THE MEASUREMENT OF FARM-SPECIFIC TECHNICAL EFFICIENCY IN KYUNGKI-REGION MILK PRODUCTION: THE STOCHASTIC FRONTIER PRODUCTION FUNCTION APPROACH*

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I. Introduction

During the last decade dairy industry has grown into a relatively well-developed sector within Korean agricultural economy. Changes in the number of cows and dairy farms are two important indicators of the remarkable transformation underway in Korean dairy industry. Between 1975 and 1986 the number of cows increased 5 times from 85,500 to 437,300 heads and dairy farms 4.5 times from 9,400 to 42,700. The average number of cows of individual dairy farms has been around 10 heads during the period.

In the dairy development process Kyungki region around Seoul has been a center of Korean dairy industry. This area, as of 1986, accounts for more than 50 percent of the total industry volume in terms of the number of cows and dairy farms and the amount of milk production.

In recent, efficient and competitive dairy farming is one of the key issues in the context of dairy development. Making dairy industry efficient, first of all, requires the concrete understanding about a farm level performance. Knowledge of an individual farm performance is very useful for micro and macro policies because it can halp policy-makers to better select among alternative strategies which can reduce efficiency gap between individual dairy farms.

An important measure of such performance is relative economic efficiency, of which technical efficiency is a component. A number of different methodologies to measure technical efficiency have been proposed in the

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literature. Of these, the stochastic frontier production function model, first developed by Aigner, Lovell, and Schmidt(1977), has been widely applied and variously modified in many efficiency studies (Battese and Corra 1977, Lee and Tyler 1978, Stevenson 1980, Pitt and Lee 1982, Jondrow et al 1982, Kalirajan 1982, Bagi and Huang 1083, Kalirajan and Flinn 1983, Schmidt and Sickles 1984, Chiao 1985, Kalirajan and Shand 1986, Battese and Coelli 1988). Among these studies, Jondrow et al., Kalirajan and Flinn, Chiao, Kalirajan and Shand, and Battese and Colli used a similar method to estimate firm specific technical efficiency.

The issues addressed in this paper are (i)how well individual dairy farms are performing and (ii)whether there exists significant technical efficiency differential between the small, medium, and large dairy farms. To derive farm speficic technical efficiency indices and test the hypotheses are applied the stochastic frontier production function.

Ⅱ. The Stochastic Frontier Production Function

An important characteristic of the stochastic frontier production function is that the equation error term consists of two components. One is a symmetric component which permits randomness of the frontier across firms and thus captures the effects of measurement error, other statistical noise, and random shocks outside the firm's control. Another is a onesided error component that accounts for the effects of inefficiency relative to the stochastic frontier.

Following Aigner, Lovell and Schmidt(1977), we can write the stochastic frontier production function of the *i-th* firm as

$$(1) \qquad Q_i = f(X_i\,;\,B) + V_i - U_i$$

where Q_i = output of the *i-th* firm(i = 1, 2, 3 ⋯ ,n);
V_i = symmetric error;
U_i = nonnegative error;
X_i = a vector of inputs (1 × K);
B = a vector of parameters(K × 1).

The distributions of V_i and U_i are assumed to be

$$V_i \overset{iid}{\sim} N(0,\ \sigma_V^2),$$

$$U_i \overset{iid}{\sim} N(0,\ \sigma_u^2),\ \text{but}\quad U_i \geq 0\quad \text{for all}\quad i,$$

and

$E(U_i,\ V_j)$ = o(independent) for all i, j

If $\sigma_v^2 = 0$, this model collapses to a deterministic frontier model and if $\sigma_u^2 = 0$, it falls to the Zellner, Kmenta, and Drèze(1966) stochastic production model. Here,

$$Q_i \leq Q^* = f(X_i; B) + V_i$$

so that the frontier itself is clearly stochastic.

The economic logic behind this specification lies in the production function subject to two economically distinguishable error terms with different characteristics. The non-negative disturbance U_i implies that individual firm's output lies on or below its frontier. Since U_i is the firm specific technical inefficiency parameter, if the firm is technically efficient U_i takes the value zero and the firm obtains the maximum possible output Q_i^*, while, if inefficient, the firm's U_i takes the value greater than zero and thus the firm obtains its output $Q_i < Q_i^*$. The magnitude of the Ui value will vary among firms depending on factors under the firm's control. An important merit of this model is that the second moments of U_i and V_i can be estimated so as to get evidence on their relative size.

