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ELSEVIER

Agricultural Economics 16 (1997) 185–192

AGRICULTURAL ECONOMICS

Technical efficiency in paddy farms of Tamil Nadu: an analysis based on farm size and ecological zone

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Accepted 18 March 1997

Abstract

Despite the wider application of efficiency analysis in Indian agriculture, little has been done on the investigation of intra and interecological variations, size differences and their interactions. However, ecological issues have paramount implications for the low-input sustainable agricultural production. Furthermore, due to the various causes of efficiency, the age-old size-based debate on efficiency differences is not yet resolved. The present study examines the level of technical efficiency across ecological zones and farm size groups in paddy farms of the southern Indian state of Tamil Nadu. The study showed that 90% of the variation in output among paddy (IR-20) farms in the state is due to differences in technical efficiency. Land, animal power and fertilisers have significant influence on the level of paddy production. Varying from 0.59 to 0.97, the mean technical efficiency was found to be 0.83. The use of F-test in two-way analysis of variance (ANOVA) and censored regression (Tobit model), with dummies for ecological zones, farm size groups and their interactions, has shown that, at mean level, the level of technical efficiency among paddy farms of the state differs significantly across agro-ecological zones and size groups as well. The study further indicated that small-sized paddy farms in zone II and medium-sized paddy farms in zone III are represented by ecologically size-biased production techniques; thus achieving higher technical efficiency. © 1997 Elsevier Science B.V.

1. Introduction

The measurement of efficiency (technical, allocative and economic) has remained an area of important research both in the developed and developing countries. Especially in developing agricultural economies, where resources are meagre and opportunities for developing and adopting better technologies are dwindling, (Ali and Chaudhry, 1990) efficiency measurement is very important because it is a factor for productivity growth. Such studies help benefit these economies by determining the extent to which it is possible to raise productivity by improving the neglected source, i.e., efficiency, with the existing resource base and the available technology. Hence, by doing so, they could also help decide whether to improve efficiency first or develop a new technology in the short run.

Pertaining to the enduring view in literature that farmers practising traditional agriculture are 'poor but efficient', and the resulting emphasis on increased investments in generating new and more productive techniques, several studies that investigated the relationship between farm size and output in Indian agriculture have been conducted since the late 1950s. Regional variations, together with

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PII S0169-5150(97)00004-2

input–output relations and enterprises, have also been taken into account since the 1960s. These include the works of Saini (1969), Sahota (1968), Hopper (1965). These studies were conducted to evaluate, recommend and formulate appropriate productive techniques that lead to improved resource-use efficiency. However, as they represented the production process of the sample farms on an input–output space (production function) with a given technology, they were not able to separate causes of efficiency due the biological nature of agricultural production from the farm-specific differences in the use of the available technology.

Later, despite the conceptual difficulties and analytical differences, efficiency measurements have been attempted in Indian agriculture since the 1970s (see for example, Huang and Bagi (1984), Kalirajan (1981), Junankar (1980), Sidhu (1974), and Lau and Yotopoulos (1971); in fact, the latter two measured relative technical efficiency using shadow profit function). With particular reference to rice farming, the studies by Shanmugam and Palanisami (1993) in Tamil Nadu, Datt and Joshi (1992) in Uttar Pradesh, and Jayaram et al. (1987) in Karnataka are among the prominent works. These studies, although framed on deterministic or probabilistic estimates of the frontier production function, reported a mean technical efficiency of 75%, 66% and 74% among paddy farms in the respective states.

On the other hand, although we observe wider applications of efficiency measures in paddy farms of India, only very few of these studies have investigated the same across size groups and agro-ecological regions (zones) simultaneously. Besides, there is no consensus among the available studies on the age-old debate of efficiency differences in the small- vs. large-sized farms. The earlier notion was that, under the traditional labour intensive technology, output per hectare on large farms was lower mainly because of higher cost of hired labour. Nevertheless, with the progressive introduction of technology, new production possibilities have been opened for large farms (Singh, 1992). Therefore, with their better capital position, as well as institutional, extension and credit advantages, large farmers are able to substitute manpower by labour-saving devices; thus, they are more efficient than small farms. Available evidence suggests that various factors cause differences in efficiency even among farms of similar size and other factors of production. The debate will further be heated when ecological (environmental) issues are incorporated. This is an important issue of the present time, because ecological issues are the core elements of sustainable development. The present study, therefore, is an attempt partly aimed at investigating technical efficiency in paddy farms across ecological zones and farm size groups and their interactions in the southern Indian state of Tamil Nadu.

