5. Analysis of Efficiency and Productivity Changes in Grain Farming: Stochastic Frontier Production Function Approach

5.1 Introduction

This chapter analyses efficiency and productivity issues in grain production of Mongolian agriculture in the period 1976-1989 using the traditional partial factor productivity (PFP) measures and stochastic frontier production function (SFPF) models. The chapter is organised as follows. Section 5.2 discusses the PFPs in grain production and depicts the PFP indicators. Section 5.3 discusses the specification of the SFPF model with time-varying inefficiency effects model and applies it to Mongolian grain farms in the period 1976-1989. In this section, the specifications of adequate models were determined in two stages. In the first stage, a series of statistical tests was conducted to select the appropriate functional form. In the second stage, four alternative inefficiency-effects models were estimated from which the preferred models were identified for final reporting. The output elasticities with respect to individual inputs, the changes in technology, and the levels and changes in efficiency are reported for each of the three sub-periods. In Section 5.4 a SFPF model with inefficiency-effects model is estimated for grain farms. This model aims to determine the factors affecting efficiency levels among the grain farms and considers only 1987-1989 data as dictated by data availability. Section 5.5 concludes the chapter.

5.2 Partial Factor Productivity Measures

PFP is most widely used by practitioners for its simplicity of calculation and usefulness in various policy analyses. Among the most widely used PFPs in agriculture are land productivity (yield per ha) and labour productivity (output per manday). In the centrally-planned economies these PFPs have often been used as a major determinant for farm income and wages (Wong, 1986, p. 50). Despite the advantage of simplicity, these PFPs have major shortcomings in that they cannot separate the effects of technical progress and factor substitution in overall productivity improvement (Wong, 1986, p. 50). Moreover, the differing results of the individual PFPs may fail to give the overall picture of total factor productivity change. But if one finds that all the PFPs point towards the same direction, then a conclusion on the overall trend of total factor productivity may be drawn with less ambiguity. In the current section five PFPs were calculated and are defined as follows:

Land productivity- the total harvested quantity of grain divided by the total sown area (kg/ha);

Labour productivity- the total harvested quantity of grain divided by the total labour used in its production (kg/manday);

Fertiliser productivity- the total harvested quantity of grain divided by the total fertiliser expenses (kg/ g);

Capital productivity- the total harvested quantity of grain divided by the total cost of depreciation and machinery services (kg/tg);

Other costs' productivity- the total harvested grain divided by total other costs (kg/tg).

All these PFPs were calculated on an annual basis. Those inputs expressed in value terms (i.e., the cost of depreciation and machinery services, and other costs) were deflated for the last three years of the study period (1986-1989) by the respective official deflation rates[1] to make them comparable with the data of the previous years.

The PFP of individual inputs in period t can be written as:

[1] The deflation rates used for depreciation and machinery services as well as the other costs are presented in Chapter 4.

$$(5.1) \qquad PP_{it} = Y_t/X_{it}$$

where PP_{it} is the PFP of the i-th resource in the t-th period; i = land (ha), labour (mandays), fertiliser (tgs), capital (tgs) and other costs (tgs); $t=1,2,...14$; and Y_t is the total harvested grain of all farms in year t expressed in kg; and X_{it} is the total quantity of the i-th input used for production of grain in year t.

The five PFPs are reported in Table 5.1. In 1989, the land productivity was 1 126 kgs/ha and labour productivity was 419 kgs/manday; fertiliser productivity was 42 kgs/tg, and capital and other costs productivities were 6 kgs and 30 kgs of grain for each tg of their respective costs.

The annual growth rates of PFPs, calculated by regressing the logged indices upon a linear time trend, are given by:

$$(5.2) \qquad Ln\ Z_t = a + bT + e_t$$

where Z_t is the PFP index of interest (i.e., index of land, labour fertiliser, capital cost or other costs) and T is time (T = 1,2,3...14). The parameter b is interpreted as the annual percentage growth rate of the variable under investigation. As shown in the last row of Table 5.1, average PFPs for land, labour, capital and fertiliser have respectively increased by 5.31, 3.01, 2.92, and 1.21 per cent annually whereas the PFP for other costs has declined by the 6.1 per cent annually, over the whole study period (1987-1989).[2]

The positive and moderately high annual growth rates of partial productivities of land, labour, capital and fertiliser may suggest that the policy of increased use of modern inputs undertaken by the Ministry of Agriculture was somehow translated into increased output productivity.

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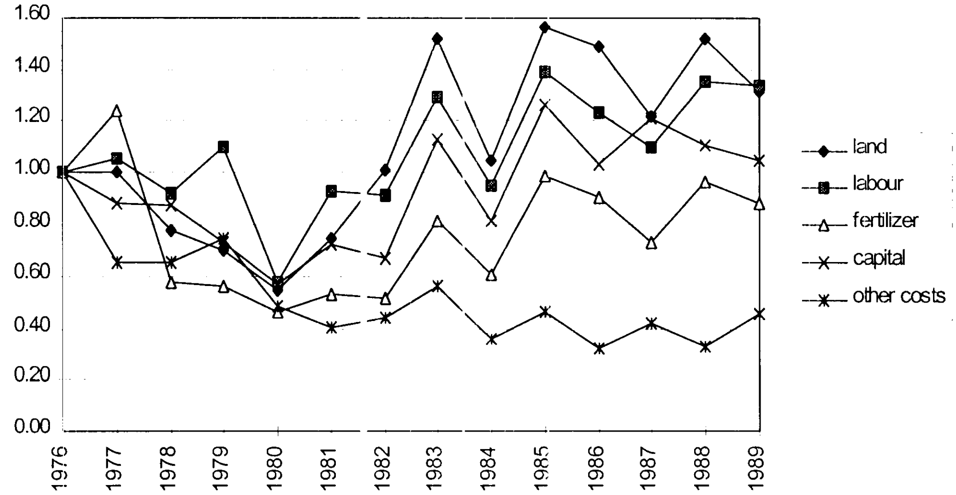
[2] The estimation results of the annual growth rates of PFPs for individual inputs in grain production are reported in Appendix 1, Tables A1.1 and A1.2. The results suggest that the PFP growth rates of all individual inputs are significant at five percent level except that of fertilizer.

Table 5.1 Partial factor productivities of grain farms, 1976-1989

	Partial factor productivity of:				
Year	Land (kg/ha)	Labour (kg/manday)	Fertiliser (kg/tg)	Capital (kg/tg)	Other costs (kg/tg)
1976	857	312	48	5	64
1977	853	328	59	5	42
1978	665	287	28	5	42
1979	599	343	27	4	48
1980	471	181	22	3	31
1981	635	289	25	4	26
1982	861	285	25	4	28
1983	1 299	403	39	6	36
1984	898	296	29	4	23
1985	1 337	433	47	7	30
1986	1 276	384	43	6	21
1987	1 045	342	35	7	27
1988	1 297	422	46	6	21
1989	1 126	419	42	6	30
Annual growth rate (per cent)	5.31	3.01	1.21	2.92	-6.1

Figure 5.1 **Partial factor productivity indices of grain farms, 1976-1989**



As Figure 5.1 depicts, despite considerable year-to-year fluctuations, some patterns of change in PFP indices can be observed over time:[3] until 1980, a sharp decline in the partial productivities was observed for almost all inputs. After 1980, partial productivities of land, labour and capital gradually picked up and exceeded the productivity levels of the base year. The increases in partial productivities of land and labour were relatively high.

Although year-to-year fluctuations of the individual PFP indices followed a similar pattern, one can observe the overall divergence in the trend of PFPs between other costs and the other inputs. This divergence suggests that it is not possible to determine without ambiguity the overall trend of productivity growth in the grain sector from the results of PFP. Therefore, a more generalised approach which enables one to correctly identify and quantify the productivity growth is needed.

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[3] These are the cumulative PFP indices where 1976 was selected as the base year.

5.3 Stochastic Frontier Production Function with Time-varying Inefficiency Effects Model

The choice of the principal analytical method used in this study was influenced by the nature of the centrally-planned economic system. The basic assumptions underlying market-based models (e.g. cost functions, profit functions etc.), such as competitive input and output markets and a firm's cost-minimising or profit-maximising behaviour, are not applicable in this case. Instead, output-maximising behaviour is believed to be more in line with the output target system in the centrally-planned system. For this reason, the majority of empirical studies involving centrally-planned economies have opted for the use of production functions which are based on the assumption of output-maximising behaviour stated above.

Within the overall production function approach, SFPF models – see Lovell (1993) and Coelli (1995b) -- were used in this section. They were chosen for several reasons. First, as noted by Coelli (1995b), the SFPF approach is well suited to the analysis of production efficiency in industries in which data noise is likely to be a particular problem. Mongolian crop farming experiences large variability in yields as a consequence of a hostile and volatile climate. A second reason for the choice of the SFPF method is that, when applied to panel data, SFPF models are capable of capturing both efficiency change and technical change as components of productivity change. This contrasts with the traditional productivity measurement methods – index numbers and aggregate production analyses – which, because they ignore efficiency effects, result in potential biases (Grosskopf 1993). The decomposition of productivity changes into efficiency changes and technical changes introduces an additional dimension to the analysis from the policy perspective, where each decomposed element often entails different policy recommendations (Nishimizu and Page, 1982; Perelman, 1995).

A SFPF differs from a conventional OLS production function in the structure of the error term. The SFPF error term is divided into two elements: (i) a symmetric random error, associated with measurement error of the output variable and the contribution of the omitted variables from the model, and (ii) a non-negative random variable associated with technical inefficiencies of production.

A SFPF for panel data may be defined as:

$$(5.3) \qquad Y_{it} = f(X_{it};\beta)exp(V_{it} - U_{it}), \qquad i = 1,2, ..., N, t = 1,2, ..., T,$$

where Y_{it} denotes the production level for the i-th farm in the t-th year; X_{it} is a vector of inputs associated with the production of the i-th farm in the t-th period of observation; β is a vector of unknown parameters associated with the X-variables; $f(.)$ is a suitable function describing the production technology (such as the translog discussed below); V_{it}s are assumed to be independent and identically distributed random errors following a normal distribution with zero mean and variance, σ_V^2; and U_{it}s are non-negative random variables, called the technical inefficiency effect. Individual inefficiency-effects models in a SFPF framework differ among each other in the way the technical inefficiency effects, U_{it}s, are modelled. The next section discusses the technical inefficiency-effects model with a parametric time-varying structure, which was used in the current study.

5.3.1 Model specification and estimation

The time-varying inefficiency effects model in the SFPF (Battese and Coelli, 1992) are defined as:

$$(5.4) \qquad U_{it} = \eta_{it}U_i = \{exp[-\eta(t-T)]\}U_i, \qquad t \in \tau(i),$$

where η is an unknown parameter to be estimated; U_i is an independent and identically distributed random variable having a truncated normal distribution with unknown mean μ and variance σ^2; and $\tau(i)$ is the sub-set of T_i time periods of the total set of T periods for which the observations for the i-th firm are available.

It is observed that as t increases, U_{it} (inefficiency) decreases, increases, or is constant through time if η is positive, negative, or zero, respectively.

The formulation (5.4) assumes that the technical inefficiency effect for a given firm in a particular time period is the product of a random variable associated with that firm and an exponential time trend.

The technical efficiency (TE) of the *i*-th farm in the *t*-th year is defined by the ratio of the observed output level to the corresponding frontier output level defined by the inefficiency effect being zero. Given the specifications of the SFPF model (5.3 and 5.4), technical efficiency is defined as:

(5.5) $$TE_{it} = exp(-U_{it}).$$

Battese and Coelli (1992) show that the minimum mean-squared-error predictor of technical efficiency for the *i*-th firm in the *t*-th time period can be written as:

(5.6) $$E\left[exp(-u_{it})|E_i\right] = \left\{ \frac{1 - \Phi\left[\eta_{it}\sigma_i^* - \left(\mu_i^* / \sigma_i^*\right)\right]}{1 - \Phi\left(-\mu_i^* / \sigma_i^*\right)} \right\} exp\left[-\eta_{it}\mu_i^* + \frac{1}{2}\eta_{it}^2\sigma_i^{*2}\right]$$

where E_i depicts a $(T_i \ x \ 1)$ vector of E_{it}'s (expected values) associated with the time periods observed for the *i*-th firm, where $E_{it} = V_{it} - U_{it}$; and

(5.7) $$\mu_i^* = \frac{\mu\sigma_\upsilon^2 - \eta_i' E_i \sigma^2}{\sigma_\upsilon^2 + \eta_i'\eta_i\sigma^2}$$

(5.8) $$\sigma_i^{*2} = \frac{\sigma_\upsilon^2\sigma^2}{\sigma_\upsilon^2 + \eta_i'\eta_i\sigma^2}$$

where η_i is the $(T_i \ x \ 1)$ vector of η_{it} values associated with the time periods observed for the *i*-th firm; and $\Phi(.)$ is the distribution function for the standard normal random variable.

