No. 844

Production Structure and Technical Change in Thai Agriculture, 1972-1994

by

Wirat. Krasachat and Yoshimi Kuroda

November 1999

Production Structure and Technical Change in Thai Agriculture, 1972-1994

Wirat. Krasachat

Department of Agribusiness Administration, King Mongkut's Institute of Technology, Ladkrabang, Bangkok 10520, Thailand

Yoshimi Kuroda

Institute of Policy and Planning Sciences, University of Tsukuba, Tsukuba, Ibaraki 305, Japan

Correspondence to

Department of Agribusiness Administration, King Mongkut's Institute of Technology, Ladkrabang, Bangkok 10520, Thailand

---

Abstract

The main purposes of this study are to quantitatively investigate the production structure and the pattern of technical change in Thai agriculture for the period of 1972-94. A translog variable cost function framework is used to estimate a system of the cost function and the associated cost share equations for Thai agriculture. The system is estimated using the iterative seemingly unrelated regression method applied to a panel of 92 observations, comprising annual data from 1972 to 1994 for four regions in Thailand. The analytical results indicate that there were scale economies, low technical progress, and complementarities between capital and fertiliser, capital and hired labour, and capital and unpaid family labour. Technical change was biased toward saving hired labour, operator labour and unpaid family labour and also biased toward using fertiliser and capital.

JEL Classification code:

Keywords: production structure, technical change, Thai agriculture

1. Introduction

Thai agriculture has experienced rapid growth over the past three decades. During the periods 1963 to 1975, 1975 to 1985, and 1963 to 1985, the annual growth rates of gross value added averaged approximately 4 per cent (Onchan and Isvilanonda, 1991). Although the agricultural sector recorded a negative growth rate of 2 per cent in 1987, due to the drought crisis, agriculture still grew at a high average rate of nearly 4 per cent per annum during the 1980s (Asian Development Bank 1990) and 3 per cent per annum from 1990 to 1995 (Bank of Thailand 1998).

Although over the past three decades Thai agriculture grew at the relatively high rate as mentioned earlier, there are at least three causes for worry concerning the future role of agriculture in Thailand. First, the relatively high growth rate of the agricultural sector in Thailand was achieved mainly through the expansion of cultivated areas (by deforestation). This pattern of growth can no longer continue since Thailand reached its land frontier over two decades ago. Therefore, a new strategy for agricultural development has been used in the recent years with emphasis placed on increasing agricultural land productivity. New technology inputs, such as modern varieties of plants, fertiliser, irrigation, mechanisation and chemicals, have been widely adopted. Second, Puapanichya and Panayotou (1985) also indicated that 85 per cent of the 'poor', particularly those in the Northeast Region and some parts of the North Region, are farmers, most of them small farmers, and agricultural workers in rural areas. Finally, there has been a decline in the price index of Thailand's 20 major crops of approximately 0.1 per cent a year from 1961 to 1985, and approximately 5.6 per cent a year from 1981 to 1985 as calculated by the Thailand Development Research Institute (1988). It is possible that when demand for agricultural labour decreases because of the above causes, there will be an increase in unemployment and poverty in rural and urban areas in Thailand.

The main purpose of this study is to quantitatively investigate the production structure and the pattern of technical change in Thai agriculture for the period of 1972-94. To achieve the these objectives, a translog variable cost function framework is used to construct a system of the cost function and associated cost share equations The resulting system of equations are estimated using panel data comprising 23 years of annual data (1972 to 1994) on the four regions in Thailand. Price elasticities of the variable input demands, scale economies, the rate and biases of technical change are calculated from these estimates.

A number of studies have estimated a system of output supply and input demand equations of Thai agriculture (e.g., Puapanichya and Panayotou, 1985; Jieamanugulgit, 1989; Setboonsarng and Evenson 1991; Warr, 1994). However, this study, to the best of our knowledge, has been the first application of the translog cost function in order to quantitatively investigate the production structure of Thai agriculture. In addition, the present study differs from those previous studies of Thai agriculture in two main points.

First, in this study, agricultural labour demand is disaggregated into three categories: hired, operator and unpaid family labour. This degree of disaggregation has not been considered in any other study of this type. This enables more detailed understanding of the nature of labour demand in Thai agriculture.

Second, in this study, the Caves, Christensen and Diewert (1982) multilateral index is used to construct any required aggregate variables. This is because this index is a theoretically more consistent method to use in multilateral comparisons than a regular Tornqvist or Fisher index due to its transitivity property, which implies that the set of all pairs of comparisons are consistent.

This paper is organised into five sections. Following this introduction, the model specification is described. Next, data and their sources are described. The last two sections cover the empirical findings of this study, and conclusions.

