DYNAMICS OF AGRICULTURAL PRODUCTION IN THAILAND*

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ABSTRACT

The primary purpose of this study is to investigate the dynamic nature of agricultural production in Thailand during the period 1971 to 1990. An intertemporal generalised Leontief value function in an adjustment cost framework is used to derive a dynamic system of six equations: an output supply equation; fertiliser and hired labour variable demand equations; and operator and unpaid family labour and capital quasi-fixed demand equations for Thai agriculture. The system is estimated using non-linear three stage least squares applying to annual data from 1971 to 1990 for four regions in Thailand. The results provide valuable information on technical change, speed and independence of adjustment of quasi-fixed factors and elasticities of output supply in Thai agriculture.

Keywords: intertemporal duality, Thai agriculture, adjustment costs

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1. Introduction

Thailand has experienced rapid growth in agriculture over the past three decades. During 1963 to 1985, the annual growth rates of gross value added averaged approximately 4 per cent (Onchan and Isvilanonda 1991, p. 60). Although, the agricultural sector recorded a negative growth rate of 2 per cent in 1987, due to the drought crisis, the agriculture still grew at a high average rate of nearly 4 per cent per annum during 1981 to 1990 (Asian Development Bank 1990).

This paper has a main objective. It seeks to explain how Thai farmers responded to price incentives to sustain the growth of farm output despite the very high government intervention in the sector, the limited potential for expanding agricultural land, and the declining real prices of primary commodities in the world market.

To achieve the above objective, we utilise a dynamic dual approach, under an adjustment cost framework, to construct a set of output supply and input demand equations, employing a modified generalised Leontief functional form for the value function. The resulting system of equations are estimated using panel data comprising 20 years of annual data (1971 to 1990) on the four regions in Thailand. The responsiveness of the farmers to price changes are calculated from these estimates

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 and suggestions for further research.

2. Model Specification

The dynamic models used in many past dual analyses of production have involved the inclusion of *ad hoc* lag structures into otherwise static models (e.g., Jorgenson 1965, Prucha and Nadiri 1986, Tsigas and Hertel 1989, among others). The lack of theoretical justification for these models prompted the development of an approach which involves the derivation of dynamic models from intertemporal value functions (in the form of Hamilton-Jacobi equations) using optimal control theory. The behavioural equations of these models have been derived in two different ways. First, a primal approach, using first-order Euler equations, was developed by Treadway (1970) and subsequently applied by Berndt, Fuss and Waverman (1979), Lopez (1985) and others. A dual approach was developed by Cooper and McLaren (1977), McLaren and Cooper (1980), and Epstein (1981) and has since been applied by Taylor and Monson (1985) and Howard and Shumway (1988), among others. The latter approach is not limited to the specification of a single quasi-fixed input (as the primal approach is) and hence is the method used in this analysis where the consideration of three quasi-fixed inputs is desired.

Following the approach of Howard and Shumway (1988), we begin the intertemporal optimisation problem with the specification of a value function. At time $t = 0$, a firm is assumed to solve:[1]

$$(1) \qquad J(P, W, C, r, K_0) = Max \int_0^\infty e^{-rt}\left[P \cdot F(X, K, \dot{K}) - W'X - C'K\right]dt$$

subject to $X, K > 0$, $\dot{K} = I - \delta K$, $K(0) = K_0 > 0$,

where $F(X, K, \dot{K})$ is a twice continuously differentiable, concave production function using a variable input vector, X, quasi-fixed input vector, K, and a vector of net investment of the quasi-fixed inputs, $\dot{K}$ (which may be negative or positive); P, W and C are the price of output, a vector of prices of variable inputs and a vector of prices of quasi-fixed inputs, respectively; δ is a constant depreciation rate; r is the real discount rate; K_0 is the initial endowment of K; and I is a vector of gross investment in quasi-fixed inputs. All variables are implicit functions of time. To avoid complexity of notation, time subscripts are ignored.

In this study, labour is divided into three groups: hired labour, operator labour and unpaid family labour at aggregate level.[2] In a study of U.S. agriculture, involving a dynamic simultaneous equation model which included equations for the above three labour groupings, Tyrchniewicz and Schuh (1969) found that the elasticity of adjustment was largest (0.53) for hired labour demand, approximately one fourth for unpaid family labour and almost zero for operator labour. Since hired labour can be easily adjusted in the short term, it is classified to be a variable input. Operator labour

[1] In this study, the assumption of static price expectation is assumed to maintain the duality between the production function and value function (Weersink 1990). Alternative forms of price expectations are considered in Epstein and Denny (1983) and Warjiyo (1991).

[2] The theoretical model discussed above considers dynamic optimisation decisions at the farm level. But in this study, aggregated regional data are used. In order to apply farm-level theory to the regional level, the value function must have a form such that $J_{KK} = 0$. This implies that the value function relies solely on the regional quantity of quasi-fixed inputs. In other words, the firms are aggregated linearly to the regional level. For further discussion see Warjiyo (1991, pp. 38-41). Weersink (1990, p. 13) indicates that the modified generalised Leontief and the normalised quadratic functional forms both satisfy this requirement.

and unpaid family labour, on the other hand, are much more difficult to adjust in the short run; thus they are treated as quasi-fixed inputs.

In this study, the value function is specified as a modified generalised Leontief value function:[3]

$$(2)\quad J(P,W,C,K,T) = [PW]AK + C'B^{-1}K + [P^{5}W^{5}]EC^{5} + C^{5}FC^{5}$$
$$+[P^{5}W^{5}]G[P^{5}W^{5}] + TH[PWC'],$$

where P is the price of agricultural products, W is the (2×1) vector of prices of variable inputs (W_1 is the price of fertiliser, and W_2 is the wage ra ired labour), C is the (3×1) vector of prices of quasi-fixed inputs (C_1 is the pric apital, C_2 is the wage rate of operator labour and C_3 is the wage rate of unpaid family labour), K is the (3×1) vector of quasi-fixed inputs (K_1 is capital, K_2 is operator labour and K_3 is unpaid family labour), and T is a time trend introduced to proxy disembodied technical change. A, B^{-1}, E, F and G are (3×3) matrices of parameters, and H is a (5×1) vector of parameters.

