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TIME VARYING TECHNICAL EFFICIENCY, EVIDENCES FROM RAINFED RICE AREAS OF THE PHILIPPINES

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A linearised version of the Cobb-Douglas stochastic frontier production function with time-varying technical efficiencies is estimated. The panel data (1990-1995) collected by the International Rice Research Institute (IRRI) from paddy farmers in the rainfed rice ecosystem of Tarlac, Philippines is used. Firm effects are assumed to be an exponential function of time. The result of the hypothesis testing indicated that significant inefficiency exists in the panel data. Empirical analysis demonstrated that paddy farms in the rainfed rice ecosystem of the Philippines have time-variant technical efficiency and this conclusion is along the lines of earlier findings in the literature. The results also depicted that technological change is not accounting for improvement in technical efficiencies which contradicts the earlier findings. Hence, empirical findings are area specific and cannot be generalised for all ecosystems and regions. On average, technical efficiency estimates improved from 80 per cent in 1990 to 91 per cent in 1995, implying that further potential that can be explored exists.

I. Introduction

Rice is the lifeblood of Asia. The world's rice production is 650 million tonnes and Asia as a whole contributed more than 90 per cent in total rice production during the year 2007, [IRRI (2009)]. Substantial increase in demand for rice over the next few decades is expected to arise because of increasing population. In the next two decades, the area under rice is expected to decline sharply due to rapid industrialisation and increase in population pressure. To mitigate the effect of reduction in the area of rice cultivation, yield has to increase faster to achieve the targeted increase in rice demand. The yield of rice in rainfed areas can be in-

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creased through the introduction of high yielding varieties that require high inputs, and by improving resource use efficiency (i.e., technical efficiency of existing technologies).

The green revolution has had very little impact on unfavourable areas such as the rainfed lowlands and uplands. Quite a large number of people depend on these ecosystems for food security. However, yield-enhancing technologies for these environments are not yet available, [Pandey (1996)]. Developing varieties and associated crop management technologies for the more difficult environments is becoming an increasingly important area of future rice research. Barker et al. (1985) found that the research in rainfed lowland rice would produce higher rates of return than research in irrigated rice for countries with dominant rainfed lowland rice culture. Because of this ecosystem's high potential Hossain (1994) proposed to change the focus of rice research from the irrigated to the rainfed ecosystem.

The resources of production in developing countries are limited and competing demand for these scarce resources is high. Economic inefficiency in these economies is assumed to be a major source of low yield. The efficient use of inputs in the production system leads to an improvement in profitability and therefore, it is considered to be an important area to contribute to. Economic inefficiency consists of technical and allocative inefficiency but empirical evidence shows that technical inefficiency is dominant and contributes a major share to economic inefficiency [Herdt and Mandac (1981), Ali and Flinn (1989), Kalirajan (1985)]. Therefore, the present study concentrates only on technical inefficiency.

Overtime, improvement in technology and efficiency in rice production take place together but erroneously technological change can be referred to improvement in technical efficiency and this can generate wrong signals to policy managers. The contribution of each component needs to be identified because both can alternatively stand for each other. The present study employs six year panel data of paddy farms from the Philippines. The main objective is to investigate time-varying efficiencies of paddy farmers and to quantify the role of technological change and technical efficiency in the rain-fed rice ecosystem.

The paper is organised as follows. The next section (Section II) delineates the analytical and empirical framework. Section III provides a brief description of the data set. Empirical results are presented in Section IV and conclusions are drawn in Section V.