2. Model Specification

Christensen and Greene (1976) indicated that the cost function has two attractive features. First, it implies a set of derived demand equations which are linear in their parameters. Second, the production structure can be obtained, even though it may not be possible to derive it from an explicit production function. In this study, the translog variable cost function is used. Following Kuroda (1998) it can be specified as:

$$\ln C = \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^{5} \alpha_i \ln P_i + \beta_B \ln Z_B + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5}\gamma_{ij} \ln P_i \ln P_j$$

$$+ \sum_{i=1}^{5} \theta_{iB} \ln P_i \ln Z_B + \frac{1}{2}\theta_{BB}(\ln Z_B)^2 + \sum_{i=1}^{5} \delta_{Qi} \ln Q \ln P_i + \delta_{QB} \ln Q \ln Z_B$$

$$+ (\beta_T + \beta_D D_S)T + (\mu_{QT} + \mu_{QD} D_S)(\ln Q)T + \sum_{i=1}^{5}(\mu_{iT} + \mu_{iD} D_S)(\ln P_i)T$$

$$+ (\beta_{BT} + \beta_{BD} D_S)(\ln Z_B)T + \frac{1}{2}(\beta_{TT} + \beta_{TD} D_S)T^2, \qquad (1)$$

where $\gamma_{ij} = \gamma_{ji}$ and $i = j = F$ (fertiliser), H (hired labour), K (capital), O (operator labour), and U (unpaid family labour); P_i, are the prices of variable inputs X_i $(i = F, H, K, O, U)$; Z_B is the quantity of land; T is a time trend introduced to proxy disembodied technical change; D_S is a dummy variable interpreted for shifts in technical change parameters (1972-77=1; otherwise = 0);[1] C is the variable cost composed of fertiliser costs $(C_F = P_F X_F)$, hired labour costs $(C_H = P_H X_H)$, capital costs $(C_K = P_K X_K)$, operator labour costs $(C_O = P_O X_O)$ and unpaid family labour costs $(C_U = P_U X_U)$; and $\alpha_0, \alpha_Q, \alpha_i, \beta_B, \gamma_{QQ}, \gamma_{ij}, \theta_{iB}, \theta_{BB}, \delta_{Qi}, \delta_{QB}, \beta_T, \beta_D, \mu_{iT}, \mu_{iD}, \mu_{QT}, \mu_{QD}, \beta_{BT}, \beta_{BD}, \beta_{TT}$, and β_{TD} are parameters to be estimated. All variables are implicit functions of time. To avoid complexity of notation, time subscripts, t, are ignored.

A well behaving variable cost function must be homogeneous of degree one in input prices. Thus, in the translog cost function (1), this condition requires that $\sum_{i=1}^{5}\alpha_i = 1$, $\sum_{i=1}^{5}\gamma_{ij} = 0$, $\sum_{i=1}^{5}\delta_{Qi} = 0$, $\sum_{i=1}^{5}\theta_{iB} = 0$, $\sum_{i=1}^{5}\mu_{iT} = 0$ and $\sum_{i=1}^{5}\mu_{iD} = 0$, for $i = j = F, H, K, O, U$.

Note that labour is divided into three groups: hired labour, operator labour and unpaid family labour at the aggregate level. A study of U.S. agriculture by

---

[1] Patamasiriwat and Suewattana (1990) suggested that the patterns of growth of Thai agriculture can be divided into two periods. As mentioned earlier, before 1978, the relatively high growth rate of agriculture was achieved mainly through the expansion of cultivated areas by clearing the forests. Since 1978, this pattern of growth could no longer continue because Thailand had reached its land frontier. Therefore, new technology inputs such as fertiliser, modern varieties of crops and water have been widely used in this latter period. The dummy variable, D_S, is included to permit the rate of technical change to vary between these two time periods.

Tyrchniewicz and Schuh (1969) found that the magnitudes of the own-price elasticities of demands for hired labour, operator labour and unpaid family labour were quite different in both the short run and long run when estimated from a dynamic simultaneous model involving equations for the above three labour groupings. In addition, a study of Thai agriculture by Krasachat (1997), using a dynamic dual model, also indicated that operator labour and unpaid family labour are different inputs. Thus, this study uses the cost function to estimate the effects of operator and unpaid family labour inputs separately.

Observe that, in this study, land is assumed as a quasi-fixed input due to the fact that, similar to Taiwanese agriculture as indicated by Kuroda (1998), the farmland market does not seem to be competitive because various regulations have been imposed on land movements in Thai agriculture. Thus, it is unlikely that the firm utilises the optimum level of land for agricultural production in Thailand.[2]

Applying Shephard's lemma to equation (1) yields a system of cost share (S_i) equations:

$$S_i = \alpha_i + \sum_{j=1}^{5} \gamma_{ij} \ln P_j + \theta_{iB} \ln Z_B + \delta_{Qi} \ln Q + (\mu_{iT} + \mu_{iD} D_S)T \qquad (2)$$

$$i = j = F, H, K, O, U.$$

Three hypotheses involving the production technology will be tested in this study. First, constant returns to scale (CRTS) can be tested in the translog variable cost function framework. Kuroda (1998) indicated that the cost function can be written as $C(Q, P, Z_B, T) = G(Q, Z_B) \cdot H(P, T)$ if the primal production function exhibits constant returns to scale. Thus, in the translog cost function (1), this condition requires that $\alpha_Q + \beta_B = 1$, $\delta_{Qi} + \theta_{iB} = \delta_{QB} + \theta_{BB} = \gamma_{QQ} + \delta_{QB} = \mu_{QT} + \beta_{BT} = \mu_{QD} + \beta_{BD} = 0$, for $i = F, H, K, O, U$. Second, Hicks-neutral technical change in variable factor inputs is tested by imposing the conditions: $\mu_{iT} = 0$ and $\mu_{iD} = 0$, for $i = F, H, K, O, U$. Third, neutrality of technical change with respect to output scale is tested by imposing the conditions: $\delta_{Qi} = 0$, for $i = F, H, K, O, U$.

