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Research and productivity in Thai agriculture

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This paper examines the impact that publicly funded agricultural research has on productivity in crop production within Thailand. It tests empirically the two hypotheses that, first, publicly funded research and development (R&D) in crop production is a significant determinant of total factor productivity (TFP) in the crop sector and, second, that its social rate of return is high. The statistical analysis applies error correction methods to national level time series data for Thailand, covering the period 1970–2006. Emphasis is given to public research in crop production, where most publicly funded agricultural R&D has occurred. The role of international research spillovers and other possible determinants of TFP are also taken into account. The results demonstrate that public investment in research has a positive and significant impact on TFP. International research spillovers have also contributed to TFP. The results support the finding of earlier studies that returns on public research investment have been high. This result holds even after controlling for possible sources of upward biases present in most such studies, due to the omission of alternative determinants of measured TFP. The findings raise a concern over declining public expenditure on crop research, in Thailand and many other developing countries.

Key words: agricultural research, error correction model, productivity, Thai agriculture.

1. Introduction

It has long been recognised that agricultural growth is important for overall economic development and poverty reduction, especially in developing countries (Johnston and Mellor 1961). Several features of the modern world point to the increased long-term importance of agricultural productivity. They include rapid population growth, diminishing returns to traditional factor inputs, high fuel and fertiliser prices, environmental degradation, the possibility of output-reducing climate change, and declining availability of arable land, fresh water supplies and other natural resources. Agricultural research is widely considered an important source of productivity growth. Research-induced productivity growth therefore seems a possible solution to the challenge of raising agricultural output in a manner that minimises input use and protects the natural resource base (CGIAR 2009; Pardey *et al*. 2006).

But does it really work? Many earlier studies, dealing with a wide range of countries, have generally concluded that the answer is yes. Nevertheless, most such studies can be criticised for analytical and statistical deficiencies that could produce an unintended upward bias in the estimated effects of public research. This paper studies these matters in the

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context of crop production in Thailand, one of the world's major agricultural producers and exporters, using methods that correct for the common sources of statistical bias.

Earlier studies on Thai agriculture have estimated that over recent decades the growth of total factor productivity (TFP) has accounted for between one-fifth and three-fifths of total output growth (Tinakorn and Sussangkarn 1996; Chandrachai *et al.* 2004; Poapongsakorn 2006; Warr 2009). Nevertheless, there is very little empirical evidence as to what determines the seemingly high growth rate of TFP in Thai agriculture. Public investment in agricultural R&D is often mentioned as contributing to TFP growth (Tinakorn and Sussangkarn 1998; Poapongsakorn 2006), but this conjecture has not been tested empirically. The returns to research are also widely believed to be high, yet the empirical evidence in the case of Thai agriculture is very limited. This study aims to fill this gap. It examines the impact that public agricultural research has on TFP in crop production and measures the corresponding social rates of return. The statistical analysis applies error correction modelling (ECM) techniques to time series data covering the period 1970–2006.

The empirical relationship between research and productivity involves statistical issues of research lags and possible omitted variable bias resulting from ignoring the role of international research spillovers and other factors potentially affecting productivity (Griliches 1979; Evenson 2001; Fuglie *et al.* 2007). In dealing with lags in the impact of research, the usual practice has been to impose arbitrary restrictions on the lag structure such as the second-degree polynomial distributed lag (bell-shaped lag structure). However, imposing a lag structure that is too short or is otherwise inappropriate tends to bias upwardly the estimated research impact and associated rate of return (Alston *et al.* 1998a,b; Alston *et al.* 2000).

Error correction modelling offers an improved method to estimate the long-run dynamic relationship among time series economic variables (Makki *et al.* 1999). The ECM guards against the possibility of spurious regression, which can arise from the use of time series data (Hendry 1995). Moreover, it allows for both short-term and long-term relationships among variables and does not need to impose any restrictive pre-specified form or duration of lags (Wickens and Breusch 1988).

Most empirical studies at the country level ignore all research carried out abroad, although there is evidence that international technology transfers influence local productivity (Alston *et al.* 1998a,b; Alston 2002). Ignoring spillover benefits from international research can produce an upward bias in estimates of the returns to local research investment. In the case of Thai crop agriculture, there is a likelihood that foreign research outcomes, such as rice varieties developed by the International Rice Research Institute (IRRI), may have benefited local productivity. Hence, this study incorporates international research spillovers and other factors potentially affecting TFP.

The paper proceeds as follows. Section 2 briefly describes the agricultural research system in Thailand. Section 3 discusses the model of TFP determinants used in the empirical analysis. Section 4 summarises the sources of data and definitions of variables. Section 5 explains the ECM estimation method and the results are presented in Section 6. Section 7 estimates rates of return to agricultural research and Section 8 concludes.

