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Total Factor Productivity of Main and Second Rice Production in Thailand*

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This paper provides empirical evidence on the total factor productivity (TFP) of the Thai rice sector. It measures growth rates of TFP for the main and second crops and investigates the factors influencing the growth. The study employs pooled cross-section and time-series data covering four regions (North, Northeast, Central and South) over the period 1995-2011. TFPs of the main and second rice crops are measured separately using the Solow-type growth accounting method. The TFP measures are decomposed to identify their determinants using the panel data estimation techniques. The results show that TFP has generally been the main source of growth in rice production, for both main and second crops. The TFP growth, however, has been declining in recent years, particularly of the main crop, threatening long-term growth of the Thai rice industry. The results suggest public investment in research and adoption of high-yielding rice varieties are the key to sustaining long-term growth of both the main and second crops.

Keywords: total factor productivity, productivity growth, rice production

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Introduction

The rice industry plays a vital role in the Thai economy: rice is the major staple crop, a major export commodity and rice farming is a significant source of rural income. Sustaining its growth is crucial to maintaining export competitiveness and improving the living standards of farmers. But the question is whether the rice output growth could be maintained sustainably given the numerous challenges that include diminishing returns on inputs, declining arable land, labor and water supplies, the impact of climate variability, environmental degradation, and high fuel and fertilizer prices. To answer this question, an empirical evidence on the total factor productivity (TFP) of Thai rice production is required.

TFP is a measure of the ability to produce more output using less resource. Identification of the factors driving the TFP would provide a good basis for sustaining growth. An increase in TFP indicates real cost reduction which increases competitiveness and improves standard of living. It is also an indicator of long-term growth potential as an increase of TFP growth rate in one sector means output in that sector can be raised using fewer inputs which then releases resources to develop other sectors (Warr, 2009; Fuglie *et al*., 2012). The concept of TFP has been applied in a number of studies and has increasingly become the focus of development policy in many countries to sustain high level of growth (Oguchi, 2004). It is widely recognized that technological progress is the key driver of TFP growth and hence more investment in research or adoption of new technology can stimulate TFP growth. It would thus be useful to find out if the widespread adoption of modern rice varieties during the last two decades has raised the productivity growth of the Thai rice sector.

There have been numerous studies measuring and analyzing sources of agricultural TFP growth but there is very limited empirical evidence on the rice TFP in Thailand (Evenson and Pray, 1991; Tinakorn and Sussangkarn, 1996; Evenson and Gollin, 2003; Suphannachart and Warr, 2012). Most of the studies have concentrated on partial productivity namely land productivity and labor productivity (Facon, 2000; Dawe and Barker, 2002; Isvilanonda, 2009; Mohanty *et al*., 2010). These partial productivity measures ignore factor substitution; TFP would be a better measure of overall productivity. This paper aims to fill this gap by measuring TFP growth of rice production and describing the factors affecting it.

There are two rice cropping seasons in Thailand, one grown in rainy season (in-season rice) and the other grown in dry season (off-season rice). Analyzing rice productivity by aggregating in-season and off-season rice may yield misleading results as they have different input patterns and use different varieties. The agricultural statistics of Thailand also classifies rice statistics according to these two seasonal categories; the in-season rice is called “main rice crop” and the off-season rice is called “second rice crop” (Office of Agricultural Economics, 2011). This paper adopts these terminologies and henceforth the two categories of rice are referred to as “main rice” and “second rice”.

This paper makes the first attempt at estimating TFP growth for main and second rice, individually, and examines the factors influencing it. The main task of this paper is to explain the rice TFP growth using the two-step approach. The first step is to measure the rice TFP using the growth accounting method. The TFP is decomposed to identify its determinants using regression analysis. The result is expected to suggest policy that can sustain output growth of the main and second rice crops. The study focuses only on the long-term aspect of rice productivity at an aggregate level. It employs annual data at regional level, covering four regions (North, Northeast, Central and South) from 1995 to 2011 where modern rice varieties have been widely adopted. The next sections discuss the conceptual framework, methods and data, results, and conclusion.

Conceptual Framework

This study consists of two parts. The first part measures the TFP growth of the main and second rice crops, separately, in order to obtain empirical evidence on the contribution of TFP; the second investigates factors affecting the TFP so that implications can be drawn on how to sustain the growth in rice productivity. Factors affecting the TFP are classified into three groups: technological factors, factors affecting efficiency change, and natural factors. As TFP is generally considered a measure of technological change an emphasis is given to technological factors. The concept of the measurement and determinant of TFP are described as follows.

