Total Factor Productivity in Thai Agriculture
Measurement and Determinants*

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ABSTRACT

This paper studies total factor productivity (TFP) in Thai agriculture to provide better empirical evidence on the TFP measure and the factors influencing it. It employs time-series data at an aggregate level over the period 1970-2006 for both crops and livestock, individually, using the conventional growth accounting framework. The TFP measures are then used to investigate their determinants using the error correction modeling technique. The results confirm the general expectation from previous studies that TFP makes an important contribution to output growth and that agricultural research plays an important role in determining TFP in both the crop and livestock sectors.

Keywords: total factor productivity, TFP decomposition, Thai agriculture

1. Introduction

It has long been recognized that agricultural growth is important for overall economic development (Johnston and Mellor, 1961). In developing countries, where the majority of poor people lives in rural areas and depends directly or indirectly on agriculture for their livelihood, sustaining agricultural growth is of critical importance. The diminishing returns on factor inputs, declining arable land, water supplies and natural resources, concern over climate change and environmental degradation and high fuel and fertilizer prices continue to pose challenges for agriculture.

In the Thailand context, agriculture plays a crucial role in contributing to overall economic growth using fewer resources. Thai agriculture is well-known as a major producer of world agricultural exports, thereby being an important source of export earning and rural income. Sustaining agricultural growth is thus important for maintaining export competitiveness and improving the living standards of the majority of poor people residing in rural areas and directly involved in agricultural production (Warr, 2004).

Total factor productivity (TFP) has been shown to contribute significantly to output growth in the Thai agricultural sector and its contribution was substantially greater than in the non-agricultural sectors (Tinakorn and Sussangkarn, 1996, Chandrachai *et al*., 2004; Warr, 2006). However, there is limited empirical evidence as to what determines the relatively high growth rate of TFP in Thai agriculture. The majority of previous studies focus on the determinants of TFP in the overall economy (Tinakorn and Sussangkarn, 1996, 1998; Chandrachai *et al*., 2004). They only investigate factors affecting TFP expressed in growth-rate terms, ignoring level or long-term information and often impose arbitrary restrictive forms of lags.

Moreover, there has been a slowdown in TFP growth in recent years. Refocusing attention on what determines TFP in Thai agriculture is thus important for understanding and sustaining long-term agricultural growth and thereby maintaining its contribution to overall economic growth.

This study measures TFP in Thai agriculture and examines the factors influencing it. It employs time-series data at an aggregate level, covering the period from 1970 to 2006. The scope of the study focuses on crop and livestock as these two subsectors dominate agricultural output.[1] The measurement and the investigation of TFP determinants are undertaken separately for crops and livestock.

2. Review of TFP Measurement and Determinants

In general, the TFP measurement methods that have been used in empirical productivity studies can be grouped into two main approaches: conventional or non-frontier methods and frontier analysis. The first approach assumes outputs are efficiently produced on the production frontier while the second allows for outputs being produced off the frontier. The frontier analysis is often applied to cross-sectional or panel data, whereas the conventional approach is mainly applied to time series macro-productivity data sets.

Both the conventional and frontier approaches can be further classified into parametric and nonparametric methods. The nonparametric method does not impose a specific functional form, whereas the parametric method imposes a functional form and employs econometric techniques in estimating a production function, a cost function or a profit function. Table 1 summarizes the principal

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[1] The fisheries subsector is not included because of the different nature of production and input types.

methods used in measuring TFP and the corresponding data requirements.

Table 1. Summary of TFP measurement methods and data requirements

	Conventional approach		Frontier approach	
	Nonparametric	Parametric	Nonparametric	Parametric
Principal methods	TFP index/ GA	LS/ GA	DEA	SFA
Estimation of specific functional form and statistical tests	no	yes	no	yes
Data used:				
Cross sectional	yes	yes	yes	yes
Time series	yes	yes	no	no
Panel	yes	yes	yes	yes
Basic method requires data on:*				
Input quantities	yes	yes	yes	yes
Output quantities	yes	yes	yes	yes
Input prices	yes	no	no	no
Output prices	yes	no	no	no

Note: * This list applies to production function method only.
Source: adapted from Coelli *et al*. (2005, p.312); GA = Growth Accounting, LS = Least Squares, DEA = Data Envelopment Analysis, SFA = Stochastic Frontier Analysis.

In examining TFP determinants, TFP is generally decomposed into embodied and disembodied technical change. Embodied technical change is referred to as change that is captured in factor inputs, such as improved seeds, breeds or a new type of machinery (Alston *et al*., 1998). Disembodied technical change is referred to as technological change that is not embodied in factor inputs but takes place like manna from heaven in the form of better methods and organization that improve the efficiency of factor inputs (Chen, 1997), such as more effective production methods that improve input usage.