Applying the Hamilton-Jacobi equation and utilising the envelope theorem to the value function yields a simultaneous dynamic system involving six equations, namely the output supply equation, and the fertiliser, capital, hired labour, operator labour and unpaid family labour demand equations.

$$(3)\quad Y = a_{11}(rK_1 - \dot{K}_1) + a_{12}(rK_2 - \dot{K}_2) + a_{13}(rK_3 - \dot{K}_3)$$
$$+(r/2)\{e_{11}(C_1/P)^{5} + e_{12}(C_2/P)^{5} + e_{13}(C_3/P)^{5}$$
$$+2g_{11} + 2g_{12}(W_1/P)^{5} + 2g_{13}(W_2/P)^{5}\} + rh_1t + \varepsilon_1$$

$$(4)\quad X_1 = a_{21}(\dot{K}_1 - rK_1) + a_{22}(\dot{K}_2 - rK_2) + a_{23}(\dot{K}_3 - rK_3)$$
$$(r/2)\{e_{21}(C_1/W_1)^{5} + e_{22}(C_2/W_1)^{5} + e_{23}(C_3/W_1)^{5}$$
$$+2g_{22} + 2g_{12}(P/W_1)^{5} + 2g_{23}(W_2/W_1)^{5}\} - rh_2t + \varepsilon_2$$

3 The two functional forms which have been used most often in agricultural applications are the modified generalised Leontief (e.g., Howard and Shumway 1988) and the normalised quadratic (e.g., Taylor and Monson 1985). Past applications of these functional forms tend to indicate that the modified generalised Leontief should be preferred because it has provided more significant parameters and higher R^2 values, along with quite robust results in testing accordance with theoretical properties (e.g., Howard and Shumway 1988, 1989, Weersink 1990). Furthermore, in order to maintain flexible accelerator investment in quasi-fixed inputs, Howard and Shumway (1988) recommended that the value function should be of a form such that J_{KC} is not a function of prices.

$$(5)\qquad X_2 = a_{31}(\dot{K}_1 - rK_1) + a_{32}(\dot{K}_2 - rK_2) + a_{33}(\dot{K}_3 - rK_3)$$
$$-(r/2)\{e_{31}(C_1/W_2)^{.5} + e_{32}(C_2/W_2)^{.5} + e_{33}(C_3/W_2)^{.5}$$
$$+2g_{13}(P/W_2)^{.5} + 2g_{23}(W_1/W_2)^{.5} + 2g_{33}\} - rh_3t + \varepsilon_3$$

$$(6)\qquad \dot{K}_1 = (b_{11} + r)K_1 + b_{12}K_2 + b_{13}K_3$$
$$+(r/2)b_{11}\{e_{11}(P/C_1)^{.5} + e_{21}(W_1/C_1)^{.5} + e_{31}(W_2/C_1)^{.5}$$
$$+2f_{11} + 2f_{12}(C_2/C_1)^{.5} + 2f_{13}(C_3/C_1)^{.5}\}$$
$$+(r/2)b_{12}\{e_{12}(P/C_2)^{.5} + e_{22}(W_1/C_2)^{.5} + e_{32}(W_3/C_2)^{.5}$$
$$+2f_{12}(C_1/C_2)^{.5} + 2f_{22} + 2f_{23}(C_3/C_2)^{.5}\}$$
$$+(r/2)b_{13}\{e_{13}(P/C_3)^{.5} + e_{23}(W_1/C_3)^{.5} + e_{33}(W_2/C_3)^{.5}$$
$$+2f_{13}(C_1/C_3)^{.5} + 2f_{23}(C_2/C_3)^{.5} + 2f_{33}\}$$
$$+r(b_{11}h_4t + b_{12}h_5t + b_{13}h_6t) + \varepsilon_4$$

$$(7)\qquad \dot{K}_2 = (b_{22} + r)K_2 + b_{21}K_1 + b_{23}K_3$$
$$+(r/2)b_{21}\{e_{11}(P/C_1)^{.5} + e_{21}(W_1/C_1)^{.5} + e_{31}(W_2/C_1)^{.5}$$
$$+2f_{11} + 2f_{12}(C_2/C_1)^{.5} + 2f_{13}(C_3/C_1)^{.5}\}$$
$$+(r/2)b_{22}\{e_{12}(P/C_2)^{.5} + e_{22}(W_1/C_2)^{.5} + e_{32}(W_3/C_2)^{.5}$$
$$+2f_{12}(C_1/C_2)^{.5} + 2f_{22} + 2f_{23}(C_3/C_2)^{.5}\}$$
$$+(r/2)b_{23}\{e_{13}(P/C_3)^{.5} + e_{23}(W_1/C_3)^{.5} + e_{33}(W_2/C_3)^{.5}$$
$$+2f_{13}(C_1/C_3)^{.5} + 2f_{23}(C_2/C_3)^{.5} + 2f_{33}\}$$
$$+r(b_{21}h_4t + b_{22}h_5t + b_{23}h_6t) + \varepsilon_5$$