The productivity analysis is based on the production function

$$Q^t = h(X^t, Z^t) \tag{1}$$

where Q denotes output, X denotes conventional farm-level inputs such as labor, land and capital and Z denotes unconventional inputs, such as research, extension, infrastructure, weather and case-specific factors, all measured at time t. It is mathematically convenient, but not essential, to assume that the function h is separable between conventional and non-conventional inputs, giving

$$h(X^t, Z^t) = f(X^t)g(Z^t) \tag{2}$$

By definition, TFP is an index of aggregate output relative to an index of aggregate conventional inputs, combined. TFP is therefore a function of the levels of non-conventional inputs. Thus

$$TFP^t = Q^t / f(X^t) = g(Z^t) \tag{3}$$

Assuming $h(X^t, Z^t)$ to be differentiable, it is familiar that

$$q^t = \sum_{i=1}^{I} \varepsilon_i^t x_i^t + \sum_{j=1}^{J} \eta_j^t z_j^t \tag{4}$$

where q^t, x_i^t and z_j^t denote the proportional rates of change of q^t, x_i^t and z_j^t, respectively. Thus, $q^t = (dQ^t / dt) / Q^t$. The parameters $\varepsilon_i^t = h_{xi} X_i^t / Q^t$ and $\eta_j^t = h_{Zj} Z_j^t / Q^t$ denote the elasticities of output with respect to the inputs x_i^t and z_j^t, respectively. The growth rate of TFP is now given by

$$TFPG^t = q^t - \sum_{i=1}^{I} \varepsilon_i^t x_i^t = \sum_{j=1}^{J} \eta_j^t z_j^t \tag{5}$$

Accordingly, a change in TFP is measured as the residual part of the movement in output left unexplained by the growth of conventional factor inputs, broadly known as Solow residual (Solow, 1957; Jorgenson and Griliches, 1967; Griliches, 1996). As is well known, if the producer equilibrium condition holds where these conventional factors are paid according to their marginal value products, then the elasticity parameters ε_i^t are equal to the corresponding factor cost shares at time *t.*

In examining TFP determinants, TFP is generally decomposed into embodied and disembodied technical change. Embodied technical change is changed 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 technological change that is not embodied in factor inputs but takes place 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, when TFP is measured as a residual part of output that cannot be explained by the combined contribution of conventional inputs, its determinants are not confined only to technology factors but also incorporate other case-specific and natural factors such as weather shocks and disease outbreak. Typical factors that have been found to influence crop TFP are expenditures on research and extension, crop genetic improvement, improved skills of farmers and farm managers, infrastructure investment and climate factors (Evenson, 2001; Evenson and Gollin, 2003; Suphannachart and Warr, 2011).

Determining 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. This study follows a recent study on the TFP of Thai agriculture by Suphannachart and Warr (2012) which classified factors affecting the TFP into three main categories, that is, technological factors such as research expenditure and high yielding varieties, factors affecting efficiency gains such as infrastructure and education, and natural or case-specific factors such as rainfall, natural disaster and epidemics. Regarding economic policy and government farm programs, an inclusion of policy proxies can cause a double counting problem because the effects of policies are mostly reflected in the measures of prices and quantities of inputs and outputs (Alston *et al.*, 1998: 166). The effects of government policies are also reflected in the provision of public goods such as rural roads, education, irrigation and agricultural research and extension. These factors have already been captured in the three main categories affecting the TFP (see more details in Suphannachart, 2009).

Methods and Data

Two methods are employed in this study. The first is growth accounting (nonparametric method) which is used to measure the TFP growth of main and second rice crops. The second method is panel data estimation techniques, fixed effects and random effects models (parametric method). They are used to estimate the TFP determinant models in order to identify factors influencing the TFP. These two-step methods (growth accounting and regression analysis) are commonly used in previous studies investigating the role of TFP at an aggregate level, for examples, Tinakorn and Sussangkarn (1996), Oguchi (2004), Suphannachart and Warr (2011), and Suphannachart and Warr (2012). Details are discussed as follows.

The measurement of TFP employs the Solow-type growth accounting method. Under this method, output growth can be decomposed into the growth rate of the efficiency level and the growth rate of primary factor inputs, weighted by their cost 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).