2. Review of the Thai agricultural research system

The agricultural research system in Thailand is dominated by government agencies under the Ministry of Agriculture and Cooperatives (MOAC), mainly funded from the annual government budget. The MOAC also plays a dominant role in the dissemination of research results. Altogether, the MOAC accounts for around 95 per cent of the total government budget for all agricultural research and extension (R&E) (Poapongsakorn 2006, p. 54). More than half of the MOAC's R&E budget is allocated to crops, and the availability of data relating to crop research far surpasses that for livestock, forestry or fishery. This paper consequently focusses on research related to crop production.

Before the 1960s, public R&E programs concentrated on rice, particularly irrigated rice. There has since been some diversification of R&E from rice to other crops, particularly rubber and field crops such as corn, sorghum and cotton (Poapongsakorn *et al.* 1995, p. 95). Figure 1 shows that from 1961 to 2006, crop research intensity – expenditure on research as a percentage of total value added in the sector – averaged 0.47 per cent, ranging from near zero to almost 1.8 per cent. Research intensity increased over the three decades from 1961, but began to decline from the mid-1990s, and particularly after 2000.

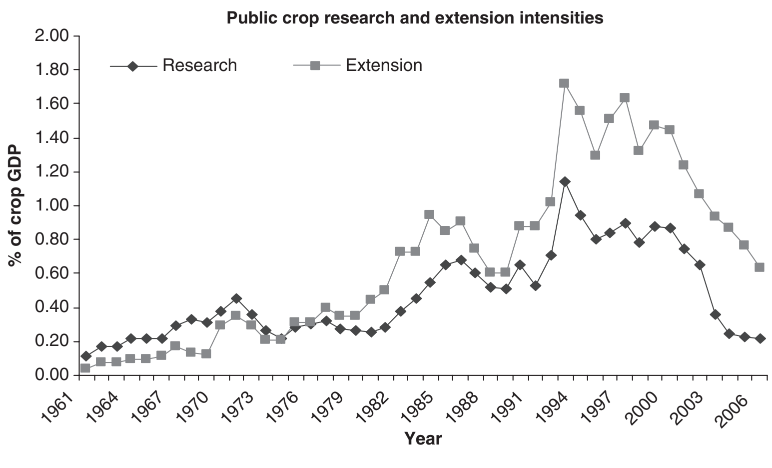

Figure 1 Crop R&E Budget Relative to Crop Gross Domestic Product, 1961–2006. Source: Public agricultural research and extension budget from the Bureau of the Budget and agricultural Gross Domestic Product from the National Economic and Social Development Board.

Foreign research plays a clear role in transferring technology and knowledge to research agencies in Thailand. In the early 1960s, collaborative research was initiated between Thailand and the IRRI, which was established in 1960 and was later included under the umbrella of the Consultative Group on International Agricultural Research (CGIAR) (Isarangkura 1986). The CGIAR, established in 1971, now sponsors 15 international research centres world-wide and works in collaboration with national agricultural research agencies in many countries. The flows of agricultural technology between developed and developing countries, notably through the CGIAR system, increased markedly after 1960 but began to decline from the early 1990s (Pray and Fuglie 2001).

The most prominent example of technology transfer to Thai agriculture has been in irrigated rice varieties developed by IRRI. The first IRRI scientist assigned to Thailand, from 1966 to 1982, brought a large collection of IRRI rice genetic materials. They were crossed with Thai varieties yielding the first non-glutinous, semi-dwarf, photoperiod-insensitive, high-yielding varieties, and these were subsequently released to Thai farmers (IRRI 1997). A number of joint research and training programs followed, primarily between IRRI and the MOAC.

Thai agricultural research agencies also work in collaboration with other CGIAR centres, namely the International Maize and Wheat Improvement Centre (CIMMYT) for maize and wheat research and the International Centre for Tropical Agriculture (CIAT) for cassava research. CIMMYT introduced plant materials in 1963 which led to organised wheat research in Thailand. Likewise, hybrid seeds from CIAT were introduced in 1975 for breeding purposes which formed the initial basis for cassava varietal improvement in Thailand (Isarangkura 1986). Germplasm was introduced from many other countries, including India, Japan, the United States and Australia, as well as through the Food and Agriculture Organization. However, the research results using materials from these other sources were not as fruitful as the rice varieties developed by IRRI.

Although the private sector has been actively involved in some aspects of agricultural research in Thailand, there is no systematic record of its magnitude. Based on a survey of private investment in agricultural research in 1996, Fuglie (2001) estimated that the private sector was responsible for about 13 per cent of total agricultural research in Thailand, but was focussed heavily on livestock production, rather than cropping. For crops, private R&D is concentrated in developing hybrid seeds for field crops, especially maize used in animal feeds.