[2] A formal test for classifying a factor as a quasi-fixed input can be used by applying the approach of Conrad and Unger (1987) but, due to lack of consistent data, this is not applied in this study.

In this study, a few economic indicators to investigate the technology structure of Thai agriculture can be obtained by applying the following equations.

First, following Binswanger (1974), the Allen partial elasticity of substitution (AES) can be calculated as:

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}, \qquad i, j = F, H, K, O, U, \; i \neq j, \tag{3}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2}, \qquad i = F, H, K, O, U. \tag{4}$$

Second, the own and cross price elasticities are obtained, with land held fixed, by:

$$\varepsilon_{ii} = S_i \sigma_{ii}, \qquad i = F, H, K, O, U, \tag{5}$$

$$\varepsilon_{ij} = S_j \sigma_{ij}, \qquad i, j = F, H, K, O, U, \; i \neq j. \tag{6}$$

Third, following Christensen and Greene (1976), scale economies (SCE) for the translog cost function can be defined as:

$$SCE = 1 - \frac{\partial \ln C}{\partial \ln Q} = 1 - \varepsilon_{CQ} \tag{7}$$

where the cost-output elasticity (ε_{CQ}) is obtained by,

$$\varepsilon_{CQ} = \alpha_Q + \gamma_{QQ} \ln Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \delta_{QB} \ln Z_B + (\mu_{QT} + \mu_{QD} D_S) T,$$

$$i = F, H, K, O, U. \tag{8}$$

A positive value of SCE indicates scale economies and a negative one implies scale diseconomies.

Fourth, as mentioned earlier, T is a time trend introduced to proxy disembodied technical change. Using the cost function (1), the rate of technical change (υ_t) can be expressed as:

$$\upsilon_t = -\frac{\partial \ln C}{\partial T} = -\left\{(\beta_T + \beta_D D_S) + \sum_{i=1}^{5}(\mu_{iT} + \mu_{iD} D_S)\ln P_i + (\mu_{QT} + \mu_{QD} D_S)\ln Q\right.$$

$$\left.(\beta_{BT} + \beta_{BD} D_S)\ln Z_B + (\beta_{TT} + \beta_{TD} D_S)T\right\}, \; i = F, H, K, O, U. \quad (9)$$

Note that, in this study, technical progress is defined as cost diminution over time. Similar to many studies (e.g., Daly and Rao, 1985; Bhattacharyya, Bhattacharyya and Mitra, 1997), in order to get a positive estimate of technical change in a case of decreasing cost, a negative sign is applied to the above partial derivative.

Finally, technical change specified in the translog cost function (1) is allowed to be a non-neutral change in inputs. This study measured the biases of technical change using the approach of Antel and Capalbo (1988) and subsequently applied by many studies (e.g., Karagiannis and Furtan, 1993; Kuroda, 1998). Using the cost function (1), the biases of technical change can be calculated, with land held fixed, by:

$$B_i = \frac{(\mu_{iT} + \mu_{iD} D_S)}{S_i} + \frac{\delta_{Qi}}{S_i}\lambda, \; i = F, H, K, O, U \quad (10)$$

where

$$\lambda = -\frac{\partial \ln C/\partial T}{\partial \ln C/\partial \ln Q} = -\frac{\partial \ln C/\partial T}{\varepsilon_{CQ}}. \quad (11)$$

Note that the first term of equation (10) is the pure bias effect (a shift in the expansion path) while the second term is the scale effect (a movement along the non-linear expansion path). If there is neutrality of technical change with respect to output scale (that is, $\delta_{Qi} = 0$, for all $i = F, H, K, O, U$), the scale effect disappears. Thus, the measurement of biases in technical change contains only the effect of a shift in the expansion path. Technical change is Hicks-saving or -using in input i if B_i is negative and positive, respectively.