The estimation of TFP growth can be expressed as the residual part of output growth that cannot be explained by the combined growth of primary inputs. The primary conventional factor inputs used in this study include land, labor, capital and fertilizer. Aggregate input is weighted average of growth of each input where weights are their varying cost shares. The formula used in calculating the total factor productivity growth is as follows

$$TFPG_{it} = \hat{Q}_{it} - S_{it}^{H}\hat{H}_{it} - S_{it}^{L}\hat{L}_{it} - S_{it}^{K}\hat{K}_{it} - S_{it}^{F}\hat{F}_{it} \quad (6)$$

where denotes total factor productivity growth, $\hat{Q}$ denotes output growth, $\hat{H}$ denotes growth rate of land area, $\hat{L}$ denotes growth rate of labor, $\hat{K}$ denotes growth rate of capital, $\hat{F}$ denotes growth rate of fertilizers, S^{H}, S^{L}, S^{K}, and S^{F} represent cost shares of land, labor, capital and fertilizer, respectively. The subscript *i* denotes region and *t* denotes year.

As TFP is measured as a residual of output growth the measurement of TFP depends a great deal on the data set, the period under study, the variables definition and the methodology. Although the estimates of agricultural TFP growth differ widely across studies, the main findings confirm technological improvements in the agricultural sector have played an important role in explaining the productivity growth (Evenson, 2001; Suphannachart, 2009). As a result, the TFP determinants model employed in this study incorporates factors affecting mainly the technological change such as seed technology and expenditures on research and development. Other relevant economic and noneconomic factors are included to explain the residual TFP such as infrastructure, rainfall and natural factors. Research lags are also incorporated to allow for research benefits that usually take a certain period of time to be reaped. As TFP is a long-term concept, all variables are expressed in level in order to capture the long-term information. The TFP growth is converted to TFP index using 1995 as a base year. In stylized form, the model is

$$TFP_{it} = f(R_{it}, HYV_{it}, Rain_{it}, I_{it}, W_{it}) \quad (7)$$

where *TFP* denotes total factor productivity of rice (TFP1 is main rice TFP index and TFP2 is second rice TFP index), *R* denotes real rice research budget, *HYV* denotes actual adoption of high-yielding varieties, *Rain* denotes amount of rainfall, *I* denotes irrigated area, *W* denotes weather-related and natural factors.

Agricultural research is widely recognized as a major source of technical change that raises productivity and sustains output growth (Pardey *et al.*, 2012). An increase in rice research budget is expected to raise TFP. Only national public research is considered because rice research in Thailand has long been conducted by the public sector at national level and there are data limitations on other funding sources of research and extension. Seed technology is also included using the adoption of high-yielding rice varieties as it plays a crucial role in determining rice productivity (Evenson and Gollin, 2003). The adoption is measured as areas planted to HYVs, which are different among regions and between main and second rice production. Regional rainfall is included in the main rice model because main rice is grown in rain-fed areas. Irrigation allows multiple cropping. It is then included in the second rice model as the second rice relies on irrigation. The natural factor, measured as a proportion of rice harvested to total rice planted area, is also included. It represents the weather shock such as drought, flooding, disease and insect or pest infestation. Good weather like less occurrence of drought or flooding or pest infestation should raise TFP. This natural factor proxy has been used in earlier studies, for examples, Setboonsarng and Evenson (1991), Pochanukul (1992), and Suphannachart and Warr (2012).

The TFP determinant models are estimated for main rice and second rice, individually, using the panel data techniques, fixed effects and random effects models. The techniques are commonly used with panel data which suit well with the data employed in this study containing repeated observations on the same individuals (regions) at different points in time. Regions are expected to have various degrees of technological development and different climate factors so that region-specific fixed effect should be considered in the estimation model. To test this assumption, the Hausman test is conducted to determine whether fixed effects (FE) or random effects (RE) is more suitable. The null hypothesis under the Hausman test is that the region-specific fixed effect is correlated with the explanatory variables. If the null hypothesis is rejected, then the fixed effect is correlated with the explanatory variables. Hence, the omitted variable bias is a problem and the FE model is preferred (Wooldridge, 2006).