The technical efficiency indices of individual firms should be measured by the ratio

$$(2) \qquad Q_i / [f(X_i; B) + V_i]$$

rather than by the ratio

$$(3) \qquad Q_i / [f(X_i; B)]$$

This distinguishes technical efficiency from other sources of disturbances that are beyond the firm's control. For example a dairy farmer whose milk production is decimated by unexpected diseases is unlucky by the measure (2) but technically inefficient by the measure(3).

The measurement of U_i across farms is necessary for calculating the farm-specific technical efficiency and requires the computation of the conditional probability of U_i given $\varepsilon_i : h(Ui \mid \varepsilon_i)$. According to the conditional probability theory,

$$(4) \qquad h(U_i|\varepsilon_i) = \frac{h(U_i, \varepsilon_i)}{h_\varepsilon(\varepsilon_i)}$$

where $\varepsilon_i = V_i - U_i$. For convenience, the firm subscription i is left out. The joint probability density function of U and V is the product of their individual densities; since they are independent

$$(5) \qquad h(U, V) = \frac{1}{\Pi \sigma_u \sigma_v} \exp[-\frac{1}{2\sigma_u^2} U^2 - \frac{1}{2\sigma_v^2} V^2], \; U \geq 0$$

Because $\varepsilon = V - U$, the joint density of V and U is

$$(6) \qquad h(U, \varepsilon) = \frac{1}{\Pi \sigma_u \sigma_v} \exp[-\frac{1}{2\sigma_u^2} U^2 - \frac{1}{2\sigma_v^2} (U^2 + V^2 + 2U\varepsilon)]$$

The density function of ε is defined as follows:

(7) $$h_{\varepsilon}(\varepsilon) = \frac{2}{\sigma} g\left(\frac{\varepsilon}{\sigma}\right)\left[1 - G\left(\frac{\varepsilon\lambda}{\sigma}\right)\right], \quad |\varepsilon| \leq \infty$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \frac{\sigma_u}{\sigma_v}$ and $g(.)$ and $G(.)$ are the standard normal density and distribution function, respectively. The composite error term, ε, has an asymmetric distribution around zero with its mean and variance:

$$E(\varepsilon) = E(U) = -\sqrt{\frac{2\sigma_u^2}{\Pi}}$$

and

$$AR(\varepsilon) = VAR(U) + VAR(V)$$
$$= \left(\frac{\Pi - 2}{\Pi}\right)\sigma_u^2 + \sigma_v^2$$

Therefore, the conditional density function of U given ε is the ratio of the equations (6) and (7):

(10) $$h(U|\varepsilon) = \frac{1}{(1-G)\sqrt{2\Pi\sigma_*^2}} \exp\left[-\frac{1}{2\sigma_*^2}\left(U + \frac{\sigma_u^2\varepsilon}{\sigma^2}\right)^2\right], \quad U \geq 0$$

where $\sigma_* = \sigma_u \sigma_v / \alpha^2$. This conditional distribution can be used for deriving inferences about U. As a point estiomate of U, we can use the mean of its conditional distribution. The conditional expectation of U given ε is

(11) $$E(U|\varepsilon) = U_* + \sigma_* \frac{g(-U_*/\sigma_*)}{G(-U_*/\sigma_*)}$$

where $U_* = -\sigma_u^2 \varepsilon / \sigma^2$. Since $-U_* / \sigma_* = \frac{\varepsilon\lambda}{\sigma}$ and $\lambda = \sigma_u / \sigma_v$, the equation (10) can be rewritten by

(12) $$E(U|\varepsilon) = \sigma_*\left[\frac{g(\varepsilon\lambda/\sigma)}{1-G(\varepsilon\lambda/\sigma)} - \frac{\varepsilon\lambda}{\sigma}\right]$$

Note that the expression (12) is nonnegative and monotonic transformation in ε. Thus, the ranking of individual technical inefficiencies must be the same as that of the regression residuals.

Ⅲ. Sample Data

The production records were collected during the 1986 calendar year from the 80 dairy farms which participated in the dairy farm management improvement program in Kyungki region, called Seoul Quantity Quality Milk (SQQM) program. The SQQM program is a sort of integrated extension program which aims at enhancing dairy productivity and dairy farm income. The contents of the program include a variety of extension fields: feeding, disease prevention and treatment, cow performance test, and low quality cow culling problems.

This data set was already used in an economic analysis of feed utilization and dairy management in Kyungki regrion (Yoo et al. 1987). Since the detailed description of the sample data is in Yoo et al., this section describes only the variables employed in the study, which are the number of cows (N), concentrate (C), roughage (R), and Labor (L).