2. The study area and data

The state of Tamil Nadu is one of the major rice-growing regions of India that is located in the southeastern extremity of the Indian peninsula. With basically a tropical climate of 18°C–43°C (minimum and maximum daily temperatures), the state receives an average of 925 mm annual rainfall distributed over four major seasons: the Southwest monsoon (Jun.–Dec.), Northeast monsoon (Oct.–Dec.), Winter (Jan.–Feb.) and Summer (Mar.–May). A predominantly red loam, lateral black and alluvial soils suitable for cultivation of cereals and fibre crops prevail in the state.

The state is divided into seven distinct agro-climatic zones; viz., the Western zone (Zone-I in this study), Southern zone (Zone-II), Northeastern zone (Zone-III) and the Cauvery Delta area (Zone-IV). The remaining three zones include the Northwestern (dry belt) zone, the high-rainfall coastal areas and the hilly zone, which altogether account for relatively less than 15% of the total area under rice in the state. Due to their special features and the minimal area under rice, the last three zones were not considered in this study.

Data pertaining to crop cultivation in all agro-climatic zones of the state, collected from 60 clusters taken on a proportionate random sampling basis, are available for each year in the comprehensive scheme for estimating the cost of cultivation for principal crops (CCPC) in the Department of Agricultural Economics, Tamil Nadu Agricultural University. Data for the present study refer to 129 high-yielding variety rice (IR-20) cultivators distributed over the four zones during the major production season of

October–December (Northeast monsoon) for the year 1992/1993. Although rice is grown in two seasons, a single production season was selected in order to minimize the effect of seasonal variation on input use and the yield. HYV rice (IR-20) was selected due to its wider cultivation in the state during the particular season. Further, the analysis was limited to the first four zones in order to maintain homogeneity, by excluding zones with special features and which are less suitable for rice cultivation.

3. The econometric model

Following the Aigner et al. (1977) and Meeusen and Van den Broeck (1977) method of estimating a stochastic frontier production function in which the disturbance term (ϵ) is composed of two parts, a systematic (V) and one-sided (U) components, a Cobb-Douglas production function of the following form was specified:

$$\ln Y_j = \ln \beta_0 + \Sigma_i \beta_i \ln X_{ij} + \epsilon_j \quad (1)$$

where Y_j = paddy output in Quintals, X_{1j} = land area under paddy in ha, X_{2j} = human labour used in man-days, X_{3j} = animal power used in bullock h, X_{4j} = machine power used in tractor h, X_{5j} = fertilizer (NPK) used in kg, X_{6j} = Seed used in kg, X_{7j} = expenses on irrigation water, pesticides and chemicals in rupees (Rs), ln = natural logarithm, and the error term (ϵ_j) is defined as

$$\epsilon_j = V_j - U_j \quad (2)$$

$j = 1, 2, \dots n$ farms.

The systematic component V_j, which captures random variation in output due to factors outside the control of the farmer, is assumed to be independently and identically distributed as $N\ (0, \delta^2 v)$, independent of U_j which measures the technical efficiency relative to the stochastic frontier. Following most of the empirical literature, Neff et al. (1993) and Dawson and Lingard (1989), U_j is assumed to have a non-negative (one-sided) half-normal distribution with $|N\ (0, \delta^2 u)|$.