In the context of agricultural productivity, typical factors that have been found to influence TFP are public and private agricultural research, extension services, infrastructure investment, education of farmers and economic policies (Mundluk, 1992; Huffman and Evenson, 2005). There have been numerous studies investigating the sources of productivity growth, though their theoretical foundations differ (Aswicahyono, 1998: 24).[2] Determining the factors that influence TFP is a matter of empirical study. Explanatory variables are often chosen in light of the theory and empirical evidence that guides their potential connection with productivity.

3. Analytical Framework

The productivity analysis is based on the concept of the production function (Jorgenson and Griliches, 1967). For a simple production function: $Q = f(X, Z)$

where Q = output
X = conventional inputs - labour, land and capital
Z = unconventional inputs, such as research, extension, infrastructure, weather, etc.

By definition, TFP is viewed as an index of aggregate output relative to an index of aggregate conventional input, $TFP = Q/X$. In other words, TFP is defined as output per unit of all conventional inputs combined. Accordingly, TFP is measured as the residual part of the movement in output left unexplained by major factor inputs (Solow, 1957; Jorgenson, 1995). [3]

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[2] See, for example, Griliches (1996), Evenson and Pray (1991), Mundlak (1992), Mahadevan (2002), and Huffman and Evenson (2005).

[3] Although TFP is often referred to as 'a measure of our ignorance' (Abramovitz, 1956), it is a preferred measure of productivity compared with partial productivity.

To examine factors affecting TFP, the simple production function implies $TFP = g(Z)$ meaning that TFP is a function of unconventional inputs. There are several factors captured in the unconventional inputs (Z), which can be categorized into 3 main groups: 1) pure technical change 2) efficiency gain and 3) economies of scale (Coelli *et al.*, 2005). The three main categories of productivity change can be illustrated by Figure 1.

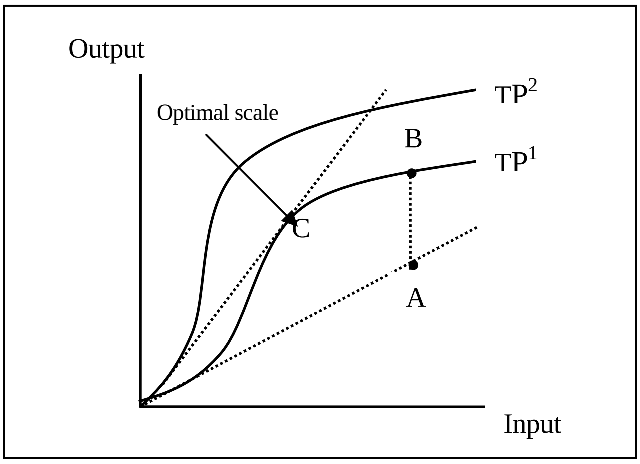

Figure 1. Technical change, efficiency gain and scale economies
Source: Coelli *et al.* (2005: 5-6)

Pure technical change is identified with a shift in a production function. An advance in technology is depicted by an upward shift in the production function from TP^1 to TP^2. Efficiency gain is a movement toward the production function, from point A to the technically efficient point B. Economies of scale refer to a movement

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TFP measurement takes into account all major inputs (land, labour and capital) thereby capturing the technology component.

along the production function toward the optimal scale at point C where maximum productivity can be achieved. Factors affecting the deviation from technically efficient point such as market distortions and real cost reductions can explain efficiency improvement and an exploitation of scale economies.

As TFP is viewed as a residual part of output that cannot be explained by the combined contribution of conventional inputs, its determinants are not confined only to the three main components depicted in Figure 1. The Handbook of Agricultural Economics (Evenson, 2001) and other productivity studies (Evenson and Pray, 1991; Alston *et al*., 1998; Morrison Paul, 1999) have incorporated other case-specific and natural factors such as weather, environmental degradation, epidemics and natural disasters.

In sum, there are four main groups of factors that form the basis for examining the determinants of TFP in this study. These factors are potential candidates for inclusion in the TFP determinants model, discussed below.

4. Methodology

This section is divided into three subsections. The first subsection explains the TFP measurement method used in this study. The second describes the TFP determinants model and the third describes the estimation method used in the present study.

4.1 TFP Measurement

Although there are several approaches for measuring TFP (as shown in Table 1), a suitable approach depends on the objectives of the study and data availability. Since this paper aims to examine sources of agricultural growth at an aggregate level, the growth accounting framework is considered the most appropriate. The competitive equilibrium conditions which are the underlying assumptions of the growth accounting approach are reasonable for the case of Thai agriculture. The agricultural sector is well characterised by a perfectly competitive market in the sense that there are a large number of farmers who maximise profit (or minimise cost) and take prices as given. It is generally recognized that Thai farmers are price takers in input and output markets (Pochanukul, 1992: 168). Compared with other industries, such as manufacturing and services, the agricultural sector is considered a suitable case study for applying the growth accounting method. This method is also widely applied in the previous Thai studies (for example, Tinakorn and Sussangkarn, 1996; Chandrachai *et al*., 2004; Poapongsakorn, 2006).

