Estimation of technical efficiency in Greek livestock farms

Ioannis ANDREAKOS,
Vangelis TZOUVELEKAS,
Konstantinos MATTAS,
Evangelos PAPANAGIOTOU

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Ioannis ANDREAKOS*, Vangelis TZOUVELEKAS**, Konstantinos MATTAS***, Evangelos PAPANAGIOTOU***

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Summary *– In this present paper we use a panel data set during the period 1989-1992 to explore the distribution of productive efficiency among small sheep-breeding farmers operating in Greece. The results show that the average technical efficiency of the stock farmers was quite low (75.80%) and suggest the need for an advanced development strategy to improve their economic performance. Finally, the farmer's age and formal education, the credit access, the lack of successors and the farm's location are important factors explaining efficiency variation among farmers.*

Key-words:
technical efficiency, sheep-breeding farms, stochastic frontier, Greece

L'efficacité technique des exploitations d'élevage en Grèce

Résumé – Cette étude traite du rendement technique des exploitations d'élevage en Grèce en 1989-1992, afin d'évaluer l'éventuelle croissance ou diminution du cheptel en termes de productivité.

Nous utilisons une enquête effectuée de 1989 à 1992 sur la répartition des gains de productivité dans les petites exploitations d'élevage en Grèce. Selon les résultats, le rendement technique moyen de ces exploitations est assez bas (75,80%); d'où la nécessité de mettre en place une stratégie de développement dynamique afin d'améliorer les résultats économiques. En fin de compte, l'âge de l'exploitant, le niveau de formation, l'accession au crédit, l'absence de successeurs ainsi que la localisation de l'exploitation sont autant de facteurs pouvant jouer sur les variations de rendement entre exploitations.

Mots-clés:
productivité, exploitation d'élevage, Grèce

* *National Agricultural Research Foundation, 184C, Kifissias av, 145-62 Kifissia, Athènes, Grèce (senior authorship is not assigned).*

** *The University of Wales, Aberystwyth Llanbadarn Fawr, SY23 3AL, Aberystwyth, Royaume-Uni.*

*** *Aristotelio Panepistimio Thessalonikis, University campus, 54006 Thessaloniki, Grèce.*

MEASUREMENT of farm efficiency can provide useful insights into the competitiveness of farms and their potentials for raising productivity and improving resource use. In view of its important implications, the measurement of farm-level efficiency in production has received considerable attention from researchers in the last two decades (Schmidt, 1986; Battese, 1992; Bravo-Ureta and Pinheiro, 1993; Coelli, 1995). However, the investigation of causes of inefficiencies in production besides the estimation of inefficiency levels can clearly indicate means by which efficiency may be improved by increasing agricultural output. In addition, for individual farms gains in efficiency are particularly important in periods of financial stress and agricultural policy changes, since efficient farms are more likely to generate higher incomes and thus stand a better chance of surviving and prospering. In particular, efficiency in livestock production can be proved as a key determinant for stock-farms survival since the seemingly oversupply of dairy products within European Union (EU), as well as the reduction in the fiscal outlays for supporting agricultural plans, suggest that the trend towards fewer stock-farmers is likely to continue in the foreseeable future. Issues relating to the survival of the small family farms as well as the influence of the EU agricultural policy reforms upon smaller farmers, remain very important and extremely controversial. EU's sheep meat production totally comes from small stock-farms operating mainly in Greece, Spain and United Kingdom. In particular Greek small stock-farmers produce the 11.95 per cent of the total EU's meat production settled in the third place after UK (33.48 per cent) and Spain (19.87 per cent).

The present study purports to contribute to the efficiency literature by estimating the technical efficiency of sheep-breeding stock-farms in Greece for the period 1989-1992 in order to assess the potential gains or losses in livestock output through productivity growth. Moreover, the role of farm management and technology implementation in the production process as well as the socio-economic factors that affect the managerial capacity of stock-farmers are explored, since it is conjectured that the wide variation in farm net returns is primarily caused by the corresponding variation in managerial capacity of the farmers. The paper is organised as follows. First a brief description of the theoretical underpinnings associated with inefficiency concept is given; then the data and the empirical models are discussed followed by a section exposing the results and their interpretation; ultimately, the last section proceeds to the review of some concluding results and policy implications.