Battese and Coelli (1992) further proposed that the mean technical efficiency of the sample firms in the *t*-th period, $TE_t = E[exp(-\eta_t U_i)]$, where $\eta_t = exp[-\eta(t-T)]$, be estimated by

(5.9) $$TE_t = \left\{ \frac{1 - \Phi\left[\eta_t \sigma - \left(\mu/\sigma\right)\right]}{1 - \Phi\left(\mu/\sigma\right)} \right\} exp\left[-\eta_t \sigma + \frac{1}{2}\eta_t^2 \sigma^2\right].$$

The method of maximum likelihood is used to estimate the parameters of the model (5.1) and the technical efficiency predictors. This was done using the computer program, FRONTIER, Version 4.1 – see Coelli (1994). The derivations of the likelihood function and the maximum-likelihood estimators of this frontier model are given by Battese and Coelli (1992).

A major advantage of this model is that it is a fairly general formulation and its less general nested models can be tested in successive stages in order to select the preferred model (Battese and Coelli, 1992). Therefore, after estimating the original model given by equations (5.3-5.5), three special cases, each involving different restrictions on the original model, have been estimated. These additional restrictions are as follows. First:

(5.10) $\eta = 0.$

This restriction involves the assumption that firm inefficiency effects are time-invariant. In this case the original model (5.3-5.5) collapses to the time-invariant inefficiency effects model of Battese, Coelli and Colby (1989). Second:

(5.11) $\mu = 0.$

This restriction assumes that the original model (5.3-5.5) involves a half-normal distribution. Third:

(5.12) $\gamma = \eta = \mu = 0.$

This last specification imposes the assumption that the traditional average response function is adequate representation for the production technology.

5.3.2 Functional forms, variables and statistical tests

In this study, the SFPF with time-varying inefficiency effects model was estimated for two popular functional forms, i.e., translog and Cobb-Douglas.[4] The major advantage of using these functional forms is that because the estimated parameters are linear in their logarithmic form, the estimation and interpretation of the parameters are less problematic. The basic features of the two functional forms, i.e., translog and Cobb-Douglas, used in the study are discussed below.

Translog function

The translog function, first proposed by Heady and Dillon (1961, pp. 205-8) and followed up by Christensen *et al.*, (1973), is a generalised version of the Cobb-Douglas functional form. It is known as a flexible functional form because it needs a minimum number of parameters without imposing any arbitrary restrictions on economic behaviour of production units (Fuss, McFadden and Mundlak, 1974). The translog function is non-homogeneous and does not impose any restrictions upon returns to scale and substitutability between the inputs. Also, the fact that the parameters of the translog function are linear makes its estimation less difficult compared to other flexible such as CES and Generalized Leontief, which are non-linear in their parameters.

However, the main weakness of the translog function is that, because there may be a substantial number of parameters to be estimated, multi-collinearity and degrees of freedom problems may arise. Furthermore, as the parameter coefficients of the translog function are not directly interpretable because of the second-order terms involved in the function, additional calculations are required in order to get the partial output elasticities of individual inputs. It may even get technically quite cumbersome to calculate these partial output elasticities if the translog function involved more than three inputs. However, if one considers the translog function as a second-order Taylor series approximation around the mean of the data (instead of considering it as an exact description of the production technology) and

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[4] It should be noted that the Cobb-Douglas form is a less general restricted form of translog.

normalise the data around their sample mean values, then the first-order terms of the translog function are directly interpretable as partial output elasticities at the mean of the data (Wyzan, 1981). This is because after taking the first-order derivative of (5.13) with respect to an input, the second and third components of the resulting equation (5.14) become zero. The data analysis in this chapter follows the above procedure.

The translog SFPF with five input variables and a time trend (as used in the current study) is expressed as:

$$(5.13)\qquad lnY_{it} = \beta_0 + \sum_{j=1}^{5}\beta_j lnx_{jit} + \tfrac{1}{2}\sum_{j=1}^{5}\sum_{k=1}^{5}\beta_{jk} lnx_{jit} lnx_{kit} + \sum_{j=1}^{5}\beta_{tj} t lnx_{jit}$$

$$+\beta_t t - \tfrac{1}{2}\beta_{tt} t^2 + V_{it} - U_{it}, \qquad i = 1.....N,\ t = 1.....T.$$

where the subscripts *i*, *t*, *j* and *k* represent the *i*-th farm, the *t*-th year of observation and the *j*-th and the *k*-th input respectively.

The partial output elasticity with respect to the *j*-th input is calculated as:

$$(5.14)\qquad \eta_j = \partial lnY/\partial lnx_j = \beta_j + \Sigma\beta_{jk}\, lnx_{kit} + \beta_{tj} t\,.$$

It can be seen from (5.14) that the partial output elasticity is not only firm specific but also time specific.

The rate of technical change can be calculated as:

$$(5.15)\qquad \eta_t = \partial lnY/\partial lnt = \beta_t + \beta_{tt} t + \sum_{j=1}^{5}\beta_{tj} lnx_{jit}\,.$$

Cobb-Douglas function

The Cobb-Douglas function has been by far the most widely used form in empirical studies of production primarily because of its simplicity. However, it should be noted that it is also a very restricted functional form, imposing a number of unnecessary restrictions on the production technology. These restrictions are that it is homogeneous of degree one and is characterised by constant production elasticities, constant scale economies and unitary elasticity of substitution between inputs.

If one imposes the restrictions $\beta_{tt} = \beta_{tj} = \beta_{jk} = 0$ on equation (5.13), the translog function collapses to a Cobb-Douglas function with Hicks-neutral technical change:

$$(5.16) \qquad lnY_{it} = \beta_0 + \sum_{j=1}^{5} \beta_j \, nx_{jit} + \beta_t t + V_{it} - U_{it}$$

where $i = 1.....N$, $t = 1.....T$.

In this form β_j is the partial output elasticity of the j-th input and β_t indicates the rate of Hicks-neutral technical change.

Variables

The following output and input variables were selected for the above models:[5]

Output (dependent variable) - harvested grain (tonnes);.

Land - sown area for grain production (hectares);

Labour - labour used in the production of grain (mandays);

Capital - the sum of the costs associated with the depreciation and machinery services of grain production (tgs);

Fertiliser - the cost of fertiliser applied to grain fields (tgs); and

Other costs - the costs associated with pesticides and other minor expenses used in production (tgs).

Furthermore, Time is used a proxy for technical change.

[5] Detailed discussion of the individual variables is presented in Chapter 4.

Statistical tests

Likelihood-ratio tests were used to select the preferred functional forms, to test for technical change and to test the significance of the variance parameters in the stochastic frontier production functions.

The likelihood-ratio test statistic (Greene, 1990b) is:

$$(5.18) \qquad \lambda = -2\{log[Likelihood\ (H_0) - Likelihood\ (H_1)]\}$$

and it has a chi-square distribution, with parameter equal to the number of parameters assumed to be zero in the null hypothesis, H_0, provided H_0 is true.

The likelihood-ratio statistic was also used to construct a Chow test to assess whether structural change had occurred during the study period.

It should be noted here that all statistical tests conducted in Chapters 5 (the current chapter) and 6 are based at five per cent level of confidence interval.

5.3.3 Empirical results

The SFPF with time-varying inefficiency effects model defined by equation (5.13), was estimated for the three separate sub-periods 1976-1980, 1981-1985, 1986-1989, as well as for the full sample period (1976-1989).

As discussed earlier in Chapter 4, each sub-period (which coincides with an individual five-year plan of the national economy) reflected a significant policy change in terms of agricultural development strategy of the sector. For instance, during the first sub-period (1976-1980) a further expansion of conventional inputs such as land and labour and a tighter top-down control of state farms were seen as major stimulators for output growth, whereas during the second (1981-1985) and third (1986-1989) sub-periods, so called “intensification factors” including introduction of new technology and granting of higher autonomy to state farms were increasingly emphasised for further output growth.

A Chow test of separate sub-period models vs. a single model for the full 14-year period (to establish if structural change was observed) supported the estimation of separate sub-period models. The parameter estimates and results of the Chow test are reported in Appendix 1, Table A1.3.

Given that separate models for the three sub-periods are appropriate, a final set of preferred models was identified in two successive stages following a similar approach to that of Kumbhakar and Hjalmarsson (1993). In the first stage, the estimation of SFPFs was conducted for alternative functional forms in each of the three sub-periods (Section 5.3.3.1) and the preferred functional forms are selected using the likelihood-ratio tests. Then, in the second stage, based on the preferred functional forms selected earlier, several alternative models for technical inefficiency effects were estimated. After conducting a series of statistical tests on the results of these alternative inefficiency models, the preferred final set of models was identified. The rationale of this two-stage approach is that the frontier production function underlying the prevailing production technology against which individual farms are assessed should be identified before efficiency estimates are calculated. As the technical change is modelled as an explanatory variable in the frontier production, the presence of technical change is identified in the first stage.

5.3.3.1 Alternative functional forms

The output elasticities of the SFPFs with time-varying inefficiency effects model for the grain farms under the alternative functional forms are reported in Table 5.2.[6] Except for fertiliser in the second sub-period, all partial output elasticities at the mean of the data were of the expected sign and magnitude. In the first sub-period, the time variable as a proxy for technical change, was found to be negative in the case of the translog function but positive in the case of the Cobb-Douglas function. In the second sub-period, positive technical change was found in both the translog and Cobb-Douglas functional forms. In the third sub-period, negative

[6] The full report of the parameter estimates of the models is given in Appendix 1, Tables A1.4-A1.6.

Table 5.2 Output elasticities of the SFPFs with time-varying inefficiency effects model for grain farms under alternative functional forms, 1976-1980; 1981-1985; 1986-1989[a]

Variables		Translog	Cobb-Douglas
1976-1980:			
Land	β_1	0.20	0.306
		(0.11)	(0.087)
Labour	β_2	0.061	0.083
		(0.051)	(0.031)
Fertiliser	β_3	0.095	0.020
		(0.039)	(0.025)
Capital	β_4	0.6396	0.635
		(0.1004)	(0.092)
Other costs	β_5	0.0145	0.046
		(0.0302)	(0.027)
Time	β_6	-0.027	0.024
		(0.066)	(0.076)
1981-1985:			
Land	β_1	0.36	0.561
		(0.11)	(0.078)
Labour	β_2	0.427	0.378
		(0.077)	(0.074)
Fertiliser	β_3	-0.054	-0.032
		(0.053)	(0.046)
Capital	β_4	0.327	0.201
		(0.096)	(0.069)
Other costs	β_5	0.068	0.008
		(0.041)	(0.035)
Time	β_6	0.133	0.160
		(0.031)	(0.038)
1986-1989:			
Land	β_1	0.329	0.397
		(0.088)	(0.061)
Labour	β_2	0.232	0.145
		(0.059)	(0.049)
Fertiliser	β_3	0.080	0.0240
		(0.039)	(0.0304)
Capital	β_4	0.415	0.430
		(0.076)	(0.056)
Other costs	β_5	0.054	0.085
		(0.027)	(0.023)
Time	β_6	-0.003	-0.033
		(0.063)	(0.024)

[a] Estimated standard errors are presented below the corresponding parameter estimates.

technical change was found in both the translog and Cobb-Douglas functional forms; however, it was statistically insignificant due to high standard errors. Thus, these results, especially those in the first sub-period, suggest that the choice of functional forms does affect the signs and magnitude of technical change.

The mean efficiency scores under alternative functional forms are reported in Table 5.3.