Under the growth accounting framework, the discrete-time Tornqvist approximation to the continuous-time Divisia index is employed. The method implicitly specifies a translog form of the production function but does not explicitly estimate the function.[4] Constant returns to scale (CRS) is assumed, implying that all factor income shares sum to one.[5] It is national income based growth accounting in the sense that most output and input data are obtained from the national accounts.

[4] The transcendental logarithmic (or translog) production function developed by Christensen, Jorgenson and Lau (1973) is a flexible functional form that does not impose constant elasticity of substitution and allows the output elasticity with respect to each input to vary with time.

[5] The use of CRS technology is sensible when dealing with aggregate country-level data (Coelli and Rao, 2003: 7). For Thailand and the agricultural sector, the CRS technology is applied in all growth accounting studies, for example, Budhaka (1987), Tinakorn and Sussangkarn (1996), Kaipornsak (1999), Chandrachai *et al.* (2004), Warr (2006), and NESDB (2006).

The growth accounting method begins with the basic production function that explains the relationship between output and input, expressed as follows (Oguchi, 2004):

$$Q_t = A_t F(L_t, N_t, K_t) \qquad (1)$$

where Q_t = real output at time t

L_t = labour quantity at time t

N_t = land quantity at time t

K_t = capital quantity at time t

A_t = level of efficiency at time t

Totally differentiating equation (1) with respect to time gives:

$$\frac{dQ_t}{dt} = \frac{dA_t}{dt} F(L_t, N_t, K_t) + A_t \frac{\partial F}{\partial L_t} \frac{dL_t}{dt} + A_t \frac{\partial F}{\partial N_t} \frac{dN_t}{dt} + A_t \frac{\partial F}{\partial K_t} \frac{dK_t}{dt} \qquad (2)$$

Dividing both sides by Q_t gives:

$$\frac{dQ_t}{dt} \frac{1}{Q_t} = \frac{dA_t}{dt} \frac{1}{A_t} + \frac{\partial F}{\partial L_t} \frac{dL_t}{dt} \frac{1}{F(L_t, N_t, K_t)} + \frac{\partial F}{\partial N_t} \frac{dN_t}{dt} \frac{1}{F(L_t, N_t, K_t)} + \frac{\partial F}{\partial K_t} \frac{dK_t}{dt} \frac{1}{F(L_t, N_t, K_t)} \qquad (3)$$

Rearranging equation (3) gives:

$$\frac{dQ_t}{dt}\frac{1}{Q_t} = \frac{dA_t}{dt}\frac{1}{A_t} + \frac{\partial F}{\partial L_t}\frac{dL_t}{dt}\frac{L_t}{Q_t}\frac{1}{L_t} + \frac{\partial F}{\partial N_t}\frac{dN_t}{dt}\frac{N_t}{Q_t}\frac{1}{N_t} + \frac{\partial F}{\partial K_t}\frac{dK_t}{dt}\frac{K_t}{Q_t}\frac{1}{K_t}$$

$$\text{or} \quad \hat{Q}_t = \hat{A}_t + MP_L\left(\frac{L_t}{Q_t}\right)\hat{L}_t + MP_N\left(\frac{N_t}{Q_t}\right)\hat{N}_t + MP_K\left(\frac{K_t}{Q_t}\right)\hat{K}_t \qquad (4)$$

where (^) indicates the instantaneous growth rate of the variable and MP_L, MP_N, MP_K stand for the marginal product of labour, land and capital, respectively.

In a perfectly competitive market, producers maximize profit and will employ each input where its marginal product equals its real factor price. That is, the real wage rate (w) equals the marginal product of labour (MP_L); the real rate of land rent (r) equals the marginal product of land (MP_N) and the real rate of return (i) equals the marginal product of capital (MP_K). Hence, replacing marginal products with factor prices, equation (4) can be rewritten as:

$$\hat{Q}_t = \hat{A}_t + S_L\hat{L}_t + S_N\hat{N}_t + S_K\hat{K}_t \qquad (5)$$

where $S_L = wL/Q$ = share of labour income in the value of total output
$S_N = rN/Q$ = share of land income in the value of total output
$S_K = iK/Q$ = share of capital income in the value of total output

Equation (5) indicates that output growth can be decomposed into the growth rate of the efficiency level and the growth rate of labour, land and capital, weighted by their output elasticities or factor income shares. The first component is the shift in the production function (representing technical change) and the latter is the movement along the production function (representing input growth and input substitution).