II. Analytical and Empirical Framework

a) Analytical Framework

Time-varying efficiency models for firm effects have been proposed by Cornwell, Schmidt and Sickles (1990), Kumbhakar (1990), Lee and Schmidt (1993), and Battese and Coelli (1992). Stochastic frontier production function with exponential specification of time-varying firm effects as presented in Battese and Coelli (1992), is employed and it is discussed briefly below:

$$Y_{it} = f(X_{it}; \beta) exp(V_{it} - U_{it}) \tag{1}$$

where Y_{it} stands for production or yield for the *i*th firm in the *t*th period of observation; $f(X_{it}; \beta)$ is a type of production function and it can be Cobb-Douglas or Translog etc; X_{it} is a vector of inputs for the *i*th firm in the *t*th period of observation and β is a vector of unknown parameters; the V_{it}'s represents the random shocks (random error) in output due to factors which are out of control of the farm operator (weather, topography, error of observations and measurement) and are assumed to be independent and identically distributed $N(N, \sigma^2_v)$ and independent of the U_{it}; the U_{it}'s are non-negative which account for technical inefficiency in the production process due to factors that are under the control of farm operators and assumed to be independent and non-negative truncations of the $N(\mu, \sigma^2_u)$.

Cornwell, Schmidt and Sickles (1990) assumed that the firm effects were a quadratic function of time, in which the coefficients varied over firms according to the specification of a multivariate distribution. Lee and Schmidt (1993) specified the technical inefficiency effects for firms in different time periods as the product of individual firm and time effects. Kumbhakar (1990) offered a more general but considerably more difficult model to estimate time varying efficiency. The models proposed by Cornwell, Schmidt and Sickles (1990), and Lee and Schmidt (1993) are more flexible than the Kumbhakar (1990) and Battese and Coelli (1992) models, but this comes with the cost of having many more parameters to estimate [Coelli, Prasad and Battese (1998)]. We adopted a very simple exponential time varying efficiency model presented by Battese and Coelli (1992), as discussed below:

$$U_{it} = U_i \eta_t = \{U_{it} \, exp[\eta(t-T)]\}, \qquad i=1,2,....N; \; t=1,....T \tag{2}$$

where, η is an unknown parameter to be estimated. In the model presented above non-negative technical inefficiencies effects, U_{it} decreases, remains constant or increases as "t" increases, if $\eta > 0$, $\eta = 0$, $\eta < 0$, respectively.

We followed the representation of Battese and Corra (1977), who replaced σ^2_v and σ^2_u with $\sigma^2 = \sigma^2_v + \sigma^2_u$ and $\gamma = \sigma^2_u / \sigma^2$.

Technical efficiency has been described in different ways [Fare, Grosskopf and Lovell (1985])] but we consider the definition of Battese and Coelli (1988), where the technical efficiency of a given firm (at a given time period) is the ratio of its mean production (conditional on its levels of factors inputs and firm effects) to the corresponding mean production if the firm utilised its levels of inputs most efficiently. It can be written in mathematical form as it is described by Hadri and Whitaker (1999):

$$TE_i = E(\dot{Y}_i | U_i, X_i)/E(\dot{Y}_i | U_i = 0, X_i) = exp(-U_i) \tag{3}$$

where $\dot{Y}_i\, exp(Y_i)$; and the value of technical efficiency (TE_i) will remain between zero and one; value near to one indicates a high level of efficiency while near zero reflects a high level of inefficiency. The mean technical efficiency of firms at the *t*th time period is estimated as:

$$TE_t = E[exp(-\eta_t U_t)], \qquad \text{where } \eta_t = exp[-\eta(t-T)]$$

b) Empirical Model

In order to select the best specification of the production function we conducted tests of the hypotheses for the parameters of the frontier model by using the generalised likelihood-ratio statistic "LR" defined by:

$$LR = -2\ln\ [L(H_0)\ /\ L(H_1)] \tag{4}$$

where, $L(H_0)$ is the value of the likelihood function for the frontier model, in which the parameter restrictions specified by the null hypothesis, $H_0 = \beta_{ji}$, are imposed; and $L(H_1)$ is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then "LR" has approximately a chi-square (or mixed chi-square) distribution with degrees of freedom equal to the difference between the number of parameters estimated under H_1 and H_0, respectively. We use the Cobb-Douglas (CD) and the translog production function and on the basis of the test statistic we discovered that CD is the best fit to our data set. These conclusions developed from our null hypothesis which assumes that the values for the coefficient of interaction terms and square terms is zero, is accepted. On the basis of this test statistic we selected the Cobb-Douglas production function for empirical analysis. Further, it is rational to present evidence that functional form of CD has been widely used in farm efficiency analysis. Kebede (2001) and Bravo-Ureta and Pinheiro (1997) employed the similar functional form. Further, the statement can be supported by the empirical literature reviewed in Battese (1993) and in Bravo-Ureta and Pinheiro (1993). The empirical literature is also accumulating showing that the choice of the production function does not affect the efficiency slevel.[1]