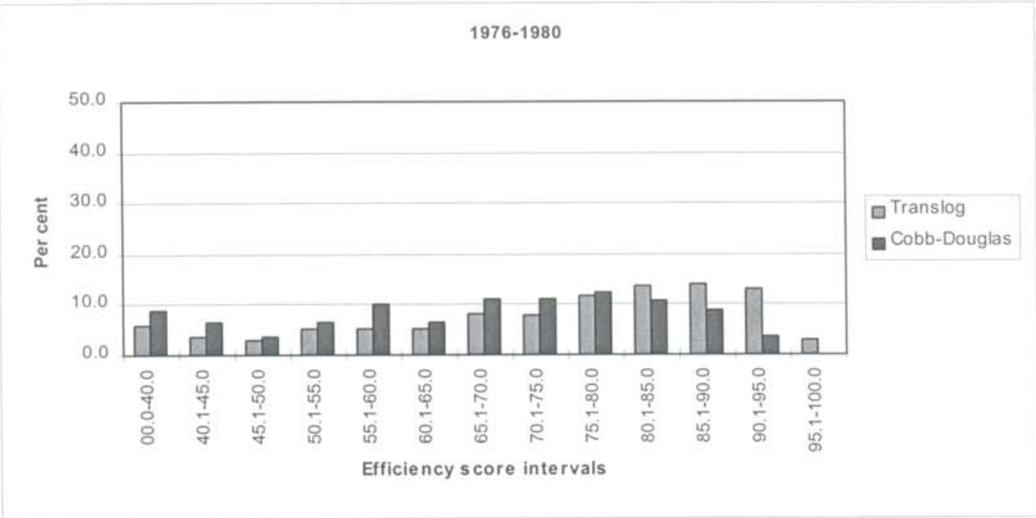
Table 5.3 Mean efficiency scores of grain farms under alternative functional forms, 1976-1980; 1981-1985; 1986-1989

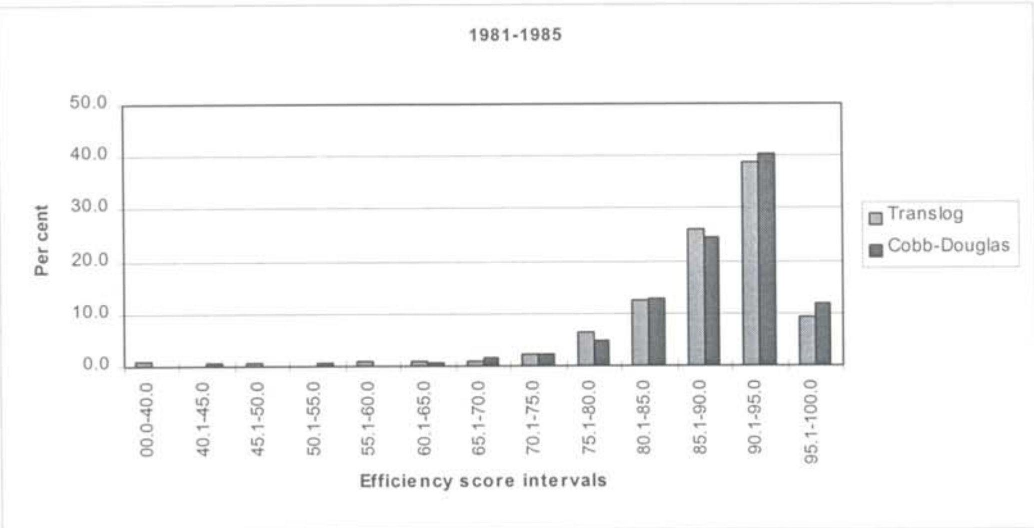
Period	Translog	Cobb-Douglas
1976-1980	0.730	0.662
1981-1985	0.872	0.884
1986-1989	0.740	0.842

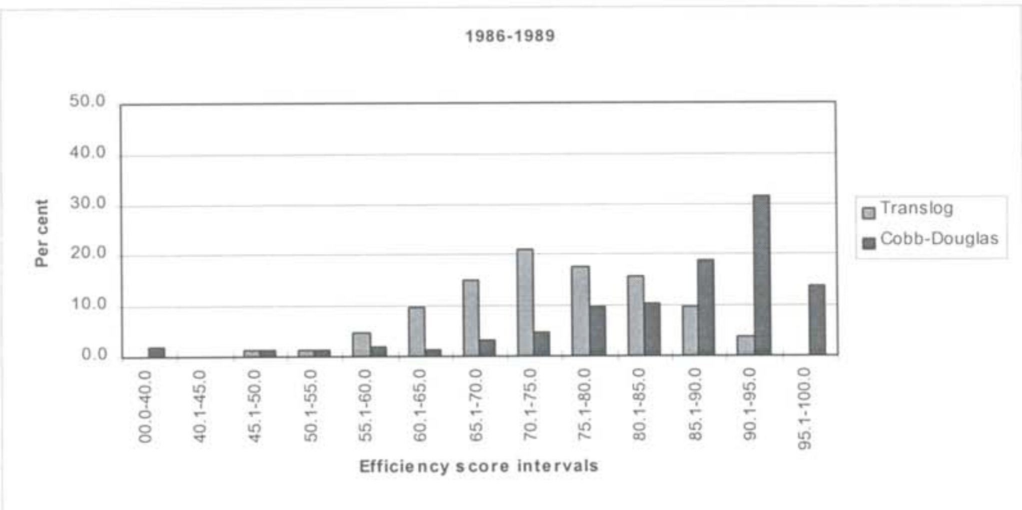
In the first sub-period, the mean technical efficiency of the translog (0.730) was higher than that of the Cobb-Douglas (0.662). In the second and third sub-periods, however, the mean technical efficiency of the Cobb-Douglas (0.884 and 0.842) was higher than that of the translog (0.872 and 0.740).

Figure 5.2 illustrates the distribution of efficiency scores estimated under alternative functional forms. In the first and second sub-periods, the translog and the Cobb-Douglas functions appeared to follow a similar distributional pattern. However, in the third sub-period, the translog function produced a more normal distributional pattern, whereas the Cobb-Douglas function produced the efficiency distribution more right of the centre. These results suggest that the selection of functional forms does effect the levels and distributions of farm efficiency. It is therefore implied that careful selection of the functional form is important. This result contradicts the findings of Good *et al.* (1993) and Ahmad (1994, p. 94) who

Figure 5.2 **Effects of alternative functional forms on efficiency scores of grain farms, 1976-1980; 1981-1985; 1986-1989**







suggest that the scores of the efficiency measures do not depend on functional form.

As Table 5.4 reports below, a series of statistical tests was conducted for each of the time periods to select the preferred functional forms for the next stage of the analysis. In addition to the tests for functional forms, another test was conducted to determine if the non-neutral technical change was present for the translog function.

The results of the statistical tests were as follows:

1) For the first sub-period (1976-1980), given the specification of the full tranlsog functional form, the null hypothesis that all second-order term variables are not significantly different from zero was strongly rejected. The translog functional form was therefore preferred to the Cobb-Douglas functional form. Also, the null hypothesis that non-neutral technical change is absent was strongly rejected. Hence, it is concluded that non-neutral technical change was exhibited by the model.

2) For the second sub-period (1981-1985), given the specification of the full tranlsog functional form, the null hypothesis that all second-order term variables are not significantly different from zero was strongly rejected. Therefore, the translog functional form was preferred to the Cobb-Douglas. The null hypothesis that non-neutral technical change is absent is also strongly rejected. The result therefore suggests that non-neutral technical change was exhibited by the model.

3) For the third sub-period (1986-1989), given the specification of the full tranlsog functional form, the null hypothesis that all second-order term variables are not significantly different from zero was strongly rejected. Therefore, the translog functional form was preferred to the Cobb-Douglas function. However, the null hypothesis that non-neutral technical change is absent was not rejected. The result therefore suggests that technical change was not present.

To sum up, the outcomes of the statistical tests suggest the following as preferred specifications:

For the first sub-period (1976-1980): translog;

For the second sub-period (1981-1985): translog;

For the third sub-period (1986-1989): translog with no technical change.

Table 5.4 **Generalised likelihood-ratio tests of hypotheses for parameters of the SFPF models for grain farms, 1976-1980; 1981-1985; 1986-1989**

Assumption	Null Hypothesis H_0	$Ln[L(H_0)]$	Value of λ statistic	Critical value	Decision
1976-1980					
1.0 Translog		-35.40			
1.1 Cobb-Douglas	H_0: $\beta_{ij}=\beta_{tj}=\beta_{tt}=0$, $i,j=1,\ldots,5$.	-67.16	63.51	32.67	Reject H_0
1.2 Translog (no technical change)	H_0: $\beta_{tj}=\beta_t=\beta_{tt}=0$ $j=1,\ldots,5$.	-57.25	43.68	14.07	Reject H_0
1981-1985					
2.0 Translog		-76.49			
2.1 Cobb-Douglas	H_0: $\beta_{ij}=\beta_{tj}=\beta_{tt}=0$, $i,j=1,\ldots,5$.	-107.04	61.11	32.67	Reject H_0
2.2 Translog (no technical change)	H_0: $\beta_{tj}=\beta_t=\beta_{tt}=0$ $j=1,\ldots,5$.	-87.14	21.30	14.07	Reject H_0
1986-1989					
3.0 Translog		13.41			
3.1 Cobb-Douglas	H_0 $\beta_{ij}=\beta_{tj}=\beta_{tt}=0$, $i,j=1,\ldots,5$.	-9.83	46.48	32.67	Reject H_0
3.2 Translog (no technical change)	H_0 $\beta_{tj}=\beta_t=\beta_{tt}=0$ $j=1,\ldots,5$.	9.81	7.18	14.07	Accept H_0

5.3.3.2 Alternative inefficiency-effects specifications

Based on the preferred functional forms selected in the previous section, the following four different inefficiency-effects models were estimated:

Model (a): time-varying inefficiency effects model (5.3-5.5) proposed by Battese and Coelli (1992)

Model (b):time-invariant inefficiency effects model (Battese, Coelli and Colby, 1989) – the restriction $\eta = 0$ of (5.10) was imposed on the model of (5.3-5.5).

Model (c): inefficiency effec follows the half-normal distribution – the restriction $\mu = 0$ of (5.11) was imposed on the model of (5.3-5.5).

Model (d): average production function – the restriction $\gamma = \mu = \eta = 0$ of (5.12) was imposed on the model of (5.3-5.5).

The partial output elasticities with respect to individual inputs in the three sub-periods under the alternative inefficiency-effects models are reported in Table 5.5. All partial output elasticities except for fertiliser in the second sub-period appear to have the expected signs and magnitude. The results suggest that the parameters of all the first-order terms across alternative inefficiency effect models tend to have similar values and signs.

The mean efficiency scores also tend to have similar values under alternative inefficiency-effects models as shown in Table 5.6.

Table 5.5 Output elasticities of the SFPFs for grain farms under alternative inefficiency-effects models[a], 1976-1980; 1981-1985; 1986-1989

Variables		Model (a) [b]	Model (b) [b]	Model (c) [b]	Model (d) [b]
1976-1980:					
Land	β_1	0.20	0.24	0.194	0.23
		(0.11)	(0.11)	(0.099)	(0.12)
Labour	β_2	0.061	0.044	0.062	0.066
		(0.051)	(0.056)	(0.049)	(0.062)
Fertiliser	β_3	0.095	0.099	0.096	0.107
		(0.039)	(0.041)	(0.038)	(0.046)
Capital	β_4	0.6396	0.662	0.627	0.64
		(0.1004)	(0.106)	(0.097)	(0.12)
Other costs	β_5	0.0145	0.010	0.016	-0.002
		(0.0302)	(0.032)	(0.029)	(0.035)
1981-1985:					
Land	β_1	0.36	0.36	0.37	0.44
		(0.11)	(0.11)	(0.12)	(0.12)
Labour	β_2	0.427	0.415	0.432	0.427
		(0.077)	(0.078)	(0.079)	(0.083)
Fertiliser	β_3	-0.054	-0.064	-0.053	-0.056
		(0.053)	(0.054)	(0.054)	(0.058)
Capital	β_4	0.327	0.334	0.3307	0.30
		(0.096)	(0.094)	(0.1004)	(0.11)
Other costs	β_5	0.068	0.076	0.068	0.065
		(0.041)	(0.041)	(0.042)	(0.045)
1986-1989:					
Land	β_1	0.278	0.240	0.278	0.304
		(0.073)	(0.075)	(0.072)	(0.082)
Labour	β_2	0.190	0.192	0.190	0.207
		(0.058)	(0.057)	(0.056)	(0.065)
Fertiliser	β_3	0.075	0.0545	0.075	0.063
		(0.039)	(0.0401)	(0.039)	(0.045)
Capital	β_4	0.452	0.5097	0.452	0.472
		(0.071)	(0.0701)	(0.071)	(0.077)
Other costs	β_5	0.068	0.058	0.068	0.043
		(0.026)	(0.027)	(0.026)	(0.031)

[a] Estimated standard errors are presented below the corresponding parameter estimates.