THEORETICAL FRAMEWORK

Among the most important features of panel data is that analysts no longer have to impose a particular *distribution* for the farm efficiency, lessening one of the most serious drawbacks deflecting a common criticism of the econometric approach to frontier estimation by mathematical programming proponents (Greene, 1993a, pp. 82-87). Two different estimation techniques for panel data models have been developed in the literature that enable to relax many of the restrictive assumptions of the single cross-sectional stochastic frontier model and giving rise to alternative measures of efficiency. These include, *fixed effects* model and the least squares dummy variable (LSDV) estimation and the *random effects* model and the generalised least squares (GLS). A general Cobb-Douglas production function frontier expressed in logarithms (or natural logarithms) in the context of panel data can be written as (Greene, 1993b, p. 465):

$$ln\, y_{it} = \alpha + \sum_{k=1}^{K} \beta_k \, ln\, x_{kit} + \varepsilon_{it} \qquad (1)$$

where, y_{it} is the logarithm of the output of the *ith* farm in period t, x_{kit} is the logarithm of the *kth* input applied of the *ith* farm in period t, β_k represents the slope coefficient of the *kth* input which is common to all individuals and $\varepsilon_{it} = v_{it} - u_i$ is composed of two independent elements; an *efficiency* component, u_i, capturing the effects of technical efficiency, which is assumed to be *constant* over time and identically and independently distributed as well as uncorrelated with v_{it}, $[u_i \approx D\,(\mu_u, \sigma_\alpha^2)]$ and a normally distributed *random* error, v_{it} capturing *random* variation in output resulting from factors outside the control of the farm (weather, diseases, etc.) which is assumed to be uncorrelated neither with u_i nor with the explanatory variables $[v_{it} \sim N\,(0, \sigma_v^2)]$. The within or fixed effects estimator assumes that u_i are fixed effects of each farm and thus, equation (1) can be rewritten as:

$$y_{it} = \sum_{k=1}^{K} \beta_k \, x_{kit} + \sum_{i=1}^{N} \alpha_i \, D_i + v_{it} \qquad (2)$$

where, D_{it} are the farm-specific dummy variables indicating the *ith* unit and take values equal to zero or one. Thus, the dummy variable will take the value of *unity* for observations on farm i, while it will be *zero* for observations on other farms. If we assume now that the dummy variable for each farm stands as a proxy of *management*, then these dummies can be interpreted as a measure of technical *efficiency* establishing a clear link between the production frontier methodology and the fixed effects model (Hoch, 1976; Lingard *et al.*, 1983; Schmidt and Sickles, 1984; Dawson *et al.*, 1991; Ahmad and Bravo-Ureta, 1995). In order to estimate technical efficiency subsequent calculations are required. Following Gabrielsen (1975) and Greene (1980) proposition according to which the shift of the regression estimates up or down so that exactly one residual is zero and the rest have the desired sign, produces a *consistent* estimate of farm's constant. Hence, the farm specific technical efficiencies can be estimated as (Schmidt and Sickles, 1984):

$$\hat{u}_i = \frac{e^{\hat{\alpha}_i}}{max\ (e^{\hat{\alpha}_i})} \tag{3}$$

The above formulation implies that one farm has a *zero* technical inefficiency and the remaining N – 1 farms have *positive* efficiency estimates. Given that the density of u_i is non-zero for some ε_i greater than zero, the technical efficiency of the most efficient farm will be indeed 100 per cent as $N \rightarrow \infty$ (Greene, 1980). Therefore the technical efficiency estimates obtained from (3) are consistent for α_i and u_i as T and N grow to infinity. The particular advantage of this approach is that it does not assume *normality* for the distribution of farm effects while it dispenses with the assumption that the farm efficiencies are *uncorrelated* with the input levels.