The entire sample is divided into three subsamples which are associated with farm sizes: S1($N \leq 5$), S2 ($5 < N \leq 15$), and S3 ($15 < N$). The summary statistics are presented in Table 1.

Availability of market, feed, labor, and higher quality cows with a genuine interest is essential factors for a person to consider in starting or maintaining a successful commercial dairy. The average number of cows of individual dairy farms in the SQQM program ranges from 2 to 21.3 heads with an average of 8.6 heads and the yearly average milk production per cow from 2,748 to 6,744. The entire amount of milk

TABLE 1 **Summary Statistics of the Variables**

		Mean	S.D.	CV(%)
Cow(heads)	(A)	8.6	4.4	50
	S1	3.8	1.0	26
	S2	8.7	2.7	31
	S3	16.7	1.8	10
Concentrate	(A)	3874.3	1090.0	28
(TDN kg /cow)	S1	3635.4	1230.0	34
	S2	3853.1	1044.3	27
	S3	4383.1	961.2	22
Roughage	(A)	1599.3	599.8	38
(TDN kg /cow)	S1	1842.6	561.2	30
	S2	1527.4	608.9	40
	S3	1505.7	556.9	40
Yield	(A)	5248.8	725.4	14
(kg /cow)	S1	4901.7	850.8	17
	S2	5323.7	679.8	13
	S3	5508.0	509.0	9
Fat Rate(%)	(A)	3.65	0.14	4
	S1	3.63	0.18	5
	S2	3.64	0.12	3
	S3	3.68	0.13	4

Note : "A"denotes the entire sample; S1 is for size 1; S2 is for size 2; S3 is for size 3.

produced is sold to Seoul Milk Cooperatives. Fat rate is a major price determinant.

In addition to cow numbers and quality, feed is one of the important milk production inputs. Due consideration should be given to the availability of concentrates and roughages and their proper combination. Since Korean climatological and geographical conditions have severely limited a pasture — based dairy development, concentrate feed has been of relative importance. The average per cow intakes of the feeds in terms of total digestible nutrients (TDN) are 3,874 and 1,599, repectively. The ratio of the two is 2.4 which is much higher than the generally recommended ratio (1.5).

If feed conditions are favorable, labor is the next most important item to consider. Most successful dairy men prefer to have more than one man could handle and hire additional help if family labor is limited. About 30 percent of the sample farms used hired labor. The labor input records imply that family labor plays a crucial role in dairy farming even in the main suburban area.

Ⅳ. Empirical Model Specification, Estimation and Results

1. Model Specification and Estimation Method

The first problem encountered with specification of production model is choice of functional forms. It is most desirable to choose a simple, flexible functional form which meet the economically reasonable restrictions and does not present unreasonably complex estimation problems (Fuss, Mcfadden, and Mundlak 1978). In practice, these requirements are difficult to fulfill.

Since interest in this ressatch centers on efficiency measurement and not an analysis of the general structure of the underlying production technology, a Cobb-Douglas (C-D) specification can provide an appropriate representation of milk production technology. The C-D frontier milk production function is given by

$$\begin{aligned} \ln Q_i = \ln I + B_1 \ln(N_i) &+ B_2 \ln(C_i) \\ &+ B_3 \ln(R_i) \\ &+ B_4 \ln(L_i) \\ &+ (V_i - U_i) \end{aligned}$$

where Q_i denotes milk production, N_i is the number of cows, C_i is concentrate, R_i is roughage, L_i is labor, and V_i and U_i are error terms. Note that $U_i > 0$ and $V \gtreqless 0$

The estimation of the model requires forming the relevant log —

liklihood function,

$$(14)\quad \ln L(Q|B,\lambda,\sigma^2) = n\ln\sqrt{\frac{2}{\pi}} + n\ln\frac{1}{\sigma} + \sum_{i=1}^{n}\ln\left[1-G\left(\frac{\varepsilon_i\lambda}{\sigma}\right)\right] - \frac{1}{\sigma^2}\sum_{i=1}^{n}\varepsilon_i^2$$

