Research and Productivity in Thai Agriculture

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Declaration

Unless otherwise indicated this thesis is my own work

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Abstract

This thesis aims to provide empirical evidence on the linkage between research and productivity in Thai agriculture with an emphasis on crops and livestock. It employs time series data at the national level to investigate the agricultural research impact on productivity growth as well as measuring the returns to research over the past 37 years from 1970 to 2006.

The empirical analysis consists of three main parts. The first measures total factor productivity (TFP) growth and provides an explanation of the sources of output growth. Conventional growth accounting is used to decompose output growth into growth from each input and TFP. Factor inputs are also adjusted for their quality changes. The results confirm the general expectation that Thai agricultural growth has relied less on the growth of land and labour inputs and more on the growth of capital inputs and improved technology, captured in the residual TFP.

The second part employs the measured TFP growth to investigate its determinants, with an emphasis on public agricultural research investment. The important issues of lags, spillovers and attribution are accounted for in the econometric models. Due to limited data availability, the models are divided into two: the general model covering the entire study period of 1971-2006 and the attribution model covering a shorter period of 1980-2006 but including more research variables. The analysis employs two methods: the growth-rate model (GRM) and the error correction model (ECM). The results using the ECM, and allowing for both short- and long-run information and dynamic lag structure, are shown to fit well with the Thai data. Expressing variables only in rate of change terms, as has usually been done in previous Thai studies, means some meaningful level information is lost. The dynamic and infinite lag structure of the ECM is shown to explain the research-productivity nexus better than imposing a restrictive form of lags, which tends to produce upward biased estimates of the productivity impact of agricultural research.

The empirical evidence confirms the general belief that public investment in agricultural research is one of the main driving forces of TFP growth in Thai agriculture. International research spillovers, which have often been omitted in previous studies, have contributed to TFP growth (notably in the crops sector) over the entire study period. For a shorter period, private research has contributed most to TFP growth, particularly in the livestock sector. The explanation for the measured TFP growth is not confined only to agricultural research, but also extends to other factors such as infrastructure, agricultural extension, weather and epidemic.

The third part estimates the social rates of return on public crops and livestock research. These estimates are apparently the first for Thai agriculture using the ECM and TFP decomposition. The results support the broad findings of the majority of previous studies that returns on public research investment have been high despite attempts to account for major sources of upward biases. The high measured rates of return imply an underinvestment in agricultural research and thereby justify additional investment. The findings also raise a concern over the declining trend of public expenditure on agricultural research. It is argued that given the limited government budget and the public good characteristics of research, public policies and incentives should be emphasized to encourage more involvement from private and foreign research, as well as enhancing research collaborations among major research institutions.

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
ADF	Augmented Dickey-Fuller
ADL	Autoregressive Distributed Lag
AM	Attribution Model
APO	Asian Productivity Organization
ARCH	Autoregressive Conditional Heteroskedasticity
ARDA	Agricultural Research Development Agency
ASTI	Agricultural Science and Technology Indicators
BB	Bureau of the Budget
BIOTEC	National Centre for Genetic Engineering and Biotechnology
BOI	Board of Investment
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture)
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Wheat and Maize Improvement Centre)
CP	Charoen Pokphand
CPF	Charoen Pokphand Foods Public Company Limited
CPI	Consumer Price Index
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DLD	Department of Livestock Development
DOA	Department of Agriculture
DOAE	Department of Agricultural Extension
DOF	Department of Fisheries
ECM	Error Correction Model
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign Direct Investment

GA	Growth Accounting
GDP	Gross Domestic Product
GFSM	Government Finance Statistics Manual
GM	General Model
GRM	Growth-Rate Model
HRDI	Highland Research and Development Institute
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IRR	Internal Rate of Return
IRRI	International Rice Research Institute
ISIC	International Standard Industrial Classification
JBN	Jarque-Bera Normality
KURDI	Kasetsart University Research and Development Institute
LFS	Labour Force Survey
LM	Lagrange Multiplier
MIRR	Marginal Internal Rate of Return
MOAC	Ministry of Agriculture and Cooperatives
MOE	Ministry of Education
MOST	Ministry of Science and Technology
NESDB	National Economic and Social Development Board
NRCT	National Research Council of Thailand
NSF	National Science Foundation
NSO	National Statistical Office
NSTDA	National Science and Technology Development Agency
OAE	Office of Agricultural Economics
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares
PDL	Polynomial Distributed Lag
PIM	Perpetual Inventory Method
RESET	Regression Equation Specification Error Test
ROR	Rate of Return

R&D	Research and Development
R&E	Research and Extension
SAM	Social Accounting Matrix
SFA	Stochastic Frontier Analysis
TDRI	Thailand Development Research Institute
TFP	Total Factor Productivity
TFPG	Total Factor Productivity Growth
TRF	Thailand Research Fund
TSIC	Thailand Standard Industrial Classification
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

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Chapter 1

1. Introduction

1.1 Significance of Issues

It has long been recognized that agricultural growth is important for overall economic development (Johnston and Mellor, 1961). Particularly in developing countries, where the majority of poor people live in rural areas and depend directly or indirectly on agriculture for their livelihood, sustaining agricultural growth is of critical importance. The diminishing returns on factor inputs, declining arable land, water supplies and natural resources, concern over climate change and environmental degradation and high fuel and fertilizer prices continue to pose challenges for agriculture. Research-induced productivity growth offers a promising solution to the major challenge of maintaining a continuous increase in agricultural output in a manner that minimizes input use and protects the natural resource base.

In general, total factor productivity (TFP) growth is widely recognized as an important source of long-term output growth in the agricultural sector. An explanation of TFP growth in agriculture is not possible without considering the role of research (Evenson and Pray, 1991, Hulten, 2002). As agricultural research is considered to be a primary source of any technical change that improves productivity and sustains output growth, a number of studies have been motivated to provide quantitative evidence for the existence and magnitude of this relationship.

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

TFP growth has been shown to contribute significantly to output growth in the Thai agricultural sector and its contribution was substantially greater than in the non-agricultural sectors (Tinakorn and Sussangkarn, 1996, Chockpisansin et al., 2004, Warr, 2006). However, there is no empirical evidence as to what determines the relatively high growth rate of TFP in Thai agriculture. While agricultural research is typically mentioned as contributing to TFP growth, as there has long been public investment in agricultural research (Tinakorn and Sussangkarn, 1996, 1998, Poapongsakorn, 2006), this view has not been empirically tested. If agricultural research is essential to raising productivity growth in Thailand, as is usually believed, the recent decline in public investment in agricultural research (demonstrated in Chapter 3 and 7) represents an alarming threat to long-term growth.

With regard to the impact of agricultural research on productivity, a large number of international studies have provided evidence that agricultural research investment can increase productivity growth and that returns to research investment have been high. The extent of the contributions and payoffs varies with empirical case studies, which have different implications for farm output, income, welfare, and research resource allocation. The number and scope of studies in this area is still limited in the Thai context. Existing studies have attempted to measure the impact of public agricultural research on productivity and calculate the rates of return on research investment focused only on crops using partial productivity measures (Setboonsarng and Evenson, 1991, Pochanukul, 1992). To date, no study has estimated the rate of return to public research in Thai agriculture using total productivity measures.

Quantifying the relationship between research and productivity has also long been a challenging topic in agricultural economics and empirical applications. There are important issues for assessing the agricultural research impact on TFP that have usually been ignored in previous studies. These issues mainly involve research lags and omitted variable bias resulting from ignoring the role of international research spillovers and private research (Alston et al., 1998b, Evenson, 2001). The process in which investment in agricultural research leads to changes in technology and hence enhanced productivity involves time lags of varying duration, making it difficult to determine the exact shape of the lag structure. Including either a too short or inappropriate lag structure tends to bias in estimating the research impact and associated rate of return. Most empirical studies at the country level ignore all research done abroad, although there is evidence that international technology transfers are possible and may influence local productivity (Alston et al., 1998b, Alston 2002, Fuglie and Heisey, 2007). This is also the case with Thai agriculture, in which 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. Ignoring spillover benefits from international research tends to produce an upward bias in estimates of the returns to local research investment.