Rearranging equation (5), the estimation of TFP growth $(TFPG_t)$ can be expressed as the residual part of output growth that cannot be explained by the combined growth of physical inputs:

$$\hat{A}_t = TFPG_t = \hat{Q}_t - S_L \hat{L}_t - S_N \hat{N}_t - S_K \hat{K}_t \qquad (6)$$

Since the differentiation is applicable only to continuous variables, the growth rate terms in the above equations refer to an instantaneous rate of change. However, in practice, discrete data, especially annual data, are normally used in empirical work. Hence, the discrete annual data can be applied to approximate equation (6) by taking the average of two consecutive periods:

$$\begin{aligned} TFPG_t &= \ln TFP_t - \ln TFP_{t-1} \\ &= (\ln Q_t - \ln Q_{t-1}) - \frac{1}{2}(S_{Lt} + S_{Lt-1})(\ln L_t - \ln L_{t-1}) \qquad (7) \\ &- \frac{1}{2}(S_{Nt} + S_{Nt-1})(\ln N_t - \ln N_{t-1}) - \frac{1}{2}(S_{Kt} + S_{Kt-1})(\ln K_t - \ln K_{t-1}) \end{aligned}$$

The labour and land inputs are adjusted for their quality changes following the method developed by Tinakorn and Sussangkarn (1996), which are suitable for Thai data. For labour, the adjustment method accounts for the effect of qualitative changes in age, sex and education. The land input used in crop production is adjusted by the effect of irrigation, to account for multiple cropping.

4.2 The TFP Determinants Model

The TFP determinants model incorporates factors affecting the four main categories of productivity changes discussed in the analytical framework section above: pure technical change, efficiency gains, economies of scale and case-specific and natural factors.

Our statistical analysis is based on a conceptual model in which the determinants of TFP include agricultural research as well as other economic and non-economic factors such as extension services, infrastructure and weather. Research lags are also incorporated, as discussed below. Other explanatory variables are explored in accordance with their potential connections with TFP in the Thai agriculture context. In stylized form, the model is (with expected signs in parentheses):

$$TFP = f(R^p, E, I, RR, TO, W, D^c, R^f), \tag{8}$$

where TFP = total factor productivity,

R^p (+)= real public agricultural research expenditure,

E (+) = real public agricultural extension expenditure,

I (+) = infrastructure (rural roads and irrigation),

RR (+) = resource reallocation,

TO (+) = trade openness,

W (+) = weather or climate factor,

D^c = case-specific dummy variable comprising:

D^{boom} (+) = dummy variable capturing the world agricultural commodity boom from 1972-1974,

D^{bird} (–) = dummy variable capturing the Avian Influenza outbreak took place in 2004,

R^f (+) = international agricultural research spillovers.

Public agricultural research, within-country, is recognized as a prime potential source of technical change that raises productivity and sustains output growth (Chang and Zepeda, 2001; Ruttan, 1987). It increases the stock of knowledge, which either facilitates the use of existing knowledge or generates new technology. Hence, an increase in research expenditure within Thailand is expected to raise TFP.

Agricultural extension involves a dissemination of research results to farmers through information distribution, training and demonstration. It may also indirectly influence the agricultural research process by conveying feedback from farmers to researchers that may improve future research. Effective agricultural extension should improve productivity.

Infrastructure is considered a fixed factor that contributes positively to agricultural growth and productivity (Evenson and Pray, 1991; Evenson, 2001). It is typically not included among the conventional inputs in growth accounting and its effect on agricultural growth is thereby captured in the residual TFP.

Resource reallocation can raise TFP at the aggregate level by allowing factors to move from lower to higher marginal productivity sectors. For instance, movement of labour from the agricultural sector to a higher productivity sector like manufacturing or services can increase TFP growth in the overall economy (Jorgenson, 1988). Within a sector, productivity growth can result from reallocation of resources among subsectors and among commodities when their levels of TFP differ and this does not necessarily require any new technology. Empirical evidence has shown that resource reallocation contributes significantly to TFP growth in Thailand (Warr, 2006; Chandrachai *et al*., 2004).

Trade openness helps achieve economies of scale by expanding market size through export. Economies of scale bring about real cost reductions, thereby increasing productivity. It also enhances market competition through import and export. Competition influences technological development, thereby increasing TFP. More open economies and international trade are generally found to be favourable to TFP (Urata and Yokota, 1994; Edwards, 1998; Acemoglu and Zilbotti, 1999: 34; Wilson, 2006).

Weather or climate variation is considered a variable explaining changes in TFP under the conventional TFP decomposition framework (Evenson, 2001). Good weather like more rainfall or less occurrence of drought or flooding should raise TFP relative to the opposite.

The world agricultural commodity boom of 1972-1974 raised the real price of internationally traded food commodities, thereby inducing more production. This price boom has been shown to be one of the main driving forces behind the rapid agricultural growth in Thailand of the early 1970s (Poapongsakorn, 2006). However, the increase in output may not have been fully reflected in the measured use of inputs. During a boom, farmers tend to utilize existing inputs more intensively, which does not necessarily show up in measured input growth. Measured productivity therefore rises, at least partly through measurement error.

Epidemic is represented by the outbreak of the Avian Influenza virus or Bird Flu that took place in 2004. A dummy variable is used to capture the effect of the Bird Flu outbreak in the livestock productivity function. It should reduce TFP in the livestock sector.