If the assumption of independence of farm efficiencies and input levels can be maintained, then the *random effects* model might be preferable. The most important difference between random and fixed effects model, is that the former instead of working *conditionally* on the farm-specific effects, α_i, it takes explicitly into account their *stochastic* nature. In other words, instead of assuming that α_i are fixed coefficients applying only to the cross-sectional units and not to additional ones outside the sample, we assume that they are independent *random* variables with a mean α_i and variance σ_u^2. This formulation seems to be appropriate when sampled farms are part of some larger population. Within the context of random effects model the farm-specific constants are given by:

$$\alpha_i = \bar{\alpha}_i - u_i \tag{4}$$

where u_i is identically and independently distributed as well as uncorrelated with the error term, ε_{it}, that is, $E(u_i) = \mu_u$, $E(u_i^2) = \sigma_u^2$ and $E(u_i \varepsilon_{jt}) = 0$. Hence, like the fixed effects model, each farm has its own intercept sharing the slope coefficients with the others. In this approach there is a unique production frontier but *one-sided* random variations are allowed in order to characterise inefficiencies. Farm specific efficiencies are obtained from the estimated values of farm intercepts as in the case of fixed effects model in (4). The farm intercepts are derived either by the mean over time of the residuals for farm *i* or by using the best linear predictor proposed by Taub (1979). However, for large T both approaches yield equivalent estimates. In our analysis we utilised the *best linear unbiased predictor* (BLUP) as it is described in Greene (1993a, p. 85).

In conclusion to this section, it is worth pointing out that in terms of policy implications it is probably more important to determine what causes efficiency differentials among farmers than simply to measure it. Determining the sources of productive efficiency provides policy makers not only with information on where potential sources of inefficiency originate, but also suggests policies that may be implemented to enhance overall economic performance of the farmers. Technical efficiency of a farmer is mostly influenced by his socio-economic environment which has direct bearing on human capital development (Lockheed *et al.*, 1980; Phillips and Marble, 1986). Nevertheless, a number of other factors associated with general demographic and environmental characteristics have been also considered to explain variations in productive efficiency (Lingard *et al.*, 1983; Hill and Kalirajan, 1993; Johnson *et al.*, 1994). Among the different developed methodologies the two step procedure has gained popularity among researchers as the most sophisticated one, inasmuch as it has been around for a long time since Timmer (1971) attempted to explain interstate variation in technical efficiency in US agriculture. In the first stage efficiency measures are obtained using any of the techniques developed in the literature. Then a linear function is estimated to relate efficiency and some of the above farm characteristics that are available (Lovell, 1993, pp. 53-55).

THE DATA AND EMPIRICAL MODEL

The data

The data used in the present paper were provided by the Agricultural Economics and Social Research Institute (Ag.ESRI). The data were collected by trained research surveyors of the Regional Agricultural Directorates, from all Greek regions according to a well-designed and pretested questionnaire. The data set consists of 60 identical farms for which observations were obtained for each of the four years of the study. The survey provides detailed information about production patterns, input use, average yields, gross revenues and net income of the surveyed farms. A summary of this information for the years 1989 and 1992 is presented in Tables 1 and 2.

As it is gleaned the average cost of the used inputs remains stable during the period of the study, which is rather logical, since the nature of stock-farming production does not allows for changes in the short-run. The dominant inputs are the family labour and animal feed totalling the 85.74 per cent of the total cost per head in 1989 and the 83.96 per cent in 1992, followed by depreciation and grazing cost. The hired labour, permanent or seasonal, constitutes a small share of the total inputs, while the mechanisation of the farms remains insubstantial. The total cost in 1992 prices has been increased by 15.11 per cent resulting in part from the increase of the wage rates. The production is directed to the meat and milk, while wool and manure are considered as by-products. Sheep-milk contribution to the total gross revenues in 1992 is 2.86 per cent higher than in 1989 while at the same time the contribution of sheep-meat to the total gross revenues was decreased from 39.89 per cent in 1989 to 34.22 per cent in 1992.