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. It is important to measure the social rate of return on public agricultural research investment because 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 also of public interest to determine the payoffs to society from past investment on public agricultural research and whether or not making additional investment is worthwhile.

1.2 Research Questions and Anticipated Contributions

In response to the key issues highlighted above, this thesis tries to address three main research questions in the context of Thai agriculture. Each research question contains sub-questions, indicated as follows:

1) What are sources of output growth in Thai agriculture?

1.1) What is the contribution of traditional inputs and TFP to output growth?

1.2) What is the trend and pattern of TFP growth over time?

2) What determines TFP growth and how has agricultural research influenced it?

2.1) Does public agricultural research contribute to TFP growth and to what extent?

2.2) Are the productivity gains largely attributable to home-grown technology or to spillovers of research results developed elsewhere?

2.3) What types of research spending – public, private, university and foreign – contribute most to TFP growth?

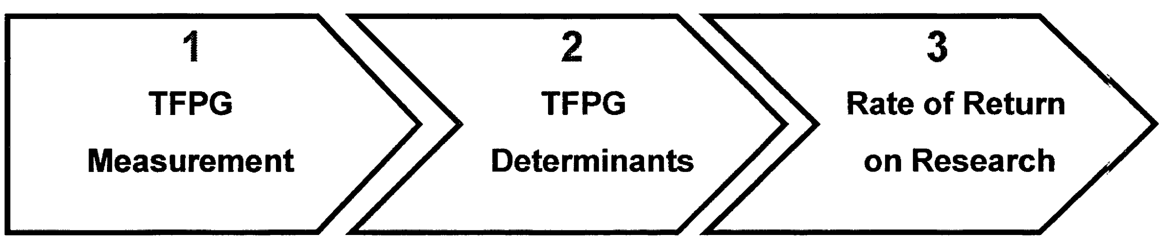
3) What is the social rate of return on public agricultural research investment?

3.1) Has the payoff to public agricultural research investment been high as has normally been found in the literature?

3.2) Has there been underinvestment in public agricultural research?

3.3) Should Thailand invest more in public agricultural research?

The three main questions can be translated into three subsequent parts of empirical estimation, illustrated in the following diagram. The first addresses the first research question by identifying the sources of output growth. In doing so, the total factor productivity growth (TFPG) is measured. The second part determines the factors affecting TFPG, using the estimates of TFPG from the first part as the dependent variable. The agricultural research impact is identified and the estimation results are employed to quantify the social rate of return of public research in the third part.



These three parts and corresponding research questions are set to fill the gaps in the literature mainly in the context of Thai agriculture. Anticipated contributions to applied and agricultural economics studies are as follows.

First, the measurement of TFPG in Thai agriculture covers the longest period among existing studies (using the growth accounting method) and is disaggregated into the crops and livestock subsectors. The TFP measure is also adjusted for input quality changes. Second, the general belief that the longstanding public investment in agricultural research contributed to TFP growth is empirically tested. Issues of lags, research spillovers and attribution, in which all potential factors are taken into account, are addressed in the TFP determinants model. In particular, other types of research variables that have usually been ignored, namely international research spillovers, private and university research are incorporated. The estimation of TFP determinants employs both the traditional method that imposes polynomial distributed lags and a time-series technique (error correction model) that allows for dynamic lag structure and long-term relationships among variables. Third, this thesis provides estimates of the social rate of return on research for both crops and livestock after accounting for the overestimation biases that have dominated the rate-of-return literature. In the Thailand context, this is the first study that measures the payoffs to livestock research. For crops research the estimate is distinguished from previous studies by carefully accounting for issues of lags, omitted variable bias and input quality changes, using TFP decomposition.

1.3 Scope of the Study

This thesis examines sources of output and productivity growth in Thai agriculture with a particular focus on crops and livestock. The overall agricultural sector comprises crops, livestock, fisheries, forestry and agricultural services. The standard practice in empirical studies of Thai agriculture has usually been to investigate the sources of growth in the overall agricultural sector. An emphasis is given to crops and livestock, particularly in measuring the returns to agricultural research, because these two subsectors dominate agricultural output. Crops and livestock research has also been conducted over a long enough period to make it possible to assess their contributions to productivity. Despite its increasingly important role, the fisheries subsector is not included because of the different nature of production and input types and because research has only become active in recent years. Forestry and agricultural services are also excluded, due to their relatively insignificant role in Thai agriculture.

The period covered is from 1970 to 2006. This is the longest period for which consistent data series on agricultural outputs and inputs are available for measuring TFP growth in the overall agricultural sector and in crops and livestock individually. The measured TFP growth is employed as the dependent variable in investigating its determinants, emphasizing the role of agricultural research. The data on public agricultural research investment are dated back to 1961, which was the year that the first national economic and social development plan began and the national research system was organized, in order to allow for lags in the research-productivity nexus. Due to data constraints, the periods covered for investigating the role of international research and private research are from 1972-2006 and 1980-2006, respectively.

The unit of analysis is the aggregate country level and the data are time-series. Using a TFP function, this thesis examines the agricultural research impact on productivity for the overall agricultural sector and for crops and livestock combined, as well as examining the impact on crops and livestock separately. The agricultural research impact on productivity is assessed as an ex post study. That is, the analysis and the estimation of the rate of return to public agricultural research are based on past investment. An emphasis is given to public agricultural research while other types of agricultural research as well as potential determinants of TFP are accounted for to avoid omitted variable bias.

1.4 Structure of the Thesis

This thesis examines the sources of growth in Thai agriculture and provides an explanation of what determines productivity growth, with a particular focus on agricultural research. The impact of public agricultural research investment is also assessed by measuring the social rate of return. Following this introductory chapter, the structure of the thesis is as follows.

Chapter 2 surveys the literature on research and productivity, mainly in the context of agriculture. It aims to review what previous studies have done and what this thesis can do to fill the gaps in the literature. The chapter begins with a survey of economic studies on agricultural research, followed by a survey of productivity studies. These surveys highlight how research and productivity are conceptually linked and why they have gained attention in the literature. Issues in assessing the agricultural research impact on productivity are then reviewed with an emphasis on methodology, measurement of research variables and issues in measuring rates of return on agricultural research. Finally, empirical evidence is provided from various country-case studies of both international and Thai studies.

Chapter 3 provides a background on Thai agriculture with a particular focus on agricultural production and the research system. It is divided into two main sections: the first provides background on Thai agriculture in general and the second concentrates on the characteristics of agricultural research. The first section covers background topics that are important for understanding the research that follows, from a review of agricultural outputs and inputs and partial productivity to the transition of Thai agriculture and agricultural policies. The second section describes the Thai agricultural research system. It begins with an historical development of the national research system, followed by the structure of agricultural research funding and an overview of major types of agricultural research investment – public, university, private and foreign. Common characteristics, problems and future challenges for the Thai agricultural research system are also reviewed.

Chapter 4 aims to measure TFP growth empirically and investigates the sources of agricultural growth during 1970-2006. The chapter begins with a brief review of TFP measurement methods and then spells out the method to be employed, together with the adjustment technique undertaken on major inputs. Conventional growth accounting is employed to measure TFP growth as a residual of output growth that cannot be explained by factor input growth. The chapter also explains in detail how outputs and inputs are measured as well as identifying data sources. The TFP estimates will be used to examine the determinants of productivity growth in subsequent chapters.