Now, let $\delta^2 u$ and $\delta^2 v$ be the variances of the parameters one-sided (u) and systematic (v). Therefore,

$$\delta^2 = \delta^2 u + \delta^2 v \quad (3)$$

and the ratio of the two standard errors as used by Jondrow et al. (1982),

$$\lambda = \delta u / \delta v \quad (4)$$

or

$$\gamma = \delta^2 u / \delta^2 \quad (5)$$

is defined as the total variation of output from the frontier which can be attributed to technical efficiency (Battese and Corra, 1977). Hence, on the assumption that U_j and V_j are independent, the parameters of the production frontier (Eq. (1)) were estimated using maximum likelihood method by an econometric software called LIMDEP. Further, given a multiplicative production frontier for which Cobb-Douglas production function (Eq. (1)) was specified, the farm-specific technical efficiency (TE_j) of the j^{th} farmer was estimated by using the expectation of U_j conditional on the random variable ϵ_j as shown by Battese and Coelli (1988). That is,

$$TE_j = \exp(-U_j) \quad (6)$$

So that,

$$0 \le TE_j \le 1.$$

After obtaining farm-specific technical efficiency using Eq. (6), the farms were segregated into their respective regions and different size groups, for which the average technical efficiency was computed and compared using F-test and censored regression (Tobit) model.

4. Results

Ordinary least squares (OLS) estimates of the parameters which show the average performance of the sample farms are presented in Table 1. With the adjusted R^2 value of 0.96, the inputs used in the model were able to explain 96% of the variation in paddy production for the state. The coefficients of land, labour, animal power and fertilizers were highly significant, but animal power has an unexpected sign. This is due to the fact that, in many of the farms, own bullocks, for which the farmer pays no hiring charge, are available. Hence, given the minimal opportunity cost of own bullocks, it is likely that animal power could be overused. Similarly, the coefficients of expenses on irrigation, pesticides and chemicals, although not significant, was unexpected.

On the other hand, the estimates of the stochastic frontier which shows the best practice performance, i.e. efficient use of the available technology, is presented in Table 2. It is evident from the table that the estimates of λ (3.1748) and σ (0.2411) are large and significantly different from zero, indicating a good fit and the correctness of the specified distributional assumption. Moreover, the estimate of γ, which is the ratio of the variance of farm-specific technical efficiency to the total variance of output, was 0.909. This would mean that more than 90% of the variation in output among the farms is due to the differences in technical efficiency.

With an upward shift in the constant term [1], the coefficient of land, animal power and fertilizers remained significant in the Cobb-Douglas stochastic frontier production function [2], implying that farmers could be advised to use more fertilizers and less animal power than what they presently use to increase production.

In addition, given the prevalence of numerous marginal and small farmers in the state, from the highly significant coefficient of land, we could infer that it is possible to increase rice production by consolidating holdings through cooperative effort.

It was also observed that the farm-specific technical efficiency varied between 0.59 and 0.97 with a mean of 0.83. Thus, in the short run, there is a scope for increasing rice production by 17%, by adopting the technology and the techniques used by the best practice paddy farms.

The frequency distribution of the farm-specific technical efficiency segregated into the four agro-ecological zones (Table 3) shows that 36.4%, 29.4%, 16.0% and 30.0% of farms in Zones I, II, III and IV, respectively, were operating at a technical efficiency of more than 90%. On the other hand, relatively more farms (15.6%) in Zone III, Zone I (12.12%) and Zone II (8.8%) were found to be the least efficient. Although, in terms of the most efficient farms, Zone IV rates second to Zone I, no farm was found operating in the least technical efficiency range (55–65%) as in the other three zones.

Overall, the average technical efficiency in the four zones varied between 80.46% in Zone III to 85.90% in Zone IV. As a result, the null hypothesis

Table 1
OLS estimates of average performance using Cobb-Douglas production function

Variables	Parameters	Coefficients
Constant	β_0	2.8970 [a] (0.382)
Land (X_1)	β_1	0.8250 [a] (0.067)
Labour (X_2)	β_2	0.1130 [b] (0.058)
Animal power (X_3)	β_3	−0.0366 [b] (0.019)
Machine power (X_4)	β_4	0.0055 (0.014)
Fertilisers (X_5)	β_5	0.0949 [a] (0.030)
Seeds (X_6)	β_6	0.0250 (0.056)
Other expenses (X_7)	β_7	−0.0054 (0.012)

$\delta = 0.906$, $R^2 = 0.96$, $F = 566.72$ [b], $N = 129$.
Figures in parentheses are standard errors.
[a] Significant at 1%.
[b] Significant at 5%.