The output and input data are pooled cross-section and time-series at an aggregate level, covering four regions of Thailand (North, Northeast, Central and South) during 1995-2011. Altogether, the data contain 68 repeated observations on the same individuals (4 regions) at different points in time (17 years). The data were obtained from the Office of Agricultural Economics. As TFP is computed for main rice and second rice separately, the data sets were obtained for each category of rice, except capital which uses total agriculture, and research expenditure which uses total rice, as proxies. As the rice research budget cannot be disaggregated into main and second rice the same data set is used for both crops. All data are available at regional level except research expenditure, which is at the national level. Definitions and sources of data used in this study are summarized in Table 1.

Table 1 Summary of the data used in TFP measurement and TFP determinants

Variables	Definitions (units)	Sources
Output	Amount of rice produced (ton) - Main rice refers to the rice grown between May and October. - Second rice refers to the rice grown between November and April.	Office of Agricultural Economics - See full definitions of rice statistics in the annual publication “Agricultural Statistics of Thailand”.
Land	Planted area (rai)	Office of Agricultural Economics
Labour	Number of rice-farming household (household)	Office of Agricultural Economics; Department of Agricultural Extension
Capital	Stock of agricultural credit (million baht) estimated using the Perpetual Inventory Method (National Economic and Social Development Board, 2006)	Author’s calculation based on the data from the Bank for Agriculture and Agricultural Cooperatives

Table 1 (Continued)

Fertilizer	Amount of fertilizer used for rice production (ton)	Office of Agricultural Economics
Cost shares of land	Share of land rent in the total cost of rice production (baht/rai)	Office of Agricultural Economics
Cost shares of labor	Share of labor cost in the total cost of rice production (baht/rai)	Office of Agricultural Economics
Cost shares of capital	Share of capital cost in the total cost of rice production (baht/rai)	Office of Agricultural Economics
Cost shares of fertilizer	Share of fertilizer cost in the total cost of rice production (baht/rai)	Office of Agricultural Economics
Research expenditure	Rice research budget expenditure allocated to the Rice Department (or Department of Agriculture prior to March 2006) deflated by implicit GDP deflator using 1988 as base year (million baht)	Bureau of the Budget; National Economic and Social Development Board
High-yielding rice varieties adoption	Planted area of rice varieties that target output increasing as share of total planted area	Office of Agricultural Economics; Rice Department
Rainfall	Amount of regional rainfall (millimetre)	Office of Agricultural Economics
Irrigation	Accumulated irrigation area (rai), including small, medium and large scale irrigation projects	Office of Agricultural Economics
Natural factor	Rice harvested as share in total rice planted area	Office of Agricultural Economics

Input and output data used in the growth accounting analysis (TFP growth calculation) are summarized in Table 2 (main rice) and Table 3 (second rice). Descriptive statistics of variables in the TFP determinant models are summarized in Table 4. Means of variables in the TFP determinant models are also provided at regional level in Table 5. It is worth nothing that the TFP growth is converted to TFP index in order to capture the long-term information. As a result, TFP data in the determinant models (expressed in level terms) are different from those obtained from the growth accounting method (expressed in rate of change terms). As this study seeks to explain the rice TFP, which is a long-term physical concept, detailed discussion on the historical development of rice production, prices and relevant policies are not mentioned here. Useful discussion on the pattern of rice outputs and inputs as well as the development of Thai rice sector has already been provided in Isvilanonda (2009; 2010). This paper shall focus on analyzing the TFP of main and second rice crops.

Table 2 Output and input data used in the growth accounting of main rice production

Items	1995-1998	1999-2002	2003-2006	2007-2011	1995-2011
Output (ton)					
North	4,862,474	5,704,412	6,553,119	6,374,055	5,902,958
Northeast	8,280,009	9,271,652	10,233,756	11,110,115	9,805,426
Central	4,190,832	4,922,632	5,455,271	5,000,949	4,898,805
South	907,224	796,251	800,488	635,539	776,091
%change	0.47	2.34	1.06	-5.95	-0.84
Land (rai)					
North	12,592,831	12,560,900	12,728,546	13,021,296	12,743,270
Northeast	31,819,421	32,589,500	32,773,758	35,699,161	33,366,266
Central	9,785,095	9,788,701	9,889,409	9,391,694	9,694,781
South	2,776,760	2,336,583	2,093,224	1,633,890	2,176,219
%change	-0.73	-1.04	0.20	-2.96	-1.24
Labor (household)					
North	923,896	929,091	921,001	864,136	911,058
Northeast	1,953,329	2,088,435	2,085,226	2,240,680	2,100,668
Central	425,178	444,334	445,857	400,537	427,304
South	353,325	295,742	269,716	169,497	266,036
%change	-1.21	-0.95	-0.04	-6.86	-2.54
Capital stock (million baht)					
North	67,925	120,911	147,050	158,880	125,761
Northeast	199,576	297,698	283,622	260,381	260,323
Central	91,240	138,184	187,441	235,218	167,268
South	49,435	73,905	88,566	102,883	80,120
%change	15.81	8.32	2.91	2.14	6.99
Fertilizer (ton)					
North	259,217	332,363	355,030	413,983	344,491
Northeast	710,612	777,624	781,044	825,364	776,702
Central	338,121	402,283	426,216	423,938	399,186
South	74,097	72,107	66,459	51,233	65,107
%change	2.45	2.68	0.59	-1.33	0.96