3. Theoretical framework and model: TFPG determinants model

Our model of the long-run determinants of TFP is based on the production function framework in which TFP growth is identified as a shift in the production function representing technical change. It is measured as that part of output growth not explained by growth of measured factor inputs (Solow 1957; Jorgenson 1995). It thus includes, but is not confined to, the effects of advances of knowledge or technological progress (Denison 1967; Jorgenson and Griliches 1967).

We hypothesise that the determinants of TFP include agricultural research on crop production as well as other economic and non-economic factors such as extension services directed to cropping technology, infrastructure and weather. Research lags are also incorporated, as discussed later. Other explanatory variables are explored in accordance with their potential connections with TFP in crop production. In stylised form, the model is

$$TFP = f(R^p, R^f, E, I, RR, TO, W, D), \tag{1}$$

where *TFP* denotes total factor productivity in the crop sector, R^p denotes real public agricultural research expenditure on crops,[1] R^f denotes international crops research spillovers, *E* denotes real public agricultural extension expenditure on crops, *I* denotes infrastructure, *RR* denotes resource reallocation, *Trade openness* (*TO*) denotes trade openness, *W* denotes weather and *D* denotes a dummy variable capturing the world agricultural commodity boom from 1972 to 1974, inclusive. An interaction term between local and foreign research is also included to test for the significance of research collaboration.

The expected relationships between TFP and the explanatory variables are as follows. Publicly funded, within-country research on crop production increases the stock of knowledge, which facilitates the use of existing knowledge and generates new technology (Ruttan 1987; Chang and Zepeda 2001). Another potential effect is to enhance the absorptive capacity of foreign research spillovers. Hence, an increase in crop research expenditure within Thailand is expected to raise TFP.

International research spillovers are potentially important sources of productivity growth. These spillovers have been ignored in the literature on the impact of agricultural research in Thailand, resulting in an omitted variable bias (Alston *et al.* 1998a,b; Alston 2002; Fuglie *et al.* 2007). Our model corrects for this bias by incorporating foreign research on crops that are relevant for Thailand. An increase in this variable is expected to raise domestic TFP.

Effective agricultural extension is also expected to improve productivity in the field, for any given level of technological knowledge. Infrastructure is considered a fixed factor that contributes positively to agricultural growth and productivity (Evenson and Pray 1991). It is typically not included among the conventional inputs in growth accounting studies, and in such cases, its effect on agricultural growth is thereby captured in the residual TFP, again leading to upward bias in the estimated effect of research.

[1] Deflators are described in Section 4, below.

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 (Chandrachai *et al.* 2004; Warr 2009).

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, promoting technological development, thereby raising TFP. More open economies and international trade are generally found to be favourable to TFP (Urata and Yokota 1994; Edwards 1998).

Under the conventional TFP decomposition framework, weather or climate variation is considered a possible explanator of changes in TFP (Evenson 2001). Good weather, like more rainfall or less frequent drought or flooding, should raise TFP.

Finally, the world agricultural commodity boom of 1972–1974, inclusive, raised the real prices 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 utilise existing inputs more intensively, which does not necessarily show up in measured input growth. Measured productivity therefore rises, at least partly through measurement error, and a dummy variable for the period of the commodity boom can control for this effect.

4. Data and variables measurement

4.1. Dependent variable: TFP measurement

Total factor productivity *growth* is measured using the growth accounting method, which means that it is a residual of output growth after subtracting labour, land and capital growth, weighted by their respective factor income shares. Output means contribution to Gross Domestic Product (GDP) at constant 1988 prices, measured as real value added in the crop sector. The factor income shares (proportional shares of factor income in the value of total output) are computed as arithmetic averages of the relative shares in two consecutive periods and so their values vary over time. To reflect technological change more accurately, TFP growth is also adjusted for quality changes in the inputs of labour (adjusted for age, gender and education) and land (adjusted for irrigation). The data used to measure TFP growth and their respective sources are summarised in Table 1.