Chapter 5 aims to provide a more structured analytical framework for empirically estimating the determinants of TFP. On this basis, key factors potentially influencing TFP in the context of Thai agriculture are identified. This chapter lays out TFP determinant models, which are divided into the general model covering the whole studied period of 1971-2006 and the attribution model covering the shorter period of 1980-2006. Due to limited data availability, the general model only includes public and international research while the attribution model accounts for all major sources of research funding – public, private, university and foreign. There are also two estimation methods. The first specifies variables in rate-of-change terms and incorporates a commonly used polynomial distributed lags. The second employs an error correction transformation which allows for both short- and long-term information as well as not imposing any restrictive form of lags. These empirical specifications are applied with the Thai data in the following chapter.

Chapter 6 continues with the second empirical estimation using the framework outlined in Chapter 5. It aims to answer the second research question and provide empirical evidence on the agricultural research impact on productivity growth. Emphasis is given to the role of public investment in agricultural research while accounting for all the potential determinants of TFP and other major sources of agricultural research expenditure. Empirical results are reported and discussed using the growth-rate model and the error correction model. The productivity effect of public agricultural research is used to estimate the social rate of return on research in the subsequent chapter. The findings also shed light on both methodological and policy implications.

Chapter 7 assesses the agricultural research impact by measuring the payoffs to past investment in public agricultural research. The measured rates of return on agricultural research provide empirical answers to the third research question. The estimation is based on the preferred results from the previous chapter using the error correction method (ECM). This method fits well with the Thai data and this work apparently represents the first attempt to quantify the returns to research in the Thai context based on the ECM while accounting for the role of international research spillovers and other major factors, such as resource reallocation, infrastructure, weather and the commodity price boom. Having controlled for all these previously omitted factors, several of which could have produced upward bias in estimates of the productivity impact of public agricultural research, it is found that the social rates of return are still high enough to justify continued public investment in agricultural research.

Finally, Chapter 8 provides a summary and conclusion and discusses the policy implications of the current research and identifies direction for future research.

Chapter 2

2. Literature Review

2.1 Introduction

The linkage between agricultural research and productivity has gained considerable attention in empirical studies as it has important implications for living standards, poverty, food security and long-term economic growth. Numerous studies have examined the impact of agricultural research on productivity, reflecting the general belief that the research benefits are large. The World Development Report 2008 highlighted that investment in agricultural research has "paid off handsomely". Accordingly, this chapter reviews the literature on research and productivity in the context of agriculture. It aims to summarize previous studies and the way in which this thesis proposes to fill the gaps in the literature, particularly in the Thai agricultural context.

The chapter consists of five sections. A survey of economic studies on agricultural research is summarized in section 2.2. Productivity studies are reviewed in section 2.3. These two sections aim to bring out important concepts and issues in the linkage between research and productivity. Issues in assessing the impact of agricultural research on productivity are provided in section 2.4. They consist of methodological issues emphasizing the standard parametric approach, measurement issues and statistical issues. Section 2.5 reviews the empirical evidence on the productivity effect of agricultural research and the corresponding rates of return. This section briefly overviews the issues and main findings to identify missing links in the literature, and provides country-specific case studies. Last, a conclusion is provided in section 2.6 summarizing important points for filling gaps in the literature.

2.2 Survey of Economic Studies on Agricultural Research

Conceptual relationship between agricultural research and productivity

Research is defined as an economic activity that involves an investment of scarce resources in the production of knowledge (Alston et al., 1998b, p.21).[1] It increases the stock of knowledge, which either facilitates the use of existing knowledge or generates new technology. In the context of agriculture, the increased stock of knowledge enables more efficient production of agricultural products and farming systems, which results in increased output per unit of input used.

In other words, an increase in productivity relates to research results that lead to the development of new or improved output, new, better or cheaper inputs, and other changes in knowledge that enable farmers to choose and combine inputs more effectively (Alston et al., 1998b, p.23). Hence, agricultural research is generally recognized as a prime source of technical change that improves productivity and sustains output growth (Ruttan, 1987, Chang and Zepada, 2001).

Unlike typical research and development (R&D) in an industry sector, the influence of agricultural research on productivity involves a significant amount of extension services (Alston et al., 1998b, Evenson, 2001). Extension services carry the research results to farmers for adoption. Cooperation is required between research and extension agencies to translate the stock of knowledge or new technology into increased output and productivity.

Significance of research-led agricultural productivity

Past increases in agricultural supply have been achieved through expansion of cultivated land. In recent years many countries have reached their land frontier, encountering higher costs of irrigation, water shortages and an end to the supply of low cost labour (Judd et al., 1991, p.7). Climate change could also worsen growing conditions for crops and further strain the capacity of agricultural land (CGIAR,

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[1] In general, agricultural research includes research on crops, livestock, forestry, fisheries, natural resources, the use of agricultural inputs, and the socioeconomic aspects of primary agricultural production, as well as post-harvest or food-processing research (IFPRI, 2007).

2009).[2] The uncertainty brought about by resource and environmental constraints makes agricultural research increasingly important in raising output and productivity. Research-induced technical change permits the substitution of knowledge for resources, allowing an economy to grow using fewer resources (Ruttan, 1987). Although there can be little doubt that research does contribute to productivity growth in agriculture, considerable effort has been devoted to measuring the impact of agricultural research on productivity or output growth (Ruttan, 1987).

Research-induced agricultural productivity growth is particularly important for developing countries because it helps increase the standards of living for a still growing population despite a shrinking natural resource base (Alston, 2002). Agricultural research investment not only yields benefits to agricultural production and provides food security, but also has an impact on poverty reduction and maintaining the quality of natural resources (Pardey et al., 2006b, Fan and Rao, 2003, Ryan, 2002). In particular, Thirtle et al., (2003) argue that research-induced agricultural productivity growth has a large impact on poverty reduction in rural areas.

Furthermore, in developing countries, disaggregating total agricultural expenditure into research and non-research spending suggests research has had a much larger impact on productivity than non-research spending such as irrigation, education and roads (Fan and Rao, 2003). Empirical evidence suggests agricultural research accounts for one-third to one-half of TFP growth in developing countries (Pingali and Heisey, 2003, Byerlee and Alex, 1998, p.13). Country case studies in Asia also show rates of return to agricultural research are far higher than other types of public sector projects (Pray, 1991, p.53).

[2] According to the CGIAR (2009), "Scientists estimate that rising temperatures and changing rainfall patterns could cause agriculture production to drop by as much as 50 percent in many African countries and by 30 percent in Central and South Asia".

Concerns over declining worldwide agricultural research investment

The literature often raises concern over a declining trend of local agricultural research expenditure in both developed and developing economies (e.g., Thirtle and Bottomley, 1989, Evenson and Pray, 1991, Pardey et al., 2006d, Poapongsakorn, 2006, p.54). In addition, recent studies have indicated concern about the changing investment pattern and declining trend of agricultural R&D in developed economies, which has been the main source of worldwide agricultural technology. These studies indicate a need for countries that have previously relied on R&D spillovers from developed countries to be more self-reliant (Pardey et al., 2006a, 2006d).

International agricultural R&D spillovers may no longer be relied upon mainly due to the growing differences in demand for agricultural technologies and innovation between developed and developing countries. Developed countries, especially the United States, Japan, Germany and France, have reduced the level of public support for productivity-enhancing research and shifted more research resources toward the environment, food quality and safety objectives (Pardey et al., 2006c, 2006d).

Further, agricultural research in developed countries has increasingly become a private sector activity while at the same time intellectual property protection has become increasingly intense (Pardey et al., 2006d). Falling agriculture R&D investment has posed a particular concern for food security in developing countries where population growth continues to expand, thereby refocusing attention on the role of agricultural research investment. Particularly for small countries, they cannot avoid being dependent on others, e.g., on the international agricultural research system or on the research systems of large countries, for much of their agricultural technology. Thus, they need to develop sufficient agricultural science capacity to be able to draw selectively on an interdependent global agricultural research system (Ruttan, 1987).