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[1] Different students conclude that choice of functional might not have a significant impact on measured of efficiency level [Good et al. (1993), Ahmad and Bravo-Ureta (1996), Wadud (1999), Villano (2005)].

Battese and Coelli (1992), and Hadri and Whittaker (1999) also employed a Cobb-Douglas type of production function to estimate time-varying technical efficiency. The stochastic production frontier for paddy farmers is empirically estimated by using the maximum likelihood estimation technique:

$$Lny_{it} = Ln\beta_0 + \sum_{j=1}^{5} \beta_j Lnx_{ijt} + V_{it} - U_{it} \tag{5}$$

where,

y_{it} = yield of rice of the i-th farm in t-th period in kg/hectare, β_0 is the intercept and β_j's are response parameters and also production elasticities for respective inputs,

x_1 = seed in kg/hectare,

x_2 = family and hired labour used for all activities except for harvest in days/hectare,

x_3 = fertiliser in kg of NPK nutrients/hectare,

x_4 = the real cost of weedicide in Pesos/hectare, estimated as the actual cost divided by the consumer price index (with a base year of 1990),

x_5 = the real cost of insecticide in Pesos/hectare, estimated as the actual cost divided by the consumer price index (with a base year of 1990),

V_{it} = a disturbance term due to random shocks with normal properties explained above, and

U_{it} = farm specific error term as defined in equation (2).

The models are estimated on per hectare basis by employing Frontier Version 4.1 developed by Coelli (1994). In contrast to Battese and Coelli (1992), and Hadri and Whittaker (1999) we estimated the production function on per hectare basis. There are two reasons to estimate on a per hectare basis: first, it is intuitively simpler to directly interpret efficiency on a per unit area as opposed to per plot basis; second, farm size is collinear with other variables included in the model.

III. Data Description

The study uses pooled time-series and cross-section survey data for six years (1990-95) from Tarlac, Central Luzon, the Philippines. The agricultural sector is dominant in the economy of Tarlac. Rice is the main crop planted during the wet season, accounting for almost 90 per cent of the total cropped area. The average rice yield for six years was 3.08 tonnes per hectare (Table 1). Monitoring of the rice production practises of 46 randomly selected farmers in the municipality of Victoria began in 1990. Farm records were developed to record data on farm operations by parcel. A team of researchers visited the study area twice a year to interview the farmers. The panel data from 46 paddy farmers located in the rainfed rice ecosystem were collected by the International Rice Research Institute (IRRI), the Philippines. Different parcels of each farmer were located in the same topographic conditions and we added their inputs and outputs to convert the parcel level data into farm level data, because parcels operating under the same management cannot have different technical efficiency. Therefore, it is rational and logical to convert the parcel level data to farm level in order to estimate farm level technical efficiency. If a farmer did not plant any parcel for more than two consecutive years it was decided to exclude him from the data set. Within six years three farmers left farming and became involved in livestock or in some other business. Finally we selected a balance panel of 37 farmers (37*6=222 observations) for analysis purposes to estimate the time-varying technical efficiency model. Further details of the survey design can be found in Pandey et al. (1999) and Villano et al. (2004). The means and the coefficients of variation (CV) of output and input variables are reported in Table 1.