Table 3 Output and input data used in the growth accounting of second rice producion

Items	1995-1998	1999-2002	2003-2006	2007-2011	1995-2011
Output (ton)					
North	1,302,874	1,832,465	2,127,809	3,091,834	2,147,751
Northeast	154,650	307,527	382,927	1,035,218	503,324
Central	2,626,317	3,052,147	3,751,099	4,312,394	3,487,072
South	60,637	100,614	87,765	163,076	106,555
%change	27.01	2.25	6.46	14.64	12.71
Land (rai)					
North	1,883,089	2,686,602	3,176,434	4,847,409	3,248,326
Northeast	349,436	645,951	765,867	1,936,153	983,869
Central	3,605,887	4,316,333	5,307,895	6,208,865	4,939,105
South	141,025	218,728	195,043	328,095	227,039
%change	23.91	1.74	5.74	14.55	11.67
Labor (household)					
North	86,261	121,902	135,928	177,801	133,257
Northeast	48,790	69,714	73,643	137,785	85,736
Central	165,143	171,615	190,972	210,572	186,105
South	15,838	21,061	18,261	25,286	20,416
%change	16.78	2.47	1.87	10.90	8.18
Capital stock (million baht)					
North	67,925	120,911	147,050	158,880	125,761
Northeast	199,576	297,698	283,622	260,381	260,323
Central	91,240	138,184	187,441	235,218	167,268
South	49,435	73,905	88,566	102,883	80,120
%change	15.81	8.32	2.91	2.14	6.99
Fertilizer (ton)					
North	86,209	130,484	153,565	235,023	156,244
Northeast	13,506	27,805	34,721	85,913	43,158
Central	205,289	260,674	305,727	358,501	287,015
South	5,670	9,547	8,403	14,722	9,888
%change	25.79	2.15	5.29	15.20	12.29

Table 4 Summary statistics of variables in the TFP determinant models (1995-2011)

Variables	Obs	Mean	Std. Dev.
Main rice TFP: lnTFP1	68	0.181	0.141
Second rice TFP: lnTFP2	68	0.342	0.214
Main rice HYV: lnHYV1	68	-0.481	0.333
Second rice HYV: lnHYV2	68	-0.082	0.133
Rice research: lnR	76	8.191	0.132
Rainfall: lnRain	68	3.189	0.120
Irrigation: lnI	68	6.643	0.293
Weather and natural factor: lnW	68	-0.029	0.016

Note: All variables are expressed in level terms and natural logs. 1 denotes main rice and 2 denotes second rice.

Table 5 Means of variables in the TFP determinant models classified by regions (1995-2011)

Regions	lnTFP1	lnTFP2	lnHYV1	lnHYV2	lnR	lnRain	lnIrrigat	lnW
North	0.179	0.315	-0.29	-0.019	8.191	3.087	6.558	-0.034
Northeast	0.185	0.343	-0.367	-0.143	8.191	3.146	6.556	-0.031
Central	0.178	0.351	-0.332	-0.096	8.191	3.176	7.111	-0.027
South	0.182	0.361	-0.934	-0.069	8.191	3.343	6.35	-0.022

Note: All variables are expressed in level terms and natural logs. 1 denotes main rice and 2 denotes second rice.

Results

This section provides empirical evidence on the rice TFP during 1995-2011 and explains its main determinants. The TFP is calculated using the nonparametric growth accounting method. The measured TFP growth is then converted into TFP index and used as a dependent variable in the TFP determinant model. As TFP growth is measured as residual of output growth after removing the contribution of main factor inputs (land, labor, capital and fertilizer) its determinants include both economic and noneconomic factors. As previously noted, the TFP measurement is sensitive to data and method and previous studies have shown that TFP estimates of the same countries or sectors can widely differ. Nonetheless, most studies agree that technological progress is the key driver of productivity growth. The results of this study provide an evidence for the case of Thai rice which conforms to the findings of previous studies. The empirical results on the TFP calculation using the growth accounting are briefly described followed by a discussion of the regression results of the TFP determinant models.

