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Research and Productivity in Thai Agriculture*

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Abstract

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 to 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, productivity, Thai agriculture, error correction model

JEL classification: O30, Q16, C32

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1. Introduction

It has long been recognized that agricultural growth is important for overall economic development and poverty reduction, especially in developing countries (Johnston and Mellor, 1961). Rapid population growth, diminishing returns on traditional factor inputs, declining availability of arable land, fresh water supplies and other natural resources, concern over climate change and environmental degradation, along with high fuel and fertilizer prices all draw attention to the long-term importance of agricultural productivity growth. Research-induced productivity growth seemingly offers a potential solution to the challenge of maintaining a continuous increase in agricultural output in a manner that minimizes input use and protects the natural resource base (CGIAR, 2009). But does it really work?

Total factor productivity (TFP) growth has been shown to be an important source of agricultural growth in Thailand and its contribution has been substantially greater than in the non-agricultural sectors (Chandrachai et al., 2004, Poapongsakorn, 2006, Tinakorn and Sussangkarn, 1996).[1] Nevertheless, there is very little empirical evidence as to what determines the high growth rate of TFP in Thai agriculture. Public investment in agricultural R&D has a long history in Thailand and is often mentioned as contributing to TFP growth (Poapongsakorn, 2006, Tinakorn and Sussangkarn, 1998). But this view 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 uses time series data and error correction modeling (ECM) techniques covering the period 1970 to 2006.

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

The statistical relationship between research and productivity involves important issues of research lags and possible omitted variable bias resulting from ignoring the role of international research spillovers and other major factors affecting productivity (Evenson, 2001, Fuglie and Heisey, 2007, Griliches, 1979). 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, Alston et al., 2000). Error correction modeling (ECM) offers an improved method to estimate the long-run dynamic relationship among time series economic variables (Makki et al., 1999). The ECM does not impose any restrictive form of lags and allows for both short-term and long-term relationships among variables. It also guards against the possibility of spurious regression, which can arise from the use of time series data (Hendry, 1995).

Most empirical studies at the country level ignore all research done abroad, although there is evidence that international technology transfers influence local productivity (Alston et al., 1998b, Alston, 2002). Ignoring spillover benefits from international research tends to produce an upward bias in estimates of the returns to local research investment. In the case of Thai crop agriculture, there is a possibility that foreign research results, 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 potential factors 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 presents 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 on agricultural research. The findings are concluded in Section 8.

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 percent 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 this form of research far exceeds that available for livestock, forestry or fishery. This paper consequently focuses on research related to crop production.

Before the 1960s, public R&E programs concentrated on rice, particularly irrigated rice. Since the 1960s, there has 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, measured as the average ratio of the crop research budget to total value added from crop production (crops contribution to GDP), was 0.47 percent. Research intensity increased over the three decades from 1961, but began to decline from the mid-1990s, and particularly after 2000. Crops research expenditure grew at an average annual rate of 4.8 percent in real terms from 1961 to 2006.[2]

[Figure 1 about here]

Foreign research plays an important role in transferring technology and knowledge to research agencies in Thailand. In the early 1960s, collaborative research was initiated between Thailand and the International Rice Research Institute (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 and works in collaboration with national agricultural research agencies in many countries.[3] The flows of agricultural technology between developed and developing countries through international agricultural research, notably the CGIAR, 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, which were crossed with Thai varieties yielding the first non-glutinous, semi-dwarf, photoperiod-insensitive, high-yielding varieties that were then released to

[2] The government budget allocated to livestock research is very modest, but livestock extension is much more significant. Livestock research expenditure grew by 5.3 percent annually in real terms over the period 1961 to 2006.
[3] The CGIAR was built on the early success of the two multidisciplinary research centres, the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Centre (CIMMYT), which were established by the Rockefeller and Ford Foundations.

Thai farmers (International Rice Research Institute, 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 organized 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 brought in from many other countries as well, including India, Japan, the United States and Australia, as well as through the Food and Agriculture Organization (FAO) (Isarangkura, 1986). 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 percent of total agricultural research in Thailand, but was focused 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 feed.

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 and Griliches, 1967, Jorgenson, 1995), Measured TFP growth therefore includes not only pure technical change, but also factors and measurement errors left unaccounted for by measurable conventional inputs (Ruttan, 1987, Alston et al., 1998b, APO, 2001, Oguchi, 2004). It thus includes, but is not confined to, the effects of advances of knowledge or technological progress (Denison, 1967, Griliches, 1996).