2.3 Survey of Productivity Studies

Concept of productivity

Productivity is defined as the amount of output produced per unit of input used. When output increases from a given set of inputs, there is said to be an improvement in productivity. Productivity is classified into two types in the literature, partial and total or multifactor productivity.[3] Partial productivity takes into account only one particular input, holding other inputs constant. For instance, labour productivity is typically measured as output per worker or output per labour-hour. Land productivity is measured as output per unit of land, often called yield. Total factor productivity (TFP) takes into account all important measurable inputs, such as land, labour, and other conventional inputs. Typically, it makes more economic sense to consider TFP growth or its changes over time. TFP growth is referred to as a residual part of output growth that cannot be explained by increases in conventional inputs.

According to the historical note on TFP by Griliches (1996), the concept of TFP has been discussed repeatedly in the literature since the 1930s and the earliest attempt to calculate TFP dates back to Tinbergen's paper[4] in 1942. In the 1950s, there was a group of pioneering studies (including Schultz, 1953; Kendrick, 1955; Abramovitz, 1956; Solow, 1957)[5] emphasizing the main message that 'growth in conventional inputs explains little of the observed growth in output' (Griliches, 1994, p.1). As a result, these studies attempted to measure and explain the residual TFP.[6]

The concept of TFP has been widely discussed and applied in many empirical studies. It is sometimes referred to as the 'Solow residual', which is generally (and loosely) considered a measure of 'technological progress' or 'technical change', but this notion is subject to many criticisms (Griliches, 1963, Jorgenson and Griliches, 1967,

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[3] Most studies use the terms 'total factor productivity' and 'multi-factor productivity' interchangeably. However, it should be noted that a recent APO publication by Mahadevan (2002) distinguished the two terms with the treatment of intermediate inputs.

[4] Tinbergen's paper in 1942 was published in German and translated into English in 1959.

[5] See Griliches (1996) for a review of these studies.

[6] See, for example, Griliches (1963, 1996), Jorgenson and Griliches (1967), Denison (1967), Mahadevan (2002, 2003), Mundlak (1992) and Mundlak et al. (2002).

Solow, 1957). As noted in Griliches (1996, p.1328) all pioneers of this subject were quite clear about the weakness of TFP calculations in that it may be misleading to identify the results as pure measures of technical progress. It is notable that Abramovitz (1956) labelled TFP as 'a measure of our ignorance'.

Debate on the calculation and interpretation of TFP is not new. It has been discussed since its invention and still captures interest in recent studies despite the tremendous efforts in improving TFP measurements (Chen, 1997, Felipe, 1997, Mahadevan, 2003). There is still room for future studies to improve explanations of TFP growth.

Significance of TFP growth

TFP has gained in importance and appeal in the literature for more than half a century, since it was recognized that output growth could not be fuelled by continuous input growth, due to the diminishing returns for input use (Mahadevan, 2002). It also has important implications for improvements in real income, living standards and competitiveness.[7]

With regard to agriculture, productivity growth has been described as greatly significant for agricultural growth, which is crucial for poverty alleviation in rural areas (Ananth et al., 2006). Agricultural productivity has particularly important implications for developing countries. These countries still face persistent population growth, diminishing supply of cultivated land per capita and relatively high income elasticity of the demand for food (Alauddin et al., 2005). The literature suggests that the growing need for food supply should originate from productivity growth rather than expansion in inputs.

Productivity growth in agriculture has made significant economic contributions through two main channels (Mundlak, 2000, Ruttan, 2002). First, it increases food supplies and lowers prices, thereby improving consumer welfare. Second, it produces

[7] Productivity is an element of competitiveness. International competitiveness, measured as a domestic resource cost (DRC) can be decomposed to (1) changes in relative prices, (2) changes to factor uses and (3) TFP change (Nishimizu and Page, 1986 cited in Aswicahyono, 1998).

more output with less labour and resources, thereby releasing labour and resources to facilitate development in non-agricultural sectors.

TFP Decomposition and its linkage to agricultural research

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

TFP decomposition is different when considering data at the aggregated and disaggregated level. The decomposition of aggregate TFP growth not only includes productivity growth in individual sectors but also the reallocation of resources among sectors (Warr, 2006). This is because aggregate TFP involves the growth of factor inputs and factor income shares in each sector as well as in the economy as a whole (Tinakorn and Sussangkarn, 1996, p.81-83). Therefore, aggregate TFP growth in the overall economy is different, and often higher, from TFP in each sector.

Intersectoral factor reallocation has been shown to make a significant contribution to economic growth. For example, Jorgenson (1988) showed that the predominant source of output growth in the U.S. during 1948-1979 were from capital and labour inputs while less than one-fourth was due to productivity growth, driven mainly by the reallocation of resources among sectors. The slowdown in U.S. economic growth after 1973 can also be traced to slower growth in productivity at the sectoral level. Using Thailand and Indonesia as case studies Warr (2006) showed empirically that this factor reallocation effect, as a major component of TFP growth, has contributed significantly to overall economic growth.

In the context of agricultural productivity, typical factors that have been found to influence TFP are public and private agricultural research, extension services, infrastructure investment, education of farmers and economic policies (Huffman and Evenson, 2005, Mundluk, 1992).[8] Several studies found the major share of TFP growth was attributable to changes in technology resulting from investment in agricultural research (e.g., Griliches, 1992, 1994, Rosegrant and Evenson, 1992, Ruttan, 2002, Pingali and Heisey, 2003). Since it is of policy interest to raise productivity and assess research payoffs, a large number of studies have concentrated on measuring the productivity effect of agricultural R&D (see section 2.5 for examples). Conventional practice in linking TFP with R&D is to remove the effects of various other (non-research) factors before attempting to attribute residual productivity growth to particular research investments (Alston and Pardey, 2001). These factors may include changes in input quality, improvement in infrastructure, economies of scale and irregular factors like weather (Morrison Paul, 1999).

In sum, much of the discussion on productivity deals with technology and its change over time (Mundlak, 2000). Griliches (1997, 1998b) summarizes the main findings from prior studies that used econometric evidence showing that technical change is a major source of TFP growth and that such technical change is not exogenous. This technical change was attributed to economic activity, especially the organization of public and private research. Griliches (1997) emphasized that the relationship between research and technology-induced productivity change requires quantitative evidence to establish a clear relationship and to provide measures of their magnitude.

Total Factor Productivity in Thai Agriculture

TFP growth (TFPG) in Thai agriculture has been an important source of output growth. Its contribution to output growth has been shown to be proportionately higher than in non-agricultural sectors. The empirical evidence shows that compared with

[8] Economic policies play an important role in shaping the economic environment that can be conducive to factor accumulation, technology innovation and hence greater productivity. For instance, policies that ease constraints on factor markets and promote investment in human capital and public infrastructure were important sources of productivity gains (Mundlak et al. 2004, Mundlak 1997).

other sectors (mining and quarrying, manufacturing, construction, electricity and water supply, transportation and communication, commerce and services) TFP growth contributed most in the agricultural sector (Chandrachai et al., 2004).

However, a closer look at the estimates of various studies can be confusing as the estimates tend to differ widely (Table 2.1). This is because the measurement of TFP depends a great deal on the data set, the period under study, the variables definition and the methodology. Hence, this review looks at some major findings and the overall trend of TFP growth over time instead of the exact estimates.