International research spillovers are potentially important sources of productivity growth. But they have often been ignored in the literature on the impact of agricultural research, resulting in an omitted variable bias (Alston *et al*., 1998; Alston, 2002; Fuglie and Heisey, 2007). The model incorporates foreign research on crops and livestock that are relevant for Thailand and it is expected to increase domestic TFP.

4.3 The Estimation Method

The error correction modeling (ECM) procedure of Hendry (1995) is employed as it allows us to investigate both short-run and long-run determinants of TFP while allowing dynamic and flexible form of lags.[6] Another reason for using this approach is that it does not require that the variables under consideration have the same order of integration. Table 2 shows that the variables used in this study are a mixture of stationary series (or I(0)) and non-stationary series integrated of order 1 (or I(1)). Most of the variables are I(1) such as public research (R^p), extension (E), irrigation ($I^{irrigation}$) and rainfall (W^{rain}). Variables that are I(0) include foreign research (R^f), roads (I^{road}) and weather conditions ($W^{weather}$). This approach minimizes the possibility of estimating spurious relationships while retaining long-run information without arbitrarily restricting the lag structure (Hendry, 1995). The ECM also provides estimates with valid t-statistics even in the presence of endogenous explanatory variables (Inder, 1993).

The estimation procedure begins with an autoregressive distributed lag (ADL) specification of an appropriate lag order.

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[6] This method is used in many time-series studies but has apparently not yet been used in TFP determinants studies. It is also known as the London School of Economics method or General to specific method (GSM) developed by Hendry and his co-researchers (Davidson *et al.*, 1978; Hendry *et al.*, 1984; Hendry, 1995).

$$Y_t = \alpha + \sum_{i=1}^{m} A_i Y_{t-i} + \sum_{i=0}^{m} B_i X_{t-i} + \mu_t \qquad (9)$$

where α is a vector of constants, Y_t is a $(n \times 1)$ vector of endogenous variables, X_t is a $(k \times 1)$ vector of explanatory variables, and A_i and

Table 2. Augmented Dickey-Fuller test for unit roots, 1970-2006

Variables	*t*-statistics for level without time trend	*t*-statistics for level with time trend	*t*-statistics for first difference without time trend	*t*-statistics for first difference with time trend
$\ln TFP_{crops}$	-1.476(0)	-3.531(0)**	-5.036(1)*	-4.950(1)*
$\ln TFP_{livestock}$	-4.370(0)*	-4.720(1)*	-6.245(0)*	-6.397(0)*
$\ln R^{p}_{crops}$	-1.296(1)	0.240(0)	-3.887(0)*	-4.135(1)*
$\ln R^{p}_{livestock}$	-2.018(0)	-1.612(0)	-5.737(0)*	-6.010(0)*
$\ln E_{crops}$	-1.655(0)	-0.145(0)	-4.784(0)*	-5.003(0)*
$\ln E_{livestock}$	-1.477(0)	-2.215(0)	-6.676(0)*	-6.732(0)*
$\ln R^{f}_{crops}$	-6.505(1)*	-4.252(1)*	-4.149(0)*	-6.382(0)*
$\ln R^{f}_{livestock}$	-3.032(1)*	-2.999(1)	-5.100(1)*	-5.038(1)*
$\ln TO$	-2.030(0)	-1.496(0)	-7.998(0)*	-8.617(0)*
$\ln I^{irrigation}$	-1.688(0)	-0.645(0)	-5.220(0)*	-5.936(0)*
$\ln I^{roads}$	-0.992(1)	-3.829(5)*	-3.351(0)*	-3.386(0)*
$\ln RR$	-1.532(0)	-1.674(0)	-5.187(0)*	-5.602(0)*
$\ln W^{rain}$	-2.454(0)	-2.083(0)	-8.379(0)*	-8.717(0)*
$\ln W^{weather}$	-6.198(0)*	-6.158(0)*	-10.070(0)*	-9.914(0)*

Notes: 1. All variables are measured in natural logarithms.
2. * and ** denote the rejection of the null hypothesis implying the variable is stationary at the 5% and 10% level, respectively.
3. Numbers in parentheses indicate the order of augmentation selected on the basis of the Schwarz criterion.

B_i are $(n \times n)$ and $(n \times k)$ matrices of parameters. The general ADL allows the initial lag length on all variables at two periods, except for the research variable where the lag length extends to four periods. The two-year lag is the established practice in modeling with annual data (Athukorala and Tsai, 2003).

Equation (9) can be rearranged by subtracting Y_{t-1} from both sides, yielding the explanatory variables in terms of differences, representing the short-run multipliers, and the lagged levels of both the dependent and explanatory variables, capturing the long-run multipliers of the system.

$$\Delta Y_t = \alpha + \sum_{i=1}^{m-1} A_i^* \Delta Y_{t-1} + \sum_{i=0}^{m-1} B_i^* \Delta X_{t-i} + C_0 Y_{t-m} + C_1 X_{t-m} + \mu_t \qquad (10)$$

where $C_0 = -\left[I - \sum_{i=1}^{m} A_i \right]$, $C_1 = \left[\sum_{i=0}^{m} B_i \right]$, I is the identity matrix and

the long-run multipliers of the system are given by $C_0^{-1} C_1$.