Table 1.
Cost elements of sheep-breeding farms

	1989		1992	
Average cost				
1. Labour (a+b+c)	21.28	43.10	33.35	42.48
a. Permanent	0.20	0.40	0.60	0.76
b. Family	20.72	41.97	32.41	41.27
c. Seasonal	0.36	0.73	0.21	0.27
2. Machinery	0.08	0.16	0.14	0.18
3. Veterinary nursing and drugs	0.45	0.91	0.72	0.91
4. Grazing and taxes	1.83	3.71	2.87	3.65
5. Fuel and electric power	0.25	0.50	1.29	1.64
6. Transportation	0.12	0.24	0.11	0.14
7. Feed (a+b)	21.05	42.64	32.57	41.48
a. Purchased	13.44	27.23	21.21	27.01
b. Produced	7.61	15.41	11.36	14.47
8. Miscellaneous	0.10	0.20	0.29	0.37
9. Depreciation	1.71	3.46	2.22	2.83
10. Insurance	0.04	0.08	0.08	0.10
11. Maintenance	0.15	0.31	0.33	0.41
12. Rents	0.37	0.76	0.22	0.27
13. Fixed assets interest	0.48	0.97	1.07	1.36
14. Current assets interest	1.47	2.98	3.41	4.34
Total cost	49.37	100.00	78.51	100.00
Net revenues	7.24		9.39	

The second and forth columns indicate the percentages of the total cost
All figures are expressed in ECU/head
Exchange rate (25.1.1995) 1 Drs = 294.718 ECU

Table 2.
Gross revenues of sheep-breeding farms

	1989		1992	
1 Meat (kg/head)	9.79		9.47	
2 Price (ECU/kg)	2.31		3.18	
2a **Value (ECU/head)**	**22.58**	39.89	**30.08**	34.22
3 Milk (kg/head)	74.47		74.86	
3a **Value (ECU/head)**	**22.83**	40.34	**37.98**	43.20
4 Wool (ECU/head)	1.03	1.82	0.78	0.89
5 Manure (ECU/head)	0.37	0.65	0.39	0.44
Total (3a+4+5)	24.23	42.81	39.15	44.54
6 Subsidies (ECU/head)	9.80	17.30	18.67	21.24
Gross revenues	56.61	100.00	87.90	100.00

The second and forth columns indicate the percentages of the total Gross Revenues
Exchange rate (25.1.1995) 1 Drs=294.718 ECU.

The producer price for meat has been increased only by 4.17 per cent despite of the substantial raise in input prices. Thus, the net revenues as a percentage of the gross revenues exhibit a small decline, about 2 per cent, although an essential increase in the amount of direct and indirect transfers [1] (from 17.30 per cent in 1989 to 21.24 per cent in 1992) took place. However, of particular interest is that the average amount of total subsidies is considerably higher than the relevant figure of net revenues (50.29 per cent in 1992) implying the strictly dependence of stock production in these transfer payments. Finally, the average yields are stable, as it was expected to be, during the entire considered period, and for meat is about 9 kg/head, while for milk the relevant figure is 75 kg/head.

The empirical model

For the estimation of the production function, the Cobb-Douglas functional form in the natural logs of the variables was chosen, as it has been the practice in most empirically studies concerning efficiency. In addition, the translog type formulation of the model resulted insignificant parameter estimates of the cross-input effects. Output was assumed to be dependent upon labour (family and hired), animal feed, veterinary expenses and some other primary inputs (fuel, maintenance, insurance, transportation, rents etc.). Ultimately, a time dummy variable to capture changes in technology and in environmental conditions was introduced. Specifically, the estimated model assuming that farmers aim at maximising their expected profits in order to surpass the existence of simultaneous bias (Zellner *et al.*, 1966), has the following form :

$$ln\, Y_{it} = \alpha + \beta_1\, ln\, X_{1it} + \beta_2\, ln\, X_{2it} + \beta_3\, ln\, X_{3it} + \beta_4\, ln\, X_{4it} + \sum_{k=2}^{T} \rho_k D_{kit} + v_{it} + u_i \qquad (6)$$

where Y is milk and meat production per farm, X_1 is the breeding fees, X_2 is the labour used, X_3 is the expenses for veterinary nursing and medicine, X_4 includes the rest of the expenses, D_{kit} are the time dummies (base year-1989) and u_i, v_i are the disturbance terms which have the properties mentioned in Section 2. Ultimately, all variables are expressed in Drs/head.