Table 2
Maximum likelihood estimates of the stochastic frontier production function

Variables	Parameters	Coefficients
Constant	β_0	3.3674 [a] (0.3771)
Land (x_1)	β_1	0.8872 [a] (0.077)
Labour (x_2)	β_2	0.1072 [b] (0.0599)
Animal power (x_3)	β_3	−0.0376 (0.0178)
Machine power(x_4)	β_4	0.00301 (0.0113)
Fertilizers (x_5)	β_5	0.05169 [c] (0.0256)
Seeds (x_6)	β_6	0.0239 (0.0606)
Others expenses (x_7)	β_7	−0.0069 (0.0126)
	λ	3.1748 [a] (1.224)
	γ	0.909
	$\sqrt{\sigma^2 u + \sigma^2 v}$	0.24113 [a] (0.0247)
	Log likelihood	−61.977
	N	129

Figures in parentheses are standard errors.
[a] Significant at 1%.
[b] Significant at 10%.
[c] Significant at 5%.

[1] An upward shift in the constant term is specific to the COLS estimation procedure. However, in the maximum likelihood estimation of the stochastic frontier, the same shift may occur, although it is not a built-in nature of the model.

[2] As an alternative to this, a more flexible production function such as the translog production function was tried. However, it gave low t-ratios for all inputs used and a highly significant constant term.

Table 3
Frequency distribution of farm-specific technical efficiency of paddy farms across agro-ecological zones of Tamil Nadu

Technical efficiency (%)	Zone I $n = 33$	Zone II $n = 34$	Zone III $n = 32$	Zone IV $n = 30$	State $N = 129$
55–65	4 (12.12)	3 (8.82)	5 (15.63)	–	12 (9.30)
66–70	1 (3.03)	–	2 (6.25)	1 (3.33)	4 (3.10)
71–75	1 (3.03)	6 (17.65)	1 (3.15)	1 (3.33)	9 (6.97)
76–80	4 (12.12)	3 (8.82)	7 (21.88)	6 (20.00)	20 (15.50)
80–85	5 (15.15)	3 (8.82)	5 (15.63)	4 (13.33)	17 (13.18)
86–90	6 (18.18)	9 (26.47)	7 (21.88)	9 (30.00)	31 (24.03)
91–95	9 (27.27)	10 (29.41)	5 (15.63)	8 (26.67)	32 (24.81)
96–100	3 (9.09)	–	–	1 (3.33)	4 (3.10)
Average TE	0.843	0.831	0.804	0.859	0.833

Figures in parentheses are percentage values.

of no difference in the mean technical efficiency across the four ecological zones, evaluated using a two-way ANOVA, was rejected. As the data are unbalanced, the two-way ANOVA was worked out through general linear model (GLM), the value of which is derived based on the sequential sum of squares. The rejection of the null hypothesis would mean that at mean level, there exists significant ($F_{6,128}$ $\alpha = 0.10$) variation in the technical efficiency achieved by paddy farms across the four ecological zones in the state.

Nonetheless, ANOVA presupposes normally distributed data. Although the data are originally normally distributed, estimated efficiency measures are decidedly (in the present analysis) half-normally distributed. Hence, the use of ANOVA may involve specification bias. Therefore, the technical efficiency measures were regressed on dummies for ecological zones, farm size and their interaction. These were censored between 0 and 1 without a constant term using Tobit regression.

The results were consistent with the ANOVA table but depicted detailed outcomes. Accordingly, with a log likelihood ratio of -94.021 for the censored Tobit regression model, t values for individual coefficients indicated that farms in Zone II and Zone III are less efficient than paddy farms in Zone IV (Table 6). However, the average efficiency attained by paddy farms in Zone I was not significantly different from that of paddy farms in Zone IV. Further comparison by using individual β coefficients of the dummy variables by t-test (Gujaratti, 1995) showed that paddy farms in Zone I operate at higher efficiency levels than those in Zone II, and the difference between efficiency of farms in Zones II and III was not significant.