Tests of Technical Change

The translog cost function (1) was specified with a dummy variable, D_S, included as an argument to reflect the influence of the availability of new land in Thai agriculture on the rate of disembodied technical change. The tests of hypotheses related to technical change can be divided into two stages. First, the hypothesis that the availability of new land does not affect the rate of technical change may be considered by testing the hypothesis that $\beta_D = 0$, $\mu_{QD} = 0$, $\beta_{BD} = 0$, $\beta_{TD} = 0$ and $\mu_{iD}=0$, for $i = F, H, K, O, U$. Second, the hypothesis of no technical change in Thai agricultural production may be considered by testing the hypothesis that $\beta_T = 0$, $\mu_{QT} = 0$, $\beta_{BT} = 0$, $\beta_{TT} = 0$, $\mu_{iT} = 0$, $\beta_D = 0$, $\mu_{QD} = 0$, $\beta_{BD} = 0$, $\beta_{TD} = 0$ and $\mu_{iD} = 0$, for $i = F, H, K, O, U$. The first group of conditions ($\beta_T = 0$, $\mu_{QT} = 0$, $\beta_{BT} = 0$, $\beta_{TT} = 0$, $\mu_{iT} = 0$) suggests that there is no technical change in Thai agriculture. The latter group of conditions implies that if there is no technical change in Thai agriculture, a shift in the rate of technical change in Thai agriculture does not exist.

Tests of Competitive Behaviour

A well-behaved cost function satisfies homogeneity in prices, monotonicity and concavity (Varian, 1984) The translog cost function (1) satisfies homogeneity in prices, as mentioned above. The conditions of monotonicity and concavity, however, are not automatically satisfied. Therefore, both monotonicity and concavity are checked in this study.[3] Violation of certain regularity conditions can provide evidence of non-competitive behaviour. Several studies (e.g., Daly and Rao, 1985; Bigsby, 1994) suggested that the monotonicity property of the cost function is satisfied if the fitted cost shares for each observation are positive.

---

[3] Since statistical testing of monotonicity and concavity of standard duality involves inequality constraints on parameters, it is generally difficult to conduct formal hypothesis tests (Lau 1978).

In addition, the concavity of the estimated cost function is satisfied if the principal minors of the hessian matrix of second order partial derivatives are negative definite (Varian, 1984). However, Nautiyal and Singh (1986) and Bigsby (1994) indicated that an equivalent test of concavity is that the symmetric matrix of Allen Partial Elasticities of Substitution (AES) is negative semi-definite, which at a minimum requires that all own AES of the matrix are negative. Since, in this analysis, symmetry is a property of the cost functional form, a study of the signs of the own AES is used to check for violations of concavity. These checks for monotonicity and concavity are conducted at all data points.

3. Data

The empirical application in this study considers aggregate data from each of the four regions of Thailand for the period 1972-94. Inputs are classified into five groups: fertiliser, hired labour, capital, operator labour and unpaid family labour. The data for quantities of labour are based on annual surveys conducted by the National Statistical Office (1997).

The data for quantities and prices of fertiliser are derived from several occasional publications of the Ministry of Agriculture and Cooperatives. Regional data on fertiliser usage are not available in fourteen of the years. The missing data are extrapolated from the whole Kingdom data.[4] Due to lack of regional price data, the average Whole Kingdom price of all nutrient fertilisers is used.

The figures for quantities of capital are collected from the *Agricultural Statistics of Thailand Crop Year* published annually by the Ministry of Agriculture and Cooperatives (1995). The imported capital prices are obtained from the *Annual Statement of Foreign Trade Statistics* (Ministry of Finance 1995).

Output is aggregated into a single index of agricultural output to conserve degrees of freedom and to avoid any further complexity in econometric modelling. The output index includes the ten major crops. They are rice, kenaf, cotton, cassava, groundnuts, soybeans, mungbeans, sugar cane, corn and sorghum. Livestock is a

---

[4] Following Setboonsarng and Evenson (1991), the missing data are acquired by multiplying the national numbers by an average share of numbers of each region to national numbers which is calculated from the data available.

sector which has been very important for Thai agriculture for a long time. Unfortunately, there are no livestock product data available. Thus, the livestock products are not included in this study. Particular regions have higher livestock output, and thus their low indexes reflect to some extent the problem of undervaluation. The data for quantities and prices of crops are also taken from the *Agricultural Statistics of Thailand Crop Year*. Note that the actual prices of ten major crops are used. Due to lack of regional price data, the average Whole Kingdom farm price of each crop is used.

As mentioned above, pooled data are used for this study. Thus, multilateral comparisons among the four regions are an important issue in this study. However, because of the disadvantage of the Tornqvist index in multilateral comparisons resulting from its failure in the transitivity property, the Caves, Christensen and Diewert (CCD) multilateral index is used to construct any price indexes which involve more than one commodity.[5] Following a number of studies (e.g., McKay, Lawrence and Vlastuin, 1980; Wall and Fisher, 1987), implicit quantity indexes are obtained by dividing the current value of each input and output by their corresponding CCD price index.

The measurement of hired and operator labour wages are similar to Krasachat (1997). In this study, a proxy for unpaid family labour wage is constructed by combining the above hired and operator labour wage series using the CCD multilateral index, as described in Krasachat (1997).

Land use, in this study, comprises land under rice, field crops, fruit trees and vegetables, grass land, idle land, other land and housing areas. Land use data are available in the *Agricultural Statistics of Thailand Crop Year*. Eight years of regional land use data are missing. Thus, missing data on land use are extrapolated from the Whole Kingdom data.