Table 2.1 Some Estimates of Productivity Growth in Thai Agriculture

Authors	Periods	Methods	Annual Output Growth (%)	Annual Input Growth (%)	Annual Productivit Growth (%
Poapongsakorn (2006)	1981-2003	Growth-accounting	3.43	2.45; 1.93 (employment; working hours)	0.98; 1.50 (28.65; 43.5
Warr (2006)	1980-2002	Growth-accounting	2.64	0.47	2.17 (82.19)
Warr (2005)	1981-2002	Growth-accounting	2.64	0.90	1.74 (65.97)
Chandracha et al. (APO 2004)	1977-1999	Growth-accounting	2.97	1.24	1.73 (58.25)
		adjusted for cyclical trend	2.97	0.54	2.43 (81.57)
Shintani (2003)	1950-1997	Index number: Divisia output over input index	4.3	3.1; 3.7 (stock; flow)	1.2; 0.6 (27.9; 13.6
Tinakorn and Sussangkarn (1998)	1981-1995	Growth-accounting	3.71	2.42	1.29 (34.77)
		Adjusted for labour quality	3.71	2.78	0.93 (25.06)
Tinakorn and Sussangkarn (1996)	1978-1990	Growth-accounting	4.01	2.06	1.95 (48.63)
		Adjusted for labour quality	4.01	2.72	1.29 (32.17)
Kaipornsak (1998)	1970-1996	Econometrics	3.69	2.72	0.97 (26.28)
		Growth-accounting	3.69	4.76	-1.07
Kaipornsak (1995)	1970-1989	Econometrics: Production function	4.14	2.79; 3.19 (exclude; include fertilizer)	1.35; 0.95 (32.5; 22.9
Budhaka (APO 1987)	1951-1981	Index number	5.9	3.3; 2.6 (stock; flow)	3.6; 2.8 (61.0; 47.4

Note: numbers in parenthesis under annual TFP growth are percentage contribution to output growth.

Although the estimates of agricultural TFPG differ widely across studies, the main findings confirm technological improvements in the agricultural sector have become increasingly important over time. Budhaka's (1987) pioneering study found that agriculture's share of TFP in output growth, for the period 1950-1981, was always positive, even though growth was quite low. The contribution of TFP to agricultural growth was large and dominant from 1981 onwards. Several studies found TFP was the second largest source of agricultural growth after capital stock (for example, Poapongsakorn, 2006, Warr, 2006, Tinakorn and Sussangkarn, 1996 and 1998). The contribution of land and labour is relatively small and becoming more limited, which is in line with the exhausted land frontier and declining share of agricultural labour force and increasing real wage rates. Using a different methodology, Shintani (2003) also found the contribution of the TFP index was large during 1985-1995.

Moreover, agricultural TFP was found to contribute significantly to overall economic growth. Chandrachai et al. (2004) has shown TFPG contributed to output growth the most in the agricultural sector, thereby drawing a policy implication to give priority to agriculture instead of the manufacturing sector (p.320). Warr (2006) has shown consistent results that indicate agricultural TFPG contributed 5 percent of total economic growth from 1980 to 2002, while the contributions from industry and services were negative. This finding highlights another crucial aspect of the productivity in Thai agriculture. Besides technical change there is another component of productivity, in the form of resource reallocation. This reallocation effect contributed to economy wide TFP growth by allowing factors to move from low to high productivity sectors. This is obvious as there has been a lot of agricultural labour moving to work in the manufacturing and service sectors. Within the agriculture sector itself, there has also been reallocation of resources among subsectors and among the commodities. This is consistent with agricultural diversification from traditional crops to high value crops as well as to livestock and fishery products.

For agricultural TFP growth by subsectors, the recent study by Poapongsakorn (2006) is the only one that estimates TFP growth for crops, livestock and fisheries from 1981 to 2003.[9] The results show the growth of capital stock makes a major contribution to its own sector's output growth. The contribution of TFP in crops is relatively large, compared to contributions in livestock and fisheries. Poapongsakorn (2006) claims that the rise in agricultural TFP growth, particularly in the crops sector reflects improved varieties of crops and changes in output composition. However, his study does not investigate what actually determines TFP growth, although the role of agricultural research is emphasized as one of the major factors that will determine the future of Thai agriculture.

Despite the relatively high rate of growth of TFP in Thai agriculture, the empirical findings on TFP determinants are limited. Most empirical studies on TFP in Thailand concentrate on measuring economy-wide TFP while the studies with a particular focus on agriculture are relatively few. Much of the recent work uses growth accounting and econometric approaches to calculate TFP and investigate the sources of growth using TFP decomposition. In most productivity studies, agricultural TFP growth is calculated but there is no detailed analysis on its determinants (see Table 2.2). For example, Tinakorn and Sussangkarn (1996, 1998) find TFP growth in the agricultural sector, with and without an adjustment for labour quality, to be positive and higher than for any other sector. They claim this provides evidence of a positive return from the continuous government expenditure on agricultural research and extension (1998, p.35). However, they have not analysed this claim quantitatively.

For studies that examine factors affecting TFP in Thai agriculture, Songsiengchai (2007) uses the ordinary least squares (OLS) method to estimate a TFP growth determinant model covering the period 1982-2004. All explanatory variables are expressed in rate of change terms, including agricultural trade openness, proportion of agricultural capital import in total agricultural capital stock, human capital (lagged one year) and agricultural R&D budget (lagged one year). The results show trade openness, capital import and agricultural R&D are major factors determining the TFP growth.

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[9] The calculated TFP was reported in two sets, one measuring labour with total employment and the other with total working hours.

Kaipornsak (1995) studied agricultural growth in five major crops (soybeans, maize, paddy, sugarcane and cassava). He found a declining trend in the use of inputs with the highest TFP growth per annum in the production of soybeans and the lowest in the production of sugarcane and cassava. In analysing TFP decomposition, two major sets of factors are investigated. These are technological advance, represented by R&D and foreign direct investment (FDI), and competitive environment, represented by the effective rate of protection, exports, concentration ratio and managerial structure. The results show public R&D spending and FDI were major determinants of TFP growth. However, the study assumes there is no lag involved and ignores the roles of research spillovers and extension services.

Table 2.2 Summary from Previous Studies on TFP Determinants under the Growth Accounting Framework

Studies	Included variables[1/]	Significant variables	Sign	Level of significance
Overall economy				
Chandrachai et al. (2004) 1981-1999	Dependent variable: TFP growth[2/] Independent variables: - degree of openness - ratio of net FDI flows to gross fixed capital formation - share of labour in the non-agricultural sectors - R&D spending - government spending - ratio of government investment to GDP - capital stock - portfolio investment - dummy variable for financial crisis	- degree of openness - ratio of FDI - ratio of FDI lagged one year	+ – +	1% 1% 1%
Chockpisansin (2002) 1978-1999	Dependent variable: TFP growth, unadjusted and adjusted (for labour quality changes) Independent variables: - export lagged one - imported capital - share of labour in the non-agricultural sectors - share of labour with university education lagged one year - R&D expenditure	Unadjusted TFPG: - export lagged one - imported capital - share of labour in the non-agricultural sectors - share of labour with university education lagged one year Adjusted TFPG: - export lagged one - imported capital - share of labour with university education lagged one year	 + + + + + + +	 5% 1% 5% 1% 5% 1% 5%