The general finding from the growth accounting analysis is that over the period 1995-2011, TFP has been the largest source of output growth in both main and second rice. The average annual rate of growth of TFP in the main rice crop is estimated at 0.34% and that of the second rice is estimated at 4.95%. The positive rates of growth of TFP indicate the ability to produce more rice with less reliance on major factor inputs. On average, the TFP growth of the second rice is 14 times higher than the main rice. This is consistent with growth rates of land and labor productivity of second rice, which are also higher than those of main rice. The wide diffusion of intensive cropping and adoption of non-photosensitive rice varieties grown in irrigated areas have stimulated yield growth in second rice (Isvilanonda, 2010: 6). However, irrigated areas account for only about one quarter of the total agricultural land area (and less likely to expand because of competition for water) suggesting that the high growth rates of TFP are concentrated in the minor group of rice production. Main rice has continued to dominate rice production in Thailand, which indicates a low rate of productivity growth in the overall rice sector.

Regarding the growth accounting of main rice production, Table 6 shows that overall (1995-2011) TFP is the largest source of rice output growth, followed by capital accumulation, fertilizer, land and labor, respectively. At the regional level, the Northeast has the highest rates of TFP growth, followed by the South while the Central plain and the North have recorded negative growth rates. Of the four regions, the Northeast has the largest shares of output and inputs (land, labor, capital and fertilizer) and the highest rate of growth of output. This may be the result of the Northeast having the largest residual growth left unexplained. Considering the changes of TFP over time (Table 7) the TFP growth had been declining during 2007-2011. This indicates an unsustainable growth of rice output. The declining trend is observed in all regions except the South.

Table 6 Sources of main rice output growth during 1995-2011 (unit: percent per year)

Regions	Output	Land $(S^H\hat{H})$	Lab $(S^L\hat{L})$	Capital $(S^K\hat{K})$	Fertilizers $(S^F\hat{F})$	TFP1
North	-0.05	0.01	-0.61	0.30	0.46	-0.21
Northeast	2.21	0.16	0.51	0.13	0.16	1.25
Central	-1.51	-0.10	-1.07	0.31	0.15	-0.80
South	-4.00	-0.57	-4.19	0.30	-0.68	1.13
Total	-0.84	-0.12	-1.34	0.26	0.02	0.34

Note: All numbers are average annual growth rates. Growth is calculated using natural logarithm.
Source: Author's calculation using equation (6). TFP1=TFP growth of main rice.

Table 7 Total factor productivity growth of main rice during sub-periods (unit: percent per year)

Regions	1995-1998	1999-2002	2003-2006	2007-2011	1995-2011
North	-0.63	3.99	0.81	-4.04	-0.21
Northeast	-0.94	2.96	2.26	0.84	1.25
Central	2.62	2.70	-0.34	-6.70	-0.80
South	0.84	0.62	0.88	1.98	1.13
Total	0.47	2.57	0.90	-1.98	0.34

Note: All numbers are average annual growth rates. Growth is calculated using natural logarithm.
Source: Author's calculation.

For the second rice crop, the TFP has contributed the most to output growth, followed by labor, fertilizer, land and capital, respectively. Similar to the findings in the main rice, the TFP growth in the Northeast is the highest, followed by the South, the North and the Central regions, as shown in Table 8. Compared with the main rice, the average annual rates of growth of the second rice TFP are all positive and relatively high in every region. Considering the changes in the TFP growth of the second crop over the past 17 years (Table 9) the productivity growth was notably high during 1995-1998 but dropped noticeably in the subsequent periods. The declining trend is observed in all regions except the Northeast.

The estimates of both main and second rice TFP growth fluctuate widely over time which is consistent with TFP growth of the agricultural sector found in previous studies using the same method (Suphannachart, 2009; Suphannachart and Warr, 2012). What could explain this volatile TFP growth is discussed next using the TFP determinant models.