Equation (10) is known as the error correction mechanism (ECM) representation of the model. Under the ECM, the long-run relationship is embedded within a sufficiently detailed dynamic specification, including both lagged dependent and independent variables, which helps minimize the possibility of estimating a spurious regression. The ECM can be estimated by OLS and the short- and long-run parameters can be separately identified. Equation (10) is the ‘maintained hypothesis’ for specification search. The full model is ‘tested down’ by dropping statistically insignificant lag terms using the standard testing procedure to obtain a parsimonious ECM.

The final preferred model is required to satisfy standard diagnostic tests, including the Breush-Godfrey LM test for serial correlation in the regression residual, the Ramsey test for functional form mis-specification (RESET), the Jarque-Bera test of normality of the residual (JBN), Engle's autoregressive conditional heteroskedasticity test (ARCH) and the Augmented Dickey-Fuller test for residual stationarity (ADF).

5. Data

The output and input data are time-series at an aggregate level, covering 37 years from 1970 to 2006. As TFP is computed for crop and livestock separately, the data sets are obtained for crop and livestock individually. Definitions and sources of data for the TFP measurement are summarized in Table 3 and those for the TFP determinants are shown in Table 4.

Table 3. Summary of the data used in TFP measurement, 1970-2006

Variables	Definitions	Sources
Agricultural output	GDP at 1988 prices (value added)	National Income of Thailand, NESDB (1970-2006)
Agricultural labour	Number of employed persons age 15 and above	Labour Force Survey, NSO (1971-2006) Poapongsakorn, 2006 and TDRI (1977-2003)
Agricultural land - Crop land - Livestock land	 - Land used in crop production - Grass and privately own area for livestock	Office of Agricultural Economics (1970-2006) Department of Livestock Development (1999-2006), Poapongsakorn, 2006 (1980-2003)
Agricultural capital	Net capital stock at 1988 prices	National Income of Thailand, NESDB (1970-2006)
Agricultural wage	Imputed wage of all workers, measured as private workers' wage adjusted by 1995 Social Accounting Matrix (SAM) wage to account for self employed and unpaid family labour	Labour Force Survey, NSO (1977-2006) Poapongsakorn, 2006 and TDRI (1977-2004) Coxhead and Plangpraphan, 1999 (1970-1976)
Land rent	Actual and imputed rent (rai)	NESDB
Labour quality-adjusted index	Qualitative changes in age, sex and education attainment of agricultural workers	TDRI (based on Labour Force Survey, NSO)
Irrigation	Accumulated irrigation area (rai), including small, medium and large scale irrigation projects	Office of Agricultural Economics (OAE)
Factor income share	Value of factor income divided by GDP at factor cost	NESDB (GDP at factor cost)

Table 4. Summary of the data used in TFP determinants model

Variables	Abbreviation	Data sources	Years
Dependent variables:			
1. Total factor productivity index (adjusted for input quality changes)*	*TFP*	Authors' calculation based on the growth accounting method	1971-2006
Explanatory variables:			
1. Publicly funded, within-country research = real public research budget in the crop and the livestock sector	R^p	- Bureau of the Budget, Office of Prime Minister	1961-2006
2. Foreign research spillovers For crops: **=** CGIAR funding to IRRI, CIAT and CIMMYT in US dollar** For livestock: = import values of animal breeds as percentage share in livestock output	R^f	- CGIAR financial statements - Office of Agricultural Economics (OAE)	1972-2006 1970-2006
3. Extension services = real public extension budget in the crop and livestock sector	E	Bureau of the Budget, Office of Prime Minister	1961-2006
4. Infrastructure **Irrigation** = percentage share of irrigated area in total agricultural land area **Road** = length of rural roads, unpaved roads and asphalt (km)	$I^{irrigation}$ I^{roads}	- Office of Agricultural Economics - Fan *et al*. (2004)	1970-2006
5. Trade openness = agricultural export and import as percentage share in total agricultural output	*TO*	Office of Agricultural Economics	1970-2006
6. Resource reallocation (only available for crop model) = non-rice household as percentage share of total agricultural households	*RR*	- Office of Agricultural Economics	1970-2006

Table 4. (Continued)

Variables	Abbreviation	Data sources	Years
7. Natural/Case-specific factors			1970-2006
Rainfall = amount of rainfall in millimetre	W^{rain}	Office of Agricultural Economics	
Weather: drought or flooding = rice harvested as share in total rice planted area	$W^{weather}$		
Bird flu outbreak = dummy variable takes value 1 from 2004 and 0 otherwise	D^{bird}		
Agricultural commodity boom = dummy variable takes value 1 from 1972 to 1974	D^{boom}		

Note: * TFP growth measure is converted into level of TFP index using 1971 as a base year, with the level of TFP set equal to unity for that year.