Kaipornsak (1998) 1971-1996	Dependent variable: TFP growth Independent variables: - share of R&D spending in GDP - share of capital import in total capital stock - share of export in GDP - trade protection (measured as domestic price level/ average prices of US and Japan) - local CPI/GDP deflator - executive or manager wage	- share of capital import - trade protection - local CPI/GDP deflator - executive or manager wage	+ – – +	10% 1% 5% 1%
Tinakorn and Sussangkarn (1998) 1981-1995	Dependent variable: TFP growth adjusted for labour quality changes Independent variables: - degree of openness - gross capital stock at constant prices - square of gross capital stock - labour share in the non-agricultural sectors	- degree of openness - gross capital stock at constant prices - square of gross capital stock - labour share in the non-agricultural sectors	+ – + +	5% 1% 1% 1%
Tinakorn and Sussangkarn (1996) 1978-1990	Dependent variable: TFP growth adjusted for labour quality changes Independent variables: - gross capital stock representing the pace of capital accumulation - ratio of exports to GDP representing the exposure of the economy to foreign markets - labour share in the non-agricultural sectors representing the impact of resource reallocation	- gross capital stock	+	10%
Agricultural sector				
Songseingchai (2007) 1982-2004	Dependent variable: TFP growth Independent variables: - degree of openness (ratio of agricultural import and export in GDP at constant prices) - share of agricultural capital import (machinery, fertilizers, pesticides) in total capital stock at constant prices, lagged one year - share of labour with upper secondary education in total agricultural labour, lagged one year - agricultural R&D budget at current prices, lagged one year	- degree of openness - share of capital import - agricultural R&D budget, lagged one year	– + +	1% 1% 10%
Kaipornsak (1995) 1977-1989	Dependent variable: TFP growth Independent variables: - R&D expenditure (mill baht) per unit value added (mill baht) - net flow of FDI (mill baht) per unit value added (mill baht) - dummy variables capturing the effect of competitive environment in five major sectors	- R&D expenditure per unit value added - net flow of FDI per unit value added	+ +	5% 5%

Note: 1/ all variables are expressed in rate of change terms.

2/ this study adjusted TFP growth for labour quality changes, business fluctuation and industrial shift effects, but did not indicate which TFP growth was used as the dependent variable in the TFPG determinants model.

2.4 Issues in Assessing the Agricultural Research Impact on Productivity

Alston et al. (1998b) and Griliches (1979) point out that the three major issues usually considered when assessing the productivity effects of agricultural research are: 1) conceptual or methodological issues; 2) measurement issues; and 3) statistical or econometric issues.

2.4.1 Conceptual or Methodological Issues

In measuring the impact of agricultural research, two broad approaches have been used depending on the purpose of the study and data availability: econometric and economic surplus approaches.[10]

- The econometric approach estimates the agricultural production function directly and then calculates the economic benefits from research as the value of the additional output or the value of the savings in inputs attributable to the lagged research expenditure.
- The economic surplus approach evaluates the research impact based on firm and industry supply functions. The benefits of research can be computed from a shift in supply function due to a change in technology.

The econometric approach is more direct and is suitable when the analysis is conducted at an aggregate level, whereas the economic surplus approach is used more for commodity, firm and industry level analysis. There are three main econometric methods: parametric, nonparametric and index-number. Most studies have used either parametric or index-number methods to estimate the productivity effects of research. These two methods are related and often used together in the analysis.

[10] See Alston et al. (1998b) for detailed explanations of each approach, including their pros and cons.

The parametric method involves specifying an explicit functional form that links inputs to outputs, using primal, dual or direct estimation of supply models (Alston et al., 1998b). The primal model estimates a production function directly. The dual model estimates a cost function and its corresponding input-demand function and then uses derivative properties to deduce supply response. It also estimates a profit function jointly with its input-demand and corresponding output-supply functions. Direct estimation of supply is single-equation supply response models for commodities, which is less popular in the existing studies.[11] The index-number method is widely used to form input and output aggregates as well as partial and total factor productivity measures. The productivity index numbers can then be used in conjunction with the parametric method to determine the effects of research, extension and other unconventional inputs.

In evaluating the contributions of research, the conceptual framework under both the primal and dual approaches have been widely used in applied studies. This has been translated into the four commonly used methods or specifications: imputation-accounting, metaproduction function, TFP decomposition and metaprofit function. The following summarizes the basic ideas of the four specifications elaborated in the Handbook of Agricultural Economics (Evenson, 2001) and the study by Evenson and Pray (1991, p.81-91).

1) Imputation-accounting is basically a growth accounting exercise that corrects residual TFP growth until it reaches a fairly complete accounting of TFP. The correction aims at extracting or identifying the invented technology out of other components associated with factor quality or scale economies. The most direct corrections are those associated with human capital, adjusting TFP growth for changes in labour quality. Once the technology is identified, the relationship with agricultural research and extension (R&E) is estimated. However, some growth accounting adjustments to inputs can affect the estimates of technology. For example,

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[11] Supply response models are generally used in commodity-specific analysis. See, for example, the study by Araji et al., (1995) that estimates the returns to agricultural research for potatoes in the U.S.

adjustments of capital stock quality may remove some of the contributions of R&E from the TFP measure.

The concept of imputation-accounting can be represented by:

$$Q = \delta f(Lq_l, Mq_m, Nq_n, Z) \tag{2.1}$$

where Q is a vector of output

δ is a scale economies parameter

q_l, q_m, q_n are quality indices that index labour (L), machinery (M), land (N) into real units of quality-constant units over time

Z is a vector of variables that characterizes technology and infrastructure contributions not channelled through scale or factor quality.

2) Metaproduction function is an extension of the conventional production function to include variables characterizing the technology environment. The term 'meta' refers to specifications that do not treat technology either as fixed or given, as is done when using a conventional production function. All variables including research and extension in the production function must be aggregated over commodities. The specification of a research variable must be consistent with the aggregation of an output variable and needs to specify both the geographic and timing relationship between production and research. This means spatial weights accounting for research spillovers across locations and time weights accounting for lags between the conduct of research and its adoption must all be considered when constructing a research variable. This method is more likely to suffer from econometric problems, particularly multicollinearity and simultaneity.

The metaproduction function can be specified as

$$Q = g(X, F, C, E, T, I, S) \tag{2.2}$$

where Q is a vector of output

X is a vector of variable factors

F is a vector of fixed factors

C is a vector of climate factors

E is a vector of soil quality factors

T is a vector of technology or inventions

I is a vector of infrastructure

S is a vector of farmer skills

3) TFP decomposition[12] begins with estimation of a productivity index and then regression on research and other explanatory variables. This method is also referred to as two-stage decomposition. Productivity is typically expressed as distributed lag function of research and other related variables. Construction of a TFP index can be based on growth accounting or a production function or cost function. The Tornqvist or Theil approximations to the Divisia index are generally considered to be the appropriate TFP calculation method. Since TFP growth is a measure of the residual, there may be other sources of productivity change besides the development of new technology. There may also be measurement errors due to "left-out" factors of production and weather-related change that reflect in the productivity measures. Therefore, this method has to be interpreted with care. Its advantage is that it is straightforward and a long series of TFP indices can be computed with reasonable price data. It may allow better estimates of technology effects on productivity.

The specification of the TFP decomposition can be derived from (2.2) as:

$$Q/X = TFP = h(C, E, T, I, S) \tag{2.3}$$

[12] This approach is applied in Chapters 4, 5 and 6.

4) Metaprofit function is a duality-based specification. The starting point is to derive the system of output supply and factor demand equations from the maximized profit function (or minimized cost function) via the Shephard-Hotelling lemma.[13] Output supply and factor demand functions normally take one of the two flexible functional forms of the generalized Leontief and normalized quadratic forms. This duality-based analysis has the advantage that as prices and other independent variables are exogenous it allows estimation of technology impacts on all endogenous variables. The computations from this approach are not only richer in detail, but also allow for the research impact on factor choice as well as on productivity. Total productivity in the profit function foundation can also be decomposed into output and factoral rates. The disadvantage with this method is that it can only be used to find the research impact on the total productivity of variable inputs, holding fixed factors constant. It is also the most data demanding.