Our statistical analysis is based on a conceptual model in which 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 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):

$$TFP = f(R^p, E, I, RR, TO, W, D^c, R^f), \qquad (1)$$

where TFP = total factor productivity in the crops sector,

R^p (+) = real public agricultural research expenditure on crops,[4]

E (+) = real public agricultural extension expenditure on crops,

I (+) = infrastructure,

RR (+) = resource reallocation,

TO (+) = trade openness,

W (+) = weather or climate factor,

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

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

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

An interaction term between local and foreign research is also tested for the significance of research collaboration. The expected conceptual relationships between each explanatory variable and TFP are as follows.

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

Agricultural extension directed towards crop production 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 (Chandrachai et al., 2004, Warr, 2006).

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 (Edwards, 1998, Urata and Yokota, 1994, Acemoglu and Zilbotti, 1999, p.34).

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

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.

Finally, 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., 1998b, Alston, 2002, Fuglie and Heisey, 2007). Our model incorporates foreign research on crops that are relevant for Thailand and it is expected to increase domestic TFP.

4. Data and variables measurement

4.1 Dependent variable: TFP measurement

TFP growth is measured for crop production specifically, using the conventional growth accounting method. It is measured as a residual of output growth after subtracting land, labour and capital growth, weighted by their factor income shares. The factor income shares (proportional shares of factor income in the value of total output) were computed as arithmetic averages of the relative shares in two consecutive periods and so their values vary over time. TFP growth is also adjusted for input quality changes in order to remove labour (age, sex and education) and land (irrigation) quality changes from the productivity measure that better reflects technological change.

The pattern of TFP growth in the crop sector, measured in the above way, fluctuates over time, as shown in Figure 2. Its average annual growth rate over the period 1970 to 2006 was 0.68 percent.

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. The dependent variable used in the long-run component of the statistical analysis, described below, is the natural logarithm of this variable. Similar measurement and adjustment methods were applied in previous Thai studies.[5]

[5] Examples include Tinakorn and Sussangkarn, 1998, Poapongsakorn and Anuchitworawong, 2006 and Chandrachai et al., 2004.

[Figure 2 about here]

4.2 Explanatory variables

Public agricultural research (R^{p}_{crops}) is measured as real government budget expenditure on R&D activities conducted by the Department of Agriculture of the MOAC, where almost all crops research occurs.[6] The budget data are from the Bureau of the Budget under the office of the Prime Minister. They are deflated by the implicit GDP deflators of the crops sector.[7]

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

Infrastructure consists of irrigation ($I^{irrigation}$) and rural roads (I^{roads}). Irrigation is represented by the percentage share of irrigated area in total agricultural land. The data from 1970 to 2006 are obtained from the Office of Agricultural Economics (OAE). The roads variable is defined as the length of rural roads (unpaved and asphalt). The data from 1977 to 2000 are obtained from Fan et al. (2004).[8] The missing data before 1977 are estimated using exponential growth trend and the data after 2000 are extrapolated using the Holt-Winter exponential smoothing method in Eviews (2004).

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[6] The government budget expenditure 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.

[7] The implicit GDP deflator is the ratio of GDP at current prices to GDP at constant (1988) prices, multiplied by 100. The deflator is computed specifically for the crop sector.

[8] The original data source is from the Public Works Department, Ministry of Interior.

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.[9]

Trade openness (*TO*) 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. Agricultural output is taken from the NESDB.

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

Case-specific factors: a dummy variable (D^{boom}) is used to capture the world agricultural commodity boom from 1972 to 1974 during which agricultural growth in Thailand increased significantly (Poapongsakorn, 2006, p.5). The prices of major crops surged, inducing more production, but the increased use of inputs was not well captured by the input data and so measured productivity increased also.

International research spillovers in the crop sector are measured as total research expenditure by the three major centres under the CGIAR with close collaboration with Thailand: IRRI, CIMMYT and CIAT. In addition, the import value of agricultural machinery and crop seeds, expressed as a share in crop value added, is

[9] Due to lack of data the ratio of non-rice households to total agricultural households during 1970 to 1974 is assumed to be the same as in 1975.

used separately to represent a package of readily available technology directly transferred into the country. The import data are obtained from the Office of Agricultural Economics (OAE). The crop value added data are from the National Economic and Social Development Board (NESDB).