The average annual growth rate of TFP in the crop sector, measured in the above way, averaged 0.68 per cent over the period 1970–2006. The TFP growth measure is converted into the *level* of TFP using 1971 as a base year, with the level of TFP set equal to unity for that year, and the resulting series is shown in Figure 2. The dependent variable used in the long-run component

Table 1 Summary of data sources (1970–2006)

Variable	Definition	Data source
Output	Gross Domestic Product (GDP) at 1988 prices (value added)	National Income of Thailand, National Economic and Social Development Board (NESDB)
Labour	Number of employed persons age 15 and above	Labour Force Survey, National Statistical Office
Land	Land used in crop production	Office of Agricultural Economics (OAE)
Capital	Net capital stock at 1988 prices	NESDB
Wage	Imputed wage of all workers, measured as private workers' wage adjusted by 1995 SAM wage to account for self employed and unpaid family labour	Labour Force Survey, National Statistical Office (NSO)
Land rent	Actual and imputed rent	NESDB
Labour quality-adjusted index	Qualitative changes in age, sex and educational attainment of agricultural workers	Thailand Development Research Institute (TDRI)
Irrigation	Accumulated irrigation area	OAE
Factor income share	Value of factor income divided by GDP at factor cost	NESDB (GDP at factor cost)

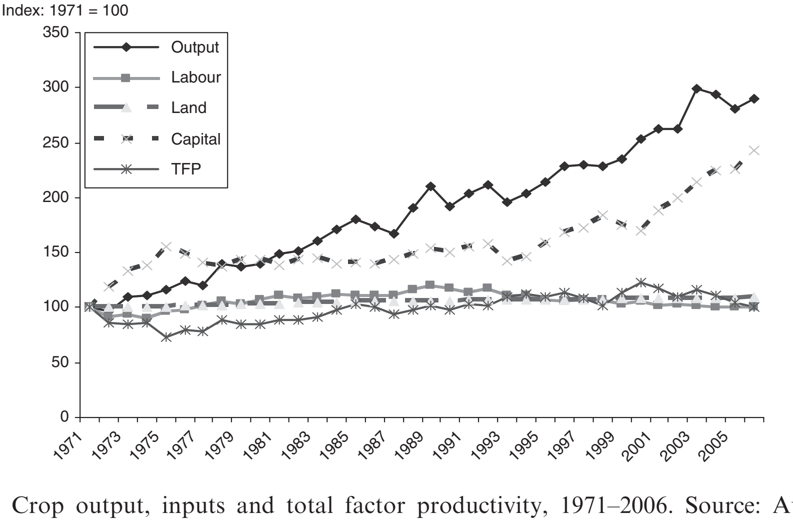

Figure 2 Crop output, inputs and total factor productivity, 1971–2006. Source: Authors' calculations.

Table 2 Sources of output growth in crop production, 1971–2006

Variable	Average cost share	Average growth rate (%)	Contribution to output growth (%)
Output	n.a.	3.26 (q)	100
Labour	0.49 (S_L)	0.64 (l)	9.56 ($100S_Ll/q$)
Land	0.10 (S_H)	3.19 (h)	9.40 ($100S_Hh/q$)
Capital	0.42 (S_K)	4.69 (k)	60.30 ($100S_Kk/q$)
Total factor productivity (TFP)	n.a.	0.68 ($TFPG$)	20.74 ($100TFPG/q$)

See Equation (2). Output means real value added in crops production. That is, the value of intermediate inputs used in production, including fertiliser, seed and fuel, have been subtracted from the value of output.
n.a. means not applicable.
Source: Authors' calculations.

of the statistical analysis, described below, is the natural logarithm of this variable.[2]

Table 2 provides an approximate summary of this calculation by presenting the components of the standard growth accounting equation with each variable evaluated at its arithmetic mean:

$$q = S_L l + S_H h + S_K k + TFPG \tag{2}$$

where q is the arithmetic mean of the annual growth rates of real value added, expressed as a percentage, l, h and k are similarly the average annual growth rates of adjusted labour input, adjusted land input and capital input, respectively, each expressed as a percentage, S_L, S_H and S_K are the arithmetic means of their cost shares and $TFPG$ is average annual total factor productivity growth, calculated as a residual. Growth of the capital stock (mechanisation) explains an average of about three-fifths of output growth, but productivity growth is substantial, accounting for about one-fifth of average output growth.

4.2. Explanatory variables

Public agricultural research (R^p) is measured as real government budget expenditure on the R&D activities of the Department of Agriculture of the MOAC, where almost all crops research occurs.[3] The budget data

[2] Similar measurement and input quality adjustment methods were applied in previous Thai studies. Examples include Tinakorn and Sussangkarn (1998), Poapongsakorn (2006) and Chandrachai *et al*. (2004).

[3] Government budget expenditure on research has commonly been used as a measure of agricultural research in Thailand, for example, Setboonsarng and Evenson (1991), Chandrachai *et al*. (2004), Fan *et al*. (2004). The budget expenditure is allocated at the national level and provides the most complete and consistent time series for agricultural research.

are from the Bureau of the Budget (2006) under the office of the Prime Minister. They are deflated by the implicit GDP deflators of the crop sector.[4]

Agricultural extension (E) is measured as the real public extension budget on extension related to crop production. The data are obtained from the Bureau of the Budget (2006). The extension service for crops is based on the budget allocated to the Department of Agricultural Extension (DOAE). The budget data are again deflated using the implicit GDP deflator for the crop sector.