[b] Model (a): Time-varying inefficiency effects model.
Model (b): Time-invariant inefficiency effects model.
Model (c): Half-normal distribution is assumed for the inefficiency term.
Model (d): Average production function where no inefficiency is assumed.

Table 5.6 Mean efficiency scores of grain farms under alternative inefficiency-effects models,[a] 1976-1980; 1981-1985; 1986-1989

	Model (a)	Model (b)	Model (c)
1976-1980	0.730	0.710	0.796
1981-1985	0.872	0.857	0.841
1986-1989	0.825	0.858	0.825

[a] Model (a): Time-varying inefficiency effects model.
Model (b): Inefficiency trend is not present.
Model (c): Half-normal distribution is assumed for the inefficiency term.

In Model (d), because an average function was assumed, no efficiency scores were calculated.

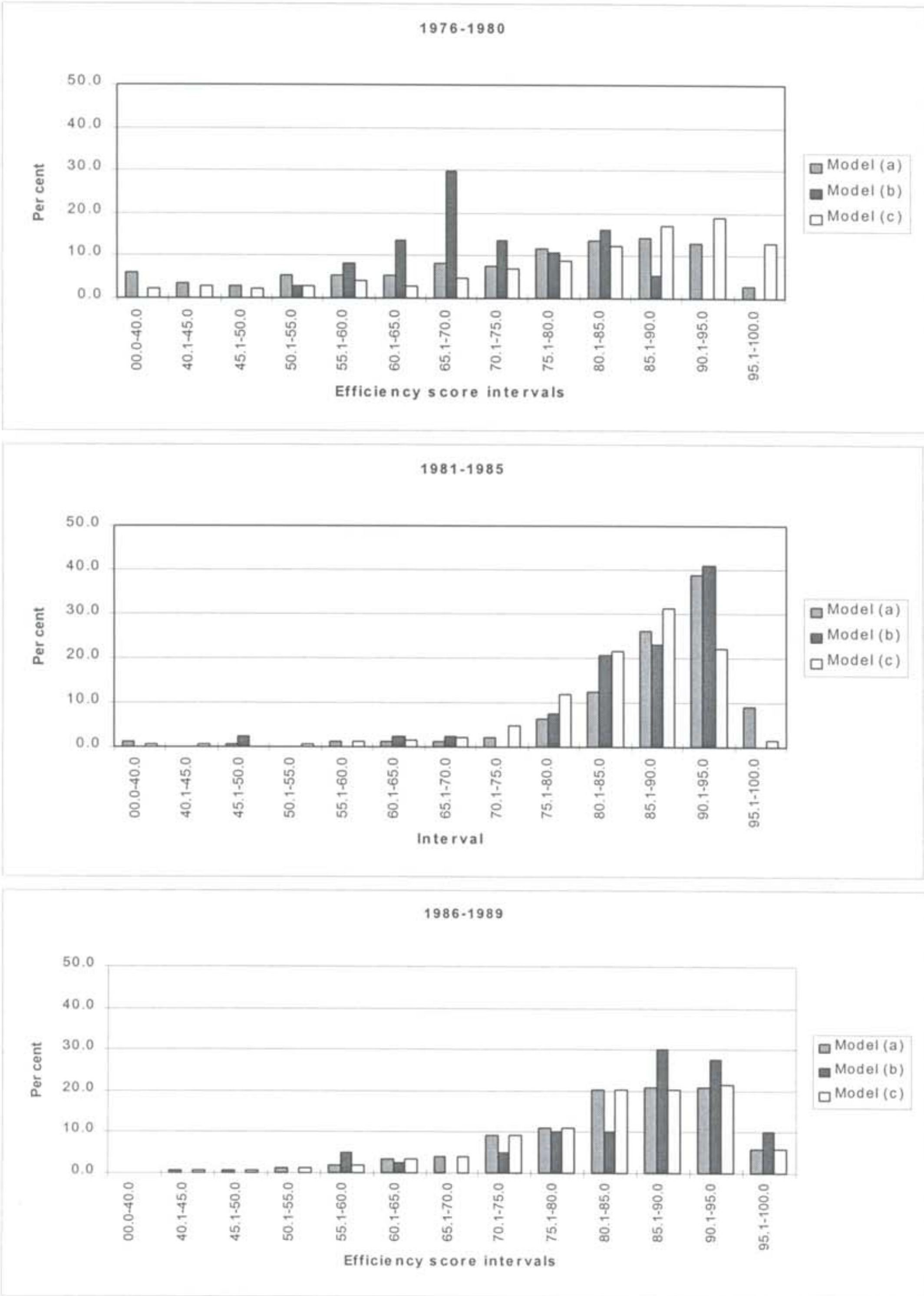
In terms of the distribution of efficiency scores, as shown in Figure 5.3, except for Model (b) in the first sub-period, all models in individual sub-periods seem to have similar distributional patterns.

The results of this section suggest that there is a little difference between alternative inefficiency-effects models either in terms of the parameter estimates of the stochastic frontier or the mean levels and distributions of farm efficiency scores.

The statistical tests for identifying the preferred inefficiency-effects model in each of the sub-periods are carried out in Table 5.7 and the results are summarised next.

For the first sub-period (1976-1980), the null hypothesis that η (the trend parameter for the inefficiency) is not significantly different from zero was rejected. Thus, a statistically significant inefficiency trend was established for this period. Next, the null hypothesis that $\mu = 0$ was not rejected, implying that the half-normal distribution for U_{it} is preferred. Finally, the null hypothesis that $\gamma = \eta = \mu = 0$ is rejected, implying that the traditional average response function in which farms are assumed to be fully efficient is not an adequate representation of the data.

Figure 5.3 **Effects of alternative inefficiency-effects models on efficiency scores of grain farms[a], 1976-1980; 1981-1985; 1986-1989**



[a] Model (a): Time-varying inefficiency effects model.
Model (b): Inefficiency trend is not present.
Model (c): Half-normal distribution is assumed for the inefficiency term.

Table 5.7 Generalised likelihood ratio tests of hypotheses for variance parameters of the SFPF models for grain farms, 1976-1980; 1981-1985; 1986-1989

Assumption	Null Hypothesis H_0	$Ln[L(H_0)]$	Value of λ statistic	Critical value	Decision
1976-1980					
Unrestricted model[a]		-35.40			
Inefficiency trend is not present	H_0: $\eta = 0$	-44.25	17.69	3.84	Reject H_0
Half-normal distribution for the inefficiency term is adequate	H_0: $\mu = 0$	-36.25	1.70	2.71[b]	Accept H_0
Inefficiency is not present	H_0: $\gamma = \eta = \mu = 0$	-49.20	27.58	7.05[b]	Reject H_0
1981-1985					
Unrestricted model[a]		-76.49			
Inefficiency trend is not present	H_0: $\eta = 0$	-77.68	2.39	3.84	Accept H_0
Half-normal distribution for the inefficiency term is adequate	H_0: $\mu = 0$	-77.66	2.34	2.71[b]	Accept H_0
Inefficiency is not present	H_0: $\gamma = \eta = \mu = 0$	-81.85	10.73	7.05[b]	Reject H_0
1986-1989					
Unrestricted model[a]		9.81			
Inefficiency trend is not present	H_0: $\eta = 0$	5.65	8.32	3.84	Reject H_0
Half-normal distribution for the inefficiency term is adequate	H_0: $\mu = 0$	9.82	0.2	2.71[b]	Accept H_0
Inefficiency is not present	H_0: $\gamma = \eta = \mu = 0$	-5.87	31.36	7.05[b]	Reject H_0

[a] Time-varying inefficiency-effects model is assumed here.

[b] If $\gamma = 0$ is included in the H_0, then λ has a mixed chi-square distribution (see Coelli, 1996a). The critical value for λ in this case is obtained from Kodde and Palm (1986).

So, in describing production technology, the SFPF is preferred to the average response function.

For the second sub-period (1981-1985), the null hypothesis that η (the trend parameter for the inefficiency) is not significantly different from zero was accepted. Thus, the result suggests that the inefficiency trend was stagnant over time for this second sub-period. Next, the null hypothesis that $\mu = 0$ was not rejected, implying that the half-normal distribution for U_{it} is preferred. However, the null hypothesis that $\gamma = \eta = \mu = 0$ is rejected, implying that the traditional average response function in which farms are assumed to be fully efficient is not an adequate representation of the data. It suggests that the SFPF is preferred to an average response function in describing production technology.

For the third sub-period (1985-1989), the null hypothesis that η is not significantly different from zero (the trend parameter for inefficiency) was rejected. However, the null hypothesis that $\mu = 0$ was not rejected, implying that the half-normal distribution for U_{it} is preferred. Finally, the null hypothesis that $\gamma = \eta = \mu = 0$ is rejected, implying that the traditional average response function in which farms are assumed to be fully inefficient is not an adequate representation of the data. So, the SFPF is preferred to the average response function in describing production technology.

In summary, the two consecutive statistical tests conducted above suggested the following specifications for the final preferred individual sub-period models:

For the first sub-period (1976-1980): Time-varying inefficiency effects model having a half-normal distribution (translog function with non-neutral technical change)

For the second sub-period (1981-1985): Time-invariant inefficiency effects model having a half-normal distribution (translog function with non-neutral technical change)

For the third sub-period (1986-1989): Time-varying inefficiency effects model having a half-normal distribution (translog function with no technical change)

In other words, the results of the statistical tests show that, in all three sub-periods, the SFPFs with inefficiency effects were favoured against the traditional average response function representations. This suggests that inefficiency was present consistently throughout the whole study period. The inefficiency trend increased in the first sub-period (1976-80), was stagnant in the second sub-period (1981-1985) and decreased in the third sub-period (1986-89). In all three sub-periods, the half-normal distributional form for U_{it} was favoured.

5.3.3.3 Parameter estimates

The parameter estimates of the preferred SFPFs in the three sub-periods are reported in Table 5.8 below The signs and magnitudes of the first-order terms interpreted as partial output elasticities were found to be reasonable except for fertiliser in the second sub-period. In that sub-period, the partial output elasticity with respect to fertiliser was found to be negative, but not significantly different from zero by an asymptotic *t*-test.

It can be seen from Table 5.8 that the partial output elasticity with respect to capital was found to be the largest among the inputs, ranging between 0.341 and 0.627. Its value decreased in the second sub-period and then slightly increased in the third sub-period. The partial output elasticity with respect to land was found to be the second largest. Its value varied between 0.194 and 0.36. In terms of trend it decreased in the second sub-period then increased in the third sub-period. The partial output elasticity with respect to labour was the third largest. In the first sub-period, the partial output elasticity with respect to labour was rather low (0.062) but statistically significant. In the second period the partial output elasticity with respect to labour jumped to a higher level (0.421), and in the third sub-period it declined (0.190). The relatively high estimates of output elasticities for traditional inputs such as capital, land and labour appear to support the relevance of the Ministry of Agriculture policy of increasing output by way of increased investment of capital, further expansion of land and an increased labour force.

These parameter estimates are also comparable with Ulziibat (1992), who estimated a Cobb-Douglas function for 19 grain farms of Forest-steppe region of Mongolia for the period 1976-1989. He estimated the partial output elasticity with respect to capital as 0.54 and that with respect to labour as 0.22.[7] The estimated output elasticity with respect to fertiliser in the present study was lower than for capital, land and labour. In the first (0.019) and third sub-periods (0.014) its value was found to be positive and significant at the five per cent level but in the second period (-0.004) it had a negative value but was not significant. These unexpectedly low or negative values of the partial output elasticity with respect to fertiliser suggest that the doubling of fertiliser use during the 14-year period (see Figure 1.2) had little influence upon yield. This was perhaps due to incorrect use of this important production input. This result seems to be in line with the findings of the earlier studies on grain production by Ulziibat (1992) and the World Bank (1995) who suggest that the impact of fertiliser use in grain production was either minimal or the estimated coefficients were not reliable due to high standard errors.