4. Empirical Results

Christensen and Greene (1976) indicated that the optimal procedure of the translog cost model is to jointly estimate the cost function and cost share equations as

---

[5] See more discussion on index number methods in Krasachat (1997).

a multivariate regression system. In this study, the system of equations (1) and (2) provide a system of a cost function and five cost share equations which is linear in parameters.[6] Because of contemporaneous correlation between the error terms of the two equations being considered, seemingly unrelated regression estimation (Zellner, 1962) is used to estimate the unknown parameters of this model.

The parameter estimates of the system of equations (1) and (2) are reported in Table 1. Approximately a half of the estimated parameters are at least twice their corresponding asymptotic standard errors. The estimated R^2 values for the translog cost function and the cost share equation of fertiliser, hired labour, capital and operator labour are, respectively, 0.99, 0.30, 0.62, 0.78 and 0.63. This implies that the equation system explains a large proportion of the variation in the dependent variables.

The time-series, cross-sectional (panel) data comprises 23 years of data on four regions, giving a total of 92 observations. Possible regional differences in climate, natural resources, etc., are accounted for through the inclusion of regional dummy variables in the cost function (1). This permits the intercepts in the cost function to differ in the different regions. In addition, applying a Wald Chi-Square test, the null hypothesis of no regional differences is strongly rejected as a composite hypothesis. The marginal effects are, however, assumed to be the same in the four regions. This assumption may be incorrect, but its validity cannot be tested with these data because of degrees of freedom limitations.

Tests of Hypotheses

Hypothesis test results regarding structure of production technology are presented in Table 2. Wald Chi-Square tests were used in all cases. Regarding the tests of the three hypotheses: constant returns to scale (CRTS), Hicks neutrality of technical change and the neutrality of technical change with respect to output scale, it was found that all three hypotheses involving the structure of production technology are rejected.

---

[6] Due to the homogeneity-in-prices property of the cost function, one cost share equation must be omitted from the equation system for the statistical estimation. In this study, the unpaid family labour

Hypothesis test results regarding technical change are also presented in Table 2. Wald Chi- Square tests were also used in all cases. To begin with we considered a hypothesis regarding differences in rates of technical change between the two sub-periods of 1972-77 and 1978-94. The null hypothesis of no differences in the technical change parameters in Thai agriculture between the two periods is rejected. This indicates that the reduced availability of new land (in the latter sub-period) appears to have affected the rates of technical change in Thai agriculture.

The null hypothesis of no technical change in Thai agriculture is rejected as a composite hypothesis. The estimated results show that technical change in Thai agriculture during the study period exists.

Note that the results of technical change in this study is consistent with other studies of Thai agriculture (e.g., Patamasiriwat and Suewattana, 1990; Krasachat, 1997).

The model was estimated maintaining homogeneity and symmetry in prices. Monotonicity and concavity in prices were checked following estimation and found not to be satisfied with respect to the prices of fertiliser and capital at some data points. The reasons for these violations could be due to data problems, or may be a consequence of imperfect competition in output and input markets, as a result of intervention by the government in certain markets in Thai agriculture. One possible method of addressing this issue is to adapt the shadow price approach of Atkinson and Halvorsen (1984) to the dual framework but this is beyond the scope of this study.

Elasticity Calculations

Applying equations (3)-(6), Tables 3 and 4 present factor demand elasticities with respect to factor prices and the Allen partial elasticities of substitution calculated at the sample means of the data with land held constant, respectively. The analysis indicates two main findings.

First, the own-price elasticities of demand for all the variable factors (i.e., fertiliser, hired labour, capital, operator labour and unpaid family labour) have a negative sign, as one would expect, but they are quite inelastic, indicating inelastic

---

equation was dropped.

demand for these factor inputs by firms. In addition, the demand elasticity for capital is the smallest in absolute values among the five elasticities. This may be because capital is a fixed rather than a variable factor.

Second, the only AESs between capital and fertiliser, hired labour and unpaid family labour are -0.48, -0.73 and -0.21, respectively. This indicates that capital and fertiliser, hired labour and unpaid family labour are complementarities.

Scale Economies

Table 5 presents the scale economies calculated using equations (7) at the sample means of the data for five sub-periods of 1972-77, 1978-83, 1984-89, 1990-94 and 1978-94 in Thailand. The empirical results show that the scale economy values were positive for all sub-periods. This indicates that Thai agricultural production operated under scale economies for all sub-periods. In other words, there exist cost advantages in increasing production scale in Thai agriculture. However, the decrease in scale economy values during the above periods, except that for the period of 1990-94, indicates that the extent of making the returns to scale in Thailand has decreased during the periods . This may be partly due to the consequence of the limitation of new land on agricultural production.