We can therefore conclude that paddy farms in Zones IV and I are more efficient than those located

Table 4
Frequency distribution of farm-specific technical efficiency in paddy farms of Tamil Nadu across size groups

Technical efficiency (%)	Small $n = 51$	Medium $n = 43$	Large $n = 35$	State $N = 129$
55–65	4 (7.80)	3 (6.90)	5 (14.30)	12 (9.3)
66–70	2 (3.90)	2 (3.90)	–	4 (3.1)
71–75	4 (7.80)	3 (6.90)	2 (5.7)	9 (6.9)
76–80	3 (5.80)	7 (16.30)	10 (28.6)	20 (15.5)
81–85	5 (9.80)	6 (13.90)	6 (17.2)	17 (13.2)
86–90	14 (27.50)	10 (23.30)	7 (20.0)	31 (24.0)
91–95	19 (37.30)	9 (20.90)	4 (11.3)	32 (24.80)
96–100	–	3 (6.90)	1 (2.9)	4 (3.1)
Average TE	0.850	0.835	0.806	0.833

Figures in parentheses are percentage values.

Table 5
Two-way ANOVA table derived using general linear model (GLM) for efficiency comparison across ecological zones and farm size groups in Tamil Nadu

Source	DF	Sequential sum of squares	Adjusted sum of squares	Adjusted mean sum of squares	F	p
Ecological zones	3	0.1330	0.1528	0.0509	3.18 [a]	0.027
Farm size	2	0.1946	0.1946	0.0973	6.07 [b]	0.003
Zone–size interaction	6	0.1768	0.1768	0.0294	1.92 [c]	0.083
Error	117	1.7957	1.7957	0.0153		
Total	128	2.3003				

[a] Significant at 5%.
[b] Significant at 1%.
[c] Significant at 10%.

in Zones II and III, respectively and consistently. This would imply that, given the existing technology for rice production in Tamil Nadu, further improvement in paddy productivity can be made by farms in Zones II and III if extension packages are geared to advising rice farms in these zones to use the practices of those in Zones IV and I.

A similar analysis was done by aggregating groups of farms into small, medium and large based upon the size of operational holdings [3]. This was done in order to provide an insight into the age-old debate on the small vs. large farm size efficiency differences (variation), which has not been resolved yet. The frequency distribution is provided in Table 4. It is evident from the table that 37% of the most efficient (91–97% technical efficiency) farms comprise those that operate small farms. The same was only 26 and 13% in medium and large farms, respectively. On the other hand, the largest proportion (14.3%) of the least efficient farms were those that operated large farms while the same was about 8 and 7% for small- and medium-sized farms.

On these bases, the two-way ANOVA, with a calculated F ratio of 6.07 at 2.128 degrees of freedom gave strong evidence to reject the null hypothesis that there is no difference in the average technical efficiency across small-, medium- and large-sized farms (Table 5). The Tobit model's dummy coefficients further revealed the existence of significant differences in technical efficiency across the farm size groups considered (Table 6). That is, paddy farms on small- and medium-sized holdings operate at a higher level of technical efficiency than large-sized farms. This is likely because under conditions where accessibility to institutional finance depends on asset position, particularly land (Lahiri, 1993), small farms will be forced to allocate their meagre

Table 6
Maximum likelihood estimates of the coefficients of censored regression (Tobit model) dummies for ecological zones, farm size and their interaction