Output elasticity with respect to other costs was the lowest among the inputs and its value varied between 0.016 and 0.074. A sudden upward jump in the second sub-period was followed by a slight decline in the third sub-period.

The partial output elasticity with respect to time, i.e., technical change (at the mean of the data) was found to exhibit technical regress (6 per cent annually) in the first sub-period and then technical progress in the second sub-period (9 per cent annually). However, the technical change in the third sub-period was not estimated because the statistical test conducted earlier (the last row of Table 5.4) suggested that no statistically significant technical change was found in this sub-period. The technical regress observed in the first sub-period coincides with the period of "extensive" growth policy (1976-1980), when the emphasis was put on

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[7] Partial output elasticity with respect to land was not calculated because all explanatory variables in the Cobb-Douglas function were measured in per ha units.

Table 5.8 **Maximum-likelihood estimates for the parameters of the SFPFs with time-varying inefficiency effects models for grain farms, the preferred models[a], 1976-1980; 1981-1985; 1986-1989**

Variables		1976-1980	1981-1985	1986-1989
Constant	β_0	0.323	0.111	0.233
		(0.065)	(0.078)	(0.045)
Land	β_1	0.194	0.36	0.278
		(0.099)	(0.12)	(0.072)
Labour	β_2	0.062	0.421	0.190
		(0.049)	(0.079)	(0.056)
Fertiliser	β_3	0.096	-0.060	0.075
		(0.038)	(0.055)	(0.039)
Capital	β_4	0.627	0.341	0.452
		(0.097)	(0.099)	(0.071)
Other costs	β_5	0.016	0.074	0.068
		(0.029)	(0.042)	(0.026)
Time	β_6	-0.062	0.090	-
		(0.031)	(0.021)	-
$(\text{Land})^2$	β_7	-0.48	-0.194	-0.267
		(0.14)	(0.085)	(0.101)
$(\text{Labour})^2$	β_8	0.029	0.162	-0.025
		(0.019)	(0.077)	(0.052)
$(\text{Fert.})^2$	β_9	0.019	-0.004	0.014
		(0.012)	(0.034)	(0.021)
$(\text{Capital})^2$	β_{10}	0.25	-0.004	-0.146
		(0.19)	(0.089)	(0.074)
$(\text{Other costs})^2$	β_{11}	0.018	0.028	0.021
		(0.013)	(0.019)	(0.021)
$(\text{Time})^2$	β_{12}	-0.007	0.020	-
		(0.016)	(0.017)	-
(Land x Labour)	β_{13}	0.17	-0.04	-0.26
		(0.12)	(0.18)	(0.11)
(Land x Fert.)	β_{14}	0.161	0.30	0.25
		(0.097)	(0.14)	(0.11)
(Land x Capital)	β_{15}	0.13	0.15	0.40
		(0.31)	(0.16)	(0.13)
(Land x Other costs)	β_{16}	0.205	-0.10	0.044
		(0.059)	(0.11)	(0.068)
(Land x Time)	β_{17}	-0.301	0.234	-
		(0.075)	(0.082)	-

(Labour x Fert.)	β_{18}	-0.071	-0.04	0.128
		(0.042)	(0.12)	(0.088)
(Labour x Capital)	β_{19}	-0.17	0.07	0.19
		(0.144)	(0.17)	(0.13)
(Labour x Other costs)	β_{20}	-0.0163	-0.210	0.076
		(0.03)	(0.089)	(0.072)
(Labour x Time)	β_{21}	0.062	-0.108	-
		(0.04)	(0.066)	-
(Fert. x Capital)	β_{22}	-0.089	-0.16	-0.257
		(0.09)	(0.14)	(0.094)
(Fert. x Other costs)	β_{23}	-0.031	-0.079	-0.024
		(0.021)	(0.041)	(0.036)
(Fert. x Time)	β_{24}	-0.003	0.007	-
		(0.0244)	(0.039)	-
(Capital x Other costs)	β_{25}	-0.196	0.192	-0.117
		(0.07)	(0.089)	(0.083)
(Capital x Time)	β_{26}	0.189	-0.070	-
		(0.0753)	(0.079)	-
(Other costs x Time)	β_{27}	0.026	-0.031	-
		(0.018)	(0.024)	-
$\sigma^2_s = \sigma^2_v + \sigma^2$		0.51	0.184	0.072
		(0.17)	(0.033)	(0.017)
$\gamma = \sigma^2/\sigma^2_s$		0.871	0.35	0.47
		(0.05)	(0.13)	(0.14)
μ		-	-	-
		-	-	-
η		-0.51	-	0.201
		(0.12)	-	(0.073)
Log-likelihood		-36.25	-78.29	9.81

[a] **Estimated standard errors are presented below the corresponding parameter estimates.**

increased input use, rather than enhanced productivity, to ensure higher output. The significant technical progress that has occurred in the second sub-period (1981-1985) coincides with substantial investments of the Ministry of Agriuclture to new seeds, machinery and human resources and agricultural research in the crop sector. However, the absence of technical change in the third sub-period (1986-1989) did not seem to have matched with major efforts of the Ministry of Agriculture of introducing so called "intensive" technology in the crop sector (see Chapter 4) thus suggesting that these efforts have not been materialised into improved farm productivity.

As Table 5.9 shows, the returns to scale at the mean of the data, defined as the sum of the first-order terms related to inputs of the SFPF, are found to be either constant or mildly increasing. Farms in the first sub-period were characterised by constant returns to scale (0.99) and in the second and third sub-periods were characterised by mildly increasing returns to scale (1.14 and 1.06 respectively). This finding that the grain farms were characterised by moderately increasing or constant returns to scale does not supply any evidence of scale problems in these large-scale farms, as is often claimed today. This may explain why in the post-reform period, the large farms were reluctant to split into smaller units and why recent action of the Ministry of Agriculture has begun to reverse this fragmentation (see Chapter 8 for more discussion).

Table 5.9 Returns to scale of grain farms, 1976-1980; 1981-1985; 1986-1989

Period	Returns to scale $\beta_1 - \beta_2 + \beta_3 + \beta_4 + \beta_5$
1976-1980	0.99
1981-1985	1.14
1986-1989	1.06

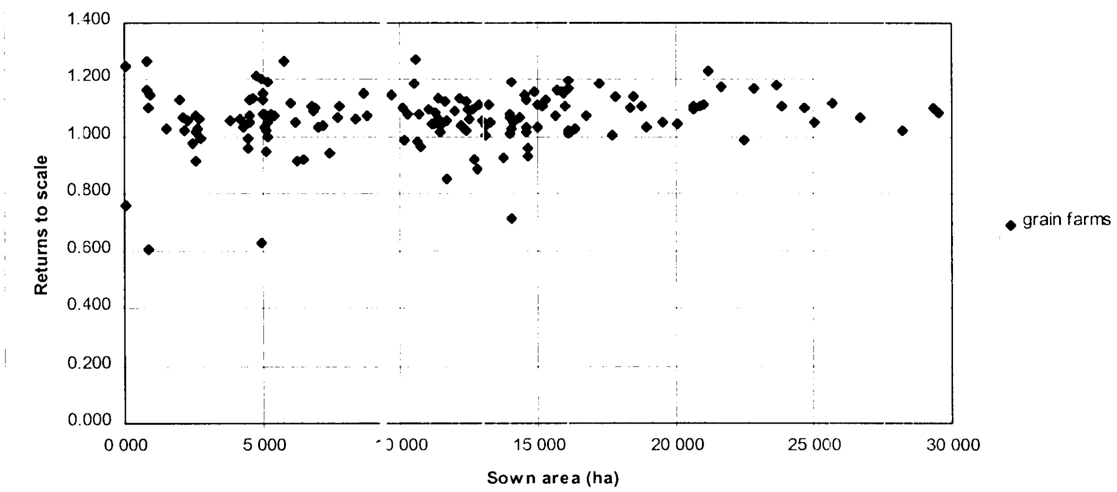
In order to identify the size at which farms were operating at constant returns to scale, the returns to scales were calculated for each farm[9] in the third sub-period

[8] Partial output elasticity with respect to land was not calculated because all explanatory variables in the Cobb-Douglas function were measured in per ha units.

[9] The returns-to-scale statistics of individual grain farms in the period 1986-1989 are reported in Appendix 1, Table A1.7.

(1986-1989) and plotted against their respective sown areas (a proxy for farm size) as shown in Figure 5.4. The result indicates that scale economies varied little across the ranges of farm scale in the sample. Nevertheless, the figure suggests that the majority of grain farms in the period 1986-1989 were operating either on or above the constant returns-to-scale region.

Figure 5.4 Relationship between farm size and scale economies for grain farms, 1986-1989



5.3.3.4 Efficiency scores and changes

A summary of the estimated technical efficiencies of the grain farms in the first, second and third sub-periods using the SFPF with time-varying inefficiency effects model is presented in Table 5.10.[10] The mean efficiency score of grain farms was 0.804 in the first sub-period, 0.829 in the second sub-period and 0.824 in the third sub-period.

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[10] The full report of the efficiency scores of the individual farms is given in Appendix 1, Tables A1.8-A1.10.

The signs and magnitudes of the trend variable for inefficiency term, η (Table 5.8), of the final preferred models suggest the following: The negative and significant value of η in the first sub-period implies that the inefficiency levels of grain farms increased during this period. Then the absence of a statistically significant trend value, η, in the second sub-period suggests that inefficiency levels remained

Table 5.10 Summary of technical efficiency scores of grain farms, 1976-1980; 1981-1985; 1986-1989

1976-1980		1981-1985		1986-1989	
Year	Efficiency score	Year	Efficiency score	Year	Efficiency score
1976	0.931	1981	0.829	1986	0.777
1977	0.889	1982	0.829	1987	0.811
1978	0.833	1983	0.829	1988	0.841
1979	0.740	1984	0.829	1989	0.869
1980	0.630	1985	0.829		
mean	0.804		0.829		0.824
std. d	0.161		0.085		0.107
max	0.931		-		0.869
min	0.630		-		0.777

unchanged during second sub-period. However, a positive and significant value of η in the third sub-period suggests that the inefficiency levels of grain farms decreased during this period. So, as reported in Table 5.10, farm efficiency decreased in the first sub-period from 0.931 (1976) to 0.630 (1980), remained constant in the second sub-period and increased in the third sub-period from 0.777 (1986) to 0.869 (1989). The data of Table 5.10 are shown graphically in Figure 5.5 to highlight the efficiency trends over time within each sub-period. The overall trend of efficiency change seems to be in line with expectations. The initial decline in farm efficiency occurs in the "extensive" growth policy period (1976-1980) when little attention was given to improving incentives, or higher autonomy for farm managers. The "intensive" growth policy which started in early 1980s appears to have not resulted in any significant change of farm efficiency in the second sub-period (1981-1985). This is most likely because the focus was on improved technologies, which take some time to be mastered and hence can cause low efficiencies when first introduced. However, in the last sub-period (1986-1989), when dramatic changes from farm re-organisation occurred, a marked upward trend in farm efficiency is observed. During this period, various forms of tenancy systems were introduced to give the producers greater incentive and the farm managers a higher autonomy (see more detailed discussion of these new farm policies in Chapter 4).

There was some concern that by splitting the overall panel of 14 years into three sub-periods and by estimating the SFPF with time-varying inefficiency effects model that one may be imposing too rigid a structure on the efficiency estimates. To investigate this issue, the SFPF model originally proposed by Aigner, Lovell and Schmidt (1977) was estimated using the same data set. This specification assumes that all u_{it}s are uncorrelated with each other. Hence, in this model, the panel nature of the data is ignored and thus the efficiencies are free to choose their own temporal pattern. The results are compared with those of the panel data models. The efficiency results of the unrestricted model[11] are plotted in Figure 5.6.

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[11] The parameter estimates and the mean efficiency scores are reported in Appendix 1, Tables A1.11 and A1.12.