The metaprofit function and its derivative output supply and factor demand functions are specified as:

$$\begin{aligned} &\pi^* = \pi(P_Q, P_X, C, E, T, I, S) \\ &\partial\pi^* / \partial P_Q = Q^* = Q(P_Q, P_X, C, E, T, I, S) \\ &\partial\pi^* / \partial P_X = X^* = X(P_Q, P_X, C, E, T, I, S) \end{aligned} \tag{2.4}$$

where P_Q is a vector of output prices

P_x is a vector of factor prices

The above reviewed methods are the standard practices predominant in the literature. There are also other methods available.[14] The methodological issues are mainly to choose a proper method and make it operational. Decisions need to be made on (Alston et al., 1998b):

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[13] Hotelling's Lemma refers to differentiating the profit function with respect to prices that gives the output-supply and input-demand functions. Shephard's Lemma refers to the differentiation of expenditure or cost function with respect to prices (Hoy et al., 1996).

[14] See, for example, Alston et al., 1998b, Chavas and Cox, 1992, Thirtle et al., 2002, Balcombe et al., 2005.

(1) Choosing primal or dual methods.

(2) Choosing functional form.

(3) Choosing the variables to be included in the model and

(4) Specifying research and extension variables in the model.

These issues depend on data availability, resources and research questions. Considerations of the following measurement and econometric issues are also helpful.

2.4.2 Measurement Issues

After deciding on the approach and variables to be included in the model, it is important to consider carefully how to measure input and output. In most cases, quantities and prices of agricultural inputs and outputs are readily provided by national statistical agencies. Although special care is required in processing and transforming these data, measurement issues in agricultural research impact studies focus on research and extension variables.

1) Measuring the research variable

In general, the research variable can be measured from either the input or output side of research (Pochanukul, 1992, p.54-55). The input side approach measures research capital using research expenditure. The output side usually uses the number of scientific publications, which is a crude measure as publications are not a homogenous output and some research results may be either not published or not observable. In practice, measuring research from the input side is more appropriate and more popular. Thus, the research variable is typically measured by research expenditure (e.g., Griliches, 1957, Evenson and Pray, 1991, Alston et al., 1998b).

Measuring the research variable has received considerable attention in the literature because research generates knowledge that can be accumulated and it takes time for research investment to affect agricultural output and productivity. There are several lags involved in the research-productivity nexus so it is difficult to determine the exact shape of the time lag structure. There is also a location issue involved in capturing technology spillovers from a nearby location and from abroad. Altogether, there are three main issues to consider: research lags, spillovers and deflator issues (Evenson, 2001).

(1.1) Research Lags: time weights

Regarding the structure of the lag between research expenditure and productivity, there are two issues involved: 1) the lag length between research investment and productivity and 2) the shape of the lag representing distribution of research contribution over a period of time. Past attempts at estimating the length and shape of the lag relationship have been inconclusive and it is a matter of case by case analysis (Alston et al., 1998b, p.167).

Lag Length

To capture properly the benefits of agricultural research on productivity, several studies suggest lags of at least 30 years (e.g., Mullen, 2007, p.15, Plastina and Fulginiti, 2007, p.77, Pardey and Craig, 1989).[15] Chavas and Cox (1992) found the lag length in the U.S. between making an investment in public research and an effect on productivity was up to 15 years, with benefits from the research results persisting for as long as 30 years. The more data-rich studies of aggregate national research systems typically use 40-50 years of annual observations of research expenditure to attempt to explain 20-30 years of variation in production or productivity (Alston and Pardey, 2001, p.146).

Given the ubiquitous data constraints, studies have typically imposed 10- to 20-year or else short lag lengths between research and productivity (see Table 2.3 for examples).[16] In contrast, some studies suggest an infinite lag between research investment and productivity using time-series methods involving data transformations (Alston et al., 1998a, Makki et al., 1999). 'More recent studies have tended to use

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[15] Note that most of these case studies are for U.S. agriculture.

[16] Although shorter lags tend to be biased and coincide with larger estimated rates of return, most econometric studies have used short lags. Infinite lags are statistically preferred but are often deemed practically inapplicable.

more flexible and longer lags' (Alston and Pardey, 2001). These studies suggest that economic theory says little about how many lags should be imposed in the model. Choosing lag lengths depends a great deal on the data.

Table 2.3 Lag Structure and Estimated Rates of Return to Research from Econometric Models

Lag structure	Mean lag (years)	Number of estimates	Average rate of return (% per year)
Length (years)			
0	0	36	48.0
1-4	9.9	408	95.2
0-15	22.3	174	58.1
>30	38.0	144	60.1
Unspecified	Unspecified	100	60.0
Form			
Polynomial	13.2	285	79.9
Trapezoidal	32.7	55	97.7
Free-form	28.0	6	26.5
Inverted-V	12.0	33	134.5
Other	13.3	304	75.6
No structure	26.6	79	45.8
No lag	0	36	48.0
All forms	16.3	762	77.9

Source: Alston and Pardey (2001), p.149.
Note: Numbers in this table encompass the results from past econometric studies of returns to agricultural research across countries.

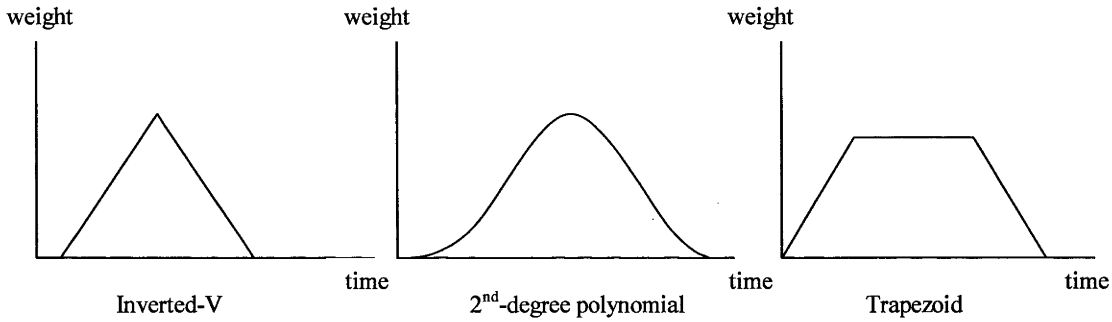
Lag Shape

The shape of the lag distribution displays a time period of research gestation between inception and completion of research, followed by a period where research results are adopted, take effect and may eventually die off. The assumed lag distribution has also varied across studies, with the shape often taking the form of an inverted-V, second-order polynomial, or trapezoid (Figure 2.1). This means the research impact on productivity is small in the current year increasing to a peak over time and probably decaying.

The difference in lag lengths and shapes was found to depend on the type of research, the nature of agricultural products and the availability of the endowment stock of research knowledge. For example, applied research that built directly on earlier work has a shorter lag profile than basic research. Varietal improvement for tree crops takes a longer time to complete than for rice or vegetables that have shorter life spans.

Conventional breeding programs for cereals usually take 6 to 10 years to develop a new variety, while similar work on perennial crops such as coconuts or bananas, can take up to 15 years (Alston et al., 1998b). As the lag structure depends on the type of research and the stage of research development, it is expected to change through time (Pochanukul, 1992, p.114).

Figure 2.1 Commonly used Forms of Lags



How previous studies incorporated lags in the research variable

The treatment of lag structure is varied across studies. Some studies have treated research knowledge as if it never depreciates; having the same impact forever once it has reached its maximum (e.g., Setboonsarng and Evenson, 1991, Alston et al., 1998a, Makki et al., 1999). Some have treated research impact as eventually becoming obsolete; the productivity effect falls to zero after a certain number of years (e.g., Griliches, 1979, Thirtle and Bottemley, 1989, Hall and Scobie, 2006). The latter refers to the commonly used forms of lag shown in Figure 2.1. The length and shape of the agricultural R&D lag profile are incorporated in the research variable through the estimation of time weights. According to Evenson (2001, p.587), there are three kinds of time weights estimation:

(i) 'free form' estimates obtained by including a number of lagged research variables;

(ii) 'segment length' estimates obtained by constructing alternative lengths and undertaking an iterative search over segment lengths to minimize mean squared error;

(iii) 'distributed lag' estimates obtained by imposing a functional form on the time shape.