IV. Results and Discussion

The Cobb-Douglas stochastic frontier model defined in equation (5) is estimated with four additional parameters associated with the distribution of the V_{it} and U_{it}-random variables by employing a computer programme, Frontier 4.1 developed by Coelli, (1994). Following Battese and Coelli, (1992), the maximum-likelihood

TABLE 1

Summary of Variables Included in the Stochastic Frontier Production Function

Years	Yield (kg)	Seed (kg)	Labour (days)	NPK (kg)	Cost of Weedicide (pesos)	Cost of Insecticide (pesos)
1990	3051.91	110.49	55.44	75.88	19.55	123.30
1991	2958.66	108.69	50.12	80.90	33.59	87.49
1992	3464.22	104.90	51.04	92.16	111.83	109.92
1993	2930.86	95.79	53.39	75.23	99.74	55.62
1994	2915.76	108.12	45.04	82.99	131.28	39.04
1995	3183.67	109.94	52.32	95.32	162.36	21.41
Mean	*3084.18*	*106.32*	*51.23*	*83.75*	*93.06*	*72.80*
*CV**	*33.17*	*39.73*	*26.81*	*44.35*	*119.24*	*152.96*

*The coefficient of variation (CV) in percentage terms = CV = (standard deviation/mean)*100.

estimates of equation (5) are obtained by imposing different assumptions on distributions of random variables and the detail of these assumptions is as given below;

Model 1-1	It involves all parameters being estimated;
Model 1-2	It assumes that $\mu = 0$;
Model 1-3	It assumes that $\eta = 0$;
Model 1-4	It assumes that $\mu = \eta = 0$;
Model 1-5	It assumes that $\gamma = \mu = \eta = 0$.

Model 1-1 is the stochastic frontier production function with time-varying farm effects as described in equation (4), where farm affects, U_{it} have the time-varying structure as discussed in the analytical section above. Model 1-2 is the special case of model 1-1 in which the U_i's have half-normal distribution (i.e., μ is assumed to be zero). Model 1-3 is the time-invariant model as it is considered by Battese, Coelli, and Colby (1989). Model 1-4 is the time-invariant in which the farm effects, $U_{i,}$ have half-normal distribution. Finally, model 1-5 estimates average response function under the assumption that farmers are fully technically efficient (i.e., the farm effects, U_{it}, are absent from the model). The empirical results of these five models are presented in Table 2.

The sign of all variables are according to our expectations. Labour and fertiliser are highly significant in all five models. The cost of weedicide and insecticide are also significant in all five models but the level of significance varies across models. Various tests of the hypotheses as represented in Table 3 involving the parameters of the distribution of the U_{it}-random variables (farm affects) are obtained by using the generalised likelihood ratio statistic. Each hypothesis considers different distributional assumptions and the corresponding statistic is reported in Table 3. Comparing the results of Model 1-1 and 1-5 and the results of the log likelihood ratio test indicates that the null hypothesis H_0: $\gamma = \mu = \eta = 0$ is rejected. It is evident that given the specification of the stochastic frontier with time-varying efficiency (Model 1-1), the traditional average response function (Model 1-5) is not an adequate representation of the data. This is an indication that technical inefficiency exists in our data set. We also tested the hypothesis of time-invariant efficiency of farms under different distributional assumptions of the random variable U_{it}. By applying the log likelihood ratio test on Model 1-1 and Model 1-3, 1-4, the null hypothesis $H_0: \eta = 0$ and $H_0: \mu = \eta = 0$, are rejected. This implies that technical inefficiency is not time invariant, rather it varies over time.

The hypothesis ($H_0: \mu = 0$) that the half normal distribution is an adequate representation for the distribution of the farm affects is not rejected. Under the assumption that half normal distribution exists, again time-invariant efficiency tested (given $\mu = 0$ and $H_0: \eta = 0$) and the null hypothesis that farm affects are time-invariant is rejected.