Figure 5.5 **Efficiency trend of grain farms, 1976-1989**

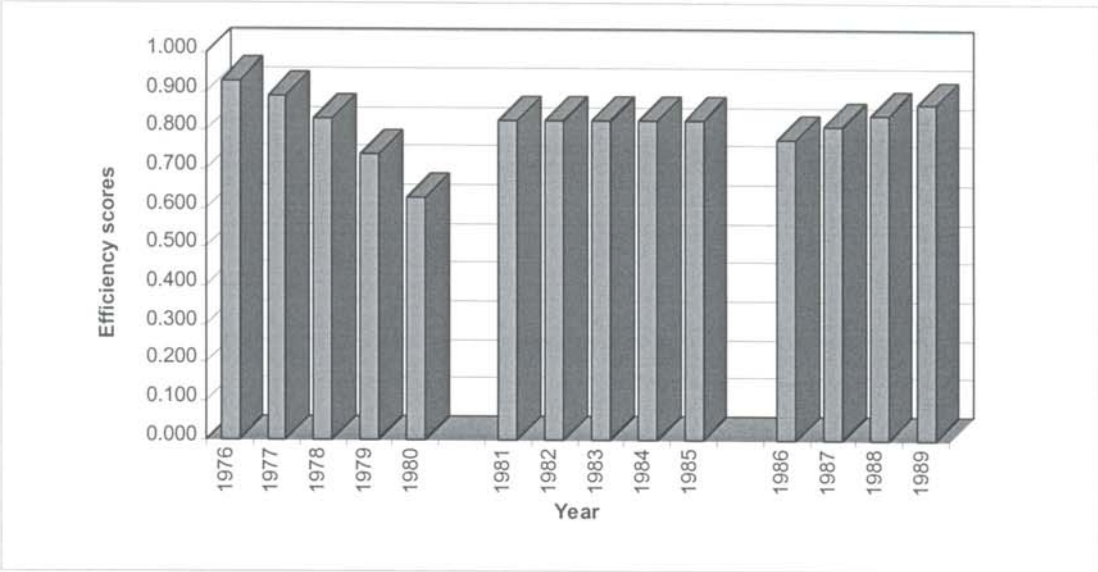


Figure 5.6 **Efficiency trend of grain farms using Aigner *et al.* (1977) model, translog, 1976-1989**

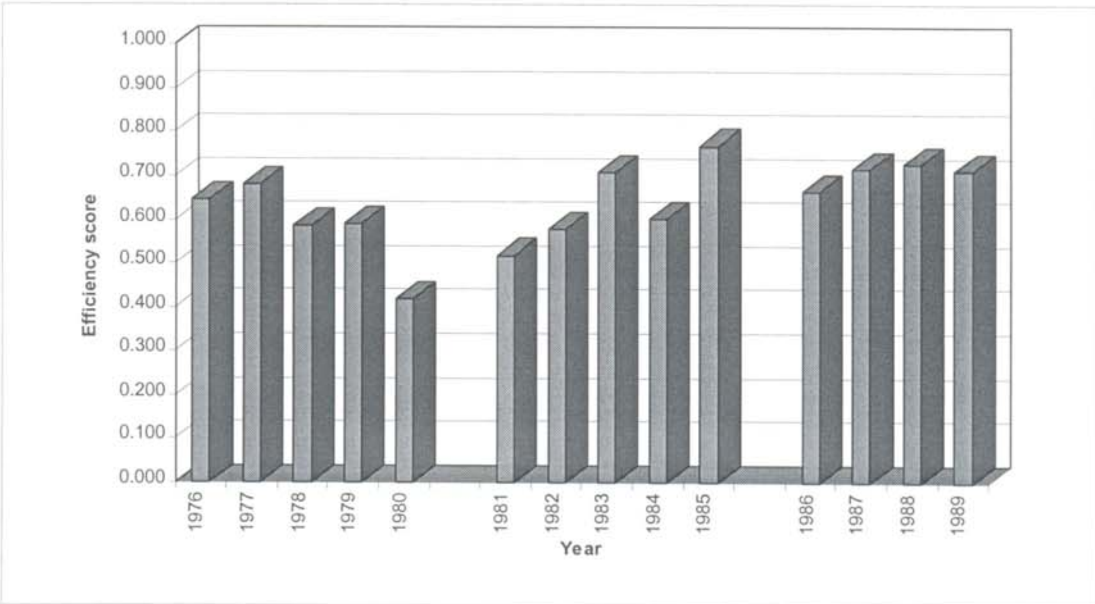
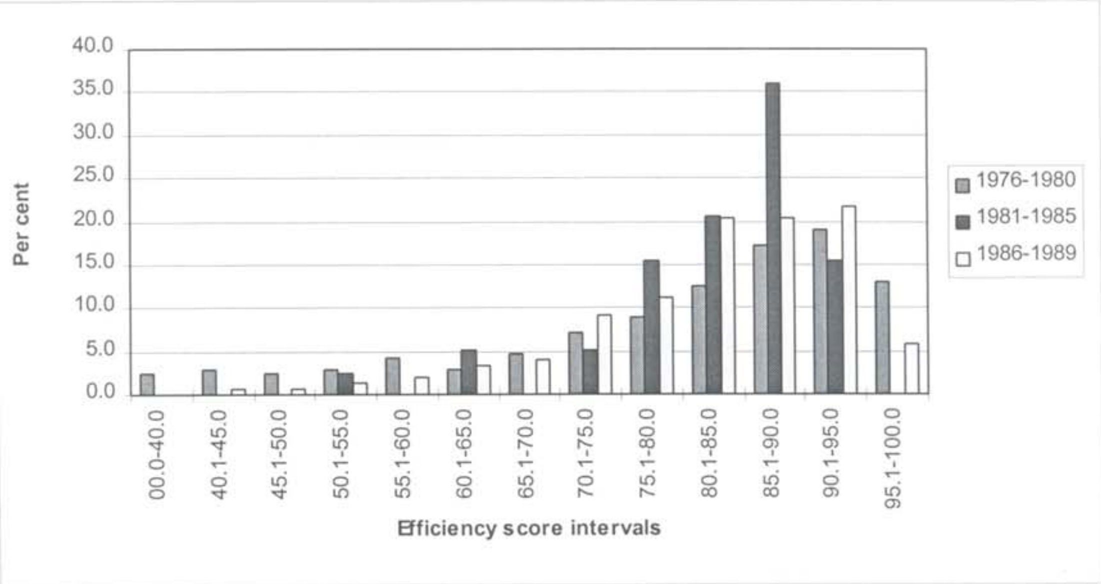


Figure 5.7 Distribution of efficiency scores of grain farms, 1976-1980; 1981-1985; 1986-1989



One can see here a similar pattern in the efficiency trends of grain farms to the case of the time-varying inefficiency effects model (Battese and Coelli, 1992) in the first and third sub-periods. In both cases the efficiency levels declined in the first sub-period and then increased in the third sub-period.

However, a some increase in the efficiency trend was seen in the second sub-period of the second model i.e., that of Aigner *et al.* (1977), whereas the efficiency trend in the main model was stagnant. Thus, the Aigner *et al.* (1977) model seems to support the efficiency trends established using the model of Battese and Coelli (1992).

The distribution of efficiency scores of farms in individual sub-periods is shown in Figure 5.7. The efficiency distributions of farms in all sub-periods have a similar shape, with a mode near 0.90 and a long left tail.

Furthermore, in the second sub-period more farms were working in the higher range of the efficiency distribution than in the other two sub-periods. However, a closer look at the efficiency distribution as detailed in Table 5.11 reveals that the percentages of farms performing below 85 per cent of efficiency levels were 51.0, 48.7, 52.5 in the first, second and third sub-periods respectively. Thus, the fact that approximately half the farms in all three sub-periods were performing in the interval below an 85 per cent efficiency level suggests that there was considerable room for efficiency improvement in grain production.

In order to investigate the relationship between efficiency score and farm size, the estimated efficiency score was ranked according to two criteria: sown area in ha and farm capital in tgs. To avoid the ambiguities associated with classifying farms into different sizes, all farms were classified into three groups: lowest 33rd percentile (small), medium 65th percentile (medium) and highest 100th percentile (large).

Efficiency ranking of grain farms by sown area (Table 5.12) demonstrated that the medium-size farms performed most efficiently in all three sub-periods (0.831, 0.861, 0.841). The small farms were found to be least efficient in all three sub-periods (0.761, 0.796, 0.799). This result suggests that medium and large farms performed at higher efficiency levels than did the smaller farms.

Efficiency scores of grain farms ranked according to farm capital (Table 5.13) suggest that the medium farms performed most efficiently in all three sub-periods (0.829, 0.867, 0.842). Large farms performed second-most efficiently in the first and third sub-periods (0.796, 0.834) and performed least efficiently in the second sub-period (0.781). The small farms performed second most efficiently in the second sub-period (0.824) and least efficiently in the first and third sub-periods (0.764, 0.798).

To sum up, when farm size was measured either by sown area or farm capital, medium-sized farms were consistently found to be the most efficient and, in most cases, large farms outperformed small farms in efficiency.

Next, in order to investigate the effects of natural conditions on farm performance, the efficiency scores of individual farms were ranked by agro-ecological region as shown in Table 5.14. It was found that the farms in the most fertile region (Selenge-Onon) were ranked as most efficient in two sub-periods (first and second sub-periods) and as the second-most efficient in one sub-period (second sub-period). The farms in the second most fertile region (Hangai-Huvsgul) were ranked as the second-most efficient in two sub-periods (first and third sub-periods) and least efficient in one sub-period (second sub-period). The farms located in the least-fertile region (the Central and Eastern Steppe) performed least efficiently in two sub-periods (first and third sub-periods) and most efficiently in one sub-period (second sub-period).

This result suggests a fairly consistent picture in efficiency ranking among the agro-ecological regions: the more fertile the agro-ecological region, the more efficient the farms. The only exception was observed in the second sub-period, where the farms in the least fertile agro-ecological region outperformed those in the other two agro-ecological regions.

Table 5.11 **Distribution of efficiency scores of grain farms, 1976-1980; 1981-1985** and 1986-1989

	Period		
Intervals	1976-1980	1981-1985	1986-1989
00.0-40.0	2 4	0	0
40.1-45.0	3 0	0	0.7
45.1-50.0	2 4	0	0.7
50.1-55.0	3 0	2.6	1.3
55.1-60.0	4 1	0	2.0
60.1-65.0	3 0	5.1	3.3
65.1-70.0	4 7	0	3.9
70.1-75.0	7 1	5.1	9.2
75.1-80.0	8 9	15.4	11.1
80.1-85.0	12 4	20.5	20.3
85.1-90.0	17 2	35.9	20.3
90.1-95.0	18 9	15.4	21.6
95.1-100.0	13 0	0	5.9
Total	100 0	100.0	100.0

Table 5.12 Efficiency scores ranked by size of farm measured as sown area; grain farms, 1976-1980; 1981-1985; 1986-1989

Period	Farm size (according to sown area)		
	Small	Medium	Large
1976-1980	0.761	0.831	0.797
1981-1985	0.796	0.861	0.830
1986-1989	0.799	0.841	0.834

Table 5.13 Efficiency scores ranked by capital; grain farms, 1976-1980; 1981-1985; 1986-1989

Period	Farm size (according to capital in tgs)		
	Small	Medium	Large
1976-1980	0.764	0.829	0.796
1981-1985	0.824	0.867	0.781
1986-1989	0.798	0.842	0.834

Table 5.14 Efficiency scores of grain farms ranked by agro-ecological region, 1976-1980; 1981-1985; 1986-1989

Period	Agro-ecological region:		
	Selenge-Onon	Hangai-Huvsgul	Central and Eastern steppe
1976-1980	0.8[illegible]4	0.770	0.718
1981-1985	0.848	0.838	0.879
1986-1989	0.856	0.755	0.683

5.3.3.5 TFP changes

After obtaining separate information on both efficiency change and technical change as elaborated in the previous section, total factor productivity (TFP) of grain farms was calculated in a similar way to Nishimizu and Page (1982). Here the information on changes in mean technical efficiency (from year to year) and estimates of technical change (evaluated at the sample means in each year) were used to obtain indices of TFP change between each pair of adjacent years over the 14-year sample period. While within the same sub-period the rate of technical change (at the mean of the data) for each year was calculated as the partial derivative of the frontier function with respect to time, technical change at the junction of two sub-periods can not be calculated that way because it involves two different technologies (a separate frontier function was calculated for each sub-period). The technical change measure for the junctions between the two sub-periods were calculated as follows. In the case of 1980/1981, mean production in 1980 was predicted using mean input data from 1980 and then mean production in 1981 was predicted using the 1980 data. The ratio of these two predictions provides a measure of technical change. This process was repeated using 1981 input data and then the geometric mean of these two technical change measures was taken as the final measure of technical change at the junction. The same procedure was used for the 1985/1986 junction. The output file of the Shazam program for the calculation of the rate of technical change between sub-periods is given in Appendix 3.