International research spillover (R^f) in the crop sector is measured as total research expenditure by the three major centres under the CGIAR with close collaboration with Thailand: IRRI, CIMMYT and CIAT.[5]

Infrastructure consists of irrigation ($I^{\text{irrigation}}$) and rural roads (I^{roads}). Irrigation is represented by the percentage share of irrigated area in total agricultural land. The data are obtained from the OAE (2006a,b), covering 1970–2006. The roads variable is defined as the length of rural roads (unpaved and asphalt). The data are obtained from Fan *et al.* (2004), covering 1977–2000 and extrapolated linearly to earlier and later years.

Resource reallocation (RR) is measured as the share of non-rice households in total agricultural households, serving as a proxy for the employment share of the higher productivity non-rice component of crop employment. This proxy is used because there are no employment data for the rice sector. The data are obtained from the socio economic household surveys conducted by the OAE. The surveys were not conducted every year and results for omitted years are interpolated linearly.

Trade openness is measured as the percentage share of agricultural imports and exports in total agricultural output. Import and export values of agricultural commodities are obtained from the OAE (2006a,b). Data on agricultural output are obtained from the NESDB (2006).

Weather factors are represented by annual average rainfall measured in millimetres (W^{rain}), using data obtained from the OAE (2006a,b) and, separately, the share of the rice-harvested area in planted area (W^{weather}), used as a proxy for drought or flooding.

[4] The ideal deflator for research expenditures would presumably be an index of scientist salaries, but no such index is available. The GDP deflator for crops behaves very similarly to the general GDP deflator, the former growing at a slightly faster rate than the latter over the period of our data. Substituting the general GDP deflator for the GDP deflator for crops makes almost no difference to our results.

[5] In addition, the import value of agricultural machinery and crop seeds, expressed as a share in crop value added, was used separately to represent a package of readily available technology directly transferred into the country. The import data were obtained from the Office of Agricultural Economics (OAE). The crop value–added data were from the National Economic and Social Development Board (NESDB). This variable was statistically insignificant in all experimental runs and was dropped from the analysis.

5. Estimation method

Applying the standard ordinary least squares (OLS) method to non-stationary data series can produce a spurious regression.[6] That is, the OLS regression can give high R^2, low Durbin Watson (DW) statistics and significant t-values of the estimated coefficients, suggesting a significant relationship between dependent and explanatory variables when in fact they are unrelated in any causal sense. Conventionally, the factors explaining TFP growth have been studied by expressing variables in rate of change form.[7] This is similar to the first-differencing of variables in time series analysis. Provided the original series is integrated of order 1, as is normally the case, expressing the variables in rate of change terms ensures a stationary data series and thus, directly addresses the spurious regression problem. However, some meaningful level information is lost with this approach (Hendry 1995).

To guard against the possibility of a spurious relationship while maintaining the level information, two main approaches offer reasonable solutions. First is the co-integration approach pioneered by Engle and Granger (1987) and later improved by studies such as Johansen (1988) and Phillips and Hansen (1990). The Engle and Granger pioneering method is appropriate when dealing with non-stationary data that are integrated of the same order – that is, all data series are integrated processes of order 1. Second is the unrestricted ECM method developed by Hendry and his co-researchers (Davidson *et al.* 1978; Hendry *et al.* 1984; Hendry 1995). Under the ECM, the long-run relationship is embedded within a detailed dynamic specification, including both lagged dependent and independent variables, which helps minimise the possibility of estimating a spurious regression. It has been argued that the ECM method developed by Hendry (1995) can legitimately be applied to data series that are integrated of different orders, provided the resulting specification makes economic sense (Athukorala and Sen 2002).

The first step of the estimation process is to conduct standard unit root tests on each variable. The Augmented Dickey-Fuller (ADF) test is employed in this study to test the time-series properties of the data series. The ADF tests the null hypothesis of non-stationarity against the alternative of stationarity (Banerjee *et al.* 1993).

The test results, reported in Table 3, show that the variables under consideration are a mixture of stationary series – I(0) – and non-stationary series integrated of order 1 – I(1). Most of the variables are I(1), such as public research (R^p), extension (E), irrigation ($I^{\text{irrigation}}$) and rainfall (W^{rain}), while I(0) variables include foreign research (R^f), roads (I^{roads}) and weather

[6] This problem was first mentioned in a classic article by Yule (1926) and re-emphasised by Granger and Newbold (1974).

