466	0.0759
blp33v	51	0.0370	0.0322	-0.0481	0.1202
blp35	43	0.0100	0.0517	-0.0973	0.1523
blp35v	44	0.0406	0.0849	-0.1491	0.2781
blp36	34	0.0119	0.0213	-0.0334	0.0623
blp36v	35	0.0227	0.1071	-0.1775	0.3087
blp37	17	0.0216	0.0211	-0.0212	0.0658
blp37v	17	0.0365	0.0316	-0.0287	0.0977
blp38	30	0.0116	0.0463	-0.0685	0.1123
blp38v	31	0.0340	0.0814	-0.0882	0.1898

Table 6 presents correlations among the (in)efficiency measures shown in Tables 4 and 5.

TABLE 6

Correlation Matrix of Technical Efficiency Measures
Shown in Tables 4 and 5, All Manufacturing

1977					
(Obs = 424)	TE	TEv	e	blp	blpv
TE	1.0000				
TEv	0.7259	1.0000			
e	-0.9920	-0.7275	1.0000		
blp	0.9920	0.7275	-1.0000	1.0000	
blpv	0.7479	0.9747	-0.7658	0.7658	1.0000
1982					
(Obs = 409)	TE	TEv	e	blp	blpv
TE	1.0000				
TEv	0.7133	1.0000			
e	-0.9858	-0.7131	1.0000		
blp	0.9858	-0.7131	-1.0000	1.0000	
blpv	0.7311	0.9682	-0.7481	0.7481	1.0000

Table 7 summarizes all seven technical (in)efficiency measures estimated in this paper for the whole manufacturing sector in the years 1977 and 1982. It also presents corresponding estimates by Caves and Barton (1990) for the year 1977.

As Table 7 shows, the estimated technical (in)efficiency measures of this paper have a significant difference from those obtained by C-B. For total manufacturing C-B obtain an average technical inefficiency of 72%, 40%, 49%, and 6% on the basis of EFFv, EFFs, ATIv, and ATIs respectively. The corresponding numbers in this paper are 10% 2%, 3%, and 0.5% respectively. The relative values of the λ are not those expected. One would expect C-B estimates of λ to be much larger, most probably greater than one. However, they are 88% (v) and 53% (s). In this paper the corresponding numbers are 67% and 29%. This comparison shows C-B estimates non-consistent with each other. The technical inefficiency estimated on the basis of Battese and Coelli (1988), as well as the blp measure of Waldman (1984) are in agreement with EFF and ATI in this work. The actual numbers (calculated on the basis of table 7) are 8%, 2%, 7%, and 2% on the basis of TEv, TEs, blpv, and blps, respectively. An explanation of the observed difference between C-B and G estimates of technical inefficiency may be that the simple arithmetic mean that C-B used in order to get their average measures are not the proper indices to be used. For instance, the difference between the minimum and maximum values reaches the magnitude of 88% in some cases (Caves and Barton, 1990, Table 4.3, p.54).

TABLE 7

Technical (In)Efficiency Measures, All Manufactures, 1977 and 1982

1977		1982	Notation
EFF C-B v	0.2780		C-B Caves-Barton
EFF G v	0.9032	0.9048	G Georganta
EFF C-B s	0.6010		v Value added
EFF G s	0.9799	0.9699	s Shipments
ATI C-B v	0.4860		TE Formula (14)
ATI G v	0.0341	0.0295	e Formula
ATI C-B s	0.0570		blp Formula
ATI G s	0.0054	0.0073	
λ C-B v	0.8860		
λ G v	0.6748	0.5955	
λ C-B s	0.5300		
λ G s	0.2930	0.4648	
S C-B v	-0.1170		
S G v	-0.0532	-0.2202	
S C-B s	-0.0370		
S G s	-0.0052	-0.0195	
TE G v	0.9152	0.9144	
TE G s	0.9805	0.9720	
e G s	-0.2380	-0.2061	
blp G v	0.0720	0.0760	
blp G s	0.0188	0.0253	

In relation to the 1982 developments, one can observe that a slight increase in technical inefficiency has taken place between 1977 and 1982. In particular, technical inefficiency increased from 7% to 8% (mean of all-except for e-inefficiency measures) on the basis of value added, and from 1.6% to 2.5% on the basis of shipments, between the two years. Turning to the correlation matrixes, the TE, e, and blp are highly related. Also, EFF and ATI, and S and λ exhibit a high negative correlation. These results are as expected.