Measurements of Rates and Biases of Technical Change

Similar to scale economies, the rates of technical change given in Table 6 were calculated using equation (9) at the sample means of the data for the sub-periods of 1972-77, 1978-83, 1984-89, 1990-94 and 1978-94. The empirical results show that the average annual rate of technical progress was -0.50 per cent during the period of 1972-77, and it increased to 1.30 per cent during the period of 1990-94. The results indicate *negative* technical progress during the first sub-period and quite low technical progress during the following sub-periods in Thai agriculture. This may be the result of a number of factors. First, as mentioned above, the relatively high growth rate of Thai agriculture was achieved by the expansion of cultivated areas for six years of the sample period providing little pressure for the application of new technology. Second, the government have applied price controls to several agricultural export commodities, especially rice and rubber, and have also implemented import quota and tariff policies in some input markets, such as fertiliser and farm machinery (Krasachat, 1997). These government policies may have depressed technical change by altering the price-cost ratio in the agricultural sector, especially in the rice sector (Warr, 1993). The low rates of technical progress indicated in the model results here are also reflected in reported low levels of adoption of new technologies such as modern high-yielding varieties of rice and fertiliser (Setboonsarng and Evenson, 1991). However, although not large, the increasing positive values of the rate of technical change since the period of 1978-83 indicate that technical progress has occurred in Thai agriculture.

The measures of biases in technical change are presented in Table 7. They were estimated at the sample means of the periods 1972-77, 1978-83, 1984-89, 1990-94 and 1978-90. The analysis indicates two main findings. First, technical change was biased toward saving hired labour, operator labour and unpaid family labour as indicated by negative rates over all sub-periods, except for the 1990-94 period when technical change was biased toward using unpaid family labour. In addition, the extent of the operator labour- and unpaid family labour-saving biases decreased over the above sub-periods in absolute value, whereas that of hired labour-saving bias increased. These findings correspond to the increasing emigration of hired labour to other sectors during the above sub-periods. Second, technical change was biased toward using fertiliser and capital. The degree of fertiliser- and capital-using biases declined consistently over the sub-periods. These findings are consistent with the rapid increases in quantities of capital and chemical fertiliser used in Thai agriculture at the aggregate level during the early 1970s and the stabilisation of usage after that period.

5. Conclusions

A translog cost function was specified for Thai agriculture. A system of six equations was derived, comprising one cost function and five cost share equations. The parameters in this system were estimated using seeming unrelated regression estimation.

The own-price elasticities of demand for all the variable factors have a negative sign, as one would expect, but are quite inelastic. Capital and fertiliser, hired labour and unpaid family labour are complementarities.

The values of scale economies are positive. This indicates that Thai agricultural production operated under scale economies. In other words, there exist cost advantages in increasing production scale in Thai agriculture.

The rate of technical progress in Thai agriculture was considerably low. Technical change was biased toward saving hired labour, operator labour and unpaid family labour and also biased toward using fertiliser and capital.

These results also indicate that there exist differences in the values of scale economies, the rates of technical change and biases in technical change between the periods of 1972-77 and 1978-94. This implies that the availabilities of new land could have an influence on Thai agricultural production.

The validity of the results, however, are called into question by observed violations of monotonicity and concavity conditions. These suggest that the assumption of competitive product and factor markets may have been false, or alternatively that the data used may not be without problems. However, it should be noted that the econometric estimates in this study appear to be essentially consistent with the present state of Thai agriculture. The concavity violations can be rationalised when the degree of government intervention into these markets is taken into account.

In order to sustain the growth of Thai farm output, despite the high government intervention in the sector, the limited potential for expanding agricultural land, and the declining real prices of primary commodities in world market, a larger scale of farming and more technical progress such as technical innovations will have to be promoted.

References

Antel, J.M., Capalbo, S.M., 1988. An introduction to recent developments in production theory and productivity measurement. In: Capalbo, S.M., Antel, J.M. (Ed.), Agricultural Productivity: Measurement and Explanation. Resources for the Future, Inc., Washington, D.C., pp. 17-95.

Asian Development Bank, 1990. Asian Development Outlook 1990. Manila.

Atkinson, S.E., Halvorsen, R., 1984. Parametric efficiency tests, economies of scale, and input demand in U.S. electric power generation. Int. Econ. Rev. 25, 647-662.

Bank of Thailand, 1998. Mon. Bull. 9, Bangkok.

Bhattacharyya, A., Bhattacharyya, A., Mitra, K., 1997. Decomposition of technological change and factor bias in Indian power sector: an unbalanced panel data approach. J. Productivity. Anal. 8, 35-52.

Bigsby, H.R., 1994. Production structure and the Australian sawmilling industry. Aust. J. Agric. Econ. 38, 271-88.

Binswanger, H.P., 1974. A cost function approach to the measurement of elasticities of factor demand and elasticities of substitution. Am. J. Agric. Econ. 56, 377-386.

Caves, D.W., Christensen, L.R., Diewert, W.E., 1982. Multilateral comparisons of output, input, and productivity using superlative index numbers. Econ. J. 92, 73-86.

Christensen, L.R., Greene, W.H., 1976. Economies of scale in U.S. electric power generation. J. Polit. Econ. 84, 655-676.

Conrad, K., Unger, R., 1987. Ex post tests for short- and long-run optimisation. J. Econometrics 36, 339-58.

Jieamanugulgit, P., 1989. Output supply and input demand of upland crops; a system equations model derived from the profit function framework. Warasan Wijai Setthasart Kaset 12, 1-35 (in Thai).