These measures[12] are summarised by the cumulative indices listed in Table 5.15 and plotted in Figure 5.8.

It was observed that over the 14-year period there was a 6.7 per cent decline in technical efficiency and a 18.1 per cent decline in technical change, resulting in an overall decline in TFP of 23.5 per cent. The fact that almost three-quarters of total TFP decline was due to declines in technical change suggests that lack of technical innovation was the major problem in Mongolian grain farming over the pre-reform period 1976-1989.

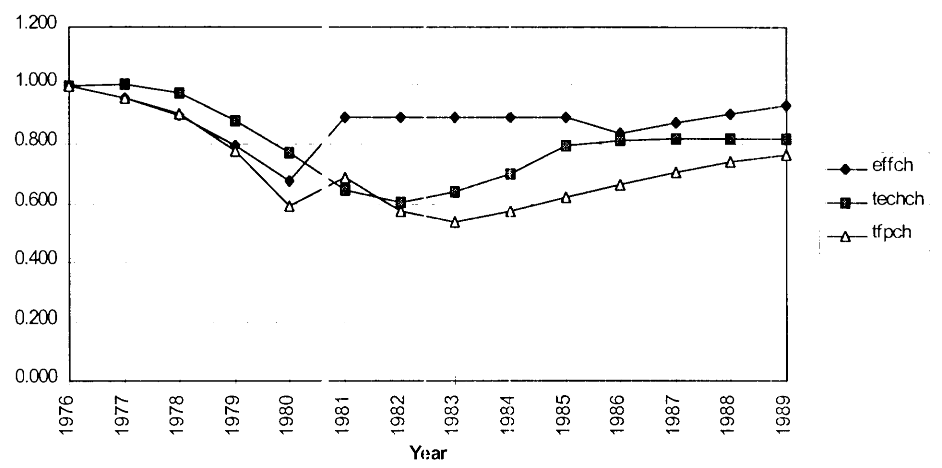
However, as Figure 5.8 illustrates, the largest fall in TFP occurred during the first five years at a time when the Ministry of Agriculture was pursuing a program of increasing production by increasing input usage. The final six years of the overall period are characterised by improving TFP levels, with the TFP index rising from 0.539 in 1983 to 0.764 in 1989, which equates to a 41.7 per cent growth in TFP. This period coincides with the "intensive" technology and incentive reform policies of the 1980s perhaps suggesting that these policies had some positive impacts on farm performance.

[12] It should be noted that these TFP measures obtained from the SFPF results do not contain information on gains or losses due to scale changes. However, as the estimates of returns-to-scale elasticity were generally close to unity (see Table 5.9), it was expected that the influence of scale on TFP results will be small. It is hoped that the conduct of future analysis will test this assertion.

Table 5.15 Cumulative index of changes in efficiency, technology and TFP of grain farms, 1976-1989

Year	Efficiency change	Technical change	TFP change
1976	1.000	1.000	1.000
1977	0.955	1.005	0.955
1978	0.895	0.975	0.899
1979	0.795	0.875	0.775
1980	0.677	0.772	0.592
1981	0.890	0.646	0.687
1982	0.890	0.605	0.576
1983	0.890	0.642	0.539
1984	0.890	0.700	0.571
1985	0.890	0.792	0.623
1986	0.835	0.810	0.661
1987	0.871	0.819	0.705
1988	0.903	0.819	0.739
1989	0.933	0.819	0.764
Total change (per cent)	-6.660	-18.148	-23.599

Figure 5.8 **Cumulative index of changes in efficiency, technology and TFP of grain farms, 1976-1989**



[a] effch - Efficiency change.
techch - Technical change.
tfpch - TFP change.

5.4 Stochastic Frontier Production Function with Technical Inefficiency Effects Model

In this section the SFPF with inefficiency-effects model (Battese and Coelli, 1995) is applied to Mongolian grain farms for the period 1987-1989. It attempts to explain the inefficiency variation among grain farms in terms of farm-specific characteristics. The reason this model was run only for three years (1987-1989) was that the variables associated with the inefficiency-effects model were available only for that period. Section 5.4.2. discusses the model specification and the variables used. Section 5.4.3 reports the empirical results from the model.

5.4.1 Model specification and estimation

The current inefficiency-effects model for panel data in the context of SFPF (Battese and Coelli, 1995) was an extension to the model of Huang and Liu (1992) for cross-sectional data. While the stochastic frontier is formulated the same way as in equation (5.3), the case for time-varying inefficiency effects, the non-negative error term, U_{it} is modelled differently. This model assumes that farm inefficiency effects are a function of farm-specific explanatory variables and are defined as:

(5.19) $$U_{it} = z_{it}\delta + W_{it}$$

where:

z_{it} is a vector of explanatory variables associated with the technical inefficiency effects;

δ is a vector of unknown parameters to be estimated; and

the W_{it}'s are unobservable random variables, which are assumed to be independently distributed, and obtained by truncation of the normal distribution with mean zero and variance σ^2 such that U_{it} is non-negative (i.e., $W_{it} \geq -z_{it}\delta$). One could equivalently say that the inefficiency effects, U_{it}, are assumed to be independent non-negative truncations of the normal distribution with mean $z_{it}\delta$ and variance σ^2. This model has several advantages over the previous inefficiency-effects models.[13] First, the statistical biases inherent in two-stage estimation methods are avoided by estimating simultaneously the parameters of both the stochastic frontier and inefficiency-effects model (Battese and Coelli, 1995). Second, as stated in Battese and Coelli (1995), W-random variables are neither identically distributed nor are required to be non-negative as compared to earlier one-stage models (Reifshneider and Stevenson, 1991).

The prediction of the technical efficiencies, which is based on its conditional expectations is given in the Appendix of Battese and Coelli (1993). The maximum likelihood method is used to estimate the unknown parameters in each of the models. This was done using the computer program FRONTIER, version 4.1–see Coelli (1994).

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[13] More discussion on this issue was given in Chapter 2.

The technical efficiency (TE) of the *i*-th farm in the *t*-th year is equal to the ratio of the observed output level to the output level predicted by the SFPF (and hence will take a value in the 0-1 interval). This can be shown to be equivalent to $exp(U_{it})$. As done in Battese and Coelli (1992, 1995), the expectation of U_{it}, conditional upon $E_{it} = V_{it} - U_{it}$ was used to predict the (unobservable) U_{it}, and hence to predict

$TE_{it} = exp(-U_{it})$.

5.4.2 Variables and statistical tests

The dependent and explanatory variables used in the frontier function of the inefficiency-effects model discussed in the previous section are essentially the same as those used in the time-varying inefficiency effects model except for one additional variable, *Natural conditions*. This additional variable was included in both stochastic frontier function and inefficiency-effects function of the model to capture and separate the effects of the differences in natural conditions on the production levels and the efficiency levels of individual farms.

Hence, the following are the explanatory variables included in the frontier function:

sown area (hectares);

labour (mandays);

depreciation and machinery service costs as a proxy for capital (tgs);

fertiliser (tg);

other costs (tgs);

time of observation; and

index of natural conditions.[14]

Grain output measured in tonnes was used as the dependent variable of the SFPF.

In order to explain the efficiency variation among grain farms, some additional data on farm-specific characteristics were obtained from separate sources. These sources included *Farm Human Resources Reports* from the Ministry of Food and Agriculture and the *Statistical Yearbooks* of the State Statistical Office.

While some of the variables used for explaining the efficiency variation among grain farms were available by individual farms (farms which introduced economic incentive systems, farms which were assisted/built by Soviets and index of natural conditions) other variables (information on farmers' technical education and experience) were available only for 13 provinces (not for individual farms) over the three-year period, 1987-1989. In the model estimation, these provincial-level data were assigned to individual farms according to the provinces in which the farms occurred. In other words, farms belonging to the same province have the same values for these variables for the given year.

The farm-specific variables used in the inefficiency-effects model were:

z_1- the percentage of mechanizators who were graduates of vocational technical schools in the total population of mechanizators;

z_2- the percentage of mechanizators with more than six years of experience in the total population of mechanizators;

z_3- time of observation, $t = 1,2,3$;

z_4- dummy variable 1 (= 1 for Soviet built/assisted farms; = 0 otherwise);

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[14] This is an aggregate index reflecting three different variables: soil quality (percentage of soil organic matter), long-term annual average precipitation (mm) and long-term annual average temperature. This variable was constructed by Enkh-amgalan and Myagmarjav (1993).

z_5- dummy variable 2 (= 1 for adopting economic incentive system; = 0 otherwise).

z_6- index of natural conditions.[15]

To specify the preferred model, a two-stage testing procedure similar to that used in the earlier analysis of Sections 5.3.3.1-5.3.3.2 was employed here. In the first stage, the adequacy of different functional forms was tested and in the second stage, the significance of the variance parameters and that of the variables of the inefficiency-effects models was tested.

5.4.3 Empirical results

5.4.3.1 Test results on functional form and inefficiency-effects formulation

The SFPF with technical inefficiency-effects model for grain farms was estimated using data from the period 1987-1989. The results of the two-stage statistical tests for the specification of the preferred model are reported in Table 5.16.

As shown in Table 5.16, given the specification of the translog form of the technical inefficiency-effects model, the null hypothesis that C-D is the preferred functional form to translog was strongly rejected. Thus it suggests that the translog, a more general functional form, better describes the technology. Also, the null hypothesis of no non-neutral technical change is rejected. Hence, technical change is suggested to be present by the model.

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[15] This variable was included both in the frontier function and as an explanatory variable for the inefficiency effects in order to establish explicitly the influence of natural conditions upon efficiency levels of the farms. It is expected that poor natural conditions not only reduce land productivity but also have an effect on the efficiency of production through reduced worker motivation. In the context of Soviet economy, Nove (1991, p. 578) has made a similar rationalization as: *...thus favourable natural conditions and reliable machinery affect the motivation and performance of the workforce.*

Table 5.16 Generalised likelihood-ratio tests of hypotheses for parameters of the SFPF models for grain farms; inefficiency effects model; 1987-1989

Null hypothesis, H_o	$ln[L(H_0)]$	Value of λ	Critical value	Decision
A. Stage One: Functional form and technical change				
Translog	32.22			
Cobb-Douglas	1.905	60.63	32.67	Reject H_o
No technical change	17.65	29.14	14.07	Reject H_o
B. Stage Two: Testing for variance parameters and inefficiency-effects variables				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$	10.39	43.65	16.92	Reject H_o
H_0: $\gamma = 0$	14.25	35.93	9.50	Reject H_o
H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$	25.66	20.54	12.53	Reject H_o

In the second stage of the test, the null hypothesis that inefficiency effects are absent from the model ($\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$) was strongly rejected at the five percent significance interval. Thus it suggests that inefficiency was present in production and that the traditional average response function in which farms are fully efficient is not an adequate representation of the data.

[16] As noted by Battese and Coelli (1995), if the parameter γ is not significantly different from zero, then the model collapses into the traditional average response function and all the δ variables associated with inefficiency become part of the explanatory variables of that function. In this case, those variables which simultaneously occurred previously in both the stochastic frontier function and the inefficiency-effects model (in this case, the time variable and the index of natural conditions) are not identified.

Then the null hypothesis ($\gamma = 0$) that the inefficiency effects are not stochastic was also rejected.[17] Finally, the null hypothesis that the inefficiency effects are not functions of the six explanatory variables was rejected. This suggests that these variables are significant in explaining the differences in efficiencies between the grain farms.

In summary, the two-stage statistical tests suggested the translog with non-neutral technical change as the preferred functional form for the SFPF with inefficiency-effects model for grain farms in the period 1987-1989.

5.4.3.2 Parameter estimates

The first-order terms of the SFPF interpreted as the partial output elasticities of production function are presented in Table 5.17. It was observed that many of the reported parameter estimates are similar to those obtained in the SFPF with time-varying inefficiency effects model discussed earlier in Section 5.3.3.3. The partial output elasticity with respect to land (0.56) was found to be largest. The partial output elasticity with respect to labour (0.52) was the second largest followed by fertiliser (0.147) and capital (0.11). However, due to its high standard error, the latter was not significant. The partial output elasticity with respect to other costs (0.087) was lowest but significant.