$$(8)\qquad \dot{K}_3 = (b_{33} + r)K_3 + b_{31}K_1 + b_{32}K_2$$
$$+(r/2)b_{31}\{e_{11}(P/C_1)^{.5} + e_{21}(W_1/C_1)^{.5} + e_{31}(W_2/C_1)^{.5}$$
$$+2f_{11} + 2f_{12}(C_2/C_1)^{.5} + 2f_{13}(C_3/C_1)^{.5}\}$$
$$+(r/2)b_{32}\{e_{12}(P/C_2)^{.5} + e_{22}(W_1/C_2)^{.5} + e_{32}(W_3/C_2)^{.5}$$
$$+2f_{12}(C_1/C_2)^{.5} + 2f_{22} + 2f_{23}(C_3/C_2)^{.5}\}$$
$$+(r/2)b_{33}\{e_{13}(P/C_3)^{.5} + e_{23}(W_1/C_3)^{.5} + e_{33}(W_2/C_3)^{.5}$$
$$+2f_{13}(C_1/C_3)^{.5} + 2f_{23}(C_2/C_3)^{.5} + 2f_{33}\}$$
$$+r(b_{31}h_4t + b_{32}h_5t + b_{33}h_6t) + \varepsilon_6,$$

where a_{ij} is the ij-th element of the A matrix, etc; Y is output supply; X_1 and X_2 are fertiliser and hired labour; $\dot{K}_1$, $\dot{K}_2$ and $\dot{K}_3$ are net investments in capital, operator and unpaid family labour, respectively; t is a time trend; r is the real discount rate; and all other variables are as defined earlier. $\varepsilon_1,\ldots,\varepsilon_6$ are error terms appended to each of these estimating equations to capture the effects of any omitted variables such as policy variables, weather, chemicals and materials. These error terms are assumed to adhere to the classical assumptions of least squares. That is, $\varepsilon_i \sim N(0,\sigma_i^2)$, for $i = 1\ldots6$. In addition, contemporaneous correlation between the error terms of the six equations is considered. That is, $E(\varepsilon_{i\tau}\varepsilon_{j\tau}) \neq 0$, for all τ (time subscripts) and for all $i \neq j$ (Pindyck and Rubinfeld 1981).

Structural Tests

The net investment demand equations (6)-(8) can be used to investigate the speed of adjustment of the quasi-fixed factors. Equations (6)-(8) can be rewritten as:

$$(9)\quad \dot{K}(P,W,C,K) = \begin{pmatrix} b_{11}+r & b_{12} & b_{13} \\ b_{21} & b_{22}+r & b_{23} \\ b_{31} & b_{32} & b_{33}+r \end{pmatrix}(K-\overline{K}),$$

where $\overline{K}$ is a 3×1 vector of long-run or desired levels of quasi-fixed inputs. Equation (9) indicates that farmers are not able to equate their actual and desired levels of quasi-fixed inputs in the short run because of the presence of adjustment costs. In other words, the adjustment costs result in disequilibrium between the short-run and the long-run levels of quasi-fixed factors (not in disequilibrium between supply and demand in particular fixed input markets). In the absence of adjustment costs, farmers can freely adjust all inputs (in the short run) when relative prices change, without any cost. The long-run or desired levels of the quasi-fixed inputs may be derived by setting $\dot{K} = 0$ in (9), and solving for $\overline{K}$ to obtain:

$$(10)\quad \overline{K} = -\begin{bmatrix} b_{11}+r & b_{12} & b_{13} \\ b_{21} & b_{22}+r & b_{23} \\ b_{31} & b_{32} & b_{33}+r \end{bmatrix}^{-1} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$$

$$\times \begin{bmatrix} \frac{r}{2}\left\{ e_{11}\left(\frac{P}{C_1}\right)^{.5} + e_{21}\left(\frac{W_1}{C_1}\right)^{.5} + e_{31}\left(\frac{W_2}{C_1}\right)^{.5} + 2f_{11} + 2f_{12}\left(\frac{C_2}{C_1}\right)^{.5} + 2f_{13}\left(\frac{C_3}{C_1}\right)^{.5} \right\} + rh_4 t \\ \frac{r}{2}\left\{ e_{12}\left(\frac{P}{C_2}\right)^{.5} + e_{22}\left(\frac{W_1}{C_2}\right)^{.5} + e_{32}\left(\frac{W_2}{C_2}\right)^{.5} + 2f_{12}\left(\frac{C_1}{C_2}\right)^{.5} + 2f_{22} + 2f_{23}\left(\frac{C_3}{C_2}\right)^{.5} \right\} + rh_5 t \\ \frac{r}{2}\left\{ e_{13}\left(\frac{P}{C_3}\right)^{.5} + e_{23}\left(\frac{W_1}{C_3}\right)^{.5} + e_{33}\left(\frac{W_2}{C_3}\right)^{.5} + 2f_{13}\left(\frac{C_1}{C_3}\right)^{.5} + 2f_{23}\left(\frac{C_2}{C_3}\right)^{.5} + 2f_{33} \right\} + rh_6 t \end{bmatrix}.$$

This model is similar to the univariate flexible accelerator model if it does not take account of interdependent adjustments among quasi-fixed inputs. In this instance, the system of equations (6)-(8) will reduce to three non-simultaneous equations. In this analysis, the independence of adjustment is considered by testing whether $b_{ij} = 0$, for $i \neq j$.

If the quasi-fixed inputs adjust fully in a single time period, then the quasi-fixed inputs are in fact variable. The hypothesis of instantaneous adjustment in quasi-fixed input i is considered by testing whether $(b_{ii} + r) = -1$ and $b_{ji} = 0$ for $i \neq j = 1,2,3$. The first restriction implies there is no disequilibrium in using input i ($\dot{K}_i = 0$; $K_i = \overline{K}_i$). The latter restriction says that if input i is variable, its stock does not affect the demands for other inputs. This is because any variable input is always in equilibrium (Warjiyo 1991, p. 60).