RESULTS

Table 3 presents the estimated production function using pooled time-series and cross-sectional data set of 60 matched farms surveyed in the period between 1989 and 1992. The adjusted R-squares indicate that the fitted regression equation explains 22.3 % of the output variation in stock

[1] These subsidies refereed to European Union structural funds as well as to the direct transfers to the producers supporting their income after the implementation of milk quotas.

production for the total model, whereas in fixed effects and random effects models the relevant estimates were considerably improved (54.5%). All the estimated coefficients have the anticipated sign, which in Cobb-Douglas functional form represents the elasticity of output with respect to inputs. Animal feed and labour (family and hired) are the factors which are most intensively used in the production exhibiting strong significant values, followed by veterinary expenses. Furthermore, other primary inputs are non-significant while the coefficients of the time dummy variables have the anticipated sign with this of 1992 more in evidence. Consequently, in 1992 either improved practices were introduced or the weather conditions were favourable for production. Finally, the significance tests examining whether or not each individual have different intercept in both models submit the rejection of the null hypothesis, that is the intercepts of the 60 farms production functions are not all the same, while the Hausman (1978) specification test suggests that the fixed effects model is not the appropriate scheme for the explanation of the different production structures across farms. Thus, for the estimation of farm level technical efficiency as well as for the analysis of the determinants in the existing efficiency variation among farms, which follows, we have used the random components estimates.

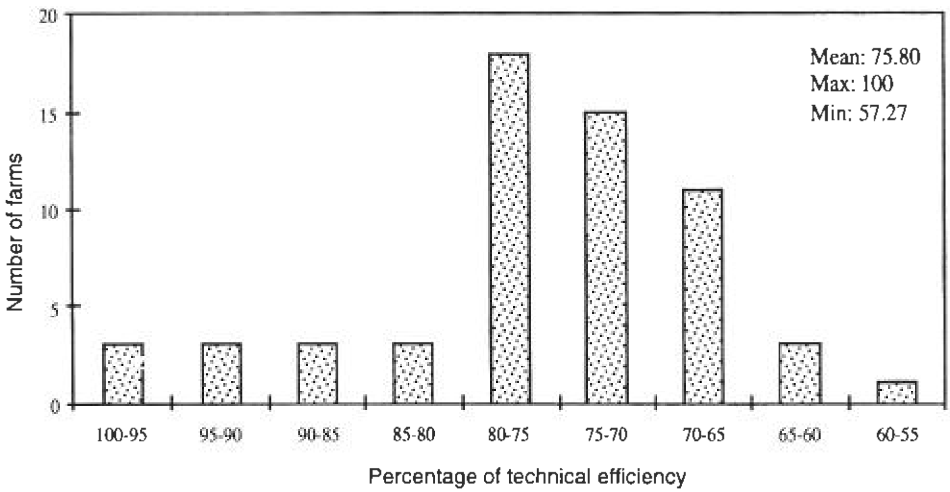
Table 3. **Estimated modified Cobb-Douglas production functions using time-series cross-sectional**

Variables	Total	Fixed effects	Random effects
Intercept	7.282 (0.495)*	7.109 (0.736)*	7.205 (0.608)*
Feed	0.167 (0.038)*	0.169 (0.039)*	0.168 (0.036)*
Labour	0.056 (0.043)	0.087 (0.045)**	0.070 (0.041)**
Veterinary nursing	0.112 (0.023)*	0.083 (0.026)*	0.099 (0.022)*
Other	-0.002 (0.013)	-0.003 (0.014)	-0.002 (0.012)
1990-dummy	0.069 (0.059)	0.080 (0.053)	0.074 (0.052)
1991-dummy	0.023 (0.061)	0.029 (0.055)	0.025 (0.054)
1992-dummy	0.116 (0.062)**	0.125 (0.056)**	0.119 (0.055)**
R^2	0.223	0.545	0.546
F-statistic	8.329*	9.490*	16584.954*
Test for equality of dummy variables:		F(59,173) = 2.089, P-value = 0.0001	
Langrange multiplier test for random effects:		Chi-squared = 16.49, P-value = 0.0000	
Hausman specification test:		Chi-squared = 2.274, P-value = 0.9431	