Taking partial derivatives with respect to B, λ, and σ^2, we can obtain the following three equations:

$$(15)\quad \partial\ln L/\partial\beta = \frac{1}{\sigma^2}\sum_{i=1}^{n}(Q_i - X_i\hat{\beta}) + \frac{\lambda}{\sigma}\sum_{i=1}^{n}\frac{g_i}{(1-G_i)}X_i = 0$$

$$(16)\quad \partial\ln L/\partial\lambda = -\frac{1}{\sigma}\sum_{i=1}^{n}\frac{g_i}{(1-G_i)}(Q_i - X_i\hat{\beta}_i)X_i = 0$$

$$(17)\quad \partial\ln L/\partial\sigma^2 = -\frac{n}{\sigma^2} + \frac{1}{2\sigma^4}\sum_{i=1}^{n}(Q_i - X_i\hat{\beta})^2 + \frac{\lambda}{2\sigma^3}\sum_{i=1}^{n}\frac{g_i}{(1-G_i)}(Q_i - X_i\hat{\beta}) = 0$$

The equations (15), (16), and (17) should be solved simultaneously for obtaining the usual maximum liklihood properties of the estimates of B, λ, and σ^2. Since, however, the parameter estimation involves nonlinearity problem, an appropriate optimization technique should be applied. In this reseasch the Fletcher Powell David(F/P/D) algorithm is used for estimating the frontier milk production function given in equation (13).

The F/P/D method has a desirable property that, for a quadratic objective function, it simultaneously generates the directions of the conjugate gradient method while constructing the inverse Hession. At each step the inverse Hession is updated by sum of two symmetric rank one matrices without explicitly using the second derivaties (Luenberger 1977, Maddala 1977). At present the F/P/D algorithm is available on the LIMDEP software written by W. Green (1986).

Based on the parameter estimates, the technical inefficiency indices were computed by equation (12) and those of technical efficiency by $[1-E(U|\varepsilon)]$. The technical efficiency(TE) comparisons between the farm sizes are made by the analysis of variance:

$$TE = \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3$$

where α_i = coefficient (i=1, 2, 3);
D_1 = 1 for $S1$, otherwise 0;
D_2 = 1 for $S2$, otherwise 0;
D_3 = 1 for $S3$, otherwise 0.

The separate null hypotheses of $\alpha_1 - \alpha_2 = 0$, $\alpha_1 - \alpha_3 = 0$, and $\alpha_2 - \alpha_3 = 0$ are made and tested to see whether there exist significant differences in the average technical efficiencies between the three different farm sizes.

2. Empirical Results

The parameter estimates of the stochastic frontier milk production function were obtained by the F/P/D algorithm with the convergence criteria: gradient = 0.0001, function = 0.000001, and parameters = 0.0001. The convergence was achieved at iteration 12. The liklihood ratio – test statistic is found to be 50.744 which is significant at the 1 percent level. An important result (Table 2) is that the two standard deviation ratio estimate $\hat{\lambda}$ is relatively large and is statistically significant at the 5 percent level.

TABLE 2 **Model Parameter Estimates**

Input	OLS	Frontier
Constant	6.8354	6.7781
	(0.7502)	(0.8777)
N	0.8984	0.8205
	(0.0825) ***	(0.0993) ***
C	0.1143	0.1335
	(0.0589) **	(0.0595)***
R	0.0287	0.0228
	(0.0473)	(0.0127) **
L	0.0553	0.0820
	(0.0796)	(0.0501) **
Lambda(λ)		3.7909
		(2.0420) **
Sigma (σ)		0.2142
Log likelihood	45.9380***	50.7440****

Notes: * Significant at the 10 percent level.
** Significant at the 5 percent level.
*** Significant at the 1 percent level.
Figures in ( ) are asymptotic standard errors.

This means that about 68 percent of the difference between the realized output and the maximum production frontier output is caused by differences in dairy farmers'/levels of technical inefficiency against the conventional random variability.

Except for the labor coefficient, all the model parameter estimates by the F/P/D method are greater in their magnitudes and more significant in t values than the OLS estimates. The signs of the estimates all are positive and consistent with economic theories.

The farm specific technical efficiency indices were computed by the formula $[1 - E(U \mid \epsilon)]$. The results (Appendix 1) show large variation in technical efficiencies between the individual dairy farms. The rating range from 0.32 to 0.95 with the mean 0.7995.

No dairy farms in the sample operated below TE 0.3. About 85 percent farms with TE higher than 0.7 demonstrated fairly good performance. Only ten samples were close to the frontier (Table 3).

TABLE 3 **Frequency Distribution of TE for Individual Dairy Farms**

Efficiency Interval	Number of farms
0.0 – 0.3	0
0.3 – 0.4	1
0.4 0.5	0
0.5 – 0.6	2
0.6 – 0.7	9
0.7 – 0.8	19
0.8 – 0.9	29
0.9 – 1.0	10
Total	80

The analysis of variance results(Table 4) indicate that there are significant differentials in the mean TE's between S1 and S2 and between S1 and S3 but no defference between S2 and S3.