Technical Change Tests

The modified generalised Leontief value function (2) was specified with a time trend, T, included as an argument to reflect the influence of disembodied technical change. This *ad hoc* inclusion of a time trend follows the approach of Taylor and Monson (1985) and Howard and Shumway (1989). As a result of the inclusion of the time trend in the value function, a time trend also appears in the derived output supply and input demand equations, equations (3)-(8). The hypothesis that technical change does not influence this production system may be considered by testing the hypothesis that $h_i = 0$, i = 1, 2, ...6.

Tests of Competitive Behaviour

The modified generalised Leontief functional form satisfies homogeneity and symmetry in prices, and concavity in quasi-fixed inputs. The conditions of monotonicity and convexity in prices, however, are not automatically satisfied.[4] Lau (1978, p. 411) points out that convexity assumptions are very important in dual analyses. If convexity conditions are violated, the signs of own- and cross-price elasticities of output supply and demand for inputs will not be theoretically consistent. Therefore, both monotonicity and convexity are checked in this study.[5] Violation of certain regularity conditions can provide evidence of non-competative behaviour. Warjiyo (1991) suggested that the monotonicity property of the value function could be easily checked by considering the first derivative of the estimated value function with respect to prices. For example, the value function is increasing in output price if $J_P > 0$; it is decreasing in input prices if $J_W < 0$ and $J_C < 0$.[6]

In addition, Vasavada and Chambers (1986) and Warjiyo (1991) reported that the convexity of the estimated value function is satisfied if the matrices of J_{PP}, J_{WW} and J_{CC} are positive semi-definite, which at a minimum requires that J_{PP}, J_{WW} and J_{CC} are symmetric matrices and do not have negative diagonal elements.[7] Since, in this analysis, symmetry is a property of the generalised Leontief functional form, a study of the signs of the diagonal elements of these matrices is used to check for violations of convexity. These checks for monotonicity and convexity 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 1971-90. Inputs are classified into five groups: fertiliser, hired labour, capital, operator labour and unpaid family labour. The data for

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[4] The properties of the modified generalised Leontief are reviewed in Krasachat, Coelli and Fleming (1994a,b).

[5] Since statistical testing of monotonicity and convexity of standard duality involves inequality constraints on parameters, it is generally difficult to conduct formal hypothesis tests (Lau 1978) and is likely to be even more difficult for dynamic duality (Epstein 1979).

[6] Note that the notation, J_P, refers to $\partial J / \partial P$, etc.

[7] Note that J_{PP} refers to $\partial^2 J / \partial^2 P$, etc.

quantities of labour are based on annual surveys conducted by the National Statistical Office (1993). The data on hired and operator labour wages are similar to Krasachat, Coelli and Fleming (1994a,b). Hired and operator labour wages are combined using the Tornqvist method, to provide a proxy for the unpaid family labour wage, as described in Krasachat (1994). The data for quantities and prices of fertiliser are derived from several occasional publications of the Ministry of Agriculture and Cooperatives.[8] The quantities of capital are collected from the *Agricultural Statistics of Thailand Crop Year* published annually by the Ministry of Agriculture and Cooperatives (1992).[9] The imported capital prices are obtained from the *Annual Statement of Foreign Trade Statistics* (Ministry of Finance 1991).

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 and the three main livestock products.[10] The data for quantities and prices of crops and livestock are also taken from the *Agricultural Statistics of Thailand Crop Year.*

The method of Tornqvist (1936) is used to construct any price indexes which involve more than one commodity. Implicit quantity indexes are obtained by dividing the current value of each input and output by their corresponding Tornqvist price index.[11]

All price variables are deflated by the CPI (1985 = 100).[12] A six per cent real discount rate is assumed. This rate is based upon the interest rates for agricultural credit published in the *Annual Report* of the Bank of Agriculture and Cooperatives (1991).

4. Empirical Results

The system of equations (3) to (8) is a non-linear, simultaneous equation model. The non-linear three stages least squares routine, **LSQ** procedure, a minimum distance

[8] Some regional observations were missing in some years. These were estimated by extrapolation from national quantities. For further discussion see Krasachat, Coelli and Fleming (1994a,b).

[9] Capital comprises farm machinery, water pumps and threshers. Some regional observations were missing in some years. These were also estimated by extrapolation from national quantities.

[10] The ten major crops are rice, kenaf, cotton, cassava, groundnuts, soybeans, mungbeans, sugar cane, corn and sorghum and the three main livestock products are buffaloes, cattle and swine.

[11] Because of a lack of data on the price of land, a unit value function is employed by maintaining constant returns to scale with respect to area of land. Therefore, an implicit quantity index per hectare is obtained by dividing the implicit quantity index by the agricultural land use of corresponding regions.

[12] Note that the national price index of each output and input is used for all four regions because price data at the regional level are not available.

estimator in TSP, is used to estimate the unknown parameters of this model.[13] The Davidon-Fletcher-Powell algorithm method is used in estimation. Lagged quantities of quasi-fixed inputs, lagged output price[14] and input prices are used as the instrumental variables.

The time-series, cross-sectional (panel) data comprise 20 years of data on four regions, giving a total of 80 observations. Possible regional differences in climate, natural resources, etc., are accounted for through the inclusion of regional dummy variables in each estimating equation. This permits the intercepts in each of the output supply and input demand equations to differ in the different regions. 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.

Note that $\dot{K}_t$ is approximated by $K_t - K_{t-1}$ (Howard and Shumway 1988, 1989, Luh and Stefanou 1991). This approximation is used because there is little information available regarding the depreciation rate of capital or the number of labourers retiring from the agricultural sector.