5. Estimation method

Applying the standard OLS method to non-stationary data series can produce 'nonsense correlation' or 'spurious regression'.[10] 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 completely unrelated. Conventionally, the factors explaining TFP growth have been studied by expressing variables in rate of change form.[11] 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 (Hendry, 1995). However, some meaningful level information is lost with this approach.

To guard against the possibility of a spurious relationship while maintaining the level information, two main approaches offer reasonable solutions. First is the unrestricted error correction modeling (ECM) or the London School of Economics method developed by Hendry and his co-researchers (Davidson et al., 1978, Hendry et al., 1984, Hendry, 1995). Second 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

[10] This problem was first mentioned in a classic article by Yule (1926) and re-emphasized by Granger and Newbold (1974).
[11] 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 (2006).

when dealing with non-stationary data that are integrated of the same order, that is, all data series are integrated processes of order 1. On the other hand, the ECM method developed by Hendry (1995) can be applied to data series that are integrated of different orders (Hendry, 1995, Inder, 1993).

Therefore, 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. For a variable under consideration (X) the statistical significance of γ_1 in equations (2) and (3) is examined with the null hypothesis that γ_1 is equal to zero (X is non-stationary). If the null hypothesis is rejected, X is stationary and vice versa.

$$\Delta X_t = \gamma_0 + \gamma_1 X_{t-1} + \sum_{i=1}^{p} \beta_i \Delta X_{t-i} + \mu_t \qquad \text{(without time trend)} \qquad (2)$$

$$\Delta X_t = \gamma_0 + \gamma_1 X_{t-1} + \sum_{i=1}^{p} \beta_i \Delta X_{t-i} + \gamma_2 T + \mu_t \qquad \text{(with time trend)} \qquad (3)$$

where γ_0 is a constant (drift), X is a variable of consideration, Δ is the difference operator, p is lag length on the lagged dependent variable, T is a time trend and μ is the disturbance term. The lag length (p) is determined by the Schwarz criterion to ensure that the residual is white noise.

[Table 1 about here]

The test results, reported in Table 1, show the variables under consideration do not have the same order of integration. The variables 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 ($W^{weather}$). The error correction modeling (ECM) procedure of Hendry (1995) is therefore employed.[12] 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.

$$Y_t = \alpha + \sum_{i=1}^{m} A_i Y_{t-i} + \sum_{i=0}^{m} B_i X_{t-i} + \mu_t \qquad (4)$$

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 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).

[12] This method is used in many time-series studies but has apparently not yet been used in TFP determinants studies.

Equation (4) 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 are left in the rearranged equation to capture the long-run multipliers of the system.

$$\Delta Y_t = \alpha + \sum_{i=1}^{m-1} A_i^* \Delta Y_{t-1} + \sum_{i=0}^{m-1} B_i^* \Delta X_{t-i} + C_0 Y_{t-m} + C_1 X_{t-m} + \mu_t \qquad (5)$$

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 (5) 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 (5) 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).

6. Research impact on TFP: Results from the ECM

The results are reported in the first two results columns of Table 2. 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 supports the general belief that research-induced technical change is a major driving force behind the impressive growth of TFP in Thai agriculture. It is also consistent with findings of studies of many countries (Evenson, 1993, Fuglie, 1999, Ruttan, 2002, Thirtle et al., 2003). Other major determinants of TFP are international research spillovers, agricultural extension, rainfall, rural roads and the world agricultural commodity price boom. These variables are statistically significant with the expected signs.

The TFPG determinant model in the crop sector is statistically significant at the 1% level in terms of the F test. All equations pass the standard diagnostic tests. The error correction coefficient (TFP_{t-1}) also has expected negative sign and is statistically significant at the 1% level. It indicates the speed of adjustment of TFP to exogenous shocks. The coefficients corresponding to TFP is quite large (0.87), implying a very high speed of adjustment to dissipate the shock in the absence of policy action. The choice of dropping or keeping variables in the final models was statistical acceptance in the joint variable deletion tests against the maintained hypothesis. 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.

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 TFPG 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 TFPG, which tapers off in the long-run, but does not vanish.

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

For 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 expectation that infrastructure improves agricultural productivity and that a commodity boom encourages farmers to grow more crops and use existing inputs 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.