TABLE 4 **Anova Results**

Variable	Coefficient	t Ratio	F–value
D1	0.7550	31.8878***	
D2	0.8121	55.6391***	
D3	0.8190	26.3176***	
HP1 : $\alpha_1 - \alpha_2 = 0$			4.2103***
HP2 : $\alpha_1 - \alpha_3 = 0$			2.6737**
HP3 : $\alpha_2 - \alpha_3 = 0$			0.0399

Notes: * Significant at the 10 percent level.
** Significant at the 5 percent level.
*** Significant at the 1 percent level.

This implies that the larger the farm size, the closer the output to the frontier.

V. Summary and Conclusions

Under the similar environmental and market conditions, milk production appears to vary across individual dairy farms. From a policy point of view, comparions of actual individual production estimates with those of their best practice production provide useful insights into the farm level production technology(Kalirajan and Shand 1986).

The objective of this study is (i) to investigate farm level technical performance in Kyungki region milk production and (ii) to examine whether there exists significant difference in technical efficiency between the farm sizes. The milk production records are the cross sectional data collected during the 1986 production year from the 80 dairy farms which took part in the Seoul Quantity Quality Milk Program of Seoul Milk Cooperatives.

For the purpose, this study employed the stochastic frontier production function approach. The assumptions about the structure and distribution of the error terms, U and V, are very important in the stochastic frontier model. The variable V allows the frontier itself to be stochastic and sets the maximum output level for a given set of production inputs. The independence of U and V is crucial in this analysis. In particular, the nonnegativity assumption of U provides a way to measure technical inefficiencies across dairy farms and the relative ratio of the two variances, $\hat{\lambda}$. The variance ratio helps to test whether ϵ has an asymmetric distribution and thus to choose appropriate estimation techniques.

The sample data reflected a positively shewed distribution at the 5 percent significance level. Thus, the model parameter estimates were made by a nonlinear optimizaion technique: the Flechter Powell David algorithm. The function was converged at iteration 12. The empirical results show that the technical efficiency indices range from 0.32 to 0.95 with the mean 0.7995. This suggests that there remains a large room for increasing production levels of lower efficient dairy farms. It can be noted that the farms with more than 15 cows showed the highest technical efficiency on the average.

This result may make some contribution to helping to consider (or determine) the optimal size of dairy farms. Future research should pursue clear explanation about the determinants of farm level technical efficiency.

APPENDIX 1 **Technical Efficiency Indices (TE) and Regression Residuals(RS)**

Farm I.D.	Ranking	TE	RS	Farm I.D.	Ranking	TE	RS
43	1	0.95309	0.06634	41	41	0.81899	-0.14328
40	2	0.94595	0.054639	13	42	0.81347	-0.15134
53	3	0.94233	0.048718	8	43	0.81085	-0.15515
12	4	0.93398	0.03512	46	44	0.80873	-0.15822
45	5	0.92769	0.024931	25	45	0.80681	-0.16099
47	6	0.9262	0.022514	7	46	0.8028	-0.16676
58	7	0.91761	0.008683	29	47	0.80218	-0.16765
78	8	0.90345	-0.01395	10	48	0.80181	-0.16819
76	9	0.90336	-0.0141	68	49	0.8053	-0.16891
23	10	0.90053	-0.01859	20	50	0.79682	-0.17532
71	11	0.89697	-0.02423	21	51	0.78235	-0.19572
32	12	0.89057	-0.03433	62	52	0.7793	-0.20002
74	13	0.8897	-0.0357	27	53	0.77707	-0.20313
49	14	0.88871	-0.03726	5	54	0.77691	-0.20336
70	15	0.8861	-0.04135	18	55	0.77625	-0.20427
60	16	0.878	-0.05401	79	56	0.77487	-0.20619
67	17	0.8761	-0.05698	1	57	0.77454	-0.20664
37	18	0.86786	-0.06973	31	58	0.77295	-0.20884
38	19	0.86232	-0.07826	30	59	0.7686	-0.21484
14	20	0.86218	-0.07847	24	60	0.7666	-0.21757
33	21	0.86045	-0.08111	73	61	0.75103	-0.2387
66	22	0.8603	-0.08135	2	62	0.74585	-0.24569
26	23	0.85927	-0.08292	80	63	0.74153	-0.25138
77	24	0.85915	-0.08311	75	64	0.73827	-0.25569
64	25	0.85639	-0.08732	39	65	0.72166	-0.27738
42	26	0.85577	-0.08828	28	66	0.72056	-0.2788
.34	27	0.8544	-0.09037	36	67	0.70941	-0.29307
52	28	0.85314	-0.09377	19	68	0.70685	-0.29632
6	29	0.85147	-0.09481	15	69	0.69644	-0.30941
63	30	0.85003	-0.09699	56	70	0.67656	-0.33395
65	31	0.84934	-0.09805	50	71	0.66813	-0.34419
48	32	0.84817	-0.09982	55	72	0.66572	-0.3471
35	33	0.8476	-0.10069	3	73	0.66101	-0.35277
4	34	0.84158	-0.10975	11	74	0.64969	-0.36625
69	35	0.83525	-0.11924	16	75	0.6333	-0.38551
54	36	0.83524	-0.11925	61	76	0.63255	-0.38638
57	37	0.83347	-0.12189	9	77	0.61805	-0.40315
72	38	0.83321	-0.12226	17	78	0.59661	-0.4276
44	39	0.82834	-0.12951	22	79	0.50119	-0.53284
51	40	0.8258	-0.13326	59	80	0.32478	-0.7222