The parameter estimates of the system of equations (3)-(8) are reported in Table 1. Approximately one third of the estimated parameters are at least twice their corresponding asymptotic standard errors, which is quite a favourable result when compared with other estimated modified generalised Leontief models (e.g., Howard and Shumway 1988, 1989; Weersink 1990). The Durbin-Watson (DW) values for output supply (1.21), demand for fertiliser (2.26), hired labour (1.79), capital (1.46), operator labour (1.63) and unpaid family labour (1.94), suggest autocorrelation is not a problem.

The adjustment matrix obtained from the estimated parameters is of interest. The adjustment rate of demand for capital, equal to $(b_{11}+r)$, is estimated to be -0.033, given a 6 per cent real discount rate. This implies that capital adjusts 3.3 per cent per year towards the desired level, or takes around 30 years to reach the long-run level. This estimated adjustment rate of capital in agriculture is lower than those obtained by other studies which utilise dynamic duality. For the case of U.S. agriculture, the

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13 3SLS and FIML have been used to estimate non-linear, simultaneous equation models in the past. The advantage of 3SLS over FIML has been discussed in many studies (e.g., Warjiyo 1991, p. 73, TSP international 1992, p. 62).

14 The output price from the previous period is used because the prices that farmers will receive in the current period are unknown to them at the beginning of the period, when many production decisions are made. It is assumed that previous prices contain all information about current prices.

adjustment coefficient of capital has been estimated to be -0.554 (Taylor and Monson 1985), -0.118 (Vasavada and Chambers 1986) and -0.121 (Warjiyo 1991).[15] The adjustment coefficient of operator labour is 0.017, which is a rather surprising positive sign. This is not a great concern as it does not appear to be significantly different from zero[16]. It has a t-value of 0.412, while t-values of capital and unpaid family labour adjustment coefficients are 1.953 and 3.324, in absolute value, respectively. The adjustment coefficient of unpaid family labour was estimated to be -0.337, which is not greatly different from the value of one-fourth obtained for unpaid family labour by Tyrchniewicz and Schuh (1969).[17] The results are in general quite similar to Tyrchniewicz and Schuh's results, in that the absolute value of adjustment rate of unpaid family labour is much higher than the rate for operator labour. Overall, these results indicate that the extra effort involved in specifying a model in which operator labour and unpaid family labour are included as separate quasi-fixed inputs is warranted in this instance.

Tests of Hypotheses

Hypothesis test results are presented in Table 3. Wald Chi-Square tests were used in all cases. The null hypothesis that adjustments in the three quasi-fixed factors are independent of each other is rejected as a composite hypothesis. When pairs of quasi-fixed factors are considered separately, the null hypothesis of independent adjustment between capital and operator labour is not rejected, while independent adjustments between capital and unpaid family labour and between operator labour and unpaid family labour are rejected. This indicates that the adjustments of capital and operator labour affect the adjustment decisions regarding unpaid family labour, and *vice versa*. However, capital adjustment appears to be made independently of operator labour adjustment, and *vice versa*.

Instantaneous adjustments in the quasi-fixed inputs are rejected both jointly and individually. These test results imply that there are adjustment costs associated with altering quantities of capital, operator labour and unpaid family labour. In other words, capital, operator labour and unpaid family labour are not variable inputs. The

[15] Due to the inherent differences that exist between U.S. and Thai agriculture, these comparisons may be of limited value. However, since no past dynamic analyses of Thai agricultural production could be found, a comparison with other dynamic dual studies was deemed to be the second best option.

[16] This may be because operator labour is a fixed rather than a quasi-fixed factor. Alternatively it could be a result of using data on the number of operators rather than the actual hours worked by operators. Anecdotal evidence suggests the average number of hours worked per operator appears to have declined over the sample period, as they have engaged in more off farm work.

[17] Again, this comparison is made with a U.S. study because no Thai studies of this nature have been conducted.

result for operator labour conflicts with the conclusion made earlier when considering the asymptotic t-values of the coefficients of adjustment, the b_{ii}. The contradiction between the t-test result and the chi-square test result most likely occurs because the chi-square test includes the b_{ij} as well as the b_{ii}. Since the t-test does not take account of these cross-effects, the chi-square test results are preferred in this instance.

The hypothesis of no technical change in output supply was rejected. The results indicate significant *negative* technical change in output supply in Thai agriculture during the sample period. 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 much of the sample period providing little pressure for applying 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.[18] 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, p. 37). The lack of technical progress indicated in the model results here is also reflected in reported low levels of adoption of new technologies such as modern high-yielding varieties of rice and fertiliser (Puapanichya and Panayotou 1985, pp. 36-8; Setboonsarng and Evenson 1991, p. 206).

The hypotheses of no technical change in labour and other inputs were not rejected. This suggests that there may not have been any substantial technical change in these inputs in Thai agriculture during the sample period. This may possibly be due to an over abundant supply of agricultural labour and/or due to the effects of the government policies providing little impetus for innovation or change.

The model was estimated maintaining homogeneity and symmetry in prices and concavity in quasi-fixed inputs. Monotonicity and convexity in prices were checked following estimation and found not to be satisfied with respect to the prices of fertiliser, capital and unpaid family labour at some data points. The reasons for these violations are not known at present. They 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 dynamic dual framework. This is beyond the scope of the

[18] See more detail in Puapanichya and Panayotou 1985; Siamwalla, Setboonsarng and Patamasiriwat 1993; Krasachat, Coelli and Fleming (1994a).

present paper but will be considered for inclusion in the PhD thesis of the senior author.

Elasticities

The net investment demand equations (6)-(8) permit gradual adjustment in the quasi-fixed inputs. Therefore, there will be short-run and long-run impacts if relative prices change. In the short run, $\dot{K} \neq 0$ because farmers cannot immediately adjust their quasi-fixed inputs in response to relative price changes. Short-run price elasticities are derived from the partial derivatives of the system of equations (3) to (8) with respect to prices.