* Significant at the 0.01 level; ** at the 0.05 level; *** at the 0.10 level
Data for 60 matched farms for the period 1989-1992

Individual farm technical efficiencies were computed using equation (3) and were then aggregated into a frequency distribution in figure 1, where the class intervals are 5 per cent. The results suggest a considerable variation in individual technical efficiencies across farms, ranging from a low of 57.27 per cent to a high of 100 per cent, while the mean value is 75.80 per cent. Therefore, it is evident that the gap between average and best-practice yield should be increased by a better utilisation of the available resources and gathering considerable gains in farmers gross income. The considerable variation in efficiency ratings could imply that the homogeneity assumption for the production environment is not valid for the study area and that there could be differences in the availability and use of inputs. However, considering that the stock-farmers all over Greece are using almost an homogeneous technology, the differences in the produced output could be either due to the lack of complete knowledge of the existing technology or because an improper utilisation of this technology. The later is rather true since livestock production and especially sheep-breeding is mainly labour and feed intensive and thus, production patterns are not essentially differentiated between farms. Strengthening more the above findings, the farms were mapped carefully in order to investigate whether or not specific region exhibit high technical efficient rankings. It was found that high technical efficient farms are located in different regions and thus, no geographic patterns were emerged.

Figure 1. **Frequency distribution of technical efficiency ratings**



The employed methodology in the present study poses that the existing technical efficiency differences between farms reflect differences in the managerial capacity of the farmers[2]. Hence, in order to exam-

[2] However, there is a debate in the literature concerning the study of the impact that socio-economic factors cause on the level of efficiency. Some analysts argue that these variables may have directly effects on efficiency estimates and thus, should be taken into account in the estimation of the production frontier (Battese *et al.*, 1989), while some others support that the socio-economic factors have a circular effect on production and hence, should be incorporated indirectly in the production function with a two stage process (Kalirajan, 1991 ; Shariff and Dar, 1996). In the present study these variables were excluded from the first stage since they do not command any price in the market and so they cannot meaningfully be included in the production function.

ine the determinants of efficiency variation among farms, technical efficiency measures were regressed on a series of variables which was supposed to influence the managerial capacity of the stock-farmers. The factors which were assumed, in the present study, to influence the managerial capacity of the Greek stock-farmers and hence, their efficiency level were : (a) the age in years of the farm operator ; (b) the type of the farm (equal with one for these farms which was strictly livestock and zero for the multiproduct ones) ; (c) the education level of the farm operator expressed in number of years of schooling ; (d) the credit access (equal with one for the farmers who were receiving credit and zero otherwise) ; (e) the lack of successors and (f) the farm's location (equal with one if it is located in a less favoured area and zero otherwise) ; (g) the farm size expressed in the flock size of the stock farm.

Table 4. **Regression results of the random components**

Variables	Units of Measurement	Coefficient	Std. Error
Farmer's age	years	1.317	(0.047)*
Farm	1=livestock, zero mixed	0.543	(0.472)
Formal education	years of schooling	0.051	(0.031)***
Credit access	1=yes, 0=no	0.657	(0.125)*
Lack of successors	1=yes, 0=no	0.032	(0.008)*
Farm location	1=less-favourite, 0=no	-0.457	(0.245)**
Flock size	heads	0.013	(0.131)
Adj. R2		0.405	
F-statistic		7.918*	
N		60	

* Significant at the 0.01 level ; ** at the 0.05 level ; *** at the 0.10 level
Data refer to the last year of the study (1992)