REFERENCES

Aigner, D.J., C.A. Lovell and P. Schmidt, 1977, "Formulation and Estimation of Stochastic Frontier Production Function Models," *Journal of Econometics* 6, 21 − 37.

Bagi, F.S. and C.J. Huang, 1983, "Estimating Production Technical Efficiency for Individual Farms in Tennesses," *Canadian Journal of Agricultural Economics*

31, 249 — 256.

Battese, G.E. and G.S. Corra, 1977, "Estimation of a Production Frontier Model with Applicaiton to the Pastoral Zone of Eastern Australia," *Australian Journal of Agricultural Economics* 21, 169 — 179.

Battese, G.E. and Tim J. Coelli, 1988, "Prediction of Firm - Specific Technical Efficiencies with a Generalized Frontier Production Function and Panel Data," *Journal of Econometrics* 38, 387 — 399.

Chiao, Yen Shong, 1985, Frontier Production Function Approaches for Measuring Efficiency of Egyptian farmers, Ph.D. dissertation, University of California at Davis.

Fuss, M. and D. Mcfadden, and Y. Mundlak, 1978, A Survey of Functional Forms in the Economic Analysis of Production (in *Production economics: A dual approach to theory and application* ed, By Fuss and Mcfadden), North Holland.

Green, W., 1986, *LIMDEP*, Graduate School of Business Administration, New York University.

Jondrow, J., C.A.K. Lovell, I.S. Materov and P. Schmidt, 1982, "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model," *Journal of Econometircs* 19, 233 — 238

Kalirajan,K., 1982, "On Measuring Yield Potential of the High Yielding Varieties Technology at the Farm Level," *Journal of Agricultural Economics* 33, 227 235.

Kalirajan,K. and J.C. Flinn, 1983, "The Measurement of Farm Specific Technical Efficiency," *Pakistan Journal of Applied Economics* 2, 167 — 180.

Kalirajan,K. and R.T.Shand, 1986, "Estiamting Location - Specific and Firm - Specific Technical Efficiency: An Analysis of Malaysian Agriculture," *Journal of Economic Development* 11, 147 — 160.

Luenberger,D.G., 1977, *Introduction to Linear and Nonlinear Programming*, Addison Wesley publishing Co.

Maddala, G.S., 1977, *Econometrics*, McGraw Hill Book Co.

Pitt, M.M. and L.F.Lee, 1981, "Measurement and Sources of Technical Inefficiency in the Indonesian Weaving Industry," *Journal of Development Economics* 9, 43 — 64.

Schmidt, P. and R.C. Sickles, 1984, "Production Frontiers and Panel Data," *Journal of Business and Economic Statistics* 2, 367 — 374.

Stevenson, R.E., 1980, "Liklihood Functions for Generlized Stochastic Frontier Estimation," *Journal of Econometrics* 13, 57 — 66.

Yoo, Chul H., 1987, *A Study on Dairy Feed Utilization and Management Improvement*, Report 146, Korea Rural Econ. Inst.

Zellner, A., J. Kmenta, and J.Dreze, "Specification and Estimation of Cobb - Dougeas Production Function Models," Econometrica, 34, 784 - 795