In the long run, $\dot{K} = 0$ because actual stocks of quasi-fixed inputs are equal to desired stocks, or $K = \overline{K}$. Long-run elasticities can be derived by obtaining the partial derivatives, with respect to prices, of the desired (or long-run) quasi-fixed input equation (10).

Changes in relative prices can have both direct and indirect effects upon output supply and variable input demands. The direct effects occur because changes in relative prices cause direct impacts on decisions about optimal levels of output supply and input demands. Indirect effects relate to the influence of prices upon the adjustments to the quasi-fixed inputs which in turn influence output supply and variable input demands because the quantities of the quasi-fixed inputs appear on the right hand side of the supply and demand equations.

Table 4 and 5 present direct, indirect and total elasticities for the short run and the long run, calculated at the sample means of the data from the restricted model presented in Table 1. The output supply curve has a positive slope in both the short run and long run, as one would expect. This results confirm the premises that, in aggregate level, Thai farmers respond positively to output price increases and reject the hypothesis that supply response in LDCs may have negative slope because of the argument that farmers in developing countries have a 'target' cash income and, if offered a lower price for their product, they can retain the income level by increasing production (Colman and Young (1989). In addition, the analyses indicates that the supply elasticities are highly inelastic, both in the short run and long run, and are not statistically significant unlike the study (using single static equation) of the Thailand Development Research Institute (1988).

The short run effects of input prices upon output supply are all negative, as one would expect. In the long run, the effects are same sign, with the exception of operator and unpaid family labour, which become positive. These are not theoretically inconsistent. Caputo (1990) pointed out that output supply behaviour inconsistent with static maximisation theory at a particular point of time is possible in adjustment cost framework applying to the firm.

The short-run and long-run own-price elasticities of fertiliser demand have incorrect signs. This may be partially due to inappropriate fertiliser policies introduced by the government which have been mentioned in many studies (e.g., Puapanichya and Panayotou 1985, among others). [19]

Direct own-price effects on the hired labour demand have a negative influence in the short run. However, the indirect own-price elasticities of hired labour demand are positive in both the short and long run. Therefore, the highly positive value of the indirect own-price elasticities results in a positive slope of the hired labour demand in the long run.

The short-run and long-run own-price elasticities of demand for capital have incorrect signs. Treadway noted that, in the short run, it is possible that the investment demand curve has a positive slope, but in the long run it should be negative. It may be due, in part, to certain farm machinery policies introduced by the government which have been mentioned in many studies (e.g., Puapanichya and Panayotou 1985).[20]

The demands for operator labour and unpaid family labour are two focal issues in this study. The short-run own-price elasticity of operator demand is positive, but in the long run the elasticity is negative. Thus, an increase in the wage rate of operator labour will increase their demand in the short run but decrease it in the long run. In contrast, the slope of demand for unpaid family workers is positive in both the short run and long run. It could be the case that when the wage for operator labour rises, unpaid family labour is substituted for the operator labour. Thus an increase in the operator labour wage has a positive effect upon the demand for unpaid family labour.

It should be noted, however, that of all those elasticity estimates which have incorrect signs, only those associated with fertiliser appear to be significantly different from zero at the 5 % level of significance.

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[19] Import quota and tariff policies in fertiliser market have been implemented.

[20] Import quota and tariff policies in farm machinery market have also been imposed.

5. Conclusions and Further Research

An intertemporal generalised Leontief value function was specified for Thai agriculture. A system of six equations was derived, comprising one output supply equation, two variable input demand equations and three quasi-fixed input demand equations. The parameters in this dynamic non-linear simultaneous system were estimated using non-linear three stage least squares.

The results indicate that the quasi-fixed inputs, capital, operator labour and unpaid family labour could not adjust fully, in the short run, to price changes, and that adjustments were not independent of the quantities of other quasi-fixed factors (with the exception of capital and operator labour). Results also indicate negative technical change in output supply over the sample period.

The output supply curve has a positive slope in both the short run and long run. This results confirm that, in aggregate level, Thai farmers respond positively to output price increases.

The validity of the results, however, are called into question by observed violations of monotonicity and convexity 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.

The econometric estimates in this study appear to be essentially consistent with the present state of Thai agriculture. The convexity violations can be rationalised when the degree of government intervention into these markets is taken into account. A number of areas of further statistical analysis will be considered to test the robustness of our results. These include: specification of formal hypothesis tests of the effects of government policies on the effective prices of inputs and output (in a similar manner to Atkinson and Halvorsen 1984), and an investigation of the influence of assuming a static rather than a dynamic model.

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Appendix 1: Tables

Table 1 *Non-Linear Three Stage Least Squares Structural Parameter Estimates of Output and Input Demand Equation System*