The results of the regression analysis of technical efficiencies are reported in Table 4. Although the fitted regression equation explains only the 40.5 per cent of the individual variation the most of the estimated coefficients are significant at above 90 per cent level. The clearest pattern that emerges is the age of the manager of the farm which is positive related to efficiency at the one per cent level. The differences in the years of schooling as well as in the credit access of the farmers are also important factors in improving the overall productivity. Given that education is a strong complement with most of the inputs utilised in the production, its importance is indispensable. Moreover, the area in which the farm is located (less-favoured or not) and the lack of successors have significant but eligible part to play, while there is no evidence that the pure livestock farms exhibit different efficiency levels than mixed ones. Finally, the farm size does not have any conjunction with the existing level of efficiency resulting insignificant low values. This finding is in accordance with previous studies where it was found that larger farms are not more efficient than smaller farms (Taylor *et al.*, 1986 ; Byrnes *et al.*, 1988 ; Bravo-Ureta and Evenson, 1994). This implies that the provision of institutional services to small farms that provides them with opportunities similar to those enjoyed by large farms is feasible.

DISCUSSION

Smallholder stock-farming, a quite flourishing livestock sector, constitutes an important and vital part of the Greek economy and it is also a major source of sheep milk and meat within EU. Regarding that stock-farms are located mainly in mountainous and semi-mountainous areas using traditional ways of farming, emerges the examination of the potential productivity differentials among them. The alternative employed methodologies for the estimation of the production function imply that the family labour and breeding fees are the foremost significant factors in production which virtually remains unchangeable over time.

The efficiency analysis using a stochastic frontier methodology reveals considerable deviations among stock-farms given the available inputs and technologies. Specifically, average technical efficiency was found to be 75.80 per cent which means that actual output is about 25 per cent less than the maximal output which can potentially be achieved from the existing levels of inputs. This increase can be attained without additional costs to the farmers, implying considerable gains in household incomes. Gains in productivity are important to stock-farming considering the future reductions in fiscal outlays for supporting agricultural plans.

The examination of the relationship between efficiency and various socio-economic indicators of the stock-farmers reveals some valuable information concerning the inter-farm efficiency differences. The farm operator's age and education level, the access to market's credit, the lack of successors in stock-farming and the location of the farm are important factors enhancing productive efficiency across farms. Conclusively, this mitigates the need for strengthening the existing extension services and for conducting pilot instructive programmes to acquaint the less informed farmers with advanced farming operations. Since the room for further improvement in the productivity of the stock-farmers is considerable, policy-makers might fruitfully increase their efforts in the foreseeable future for technological developments, institutional adjustments and improvements in the input-markets organisation, in order to achieve considerable gains in output through the structural adjustment of the stock production which is now based in traditional ways of farming.

REFERENCES

AHMAD (M.), BRAVO-URETA (B. E.), 1995 — An econometric decomposition of dairy output growth, *American Journal of Agricultural Economics*, 77, pp. 914-921.

BATTESE (G. E.), 1992 — Frontier production functions and technical efficiency : a survey of empirical applications in agricultural economics, *Agricultural Economics*, 7, pp. 185-208.

BATTESE (G. E.), COELLI (T. J.) and COLBY (T. C.), 1989 — Estimation of frontier production functions and the efficiencies of Indian farms using panel data from ICRISAT's village level studies, *Journal of Quantitative Economics*, 5, pp. 327-348.

BRAVO-URETA (B. E.) and PINHEIRO (A. E.), 1993 — Efficiency analysis of developing country agriculture: a review of the frontier function literature, *Agricultural and Resources Economics Review*, 22, pp. 88-101.

BRAVO-URETA (B. E.) and EVENSON (R. E.), 1994 — Efficiency in agricultural production : the case of peasant farmers in Eastern Paraguay, *Agricultural Economics*, 10, pp. 27-37.

BYRNES (P.), FARE (R.), GROSSKOPF (S.) and LOVELL (C. A. K.), 1988 — The effect of unions on productivity : US surface mining of coal, *Management Science*, 34, pp. 1037-1053.

COELLI (T. J.), 1995 — Recent developments in frontier modelling and efficiency measurement, *Australian Journal of Agricultural Economics*, 39, pp. 219-245.