Variables	Parameters	Coefficients
A) Dummies for ecological zones		
1) Zone I (D_1)	α_1	−0.0555 (0.053)
2) Zone II (D_2)	α_2	−0.1785 [a] (0.0588)
3) Zone III (D_3)	α_3	−0.0211 [b] (0.254)
B) Dummies for farm size		
4) Small (D_4)	α_4	0.0512 [a] (0.0054)
5) Medium (D_5)	α_5	0.0692 [a] (0.0236)
C) Farm size–ecological zone interaction dummies		
6) Small in Zone I (SD_1)	α_6	0.0459 (0.0731)
7) Small in Zone II (SD_2)	α_7	0.1722 [a] (0.0738)
8) Small in Zone III (SD_3)	α_8	−0.0321 (0.076)
9) Medium in Zone I (MD_1)	α_9	0.0508 (0.0733)
10) Medium in Zone II (MD_2)	α_{10}	0.1230 (0.0796)
11) Medium in Zone III (MD_3)	α_{11}	−0.1341 (0.0732) [c]
	σ	0.1167 [a] (0.0072)
	Log-likelihood	−37.313
	Limits	(0, 1)

Figures in paretheses are standard errors.
[a] Significant at 1%.
[b] Significant at 10%.
[c] Significant at 5%.

[3] Small farms are those operating less than 1.5 ha of land, while medium-sized farms are those operating 1.5 ha to 4.00 ha of land. Those operating more than 4.00 ha of land were considered large-sized farms.

resources more effectively. In this regard, the studies of Sekar et al. (1994), Bagi (1981) and Lau and Yotopoulos (1971) in different parts of India depict similar findings. Specially in the examination of the relationship between farm size and economic efficiency, Bagi (1981) has shown that using more own resources such as human labour, bullock power and fertilisers per hectare of land, small farms attain more output and better technical efficiency than large farms.

However, this study has not considered ecological effects as an important issue of the present time. To this end, the size-ecological zone-interaction-effect dummies, in the present analysis, revealed that small-sized farms in Zone II and medium-sized farms in Zone III are peculiar. That is, the dummy coefficients are significant (at $p \leq 0.01$ and $p \leq 0.05$) implying small- and medium-sized paddy farms, in these zones, are represented by ecologically size-biased production technologies (practices). This could be taken as an advantage in the short run by the state policy makers to increase rice production.

In a nutshell, we could infer that the variation in the level of technical efficiency among paddy farms in the state exists across agro-ecological regions and the size of operational holdings as well. Identification of specific factors that led to such variations in the farm-specific technical efficiency is of profound relevance for formulating strategies necessary to narrow the prevailing gap and increase productivity. With the given database, this was imponderable. However, the resource use pattern of some of the most efficient (above 90% technical efficiency) farms were examined. It was found that the most efficient farms employed 150.94 man-days of labour, 112.22 h of animal power and 11.04 tractor h, used 222.48 kg of fertilizers and 40 kg of seeds, and spent Rs484.66 as payments on irrigation, pesticides and chemicals for cultivating a hectare of land, which produced 57.49 quintals of paddy.

5. Conclusion

The results of our study showed that, with the use of more fertilizers and land, rice production could be increased. The contribution of land in increasing production is more prominent. Farmers were overusing animal power in rice cultivation.

Overall, the mean technical efficiency of 83.3% is achieved by paddy farms in the state showing the scope for increasing paddy production by 17% with the present technology (technique) itself. A significant variation was observed in the mean level of technical efficiency among the four major rice growing zones of the state, and farmers operating on small and medium sized farms achieved a higher level of technical efficiency than those with large holdings. The farm size–ecological zone interaction effects also reveal that small- and medium-sized paddy farms in Zones II and III, respectively, are operating at a higher level of technical efficiency than all other farms.

Consequently, paddy farmers, in general, could be advised on the use of less animal power, and more consolidated use of land. Besides strengthening extension services to enable farmers to follow the resource use pattern and practices of the paddy farms in Zones IV and I, special attention should be given to improve the efficiency of paddy farms with large holdings through the adoption of practices of small- and medium-sized farms, particularly in Zones II and III. This could help increase rice production in the state in the short run.

Acknowledgements

This research was carried out while the first author was completing his M.Sc. studies in India. We acknowledge the centre for Cost of Cultivation of Principal Crops, Department of Agricultural Economics, Tamil Nadu Agricultural University, for the supply of data used in this study. The anonymous referees of this journal deserve our special thanks for they have contributed commendable comments that helped further improvements in the findings of this research. Ms. Jaya Anitha Abraham's contribution in realising this research is also appreciable.

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