Parameter	Unrestricted model	Restricted Model[a]	Parameter	Unrestricted model	Restricted Model[a]
a_{11}	-0.296 (0.273)	-0.313 (0.268)	e_{23}	198.135 (356.349)	184.246 (481.957)
a_{12}	-0.090 (0.532)	-0.131 (0.530)	e_{31}	170.066 (152.775)	163.411 (143.677)
a_{13}	0.249 (0.269)	0.277 (0.266)	e_{32}	-3457.660 (1638.140)	-3427.850 (1875.890)
a_{21}	0.482 (0.177)	0.475 (0.173)	e_{33}	1811.450 (1834.740)	1795.670 (2108.340)
a_{22}	0.084 (0.387)	-0.076 (0.374)	f_{11}	-109.627 (113278.00)	-125.562 (193067.00)
a_{23}	0.109 (0.177)	0.193 (0.172)	f_{12}	-93.083 (9101.510)	-42.251 (902.551)
a_{31}	0.376 (0.246)	0.327 (0.229)	f_{13}	119.992 (2519.940)	92.024 (218.796)
a_{32}	-1.589 (0.447)	-1.602 (0.448)	f_{22}	-526.696 (281523.00)	-460.605 (2298620.)
a_{33}	0.392 (0.254)	0.464 (0.240)	f_{23}	-692.757 (5223.300)	-649.201 (3654.580)
b_{11}	0.010 (0.076)	-0.093 (0.048)	f_{33}	-164.658 (67640.400)	-182.397 (391817.0)
b_{12}	-0.064 (0.130)		g_{11}	548.720 (172.983)	548.623 (171.664)
b_{13}	-0.286 (0.133)	0.046 (0.099)	g_{12}	-56.621 (95.674)	-58.418 (91.005)
b_{21}	0.049 (0.035)		g_{13}	-62.840 (100.846)	-66.031 (98.403)
b_{22}	-0.078 (0.137)	-0.043 (0.105)	g_{22}	-381.935 (104.350)	-386.060 (97.115)
b_{23}	-0.408 (0.101)	-0.255 (0.071)	g_{23}	396.205 (79.189)	385.933 (76.044)
b_{31}	0.072 (0.061)	-0.042 (0.033)	g_{33}	380.497 (193.105)	375.920 (205.467)
b_{32}	-0.100 (0.183)	-0.071 (0.168)	h_1	-1.996 (0.968)	-2.064 (0.915)
b_{33}	-0.537 (0.145)	-0.397 (0.119)	h_2	-1.077 (0.639)	
e_{11}	-277.167 (167.281)	-285.740 (167.347)	h_3	-0.908 (0.836)	
e_{12}	4.742 (651.824)	36.430 (669.374)	h_4	45.725 (2956.210)	
e_{13}	159.062 (474.490)	143.523 (554.057)	h_5	-33.683 (7408.320)	
e_{21}	216.573 (111.408)	212.676 (105.683)	h_6	19.448 (1775.440)	
e_{22}	-356.268 (507.477)	-325.810 (549.553)			

[a] Independent adjustment between capital and operator labour, and no technical change are imposed after considering the results of the hypothesis tests.

Note: Standard errors of estimates are in parenthesis.

Table 2 *Estimates of the Regional Dummy Variables*

Parameter	Unrestricted Model	Restricted Model[a]
d_{11}	3.137 (0.775)	3.203 (0.777)
d_{12}	-1.034 (0.518)	-0.943 (0.524)
d_{13}	-1.868 (0.671)	-2.084 (0.670)
d_{14}	2.168 (1.834)	-1.621 (1.225)
d_{15}	3.660 (0.896)	2.110 (0.575)
d_{16}	5.444 (1.487)	2.766 (1.040)
d_{21}	2.480 (0.806)	2.610 (0.806)
d_{22}	-1.206 (0.538)	-1.260 (0.543)
d_{23}	-0.919 (0.699)	-1.116 (0.697)
d_{24}	2.521 (1.376)	0.159 (1.052)
d_{25}	2.548 (0.683)	1.490 (0.542)
d_{26}	3.758 (1.147)	2.142 (0.959)
d_{31}	-7.517 (0.791)	-7.514 (0.794)
d_{32}	-0.714 (0.531)	-0.753 (0.536)
d_{33}	-1.256 (0.684)	-1.495 (0.685)
d_{34}	1.045 (1.368)	-0.407 (0.971)
d_{35}	1.094 (0.900)	0.369 (0.691)
d_{36}	2.131 (1.386)	0.774 (1.175)

[a] Independent adjustment between capital and operator labour, and no technical change are imposed after considering the results of the hypothesis tests.

Note: (1) Standard errors are in parenthesis.

(2) The i and j in d_{ij} refer to the region and to the equation, respectively. For the regions: 1 = Northeast, 2 = North, 3 = South; and for the equations: 1 = Output, 2 = Fertiliser, 3 = Hired labour, 4 = Capital, 5 = Operator labour, 6 = Unpaid family labour.

Table 3 *Hypothesis Tests*

Hypotheses	Test Values	Critical Values (5 %)	Results
1. Independent adjustment of all quasi-fixed inputs	36.44	$\chi^2(6) = 12.59$	Rejected
2. Independent adjustment between capital and operator labour	2.17	$\chi^2(2) = 5.99$	Not rejected
3. Independent adjustment between capital and unpaid family labour	5.96	$\chi^2(2) = 5.99$	Not rejected[b]
4. Independent adjustment between operator labour and unpaid family labour	33.57	$\chi^2(2) = 5.99$	Rejected
5. Instantaneous adjustment of all quasi-fixed inputs[a]	1945.07	$\chi^2(7) = 14.10$	Rejected
6. Instantaneous adjustment of capital[a]	242.57	$\chi^2(2) = 5.99$	Rejected
7. Instantaneous adjustment of operator labour[a]	847.57	$\chi^2(2) = 5.99$	Rejected
8. Instantaneous adjustment of unpaid family labour[a]	193.16	$\chi^2(3) = 7.81$	Rejected
9. No technical change[a]	7.61	$\chi^2(6) = 12.59$	Not rejected
10. No technical change in output[a]	4.41	$\chi^2(1) = 3.84$	Rejected
11. No technical change in fertiliser[a]	1.68	$\chi^2(1) = 3.84$	Not rejected
12. No technical change in hired labour[a]	0.82	$\chi^2(1) = 3.84$	Not rejected
13. No technical change in capital[a]	0.003	$\chi^2(1) = 3.84$	Not rejected
14. No technical change in operator labour[a]	0.001	$\chi^2(1) = 3.84$	Not rejected
15. No technical change in unpaid family labour[a]	0.001	$\chi^2(1) = 3.84$	Not rejected

[a] Independent adjustment between capital and operator labour imposed.
[b] Rejected at 10 % critical value.