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.[13] A 1 percent increase in foreign research spending results in a steady-state (long-run) increase in TFP of 0.11 percent. This is consistent with the prior expectation that the

[13] 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.

spillovers of crop varieties, particularly rice varieties, especially from IRRI, benefits crops productivity locally. The failure to account for this factor tends to bias upward the estimated coefficient of public research.

This point can be confirmed by dropping this significant variable from the model and re-estimating it. The results of this exercise are presented in the third and fourth columns of results in Table 2. The estimated coefficient of public research increases by almost one half 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.

[Table 2 about here]

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 is particularly important 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 and possibly research policy implications. It is of public interest to determine the payoffs to society from past investment on public agricultural research in assessing whether additional investment is likely to be worthwhile.

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 TFP elasticities with respect to the public research variable.[14] This regression-based rate of return is the marginal internal rate of return (*MIRR*), calculated as the discount rate *r*, such that:

$$\sum_{t=1}^{\infty}\left[VMP_t/(1+r)^t\right]-1=0 \quad (6)$$

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 (6) is used in conjunction with these VMP estimates to find the social rate of return.

The marginal internal rate of return for crops R&D investment is estimated at 29.5 per cent, well above the opportunity cost of public funds.[15] The rate of return is high enough to justify continued public investment in agricultural research in Thailand.

8. Conclusion and implications

[14] 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.
[15] The MIRR for crops when omitting the foreign research variable is estimated at 34.22%.

The empirical evidence indicates that public investment in R&D in Thailand's crop agriculture has contributed significantly to the impressive growth of TFP in crop production. Since the majority of agricultural research is conducted by the public sector, tracking the government budget allocated to agricultural research is a good indicator of the likely future trends in TFP growth.

The high measured rate of return from publicly funded agricultural research implies underinvestment in it. The potential causes are the public-good issue, market failure and government failure. The public-good characteristic of agricultural research, together with its time-consuming nature and the uncertainty of obtaining successful results mean that the private sector is generally reluctant to invest in this form of research.

The level of government spending on public R&D is insufficient to compensate for private sector underinvestment. There are a variety of policy tools that could induce more private investment, including improving intellectual property protection and providing subsidies. If the significance of agricultural research is well recognized and it is to be used effectively as a policy tool to maintain agricultural output using fewer resources, then a greater policy commitment is necessary to overcome the inadequacy of present levels of investment.

The findings of this study also have implications for research collaboration and local research capacity. The significant role of foreign research spillovers on productivity suggests public resources could be saved if Thailand is able to choose what will be most useful to borrow from the international research system. Public or other types of local research should be strengthened in a way that makes it capable of adapting and making efficient use of foreign technology. The insignificance of the interaction term between domestic and foreign research seems to signal weak collaboration. The government could play a more active role in encouraging increased collaboration among major research performers.

Productivity-enhancing research investment in developed countries has been a major source of worldwide agricultural technology advancement (Pardey et al., 2006). Given the slowdown in the levels of funding for this research, the results of this study suggest that Thailand should now invest more heavily in its own agricultural science capacity.

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Table 1 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)*
$\ln R^{p}_{crops}$	-1.296(1)	0.240(0)	-3.887(0)*	-4.135(1)*
$\ln E_{crops}$	-1.655(0)	-0.145(0)	-4.784(0)*	-5.003(0)*
$\ln R^{f}_{crops}$	-6.505(1)*	-4.252(1)*	-4.149(0)*	-6.382(0)*
$\ln TO$	-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. TFP_{crops} denotes total factor productivity in the crops sector; R^{p}_{crops} denotes real public agricultural research expenditure on crops; E_{crops} denotes real public agricultural extension openness; $I^{irrigation}$ denotes irrigation infrastructure; I^{roads} denotes road infrastructure; RR denotes resource reallocation; W^{rain} denotes rainfall; and $W^{weather}$ denotes the share of the rice harvested area in planted area, used as a proxy for drought or flooding. The construction of these variables is described in the text.

3. * 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_1 in the auxiliary regression, expressed in equations (2) and (3).