TABLE 2

Maximum Likelihood Estimates for Parameters of Stochastic Frontier Production Functions

		MLE Estimates for Models				
Variables	Para-meters	Model 1-1	Model 1-2	Model 1-3	Model 1-4	Model 1-5
Constant	β_0	5.60***	6.03***	6.03***	5.89***	5.37***
		(0.37)[1]	(0.37)	(0.43)	(0.39)	(0.33)
Ln (seed)	β_1	0.0^{ns}	0.00^{ns}	-0.03^{ns}	-0.02^{ns}	-0.02^{ns}
		(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Ln (labour)	β_2	0.50***	0.50***	0.46***	0.46***	0.52***
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Ln (NPK)	β_3	0.10***	0.10***	0.10***	0.11***	0.13***
		(0.04)	(0.04)	(0.04)	(0.04)	(0.05) Ln
(cost of weedicide)	β_4	0.01*	0.01*	0.03***	0.02***	0.03***
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Ln (cost of insecticide)	β_5	0.02***	0.02***	0.01*	0.01*	0.01*
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
	σ^2	0.14**	0.10***	0.11***	0.14***	0.10***
		(0.09)	(0.02)	(0.02)	(0.02)	(0.02)
	γ	0.46*	0.25***	0.28***	0.43***	
		(0.38)	(0.13)	(0.15)	(0.11)	
	μ	-0.50ns		0.23*		
		(1.09)		(0.22)		
	η	0.19***	0.16***			
		(0.07)	(0.06)			
Log likelihood		-43.70	-44.01	-47.71	-47.92	-56.24

[1] Numbers in parentheses are asymptotic standard errors.

***Significant at 1 per cent. **Significant at 5 per cent. * Significant at 10 per cent.

TABLE 3

Test of Hypothesis for Parameters
of Distribution of the Farm Affects U_{it}

Assumptions	Null hypothesis H_0	χ^2-statistic	χ^2_{095} -valye	Degree of Freedom	Decision
Model 1-5	$\gamma=\mu=\eta=0$	25.08	7.81	3	Reject H_0
Model 1-4	$\mu=\eta=0$	8.44	5.99	2	Reject H_0
Model 1-2	$\mu=0$	0.62	3.84	1	Accept H_0
Model 1-3	$\eta=0$	8.02	3.84	1	Reject H_0
Model 1-2 ($\mu=0$)	$\gamma=\eta=0$	24.46	5.99	2	Reject H_0
Model 1-3 ($\mu=0$)	$\eta=0$	7.81	3.84	1	Reject H_0

TABLE 4

Predicted Technical Efficiency of Paddy Farmers in
Rainfed Rice Areas of Tarlac, Philippines

Farmers	1990	1991	1992	1993	1994	1995
1	0.77	0.80	0.83	0.86	0.88	0.90
2	0.91	0.92	0.93	0.94	0.95	0.96
3	0.77	0.81	0.84	0.86	0.89	0.91
4	0.83	0.85	0.88	0.90	0.91	0.93
5	0.90	0.92	0.93	0.94	0.95	0.96
6	0.78	0.81	0.84	0.87	0.89	0.91
7	0.94	0.95	0.96	0.96	0.97	0.97
8	0.86	0.88	0.90	0.92	0.93	0.94
9	0.87	0.89	0.91	0.92	0.94	0.95
10	0.74	0.78	0.82	0.84	0.87	0.89

(contined)

TABLE 4
(continued)

Predicted Technical Efficiency of Paddy Farmers in Rainfed Rice Areas of Tarlac, Philippines