Table 4 *Short-Run Elasticities of Quantities with Respect to Prices*

Quantities		Output	Fertiliser	Hired Labour	Capital	Operator Labour	Unpaid Family Labour
Output	Direct	0.0025 (0.0024)	-0.0008 (0.0013)	-0.0009 (0.0014)	-0.0020 (0.0012)	0.0003 (0.0048)	0.0010 (0.0039)
	Indirect	0.0001 (0.0004)	0.0001 (0.0002)	0.0008 (0.0014)	0.0002 (0.0004)	-0.0004 (0.0033)	-0.0018 (0.0062)
	Total	0.0026 (0.0022)	-0.0007 (0.0012)	-0.0001 (0.0020)	-0.0018 (0.0011)	-0.0001 (0.0057)	-0.0008 (0.0046)
Fertiliser	Direct	0.0284 (0.0443)	0.1766 (0.0457)	-0.1877 (0.0370)	-0.0517 (0.0257)	0.0790 (0.1333)	-0.0447 (0.1169)
	Indirect	0.0023 (0.0058)	-0.0037 (0.0067)	-0.0088 (0.0355)	0.0007 (0.0143)	-0.0007 (0.0454)	0.0335 (0.1132)
	Total	0.0307 (0.0424)	0.1729 (0.0437)	-0.1965 (0.0502)	-0.0510 (0.0239)	0.0783 (0.1355)	-0.0112 (0.1619)
Hired Labour	Direct	0.0092 (0.0137)	-0.0534 (0.0105)	-0.0577 (0.0288)	-0.0114 (0.0100)	0.2381 (0.1303)	-0.1248 (0.1465)
	Indirect	0.0035 (0.0081)	0.0015 (0.0060)	0.0207 (0.0232)	0.0033 (0.0048)	-0.0084 (0.0859)	-0.0043 (0.1167)
	Total	0.0127 (0.0149)	-0.0519 (0.0122)	-0.0370 (0.0403)	-0.0081 (0.0091)	0.2297 (0.1719)	-0.1291 (0.2148)
Capital		0.0006 (0.0006)	-0.0002 (0.0006)	0.0012 (0.0034)	0.0005 (0.0021)	-0.0009 (0.0062)	-0.0011 (0.0062)
Operator Labour		-0.0004 (0.0014)	-0.0004 (0.0011)	-0.0036 (0.0031)	-0.0005 (0.0007)	0.0013 (0.0150)	0.0037 (0.0177)
Unpaid Family Labour		-0.0004 (0.0017)	-0.0005 (0.0014)	-0.0044 (0.0039)	-0.0005 (0.0010)	0.0014 (0.0184)	0.0045 (0.0217)

Note: (1) Standard errors are in parentheses.
(2) Elasticities are calculated from the restricted model at mean of data set.

Table 5 *Long-Run Elasticities of Quantities with Respect to Prices*

Quantities		Output	Fertiliser	Hired Labour	Capital	Operator Labour	Unpaid Family Labour
Output	Direct	0.0025	-0.0008	-0.0009	-0.0020	0.0003	0.0010
		(0.0024)	(0.0013)	(0.0014)	(0.0012)	(0.0048)	(0.0039)
	Indirect	-0.0003	-0.0001	-0.0015	-0.0003	0.0006	0.0017
		(0.0012)	(0.0010)	(0.0088)	(0.0013)	(0.0076)	(0.0104)
	Total	0.0022	-0.0009	-0.0024	-0.0023	0.0009	0.0027
		(0.0027)	(0.0016)	(0.0087)	(0.0019)	(0.0086)	(0.0117)
Fertiliser	Direct	0.0284	0.1766	-0.1877	-0.0517	0.0790	-0.0447
		(0.0443)	(0.0457)	(0.0370)	(0.0257)	(0.1333)	(0.1169)
	Indirect	-0.0040	0.0054	0.0105	-0.0019	0.0022	-0.0160
		(0.0244)	(0.0202)	(0.1683)	(0.0376)	(0.0854)	(0.1844)
	Total	0.0244	0.1820	-0.1772	-0.0536	0.0812	-0.0607
		(0.0467)	(0.0454)	(0.1690)	(0.0515)	(0.1368)	(0.2440)
Hired Labour	Direct	0.0092	-0.0534	-0.0577	-0.0114	0.2381	-0.1248
		(0.0137)	(0.0105)	(0.0288)	(0.0100)	(0.1303)	(0.1465)
	Indirect	0.0144	0.0141	0.1249	0.0168	-0.0428	-0.1301
		(0.1065)	(0.0899)	(0.7655)	(0.1136)	(0.6290)	(0.9049)
	Total	0.0236	-0.0393	0.0672	0.0054	0.1953	-0.2549
		(0.1057)	(0.0906)	(0.7873)	(0.1128)	(0.6280)	(1.0407)
Capital		0.0175	-0.0059	0.0354	0.0137	-0.0272	-0.0335
		(0.0261)	(0.0156)	(0.1269)	(0.0670)	(0.1908)	(0.1980)
Operator Labour		0.0270	0.0230	0.2180	0.0305	-0.0768	-0.2217
		(0.1865)	(0.1572)	(1.3465)	(0.1980)	(1.1032)	(1.5784)
Unpaid Family Labour		-0.0013	-0.0016	-0.0131	-0.0016	0.0043	0.0134
		(0.0052)	(0.0042)	(0.0111)	(0.0031)	(0.0550)	(0.0638)

Note: (1) Standard errors are in parentheses.
(2) Elasticities are calculated from the restricted model at mean of data set.