Table 8 Sources of second rice output growth during 1995-2011 (unit: percent per year)

Regions	Output	Land $(S^H \hat{H})$	Labor $(S^L \hat{L})$	Capital $(S^K \hat{K})$	Fertilizers $(S^F \hat{F})$	TFP2
North	14.00	1.92	5.31	0.31	2.23	4.22
Northeast	23.10	2.27	8.43	0.16	3.01	9.22
Central	6.35	0.95	2.15	0.41	1.03	1.79
South	7.40	0.40	0.77	0.28	1.38	4.57
Total	12.71	1.39	4.16	0.29	1.91	4.95

Note: All numbers are average annual growth rates. Growth is calculated using natural logarithm.
Source: author's calculation using equation (6). TFP2=TFP growth of main rice.

Table 9 Total factor productivity growth of second rice during sub-periods (unit: percent per year)

Regions	1995-1998	1999-2002	2003-2006	2007-2011	1995-2011
North	10.63	0.85	4.10	1.90	4.22
Northeast	16.25	4.02	3.97	11.96	9.22
Central	3.60	2.58	2.05	-0.48	1.79
South	10.07	-7.37	7.56	7.33	4.57
Total	10.14	0.02	4.42	5.18	4.95

Note: All numbers are average annual growth rates. Growth is calculated using natural logarithm.
Source: Author's calculation.

With regards to the TFP determinants, the fixed effects (FE) and random effects (RE) models were applied to the compiled data set. The correlation between the region-specific (unobserved) heterogeneity and the explanatory variables is confirmed by the Hausman test, suggesting that the FE model is suitable. This means the coefficients of FE are statistically different from those of the RE model, and hence the omitted variable bias is an important problem. This also implies technological development and input uses are different among regions. The FE model shall be used to correct for the omitted variable bias. The chosen models are those estimated using the FE approach and the results are reported in Table 10. Both main rice and second rice models are statistically significant at the 1% level as suggested by the overall F-test. The estimated coefficients represent elasticities of the explanatory variables with respect to the TFP and their magnitudes indicate their relative importance.

Table 10 Factors affecting total factor productivity of rice production, 1995-2011

Explanatory variables	Coefficients (t-ratio)	
	Main rice model	Second rice model
Rice research budget (lnR_{t-2})	0.715 (6.12)***	0.990 (5.08)***
HYV adoption (lnHYV)	0.251 (4.13)***	0.289 (1.87)**
Rainfall (lnRain)	-0.497 (-2.91)***	Not included
Irrigation (lnI)	Not included	0.842 (2.73)***
Weather (lnW)	0.249 (0.30)	1.972 (0.67)
North	-0.055 (-1.48)	0.408 (2.26)***
Northeast	-0.0003 (-0.01)	0.482 (2.71)***
South	0.239 (4.25)***	0.649 (2.71)***
Constant	-4.043 (-3.31)***	-13.739 (-5.70)***
No. of observation	68	68
F-statistics	20.50***	12.35***
Adjusted R-squared	0.578	0.452
Hausman test (p-value)	0.000***	0.023**

Note: Dependent variable is lnTFP. *** ** * indicate the significant levels of 1%, 5% and 10%, respectively.

Results from the fixed effects model indicate that public rice research budget and high-yielding rice varieties adoption are the major factors positively influencing TFP in both main and second rice production. The positive and significant impact of public research and rice varieties improvement is consistent with theory and the findings of studies in other countries (Evenson and Gollin, 2003; Fuglie *et al.,* 2012). This also conforms to prior expectation and the previous study (Isvilanonda, 2009) that the wide diffusion of modern rice varieties since the 1990s has been the main source of productivity growth. The research variable has the largest impact on both main and second rice TFP as indicated by their estimated coefficients. This implies that an investment in rice research is a prime source of technical change that drives TFP. More investment in real rice research increases the stock of knowledge, which either facilitates the use of existing knowledge or generates new technology and hence raises the TFP.

The determinants of rice TFP are not confined to factors affecting pure technical change (rice research and HYV adoption), but also include rainfall and irrigation. This implies an important role of reliable water supply. For main rice, rainfall has a negative and significant impact on the TFP which is probably due to erratic amount or timing of rainfall. For instance, too much rainfall in 2011 had markedly reduced rice output in the Central and Northern regions. The range of average rainfall deemed appropriate for rice is 1,200-1,500 millimeters per year (Department of Agricultural Extension, 2012), but the average annual rainfall during the study period exceeded 1,500 millimeters, which can do more harm than good to rice productivity. For second rice, irrigation has positive and significant impact on the TFP, which is consistent with the fact that second rice is grown during dry seasons relying on irrigation. This also confirms that the widespread rice cropping intensity allowed by irrigation is an important source of output and productivity growth. There is no evidence that weather-related and natural factor, measured as a share of rice harvested to planted area, is statistically significant. It is likely that weather conditions like drought or flooding are region-specific and therefore have been controlled for in the fixed effects. Other factors left unexplained are likely to be due to measurement errors and unmeasured inputs that result from data limitations.