[7] Previous studies on TFP determinants in Thai agriculture concentrate on TFP at the national level, including Tinakorn and Sussangkarn (1998), Chandrachai *et al.* (2004), Warr (2009).

Table 3 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	−1.47 (0)	−3.53 (0)**	−5.03 (1)*	−4.95 (1)*
ln R^{p}	−1.29 (1)	0.24 (0)	−3.88 (0)*	−4.13 (1)*
ln R^{f}	−6.50 (1)*	−4.25 (1)*	−4.14 (0)*	−6.38 (0)*
ln E	−1.65 (0)	−0.14 (0)	−4.78 (0)*	−5.00 (0)*
ln $I^{irrigation}$	−1.68 (0)	−0.64 (0)	−5.22 (0)*	−5.93 (0)*
ln I^{roads}	−0.99 (1)	−3.82 (5)*	−3.35 (0)*	−3.38 (0)*
ln RR	−1.53 (0)	−1.67 (0)	−5.18 (0)*	−5.60 (0)*
ln TO	−2.03 (0)	−1.49 (0)	−7.99 (0)*	−8.61 (0)*
ln W^{rain}	−2.45 (0)	−2.08 (0)	−8.37 (0)*	−8.71 (0)*
ln W^{wather}	−6.19 (0)*	−6.15 (0)*	−10.07 (0)*	−9.91 (0)*

All variables are measured in natural logarithms.
See Equation (1) and definitions of variables.
* and ** denote the rejection of the null hypothesis at the 5% and 10% level, respectively. The t-statistics reported are the t-ratio on γ in the auxiliary regression.
Numbers in parentheses indicate the order of augmentation selected on the basis of the Schwarz criterion.

conditions ($W^{weather}$). The ECM procedure of Hendry (1995) is therefore employed.[8] This approach minimises the possibility of estimating spurious relationships while retaining long-run information without arbitrarily restricting the lag structure (Wickens and Breusch 1988; Hendry 1995).[9] 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 with long lag orders for the endogenous and exogenous variables (Wickens and Breusch (1988, p. 188)). From this, the correction mechanism (ECM) representation of the model can be derived (Banerjee *et al.* 1993; Hendry 1995). The ECM can be estimated by OLS, and the short- and long-run parameters can be separately identified. The error correction mechanism is the 'maintained hypothesis' for specification search. Under the Hendry general-to-specific approach, the full model is 'tested down' by dropping statistically insignificant lag terms using the standard testing procedure to obtain a parsimonious ECM. Pre-specification of the exact duration of lags is therefore neither necessary nor desirable (Wickens and Breusch (1988, p. 194)).

The final preferred model is required to satisfy standard diagnostic tests, including the Breusch-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).

[8] This approach, based on Hendry (1995), has seldom been used in earlier studies of agricultural TFP and has not been used in the context of Thailand.
[9] The trapezoidal lag structure, or the 2nd degree polynomial lag distribution, was tested in Suphannachart (2009) and did not fit the data.

6. Research impact on TFP: Results from the ECM

The results are reported in the first two results columns of Table 4. Public agricultural research in crop production appears to be a major determinant of TFPG. The positive and significant impact of public research is consistent with the theory and findings from previous studies. This finding supports the general belief that research-induced technical change is a major driving force behind the impressive growth of TFP in Thai agriculture, along with empirical findings from many other countries (Evenson and Pray 1991; Ruttan 2002). The results indicate that other major determinants of TFP include international research spillovers, agricultural extension, rainfall, rural roads and the world agricultural commodity price boom. These variables are all statistically significant with the expected signs.

The TFPG determinant model in the crop sector is statistically significant at the 1 per cent level (*F* test). All equations pass the standard diagnostic