DAWSON (P .J.), LINGARD (J.) and WOODFROD (C. H.), 1991 — A generalised measure of farm-specific technical efficiency, *American Journal of Agricultural Economics*, 73, pp. 1098-1104.

GABRIELSEN (A.), 1975 — On estimating efficient production functions, Working Paper n° A-35, Chr. Michelsen Institute, Dept of Humanities and Social Sciences, Bergen, Norway.

GREENE (W. H.), 1993a — The econometric approach to efficiency analysis, *in* : FRIED (H. O.), LOVELL (C. A. K.) and SCHMIDT (P.), eds, *The Measurement of Productive Efficiency : Techniques and Applications*, New York, Oxford University Press.

GREENE (W. H.), 1993b — *Econometric Analysis*, New York, Prentice Hall Inc.

GREENE (W. H.), 1980 — Maximum likelihood estimation of econometric frontier functions, *Journal of Econometrics*, 13, pp. 27-56.

HAUSMAN (J. A.), 1978 — Specification tests in econometrics, *Econometrica*, 46, pp. 1251-1272.

HILL (H.) and KALIRAJAN (K. P.), 1993 — Small enterprise and firm-level technical efficiency in the Indonesian garment industry, *Applied Economics*, 25, pp. 1137-1144.

HOCH (I.), 1976 — Returns to scale in farming : further evidence, *American Journal of Agricultural Economics*, 58, pp. 745-749.

JOHNSON (S.R.), BOUZAHNER (A.), CARRIQUIRY (A.), JENSEN (H.) and LAKSHMINARAYAN (P. G.), 1994 — Production efficiency and agricultural reform in Ukraine, *American Journal of Agricultural Economics*, 76, pp. 629-635.

KALIRAJAN (K. P.), 1991 — The importance of efficient use in the adoption of technology : a micro panel data analysis, *Journal of Productivity Analysis*, 2, pp. 113-126.

LINGARD (J.), CASTILLO (L.) and JAYASURIYA (S.), 1983 — Comparative efficiency of rice farms in Central Luzon, the Philippines, *Journal of Agricultural Economics*, 34, pp. 163-173.

LOCKHEEK (M. E.), JAMISON (D. T.) and LAU (L. J.), 1980 — Farmer education and farm efficiency : a survey, *Economic Development and Cultural Change*, 29, pp. 37-76.

LOVELL (C. A. K.), 1993 — Production frontiers and productive efficiency, *in* : FRIED (H. O.), LOVELL (C. A. K.) and SCHMIDT (P.), eds, *The Measurement of Productive Efficiency : Techniques and Applications*, New York, Oxford University Press.

PHILLIPS (J. M.) and MARBLE (R. P.), 1986 — Farmer education and efficiency : a frontier production function approach, *Economics of Education Review*, 5, pp. 257-264.

SCHMIDT (P.), 1986 — Frontier production functions, *Econometric Reviews*, 4, pp. 289-328.

SCHMIDT (P.) and SICKLES (R. C.), 1984 — Production frontiers and panel data, *Journal of Business and Economic Statistics*, 2, pp. 367-374.

SHARIFF (N. R.) and DAR (A. A.), 1996 — An empirical study of the patterns and sources of technical inefficiency in traditional and HYV rice cultivation in Bangladesh, *Journal of Development Studies*, 32, pp. 612-629.

TAUB (A. J.), 1979 — Prediction in the context of the variance components model, *Journal of Econometrics*, 10, pp. 103-108.

TAYLOR (T. G.), DRUMMOND (H. E.) and COMES (A. T.), 1986 — Agricultural credit programs and production efficiency : an analysis of traditional farming in South-Eastern Minas Gerais, Brazil, *American Journal of Agricultural Economics*, 68, pp. 110-119.

TIMMER (C. P.), 1971 — Using a probabilistic frontier production function to measure technical efficiency, *Journal of Political Economy*, 79, pp. 776-794.

ZELLNER (A.), KMENTA (J.) and DREZE (J.), 1966 — Specification and estimation of Cobb-Douglas production function models, *Econometrica*, 34, pp. 784-795.