Farmers	1990	1991	1992	1993	1994	1995
11	0.77	0.81	0.84	0.86	0.89	0.90
12	0.78	0.81	0.84	0.87	0.89	0.91
13	0.86	0.88	0.90	0.92	0.93	0.94
14	0.76	0.79	0.82	0.85	0.88	0.90
15	0.91	0.93	0.94	0.95	0.96	0.96
16	0.89	0.91	0.92	0.94	0.95	0.96
17	0.94	0.95	0.96	0.97	0.97	0.98
18	0.71	0.75	0.79	0.82	0.85	0.88
19	0.89	0.91	0.92	0.94	0.95	0.96
20	0.68	0.72	0.76	0.80	0.83	0.86
21	0.82	0.85	0.87	0.89	0.91	0.92
22	0.91	0.92	0.93	0.95	0.95	0.96
23	0.78	0.81	0.84	0.87	0.89	0.91
24	0.94	0.95	0.96	0.97	0.97	0.98
25	0.92	0.94	0.95	0.96	0.96	0.97
26	0.81	0.84	0.86	0.88	0.90	0.92
27	0.94	0.95	0.96	0.96	0.97	0.97
28	0.42	0.48	0.55	0.61	0.66	0.71
29	0.83	0.86	0.88	0.90	0.92	0.93
30	0.51	0.57	0.63	0.68	0.73	0.77
31	0.79	0.82	0.85	0.87	0.89	0.91
32	0.88	0.90	0.91	0.93	0.94	0.95
33	0.65	0.70	0.74	0.78	0.82	0.84
34	0.59	0.64	0.69	0.74	0.78	0.81
35	0.91	0.92	0.94	0.95	0.96	0.96
36	0.94	0.95	0.96	0.96	0.97	0.98
37	0.53	0.59	0.65	0.70	0.74	0.78
Mean	**0.80**	**0.83**	**0.86**	**0.88**	**0.90**	**0.91**
Maximum	**0.92**	**0.95**	**0.96**	**0.97**	**0.97**	**0.98**
Minimum	**0.42**	**0.48**	**0.55**	**0.61**	**0.66**	**0.71**