** CGIAR stands for the Consultative Group of International Agricultural Research, IRRI is International Rice Research Institute, CIAT is International Center for Tropical Agriculture and CIMMYT is International Wheat and Maize Improvement Center. There are centers that have close collaboration with Thailand.

6. Results

6.1 TFP measurement: results from the growth accounting model

The general finding from the growth accounting analysis is that TFP makes an important contribution to its own sector's output growth. Over the period 1971-2006, TFP has generally been the second most important source of output growth in both the crop and livestock sectors. Specifically, the average annual rate of growth of TFP in the crop sector is estimated at 0.68, accounting for 20.82 percent of crop output growth. Similarly, livestock TFP growth is estimated at 0.67 percent, accounting for 17.49 percent of livestock output growth. The patterns of crop and livestock TFP growth are shown in Figure 2.

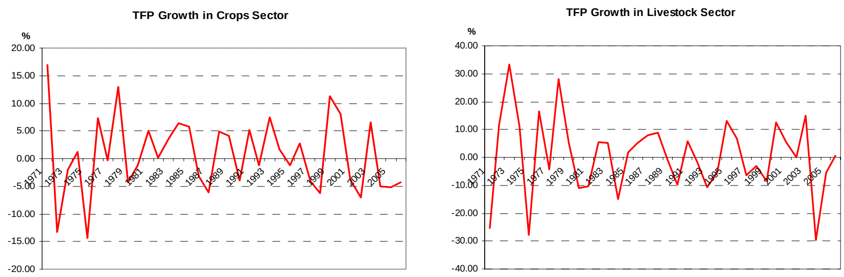

Figure 2. TFP growth in crop and livestock sectors

6.2 TFP determinants: results from the error correction models

In general, public agricultural research appears to be the major factor positively influencing TFP in both the crop and livestock sectors. The positive and significant impact of public research is consistent with the theory and findings of studies of many countries (Evenson, 1993, Fuglie, 1999; Ruttan, 2002; Thirtle *et al.*, 2003). Other major determinants of TFP turn out to be different between the crop and livestock models. The results for crops are shown in the left-hand side and those for livestock are shown in the right-hand side of Table 5.

Table 5. TFP determinants in crop and livestock sectors

Dependent variable: $\Delta \ln TFP_t^{crop}$			Dependent variable: $\Delta \ln TFP_t^{livestock}$		
	Estimated coefficients (t-ratios)	Long-run elasticity		Estimated coefficients (t-ratios)	Long-run elasticity
Constant	-1.056 (-6.460)***		Constant	0.386 (2.246)**	
$\Delta \ln R_{t-3}^{p}$	0.155 (4.423)***		$\Delta \ln E_{t-1}$	0.119 (1.728)*	
$\Delta \ln E_{t-1}$	0.137 (3.665)***		$\Delta \ln R_{t}^{f}$	0.012 (0.517)	
$\ln R_{t-3}^{p}$	0.059 (1.876)*	0.067 (2.117)**	$\ln R_{t-3}^{p}$	0.128 (2.074)**	0.173 (2.111)**
$\ln R_{t-1}^{f}$	0.092 (2.955)***	0.105 (3.045)***	$\ln E_{t-1}$	-0.089 (-1.590)	-0.121 (-1.578)
$\ln I_{t-1}^{roads}$	0.033 (1.977)**	0.038 (1.962)**	$\ln R_{t-1}^{f}$	-0.003 (-0.168)	-0.004 (-0.167)
D^{boom}	0.127 (3.104)***	0.145 (3.189)***	D^{bird}	-0.165 (-2.720)***	-0.224 (-2.593)***
$\ln TFP_{t-1}$	-0.873 (-6.664)***		$\ln TFP_{t-1}$	-0.739 (-5.510)***	
N (observations)	34			35	
k (no. of parameters)	8			8	
Adjusted R^2	0.69			0.50	
F-statistic	11.31			5.93	
S.E. of regression	0.03			0.09	
Diagnostic tests:					
$LM(1), F(1, N\text{-}k\text{-}1)$	0.06(p = 0.79)			0.00 (p = 0.99)	
$LM(2), F(2, N\text{-}k\text{-}2)$	1.42(p = 0.26)			1.47 (p = 0.25)	
RESET, $F(1, N\text{-}k\text{-}1)$	0.89(p = 0.35)			1.80 (p = 0.19)	
JBN, $\chi^2(2)$	0.77(p = 0.68)			0.86 (p = 0.65)	
ARCH, $F(1, N\text{-}2)$	0.00(p = 0.98)			1.31 (p = 0.26)	
ADF	-5.79(p = 0.00)			-4.89 (p = 0.00)	

Notes: The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms except the dummy variables.

Long-run elasticities can be computed by dividing the estimated coefficients of the level terms by the positive value of the coefficient of the lagged dependent variable, $\ln TFP_{t-1}$. Short-run elasticities are coefficients of the variables expressed in rate of change terms, with delta (Δ) operator. Note that the insignificant variables were kept in the livestock model because they increase the explanatory power of overall model in term of the standard F-test.