4. Numbers in parentheses indicate the order of augmentation selected on the basis of the Schwarz criterion.

Table 2 TFP Determinants in Crops Sector

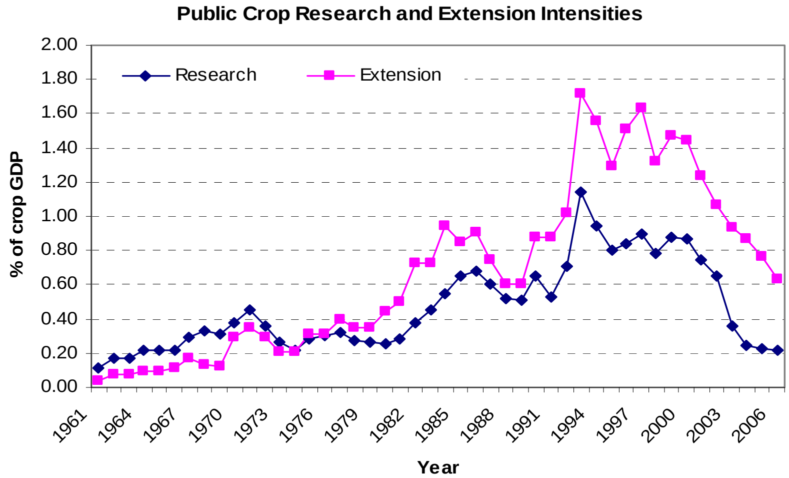
	Dependent variable: $\Delta \ln TFP_t$			
	Foreign research variable ($\ln R^f_{t-1}$) included		Foreign research variable ($\ln R^f_{t-1}$) dropped	
	Estimated coefficients (t-ratios)	Long-run elasticity	Estimated coefficients (t-ratios)	Long-run elasticity
Constant	-1.056		-0.997	
	(-6.460)***		(-5.936)***	
$\Delta \ln R^p_{t-3}$	0.155		0.180	
	(4.423)***		(4.695)***	
$\Delta \ln E_{t-1}$	0.137		0.149	
	(3.665)***		(3.679)***	
$\ln R^p_{t-3}$	0.059	0.067	0.067	0.083
	(1.876)*	(2.117)**	(2.374)**	(2.813)**
$\ln R^f_{t-1}$	0.092	0.105	-	-
	(2.955)***	(3.045)***		
$\ln I^{roads}_{t-1}$	0.033	0.038	0.055	0.068
	(1.977)**	(1.962)**	(3.161)***	(3.165)***
D^{boom}	0.127	0.145	0.038	0.048
	(3.104)***	(3.189)***	(1.230)	(1.314)
$\ln TFP_{t-1}$	-0.873		-0.801	
	(-6.664)***		(-6.317)***	
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	
S.E. 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, χ^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)	

Notes: 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 to 1974, D^{BOOM}. Long-run elasticities can be computed by dividing the estimated coefficients of the level terms $\ln R^p_{t-3}$, $\ln R^f_{t-1}$ and $\ln I^{roads}_{t-1}$ by the positive value of the coefficient of the lagged dependent variable, $\ln TFP_{t-1}$.

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

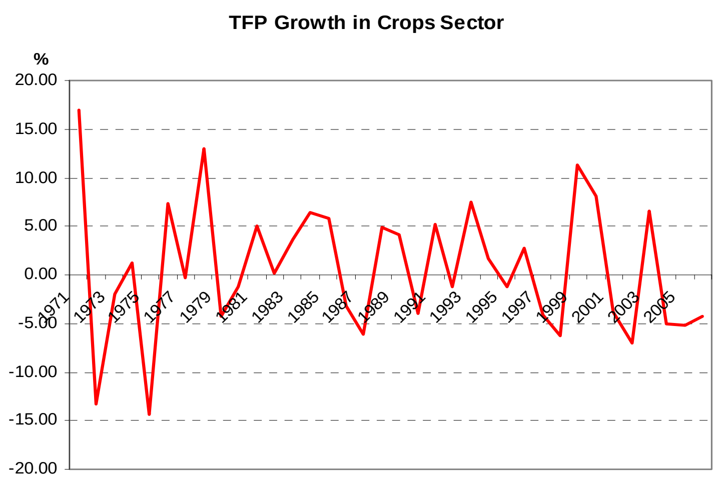
LM Breush-Godfrey serial correlation LM test;
RESET Ramsey test for functional form mis-specification;
JBN Jarque-Bera test of normality of residual;
ARCH Engle's autoregressive conditional heteroskedasticity test;
ADF Augmented Dickey-Fuller test for residual stationarity.

Figure 1 Crop R&E Budget Relative to Crop GDP



Source: Public agricultural research and extension budget from the Bureau of the Budget and agricultural GDP from the National Economic and Social Development Board.

Figure 2 TFP Growth in Crops Sector



Source: authors' calculations.

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