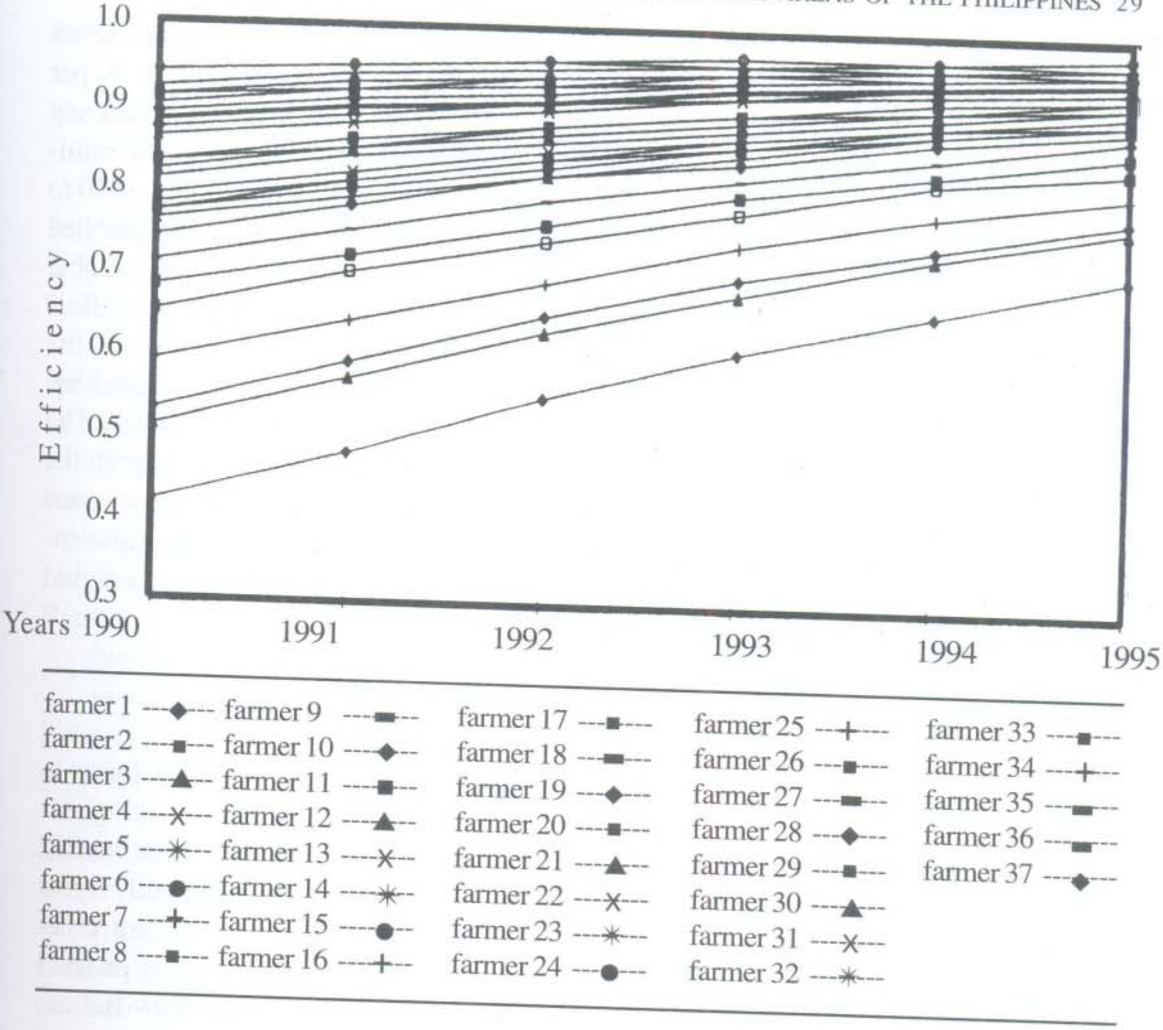

Figure 1

Predicted Technical Efficiencies

Since, ç is positive, it implies that technical efficiencies increase overtime. The general conclusion based on hypothesis testing is that technical efficiencies of paddy farmers in the rainfed rice areas of the Philippines are time-variant and are reported in Table 4. This conclusion is similar to Battese and Coelli (1992); developed for paddy farmers in India, as well as Battese and Tessema (1993).[2]

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[2] The presence of technological change is quantified by incorporating the year dummy in the model [equation (5)]. The results imply that technical efficiencies are not time-invariant and technological change does not account for improvement in technical efficiencies. It contradicts the finding of Battese and Coelli (1992) but is similar to Battese and Tessema (1993). The data used by Battese and Coelli (1992) from India is for the period when the Green Revolution started and reached to its peak, while our panel data set is collected after the completion of the Green Revolution. Hence, in our panel data, technological change does not account for technical efficiency.

The mean, maximum and minimum values of technical efficiencies for the six year are reported in Table 4. The mean technical efficiency increased fròm 80 per cent to 91 per cent in six years while the maximum value of technical efficiency improved from 92 per cent to 98 per cent for the same period. However, the minimum value of technical efficiency increased drastically from 41 per cent in 1990 to 71 per cent in 1995. The predicted technical efficiencies of 37 farmers are graphed against year of observation in Figure 1. It is observed that there is considerable variation in technical efficiencies across farms and for the same farm over different years. Further it is noted that farmers with low technical efficiencies in the starting year improve their management faster. This is consistent and logical because farmers in the same vicinity have close interaction with each other. The majority of the farmers converge to the same level of technical efficiency with the passage of time, implying that farmers are learning from each other's experience by interacting frequently. Given the assumption that farm adopts change exponentially over time, it is expected that the predicted efficiencies converge over a period of generally increasing levels of technical efficiency.

V. Conclusions

The study has measured time-varying technical efficiencies of paddy farms in the rainfed rice ecosystem of the Philippines by employing the time-varying stochastic frontier production approach. It has permitted the testing of time-variant effects. Our results revealed that given the state of technology among paddy farms in the Philippines, the technical efficiencies of the paddy farmers are not time-invariant when year of observation is excluded from the stochastic frontier production model and it is along the lines of the earlier conclusion developed by Battese and Coelli (1992), and Battese and Tessema (1993). After the inclusion of year of observation as an explanatory variable in the frontier model to account for neutral technological change, the conclusion of time-variant efficiencies remains valid and contradicts the findings of Battese and Coelli (1992), but is similar to Battese and Tessema (1993) where they concluded that technological change does not account for technical efficiencies. Hence, empirical findings in agricultural research are area specific and cannot be generalised for all ecosystems and regions. The mean technical efficiency increased from 80 per cent in 1990 to 91 per cent in 1995, implying that average efficiency has increased about 10 per cent in six years but still further scope for improvement exists, which can be explored.

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