5.4.3.3 Determinants of efficiency variations and the efficiency scores

The estimates of the coefficients of inefficiency-effects variables and the variance parameters are reported following the estimates of the first-order terms of the stochastic frontier production function in Table 5.17. Most signs on the estimates of the δ-parameters agree with initial expectations. The negative estimate

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[17] As noted by Battese and Coelli (1995), if the parameter γ is not significantly different from zero, then the model collapses into the traditional average response function and all the δ variables associated with inefficiency become part of the explanatory variables of that function. In this case, those variables which simultaneously occurred previously in both the stochastic frontier function and the inefficiency-effects model (in this case, the time variable and the index of natural conditions) are not identified.

associated with *Vocational Technical Graduates* suggests that those farms with better educated workers tend to be less inefficient. The negative sign associated with *Experience* suggests that those farms with workers with greater experience performed with less inefficiency. However, due to a large standard error, the relationship was found to be weak. The parameter estimate associated with *Time* is found to be positive. This parameter is difficult to interpret since it is likely to be a proxy for omitted factors which may vary systematically through time. However, a large standard error suggests that this variable is statistically not significant. The first dummy variable, *D-Soviet*, representing those farms built and assisted by Soviet experts, had a negative parameter estimate, which suggests that these farms were performing with less inefficiency. The second dummy variable, *D-incentive*, also had a negative value. This suggests that those farms which had a higher degree of autonomy in terms of finance and management through the incentive promotion scheme performed with lower inefficiency levels than those not involved in the scheme. The parameter estimate associated with the variable, *Natural conditions*, was found to have a positive sign implying that those farms located in better natural conditions tend to perform with greater inefficiency. Although the sign of this parameter does not agree with the initial expectation, a large standard error suggests that the variable is statistically not significant.

The mean efficiency score of grain farms was 0.815, 0.715 and 0.781 in 1987, 1988 and 1989, respectively. [18]

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[18] A summary of the estimated technical efficiencies of the grain farms in the period 1987-1989 is presented in Appendix 1, Table A1.13.

Table 5.17 Maximum-likelihood estimates for the parameters of the SFPFs with inefficiency-effects model, 1987-1989[a]

Variable		Parameter
Land	β_1	0.56
		(0.16)
Labour	β_2	0.52
		(0.16)
Fertiliser	β_3	0.147
		(0.091)
Capital	β_4	0.11
		(0.19)
Other costs	β_5	0.087
		(0.045)
Natural conditions	β_6	0.0050
		(0.0020)
Time	β_7	0.66
		(0.21)
Inefficiency-effects model		
Constant	δ_0	0.56
		(0.86)
Vocational technical graduates	δ_1	-0.0220
		(0.0053)
Experience	δ_2	-0.0084
		(0.0095)
Time	δ_3	0.09
		(0.10)
D-Soviet	δ_4	-0.42
		(0.14)
D-incentive	δ_5	-0.20
		(0.13)
Natural conditions	δ_6	0.0081
		(0.0053)
Variance Parameters		
	$\sigma^2_s = \sigma^2_v + \sigma^2$	0.225
		(0.040)
	$\gamma = \sigma^2/\sigma^2_s$	0.99999
		(0.00022)
Log-likelihood		32.219

[a] Estimated standard errors are presented below the corresponding parameter estimates.

5.5 Summary and Conclusions

In this chapter the production technology, technical efficiency, technical change and TFP of Mongolian grain farms during the period 1976-1989 were investigated using both PFPs and the SFPF framework.

PFP measures suggested that all PFPs declined sharply until 1980. Then, whereas land, labour and fertiliser productivities picked up, capital productivity remained stagnant for the rest of the period. The partial productivity for other costs declined for the rest of the period. A divergence in trends of partial productivity between other costs and the other inputs was observed. Due to the diverging trends among the partial productivities in the late 1980s, the overall trend of total factor productivity in grain farming could not be established.

The analysis based on the SFPF framework employed two inefficiency-effects models: a time-varying inefficiency effects model and an inefficiency-effects model. The first model covered the total 14-year study period. It attempted to establish the levels and trends of efficiency and technical change and TFP change in grain farms. The second, technical inefficiency-effects model aimed to determine the factors affecting efficiency variations among the grain farms in terms of certain farm-specific characteristics. However, this model was estimated only for the last three years of the study period, due to limited data availability.

A time-varying inefficiency-effects model in a SFPF for panel data was estimated for the three sub-periods (1976-1980, 1981-1985 and 1986-1989) each covering an important distinctive policy period.[20]

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[19] A summary of the estimated technical efficiencies of the grain farms in the period 1987-1989 is presented in Appendix 1, Table A1.13.

[20] There have been certain concerns that by splitting whole 14-year panel data into three sub-periods might yield in biased measures for technical change (due to a shortened period for calculating technical change) as well as for efficiency change (due to parametric nature of efficiency trends in the inefficiency effects model). However, the current study went ahead with the three separate sub-periods based on the following rationale: (i) the model was run for both

A two-stage specification procedure similar to that of Kumbhakar and Hjalmarsson (1993) was used to select the preferred functional forms and inefficiency-effects models. In the first stage, an adequate production technology, including the type of technical change, was identified through various modifications of the translog function. In the second stage, the specification of the inefficiency term was determined and the final preferred models were then estimated.

The specification result suggests that in all three sub-periods a translog functional form was favoured over the Cobb-Douglas. Non-neutral technical change was observed in the first two of the three sub-periods; in the third sub-period, technical change seemed absent. In all three sub-periods, it was strongly suggested that inefficiency was present and a half-normal distribution for the inefficiency-effects term was preferred over a truncated normal distribution. A significant inefficiency trend was established in the first and third sub-periods but was absent in the second sub-period. The results also suggested that the selection of functional forms, including the formulation of technical change and specification of the inefficiency term, affects the efficiency scores of individual farms. However, the former seemed to have more effect on the inefficiency scores and distribution than did the latter. This implies that a proper specification of production technology is necessary to obtain more realistic results.

The estimation results of the preferred models suggested the following:

In grain production, the partial output elasticity with respect to capital was found to be largest (ranging between 0.341 and 0.627) followed by land (ranging

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separate sub-periods as well as 14-year total panel period and a Chow test was conducted to select the more adequate model (i) a separate model for cross-sectional data (Aigner et al. 1977) which does not impose any pattern on efficiency change was calculated and the efficiency trend of that model was then compared with those of the separate panel models. Chow test supported the separate sub-periods against the overall 14-year total panel and efficiency trends from both separate models and cross-sectional models were similar. So, this justifies the selection of separate panel models against the 14-year total panel model.

between 0.194 and 0.36) and labour (ranging between 0.062 and 0.421) (Table 5.8). These results appear to support the relevance of the policy of increasing output by way of increased investment of capital, further expansion of land and an increased labour force by the Ministry of Agriculture. These parameter estimates also are comparable with Ulziibat (1992), who estimated a Cobb-Douglas function for 19 grain farms of Forest-steppe region of Mongolia for the period 1976-1989.

The estimated output elasticities with respect to fertiliser and other costs in the present study were lower than for capital, land and labour. Unexpectedly low or negative values of the partial output elasticity with respect to fertiliser suggest that a substantial increase in the fertiliser use during the 14-year period had little influence upon yield. This was perhaps due to incorrect use of this important production input. This result seems to be in line with the findings of the earlier studies on grain production by Ulziibat (1992) and the World Bank (1995) who suggest that the impact of fertiliser use in grain production was either minimal or the estimated coefficients were not reliable due to high standard errors. The partial output elasticity with respect to other costs was the lowest among the inputs (varying between 0.016 and 0.074) (Table 5.8).

The extent of technical change over the study period was found to be rather disappointing (Table 5.8). In the first (1976-1980) and third (1986-1989) sub-periods, either technical regress or the absence of technical change were observed. Only in the second sub-period (1981-1985) some technical progress was observed. The technical regress observed in the first sub-period coincides with the period of "extensive" growth policy (1976-1980), when the emphasis was put on increased input use rather than productivity enhancement to ensure higher output. Some technical progress that has occurred in the second sub-period (1981-1985) coincides with a substantial investment in new seeds, machinery and human resources and agricultural research in the crop sector made by the Ministry of Agriculture. However, the absence of technical change in the third sub-period (1986-1989) did not seem to have matched with major efforts of introducing so called "intensive" technology by the Ministry of Agriculture in the crop sector (see

Chapter 4) thus suggesting that these efforts have not been materialised into improved farm productivity.

The estimated results of returns to scale of grain farms at the mean of the data suggest that in all three sub-periods the grain farms were operating in the range of either constant (0.99 in the first sub-period) or mildly increasing returns to scale (1.14 and 1.06 in the second and third sub-periods respectively) (Table 5.9). This finding was further strengthened by the estimates of returns to scale of individual grain farms in the third sub-period, where the majority of grain farms were found to be operating in the economies-of-scale range above unity (Figure 5.4). This fact that the grain farms were characterised by moderately increasing or constant returns to scale does not supply any evidence of scale problems in predominantly large-scale farms, which is often claimed today. This may explain why the large farms in the post-reform period were reluctant to split into smaller units and why recent action by the Ministry of Agriculture reversed this fragmentation (see Chapter 8 for more discussion on it).

Grain farms in the period 1976-1989 operated, it would seem, significantly under their potential. They operated at estimated average efficiency levels of 0.804, 0.829 and 0.824 in the first, second and third sub-periods, respectively (Table 5.10). But the average efficiency scores of grain farms were higher than those of potato farms in all three policy sub-periods (Table 6.10). Farm efficiency decreased in the first sub-period, remained constant in the second sub-period and increased in the third sub-period. The overall trend of efficiency change seems to be in line with the initial expectation. The initial decline in farm efficiency falls into the "extensive" growth policy period (1976-1980) when a little attention was given to farm incentives. The "intensive" growth policy which started in early 1980s perhaps did not result in any significant change of farm efficiency in the second sub-period (1981-1985). However, the last sub-period (1986-1989) when dramatic changes of farm reorganisation occurred, matches with a marked upward trend in farm efficiency. During this period, various forms of tenancy systems were introduced to give the producers incentive and the farm managers a higher autonomy, which was a part of a much wider restructuring policy carried out throughout the Eastern Bloc known as "Gorbachev's Perestroika".

Farm size seemed to affect the efficiency performance of farms. Farm efficiency scores ranked according to either sown area or farm capital consistently suggested that large and medium farms tended to perform more efficiently than did small farms in all three sub-periods.

Using an inefficiency-effects model in a SFPF framework, the factors affecting efficiency levels among the grain farms were investigated. In order to explain the inefficiency variations among grain farms, a SFPF was estimated in which the inefficiency effects were modelled as an explicit function of a vector of five farm-specific characteristics and time variable. The results of this model suggest that the efficiency levels of farms were positively related to the levels of technical education and experience of farm workers, the Soviet technical assistance and the incentive system introduced in grain farms (Table 5.17). These results indicate that policies aimed at improving technical education levels and retaining experienced workers paid dividends in terms of improved technical efficiencies. The positive and significant relationship between farm efficiency and the incentive system in place may suggest that the present on-going reform process of giving farms complete management autonomy (ownership) should improve efficiency. However, the model result also suggests that all aspects of the Soviet technical systems should not be hastily thrown out since the analysis suggests that they appear to have had a somewhat positive influence upon farm efficiency in the past.

Based on the information on changes in efficiency and technology obtained from the SFPF model, the TFP of grain farms over the period 1976-1989 was calculated in similar way to Nishimizu and Page (1982) and Perelman (1995). The TFP result suggest that the overall TFP change in Mongolian grain farms was rather disappointing: over the 14-year period there was an overall 23.6 per cent decline in TFP (Table 5.15). The fact that more than three-quarters of this was estimated to be due to technical regress suggests that the lack of technical innovation in Mongolian grain farming was a major problem.

A closer look at the changing pattern of TFP reveals some interesting trends: The initial fall in TFP during the first five years of the study period was replaced by a significant improvement towards the end of the study period (i.e. during the last six years 1983-1989). During the latter period a total 41.7 per cent TFP increase was observed (Table 5.15). This suggests that the "intensive" technology and incentive reform policies of the second-half of the 1980s had some impressive success.