Karagiannis, G., Furtan, W.H., 1993. Production structure and decomposition of biased technical change: an example from Canadian agriculture. Rev. Agric. Econ. 15, 21-37.

Krasachat, W., 1997. The Dynamic Adjustment of Structure and Demand for Labour in Thai Agriculture. Ph.D. thesis, University of New England, Armidale.

Kuroda, Y., 1998. An empirical investigation of the rice production structure in Taiwan, 1976-93. Developing Econ. 36, 80-100.

Lau, L.J., 1978. Testing and imposing monotonicity, convexity and quasi-convexity constraints. In: Fuss, M., McFadden, D. (Ed.), Production Economics: A Dual

Approach to Theory and Applications. Vol. 1, North-Holland, Amsterdam, pp. 409-454.

McKay, L., Lawrence, D., Vlastuin, C., 1980. Input demand and substitution in the Australian sheep industry. Rev. Mkt. Agric. Econ. 48, 57-69.

Ministry of Agriculture and Cooperatives, 1995. Agricultural Statistics of Thailand Crop Year, 1971/72-1995/96. Centre for Agricultural Statistics, Bangkok.

Ministry of Finance, 1995. Annual Statement of Foreign Trade Statistics. Department of Customs, Bangkok.

National Statistical Office, 1997. Report on Labour Force Survey (Round 3), Whole Kingdom, 1971-1994. Bangkok.

Nautiyal, J.C., Singh, B.K., 1986. Long-term productivity and factor demand in the Canadian pulp and paper industry. Can. J Agric. Econ. 34, 21-44.

Onchan, T., Isvilanonda, S., 1991. Technology and Productivity: A Comparative Study of Thailand and Japan. Centre for Applied Economic Research, Kasetsart University, Bangkok.

Patamasiriwat, D., Suewattana, S., 1990. Sources of growth of agricultural production 1961-85: analysis based on Thailand Development Research Institute model. Warasan Setthasart Thammasart 8, 43-69 (in Thai).

Puapanichya, K., Panayotou, T., 1985. Output supply and input demand in rice and upland crop production: the quest for higher yields in Thailand. In: Panayotou, T. (Ed.), Food Policy Analysis in Thailand. Agricultural Development Council, Bangkok, pp. 23-99.

Setboonsarng, S., Evenson, R.E., 1991. Technology, infrastructure, output supply, and factor demand in Thai agriculture. In: Evenson, R.E., Pray, C.E. (Ed.), Research and Productivity in Asian Agriculture. Cornell University Press, Ithaca, pp. 206-216.

Tyrchniewicz, E.W., Schuh, G.E., 1969. Econometric analysis of the agricultural labour market. Am. J. Agric. Econ. 51, 770-787.

Wall, C.A., Fisher, B.S., 1987. Modelling a Multiple Output Production System: Supply Response in the Australian Sheep Industry. Res. Rep. 11, Department of Agricultural Economics, University of Sydney, Sydney.

Warr, P.G., 1993. The Thai economy. In: Warr, P.G. (Ed.), The Thai Economy in Transition. Cambridge University Press, New York, pp. 1-80.

Warr, P.G., 1994. Primal vs dual estimation of factor demand functions: an application to Thai agriculture. Paper presented at the Second International Conference on Asia-Pacific Economic Modelling, 24-26 August, Sydney.

Zellner, A., 1962. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. J. Am. Stat. Assoc. 57, 348-68.

Table 1
Seemingly unrelated regression parameter estimates of the translog variable cost function for Thai agriculture

Parameter	Coefficient	Parameter	Coefficient	Parameter	Coefficient
α_0	8.276	γ_{HU}	-0.009	μ_{QD}	-0.011
	(5.628)		(0.020)		(0.010)
α_Q	0.014	γ_{KO}	-0.011	μ_{FT}	0.005
	(0.665)		(0.014)		(0.001)
α_F	0.362	γ_{KU}	-0.042	μ_{FD}	0.003
	(0.134)		(0.018)		(0.004)
α_H	0.519	γ_{OU}	0.002	μ_{HT}	0.00003
	(0.094)		(0.026)		(0.0009)
α_K	0.310	γ_{UU}	0.046	μ_{HD}	-0.004
	(0.098)		(0.033)		(0.002)
α_o	0.171	θ_{FB}	-0.097	μ_{KT}	0.012
	(0.121)		(0.021)		(0.001)
γ_U	-0.362	θ_{HB}	-0.143	μ_{KD}	0.005
	(0.155)		(0.013)		(0.004)
β_B	-2.091	θ_{KB}	-0.178	μ_{OT}	-0.007
	(2.699)		(0.021)		(0.001)
γ_{QQ}	0.334	θ_{OB}	0.120	μ_{OD}	0.003
	(0.104)		(0.018)		(0.003)
γ_{FF}	0.039	θ_{UB}	0.298	μ_{UT}	-0.010
	(0.032)		(0.021)		(0.001)
γ_{HH}	0.072	θ_{BB}	1.180	μ_{UD}	-0.007
	(0.020)		(0.692)		(0.004)
γ_{KK}	0.090	δ_{QF}	0.033	β_{BT}	-0.021
	(0.016)		(0.010)		(0.010)
γ_{OO}	0.056	δ_{QH}	0.056	β_{BD}	0.004
	(0.029)		(0.006)		(0.018)
γ_{UU}	0.046	δ_{QK}	0.073	β_{TT}	-0.0006
	(0.033)		(0.010)		(0.0006)
γ_{FH}	-0.010	δ_{QO}	-0.079	β_{TD}	0.039
	(0.018)		(0.009)		(0.008)
γ_{FK}	-0.014	δ_{QU}	-0.082	D_2	0.046
	(0.016)		(0.010)		(0.143)
γ_{FO}	-0.017	δ_{QB}	-0.317	D_3	0.109
	(0.024)		(0.203)		(0.022)
γ_{FU}	0.003	β_T	0.092	D_4	-0.115
	(0.027		(0.045)		(0.209)
γ_{HK}	-0.023	β_D	-0.113		
	(0.010)		(0.055)		
γ_{HO}	-0.030	μ_{QT}	0.002		
	(0.019)		(0.003)		