Diagnostic tests consist of (numbers in parentheses are *p*-values of the test statistics):

LM Breush-Godfrey serial correlation LM test;

RESET Ramsey test for functional form mis-specification;

JBN Jarque-Bera test of normality of residual;

ARCH Engle's autoregressive conditional heteroskedasticity test;

ADF Augmented Dickey-Fuller test for residual stationarity.

The TFP determinant models in both crop and livestock sector are statistically significant at the 1% level in terms of the F test. Both equations pass all the standard diagnostic tests. The choice of dropping or keeping variables in the final models was statistical acceptance in the joint variable deletion tests against the maintained hypothesis. The error correction coefficient ($lnTFP_{t-1}$) has the expected negative sign and is statistically significant at the 1% level. It indicates the speed of adjustment of TFP to exogenous shocks that cause the system to deviate temporarily from the steady state described by the long-run coefficients. The coefficients corresponding to $lnTFP_{t-1}$ are quite large (0.87 and 0.74), implying a very high speed of adjustment to dissipate such shocks. Since all variables are measured in logarithms, the regression coefficients can be interpreted as elasticities and the size of the coefficients also indicate the magnitude of their relative influence. Factors affecting TFP in each sector are discussed below. [7]

[7] The dummy variable capturing the 1997 financial crisis was introduced in the regression but it was not statistically significant. This confirms earlier findings that the financial crisis had little discernable effect on Thai agriculture, although it did have large and significant effects on industry and services (Warr, 1999).

Crops: Major factors affecting TFP are crop production research, both public and foreign, agricultural extension, infrastructure and the commodity boom. Public agricultural research (R^p) is statistically significant at the 1% and 5% level in the short run and long run, respectively. In the short run, an increase in public agricultural research spending of 1 percent leads to an increase in TFP growth of 0.16 percent. The short-run effects operate with three-year lags. In the long-run, a 1 percent increase in public research spending raises TFP by 0.07 percent. The larger short-run impact indicates that research produces an initial surge in TFP growth, which tapers off in the long-run, but does not vanish.

Foreign research spillovers (R^f), measured as the CGIAR spending on IRRI, CIMMYT and CIAT, have a positive and significant impact on TFP in the long run.[8] A 1 percent increase in foreign research spending results in a steady-state (long-run) increase in TFP of 0.11 percent.

Agricultural extension (*E*) affects crop TFP only in the short run. The estimated coefficients of the change term of E are statistically significant at the 1% level and are positively signed. However, there is no evidence that extension services significantly influence TFP in the long run.

Infrastructure as represented by the rural roads variable, and case-specific factors as represented by the agricultural commodity boom, are shown to have a positive and significant impact on TFP. This is consistent with the literature and with the general expectation that infrastructure improves agricultural productivity and that a commodity boom encourages farmers to grow more crops and use existing inputs

[8] The interaction term between public and foreign R&D does not appear to be statistically significant from various experimental runs and therefore was dropped out of the final parsimonious model.

more intensively to reap the benefits of a world agricultural price surge, which in turn increased output and hence productivity. There is no evidence that other potential factors like resource reallocation, trade openness or weather condition are statistically significant.

Livestock: Major factors explaining livestock TFP are public agricultural research and the Avian Influenza outbreak. Public research has a positive and significant impact only in the long run. The estimated long-run elasticity, statistically significant at the 5% level, suggests a 1 percent increase in the government research spending leads to a 0.17 percent increase in TFP.

The dummy variable representing the Bird Flu outbreak has a negative impact on TFP, as expected. Its coefficient is statistically significant at the 1% level. The commodity boom dummy variable is not significant, confirming that it is not directly relevant for livestock, as it is in the case of crops. Other variables were tested from various experimental runs but there is no evidence that they are significant factors.

7. Conclusions

This study estimates total factor productivity in the Thai crop and livestock sectors using the conventional growth accounting method. The findings confirm that TFP makes an important contribution to both crop and livestock output growth over the study period of 1970-2006. Specifically, TFP accounts for about 21 percent of crop output growth and for 17 percent of livestock output growth. These TFP growth measures are converted into a TFP index level and are used as the dependent variables in the subsequent TFP determinants models.

The error correction modelling technique of Hendry (1995) is employed in examining factors influencing the measured TFP. The models are estimated separately for the crop and livestock sectors. Results show that major factors influencing crop TFP are the public investment in agricultural research, foreign research spillovers, infrastructure and the world commodity boom. For the livestock sector, major factors are the public research and the Bird Flu outbreak.

The determinants of TFP are not confined only to agricultural research, but also include extension services, infrastructure, weather and case-specific factors, such as the commodity boom and the Bird Flu outbreak. Other factors left unexplained are likely to be due to measurement errors and unmeasured inputs. Degradation of environmental and natural resources associated with agricultural production can be an unmeasured negative input that has been ignored in this, as in most such studies.

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