4. CONCLUDING REMARKS

This paper has measured technical (in)efficiency in the U.S. manufacturing sector at the four-digit SIC industry level, for two years, 1977 and 1982. The theoretical framework was the stochastic production frontier, and the functional form used was the translog formulation. The estimated technical (in)efficiency measures were obtained by utilizing the corrected OLS, COLS, methodology. The results show a low, 7% (1.6% if value added is used instead of shipments), technical inefficiency of the manufacturing industries on average. Technical inefficiency increases to 8% (2.5% if value added is used instead of shipments) between 1977 and 1982. These results differ significantly from the Caves and Barton (1990) estimates for 1977 at the establishment level. The difference may involve an index number problem.

The work of this paper has not considered price (in)efficiency. This aspect is under current research. Also under current research is the econometric investigation of the determining factors of technical (in)efficiency, and especially its relation to R&D and TFP growth rate, at both firm and industry level.

REFERENCES

Aigner, D. J., Lovell, K.C.A., and Schmidt, P. (1977). "Formulation and Estimation of Stochastic Frontier Production Function Models", Journal of Econometrics, 6,21-37.

Battese, G.E. (1992). "Frontier Production Functions and Technical Efficiency: A Survey of Empirical Applications in Agricultural Economics", Agricultural Economics, 7,185-208.

Battese, G.E., and Coelli, T. J (1988). "Prediction of Firm Level Technical Efficiency with a Generalized Frontier Production Function and Panel Data", Journal of Econometrics, 38, 387-399.

Bauer, P.W. (1990). "Recent Developments in the Econometric Estimation of Frontiers", Journal of Econometrics, 46, 39-56.

Caves, R. E., and Barton, D. R. (1990). Efficiency in U.S. Manufacturing Industries, Cambridge, MIT Press.

Christensen, L. R., Jorgenson, D. W., and Lau, L. J. (1973). "Transcendental Logarithmic Production Frontiers", Review of Economics and Statistics, 55, 28-45.

Farrell, M. J. (1957). "The Measurement of Productive Efficiency", Journal of the Royal Statistical Society, A, 120, 253-389.

Forsund, F. R., Lovell, K. C. A., and Schmidt, P. (1980). "A Survey of Frontier Production Functions and of their Relationship to Efficiency Measurement", Journal of Econometrics, 13, 5-25.

Gray, W. B. (1989). "Productivity Data Base", NBER internal document.

Greene, W. H. (1980). "Maximum Likelihood Estimation of Econometric Frontier Functions", Journal of Econometrics, 13, 27-56.

Griliches, Z., and Lichtenberg, F. (1984). "Interindustry Technology Flows and Productivity Growth: A Reexamination", Review of Economics and Statistics, 66, 324-329.

Jondrow, J., Lovel, K. C. A., Materov, I. S., and Schmidt, P. (1982). "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function", Journal of Econometrics, 19, 233-238.

Lee, L.F., and Tyler, W. G. (1978). "The Stochastic Frontier Production Function and Average Efficiency: An Empirical Analysis", Journal of Econometrics, 7, 385-389.

Leibenstein, H. (1966). "Allocative Efficiency vs "X-Inefficiency", American Economic Review, 56, 3, 392-415.

Meeusen, W., and Van Den Broeck, J. (1977). "Efficiency Estimation of Cobb-Douglas Production Functions with Composed Error", International Economic Review, 18, 435-444.

Olson, J.A., Schmidt, P., and Waldman, D. M. (1980). "A Monte Carlo Study of Estimators of Stochastic Frontier Production Functions", Journal of Econometrics, 13, 67-82.

Richmond, J. (1974). "Estimating the Efficiency of Production", International Economic Review, 15, 515-521.

Schmidt, P., and Lovell, K.C.A. (1979). "Estimating Technical and Allocative Inefficiency Relative to Stochastic Production and Cost Frontiers", Journal of Econometrics, 9, 343-366.

Seiford, L.M., and Thrall, R. (1990). "Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis", Journal of Econometrics, 46, 25-38.

Waldman, D.M. (1984). "Properties of Technical Efficiency Estimators in the Stochastic Frontier Model", 25, 353-364.

Weinstein, M. A. (1964). "The Sum of Values from a Normal and a Truncated Normal Distribution", Technometrics, 6, 104-105.

Yoo, S. M. (1992). "Technical Efficiency in Korea", in Caves, R. E. (ed.), Industrial Efficiency in Six Nations, Cambridge, MIT Press.

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