Standard errors of estimates are in parenthesis.

Table 2

Hypothesis tests

Hypotheses	Test Values	Critical Values (5 %)	Results
1. Constant returns to scale (CRTS)	430.20	$\chi^2(10) = 18.31$	Rejected
2. Hicks neutrality of technical change in the variable factor inputs	159.35	$\chi^2(10) = 18.31$	Rejected
3. Neutrality of technical change with respect to output scale	165.67	$\chi^2(5) = 11.07$	Rejected
4. No differences in technical change parameters	53.93	$\chi^2(8) = 15.51$	Rejected
5. No technical change	625.14	$\chi^2(17) = 27.59$	Rejected

Table 3

Demand elasticities with respect to factor prices

	Fertiliser	Hired Labour	Capital	Operator labour	Unpaid Family Labour
Fertiliser	-0.503	0.029	-0.049	0.152	0.369
	(0.338)	(0.183)	(0.167)	(0.249)	(0.284)
Hired Labour	0.021	-0.316	-0.075	0.097	0.272
	(0.134)	(0.152)	(0.078)	(0.143)	(0.152)
Capital	-0.046	-0.096	-0.013	0.224	-0.070
	(0.157)	(0.100)	(0.158)	(0.139)	(0.172)
Operator Labour	0.044	0.039	0.069	-0.500	0.347
	(0.073)	(0.057)	(0.043)	(0.089)	(0.078)
Unpaid Family	0.104	0.104	-0.021	0.335	-0.523
Labour	(0.080)	(0.058)	(0.052)	(0.076)	(0.097)

Standard errors are in parentheses.
Elasticities are calculated at mean of data set.

Table 4

Allen partial elasticities of substitution

	Fertiliser	Hired Labour	Capital	Operator labour	Unpaid Family Labour
Fertiliser	-5.235	0.219	-0.478	0.463	1.083
	(3.525)	(1.399)	(1.633)	(0.756)	(0.833)
Hired Labour		-2.410	-0.734	0.295	0.796
		(1.160)	(0.767)	(0.436)	(0.446)
Capital			-0.129	0.681	-0.205
			(1.545)	(0.423)	(0.506)
Operator Labour				-1.521	1.017
				(0.270)	(0.230)
Unpaid Family Labour					-1.534
					(0.285)

Standard errors are in parentheses.
Elasticities are calculated at mean of data set.

Table 5

Scale economies

Periods	Scale Economies (SCE)
1972-77	1.204
	(0.093)
1978-83	1.149
	(0.087)
1984-89	1.096
	(0.080)
1990-94	1.138
	(0.081)
1978-94	1.127
	(0.081)

Standard errors are in parentheses.

Table 6

Annual growth rates of technical change

Periods	Technical Change (υ_t)
1972-77	-0.005
	(0.020)
1978-83	0.006
	(0.008)
1984-89	0.006
	(0.007)
1990-94	0.013
	(0.008)
1978-94	0.008
	(0.007)

Standard errors are in parentheses.

Table 7

Measurements of biases in technical change in Thai agriculture

Periods	Fertiliser	Hired Labour	Capital	Operator Labour	Unpaid Family Labour
1972-77	0.112	-0.022	1.969	-0.014	-0.047
	(0.043)	(0.037)	(0.687)	(0.017)	(0.010)
1978-83	0.044	-0.015	0.171	-0.010	-0.017
	(0.021)	(0.022)	(0.074)	(0.013)	(0.010)
1984-89	0.026	-0.024	0.056	-0.005	-0.014
	(0.025)	(0.033)	(0.051)	(0.024)	(0.021)
1990-94	0.015	-0.053	0.020	0.002	-0.009
	(0.018)	(0.043)	(0.021)	(0.021)	(0.020)
1978-94	0.027	-0.026	0.052	-0.005	-0.015
	(0.019)	(0.029)	(0.035)	(0.018)	(0.014)

Standard errors are in parentheses.