Table 4 Total factor productivity (TFP) determinants in crop sector

	Dependent variable: $\Delta \ln TFP_t$			
	Foreign research variable ($\ln R^f_{t-1}$) included		Foreign research variable ($\ln R^f_{t-1}$) dropped	
	Estimated coefficients (*t*-ratios)	Long-run elasticity	Estimated coefficients (*t*-ratios)	Long-run elasticity
Constant	−1.056 (−6.46)***		−0.997 (−5.94)***	
$\Delta \ln R^p_{t-3}$	0.155 (4.42)***		0.180 (4.70)***	
$\ln R^p_{t-3}$	0.059 (1.87)*	0.067 (2.12)**	0.067 (2.37)**	0.083 (2.81)**
$\ln R^f_{t-1}$	0.092 (2.95)***	0.105 (3.05)***	–	–
$\Delta \ln E_{t-1}$	0.137 (3.66)***		0.149 (3.68)***	
$\ln I^{roads}_{t-1}$	0.033 (1.97)**	0.038 (1.96)**	0.055 (3.16)***	0.068 (3.17)***
D	0.127 (3.10)***	0.145 (3.19)***	0.038 (1.23)	0.048 (1.314
$\ln TFP_{t-1}$	−0.873 (−6.66)***		−0.801 (−6.32)***	
N (no. of observations)	34		34	
k (no. of parameters)	8		7	
Adjusted R^2	0.69		0.65	
F-statistic	11.31		11.71	
SE of regression	0.033		0.037	
Diagnostic tests				
$LM(1)$, $F(1, N-k-1)$	0.06 [p = 0.79]		0.24 [p = 0.62]	
$LM(2)$, $F(2, N-k-2)$	1.42 [p = 0.26]		0.33 [p = 0.72]	
$RESET$, $F(1, N-k-1)$	0.89 [p = 0.35]		0.31 [p = 0.58]	
JBN, $\chi^2(2)$	0.77 [p = 0.68]		0.95 [p = 0.62]	
$ARCH$, $F(1, N-2)$	0.00 [p = 0.98]		0.59 [p = 0.45]	
ADF	−5.79 [p = 0.00]		−5.24 [p = 0.00]	

The level of statistical significance is denoted as: *10%, **5% and ***1%.
All variables are measured in natural logarithms except the dummy variable for the commodity boom of 1972–1974, *D*.
Long-run elasticities can be computed by dividing the estimated coefficients of the level termsln R^p_{t-3}, $\ln R^f_{t-1}$ and $\ln I^{roads}_{t-1}$ by the positive value of the coefficient of the lagged dependent variable, $\ln TFP_{t-1}$.
Diagnostic tests are [numbers in square brackets are *p*-values of the test statistics]: *LM* Breusch-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.

Table 5 Trajectory of R&D impact on total factor productivity (TFP) in crops sector

Year	Estimated elasticity
1	0.0590360
2	0.0665358
3	0.0674886
4	0.0676096
5	0.0676250
6	0.0676269
7	0.0676272
8	0.0676272
9	0.0676272
∞	0.0676272

Source: Authors' calculations.

tests. The error correction coefficient (TFP_{t-1}) also has the expected negative sign and is statistically significant at the 1 per cent level. This coefficient indicates the speed of adjustment of TFP to exogenous shocks. The coefficient corresponding to TFP_{t-1} is quite large (0.87), implying rapid adjustment to dissipate a shock. The choice of dropping or keeping variables in the final model was statistical acceptance in the joint variable deletion tests against the maintained hypothesis. As 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.

Public agricultural research (R^p) is statistically significant at the 1 per cent and 5 per cent level in the short run and long run, respectively. In the short run, an increase in public agricultural research spending of 1 per cent leads to an increase in TFPG of 0.16 per cent. The short-run effects operate with 3-year lags. In the long-run, a 1 per cent increase in public research spending raises TFP by 0.07 per cent. The larger short-run impact indicates that research produces an initial surge in TFPG, which tapers off in the long-run, but does not vanish. Under the estimated ECM the research lag weights are derived from the long-run elasticity.[10] It takes approximately 7 years for crop research to have a full and stable impact on TFP, and the magnitude of the full impact is equal to the estimated long-run elasticity reported in Table 5, which shows the lag distribution implied by our results. After reaching the steady-state or long-run equilibrium, the R&D impact on TFP remains constant into perpetuity. This result fits with the experience of Thai agricultural researchers. Most research projects take < 5 years to complete and the average time to develop a new rice variety and multiply the seed for release and adoption is about 5 years.[11]

[10] A fuller discussion of the derivation of lag weights and the rate of return is provided in Suphannachart (2009).

[11] From interviews with Dr Adisak Sreesunpagit, former Director General, Department of Agriculture and Dr Apichat Pongsrihadulchai, Advisor to the Director General of the Rice Department.

Foreign research spillovers *(R^f)* have a positive and significant impact on TFP in the short-run and long run.[12] A 1 per cent increase in foreign research spending results in a steady-state (long-run) increase in TFP of 0.11 per cent. This is consistent with the prior expectation that the spillovers of crop varieties, particularly rice varieties, especially from IRRI, benefits crops productivity locally. The failure to account for this variable in many earlier studies has led to upward bias in the estimated coefficients of public research. This point can be confirmed by dropping this variable from the model and re-estimating. The results of this exercise are presented in the third and fourth columns of results in Table 4. The estimated coefficient of public research increases by about one-fourth and its level of significance also rises. The difference between this and the coefficient estimated when foreign research is controlled for can be interpreted as the bias introduced when foreign research spillovers are ignored. Taking account of these important spillovers reduces the estimated impact of public research but does not eliminate it.