Regarding the regional dummies, most of them are statistically significant, confirming regional disparities in Thai rice production. However, it may seem surprising that the second rice model indicates the Central region has higher productivity than other regions while the measured TFP growth obtained from the growth accounting (Table 8) seems to show a different result. This is because they are expressed in different forms and are not directly comparable. As mentioned in the method and data section, TFP in the determinant models are expressed in level terms while those shown in Table 8 (TFP growth) are expressed in rate of change terms. The TFP growth obtained from the growth accounting is converted to TFP index in order to capture the long-term information, as TFP is a long-term concept. On average, TFP growth of the central region is lower than that of the other regions but when considered at level terms the TFP index of the Central region is higher. This finding is consistent with the second rice output data in Table 3. The Central region has the highest level of output but when considering the average rate of change

(Table 8), it has the lowest growth rate.

In sum, despite an attempt to investigate factors affecting the main rice and second rice separately the findings are generally the same for both types of rice production. Technological factors appear to be the most important drivers of TFP, which conforms to theory and previous studies.

Conclusions

The main task of this paper is to explain the total factor productivity for Thai rice production during 1995-2011. The measurement of TFP was followed by the analysis of factors affecting it. The estimation of TFP is undertaken, separately, for main rice (in-season) and second rice (off-season), using the Solow-type growth accounting method. The findings confirm that TFP had been the largest source of rice output growth in most regions, for both crops. The exceptions are the main rice crop in the Central and Northern regions, which had a negative TFP growth. The average annual rate of growth of TFP in the main crop is estimated at 0.34%, that of the second crop is estimated at 4.95%. However, the rates of growth have been declining during recent years threatening long-term productivity growth. These TFP growth measures are converted into a TFP index level and used as the dependent variables in the subsequent TFP determinant models.

Although this study investigates factors affecting the TFP of the main and second rice crops separately, the results are generally the same for both. The TFP determinant models suggest that important factors positively affecting the TFP of both crops are the public investment in rice research and the adoption of high-yielding rice varieties. Hence, strong commitment and sustained support from all parties involved should be given to rice research and seed technology dissemination in order to maintain long-term growth. Government should place policy emphasis on factors enhancing technological progress through research and development. The current rice research budget is far lower than allocations for market-distorting farm programs such as the rice pledging scheme. As rice research variable has the largest significant impact on productivity the government should allocate more budget to research or encourage more research through collaboration with the private sector or international research agencies. Suphannachart and Warr (2011) showed that rate of return on crop research investment is 29.5%, suggesting that for an investment of one baht in crop research the Thai economy receives benefits of 29.5 baht from higher productivity. As rice occupies the largest share of the crop sector it is expected that the return on rice research investment is high. This bolsters the argument for more investment in research.

Besides, the amount of rainfall has an influential impact on the main rice TFP while irrigated areas have significant impact on the second rice TFP. This suggests the important role of water resources for sustaining rice output growth. Although rainfall is an uncontrollable factor more research can be done on how to adjust main rice production to adapt to or cope with uncertain water supplies. Development of new rice varieties that can better adapt to the impacts of climate change may help farmers cope better with unpredictable rainfall and climate-induced stress. Further studies can extend this finding in the areas of rice research priority setting.

There remains some room for further study of rice TFP particularly the inclusion of variables that are subject to data limitations. Capital stock of each category of rice should be used if the capital data are available. Labor can be measured in number of workers or working hours. Changes in input quality such as that of labor and soil should be incorporated in the measurement of TFP. There are also several other methods of measuring the TFP. Further study can explore other techniques such as Malmquist index and stochastic frontier analysis. Regarding the TFP determinants, there remain several unmeasured factors such as international research spillovers (the role of rice varieties produced by the International Rice Research Institute), expenditure on extension services, and institutional factors that drive technological progress. Nevertheless, further improvement cannot be done without adequate and consistent data on rice production and relevant variables.

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