Agricultural extension (*E*) affects TFP only in the short run. The estimated short-run coefficient is statistically significant at the 1 per cent level and positively signed. The results provide no evidence that extension services significantly influence TFP in the long run.

Regarding other explanatory variables, 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 general expectations. Infrastructure improves agricultural productivity by providing complementary inputs. A commodity boom encourages farmers to grow more crops and use existing inputs more intensively. But these increased input levels are not necessarily recorded. Output increases without a corresponding increase in measured inputs and measured productivity thereby increases. The results provide no evidence that resource reallocation, trade openness or weather conditions, as measured in this study, have statistically significant effects on productivity.

7. Returns to public investment in agricultural research

Measuring the social rate of return on agricultural research investment has been a standard practice accompanying agricultural research impact studies (Schultz 1953; Griliches 1957; Alston *et al*. 2000). This exercise is particularly relevant for developing countries where research investment is primarily a public sector activity. Government budgets are limited and there are many competing public investment alternatives. The measured rate of return can provide guidance on funding decisions.

The social rate of return on crop R&D is computed based on the estimated coefficients of the level terms of the public research variables or the long-term

[12] The interaction term between public and foreign R&D was not statistically significant in various experimental runs and was therefore dropped from the final parsimonious model.

TFP elasticities with respect to the public research variable.[13] This regression-based rate of return is the marginal internal rate of return (*MIRR*), calculated as the discount rate r, such that

$$\sum_{t=1}^{\infty}\left[VMP_t/(1+r)^t\right]-1=0. \qquad (3)$$

The *MIRR* is the discount rate that equates a stream of discounted benefits from an initial investment of 1 baht, to exactly 1 baht. The research cost of 1 baht occurs in year 0 while the research benefit begins from year 1 and extends to infinity. Under the ECM, the annual research benefit or value marginal product (VMP) may vary for a certain number of years until it reaches the long-run equilibrium, after which it remains constant and lasts into perpetuity. Equation (3) is used in conjunction with these VMP estimates to find the social rate of return.

The estimated *MIRR* for crops R&D investment is 29.5 per cent.[14] This is well above the opportunity cost of public funds and certainly high enough to justify continued public investment in agricultural research in Thailand.[15]

8. Conclusion and implications

This paper decomposes output growth in Thai crop production over the period 1970–2006 into input growth and productivity growth. Growth of the capital stock (mechanisation) accounts for 60 per cent of output growth, growth of quality-adjusted labour and land inputs each account for another 10 per cent and growth of total factor productivity accounts for a further 20 per cent. The main task of the paper is to explain this growth of productivity.

The analysis uses error correction statistical methods to minimise the possibility of spurious regression and controls for relevant variables omitted from most earlier studies. The estimation approach permits the length of response lags to be determined empirically, within the analysis, rather than being prespecified. The analysis therefore avoids important sources of upward bias in the estimated effects of public research that are present in most earlier studies.

The results indicate that public investment in research and development in Thailand's crop agriculture contributed significantly to the growth of productivity, as did public investment in infrastructure. This qualitative finding

[13] Under the ECM, the short-run impact represented by the estimated coefficient of a variable expressed in a change term disappears in the steady state.

[14] The MIRR for crops when omitting the foreign research variable is estimated at 34.2 per cent.

[15] Two earlier studies, both using the Metaprofit function approach, report somewhat higher marginal returns to R&D in Thai agriculture. Setboonsarng and Evenson (1991) reported a rate of return to national crops research of 42 per cent, and extending that study, Pochanukul (1992) incorporated intranational research spillovers and found a slightly higher rate of 44.95 per cent. Neither study adjusted for input quality changes or for international research spillovers.

remains after allowing for the contributions of other potentially relevant variables, including foreign agricultural research spillovers, which also contributed significantly to Thailand's productivity growth. Controlling for the common sources of statistical bias reduces the estimated productivity-enhancing effects of public research, but only marginally.

The rate of return to public investment in agricultural research is estimated at around 30 per cent, well above the opportunity cost of public funds, implying underinvestment in research. The private sector is generally reluctant to invest in this activity, primarily because of the difficulty of capturing its benefits.[16] The level of government spending on public R&D is insufficient to compensate for private sector underinvestment. Given the slowdown in the levels of funding for public research, the results of this study suggest that Thailand should now invest more heavily in its own agricultural science capacity.

The findings also have implications for research collaboration. The significant effect of both domestic research and foreign research spillovers, combined with the insignificant interaction between them, seemingly signals weak collaboration between domestic and foreign research agencies, and this collaboration could presumably be improved.

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[16] Partial exceptions include private investment in seed production and livestock feeds, especially for poultry.

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