The free-form and segment-length types are not as commonly used as the distributed lag. The free-form involves a number of lagged values of research expenditure and too many coefficients must be estimated, most likely encountering problems of multicollinearity. The segment length method imposes shape weights for each segment and is likely to be applicable to the non-parametric approach (Evenson, 2001, p.588).

Due to data limitations, the usual practice has been to impose arbitrary restrictions on the length and shape of the research lag profile (Alston et al., 1998a). The estimation of lag is usually based on a standard distributed lag model such as the Almon polynomial (2^{nd} degree polynomial) distributed lag (Lu et al., 1979, Evenson, 1982, Thirtle and Bottomley, 1989). The pioneering study by Griliches (1957, 1958, 1979) established this tradition by arguing that as there are many types of R&D, 'aggregation of many lag structures should lead to a rather flat but somewhat bell-shaped lag structure' (Griliches, 1979, p.101). Griliches (1998b) added that the usual geometric depreciation, for instance, the declining research effects assumed under the Perpetual Inventory Method (PIM) or the Koyck transformation, does not seem to fit well with the likely gestation, blossoming and eventual obsolescence of research results (Hall and Scobie, 2006).

Arbitrary restrictions were also applied in the case studies of Thai agriculture. Setboonsarng and Evenson (1991, p.210) created a single aggregate research variable, as a weighted sum of past crops research expenditure, by imposing fixed weights of 0.2, 0.4, 0.6 0.8 and 1, on the lagged research expenditure. That is, the impact of crops research was assumed to rise constantly from the first to the fifth period and then remain constant without depreciation of research knowledge.

Another Thai study by Pochanukul (1992) employed two methods; i) a polynomial distributed lag model ii) a direct search method that varies the lag structure of each crop and finds the structure most appropriate to minimize the sum of squared errors. The lag form was assumed to have four phases. Phase A represents the lag between research spending and the finding with zero weight; phase B represents the lag between research finding and adoption with linearly increasing weight from zero to one; phase C is the period of maximum contribution with a constant weight of one; and phase D is the lag between the start of technology depreciation and obsolescence with a declining weight from one to zero. The lag structure of Thai crops research was found to take either an inverted-V or trapezoid shape with the mean lag ranging from 6 to 13 years.

Alston et al., (1998a) pointed out that the use of mis-specified form of lags is likely to lead to biased estimates of both the agricultural research impact on productivity and the rate of return on research. They argued that research generates new knowledge that adds to the existing stock of knowledge, 'and while knowledge itself does not deteriorate, its utilization, and hence the relevant stock of knowledge, may change as circumstances change' (Alston et al., 1998a, p.3). In contrast to the restrictive and finite research lag applied in the majority of studies, they suggested a dynamic and infinite lag structure is more appropriate. Some recent studies have employed error correction models, which allow for dynamics and infinite research effects (e.g., Makki et al., 1999, Schimmelpfennig and Thirtle, 1994, Thirtle et al., 2002).

(1.2) Research Spillovers: spatial weights

It is also important to consider the role of international and intra-national technology spillovers because new research knowledge from other regions or countries may have a positive effect on performance and payoff for local research. There is strong evidence (from both statistical models and observation of trade in agricultural inputs that embody new technology) that agricultural research done in one location affects productivity in other regions or even other countries (Fuglie and Heisey, 2007).

Spatial spillovers from public agricultural research, both within and among countries, account for a significant share of agricultural productivity growth and hence have implications for measuring the research impact on productivity and corresponding research benefits (Alston, 2002). The failure to incorporate spillover effects is shown to result in biased (higher) estimates of the return to local agricultural research investment (Pardey et al., 2006b, Plastina and Fulginiti, 2007, Schimmelpfennig and Thirtle, 1999). The bias arises because the research spillovers tend to have a positive effect on agricultural productivity so that omitting such variables could give rise to an upward bias in the estimates.

The role of international research spillovers

Although the importance of spillover effects has been emphasized and various attempts to measure spillovers and spatial weights have been studied, as reviewed by Griliches (1992),[17] only a small proportion of empirical studies actually allow for these spillovers, particularly international spillovers (Alston, 2002). In practice, most regression-based studies at the country level exclude all research done abroad, although there is clear evidence that substantial international technology transfers are possible (Alston et al., 1998b, p.186). This is due both to the lack of data and the difficulties in measuring technological distance from the source of knowledge to assign spatial weights for constructing a research spillover aggregate. Nonetheless, more recent studies have found evidence of considerable international spillovers contributing to high payoffs to agricultural research investment (Evenson, 2001, p.616, Alston, 2002). 'In many cases, international spillovers accounted for half or more of the total research benefits in studies of individual countries' (Alston, 2002, p.333).

Research impact studies that have incorporated international spillovers at the country level are limited, both in number and scope. The majority of these studies were commodity-specific and mostly concentrated on crop varietal improvements (Alston, 2002, p.326).[18] For instance, the recent study by Pardey et al. (2006b), allowed for technology spillovers both within and among countries in the assessment of crops research in Brazil, and confirmed findings from previous studies that international

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[17] Spillovers were defined in Griliches (1992) as ideas from the research results in one industry borrowed by local research teams in another industry.

[18] See Alston (2002) for a review of crop-specific studies that allow for country-country spillovers.

and intra-national spillovers of research results are important. However, it has been found that even allowing for the spillovers, the rate of return to local agricultural research is still high (Pardey et al., 2006b).

The way country-specific studies (e.g., Hossain et al., 2003, Pardey et al., 2006b) allow for international spillovers is to value the benefits to particular countries from research conducted at major international research centres, such as the International Wheat and Maize Improvement Centre (CIMMYT)[19] and the International Rice Research Institute (IRRI).[20] These research centres are supported by the Consultative Group on International Agricultural Research (CGIAR).[21] Some studies use patent data to develop a measure of spillovers (Griliches, 1992, p.S37, Johnson and Evenson, 1999).

The role of intra-national research spillovers

The literature, using cross-section and panel data, has given more attention to technology transfer between regions or states within a country. Direct transfer takes place when one region implements technology generated in another region without further modification, whereas indirect transfer occurs when one region modifies technology generated in another (Evenson, 1993).

The applicability of agricultural research in a particular location depends upon agro-ecological characteristics, such as climate, terrain, and soil types, as well as economic factors, such as the relative prices of inputs and outputs and the institutional setting (Alston, 2002). Spillovers from livestock research are generally greater than spillovers from crops research because livestock production is less constrained by agro-ecological factors like soil and climate (Fuglie and Heisey, 2007).

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[19] The abbreviation "CIMMYT" derives from the centre's name in Spanish: Centro Internacional de Mejoramiento de Maiz y Trigo. CIMMYT is a non-profit research and training centre with direct links to about 100 developing countries (http://www.cimmyt.org).

[20] IRRI is a non-profit agricultural research and training centre. It is located on the campus of the University of the Philippines, Los Banos (http://www.irri.org).

[21] The CGIAR is a coordinating organization through which funds for international agricultural research are administered to various centres. It consists of donor countries, international and regional organizations, development banks, and private foundations (http://www.cgiar.org).

The role of technology transfer between regions requires the construction of regional spillovers weights. According to Evenson (2001), spatial spillovers have been handled in three ways. First, many studies have either ignored the issue or implicitly argued that spatial spill-ins are roughly offset by spatial spill-outs. Second, some studies have utilized geo-climate region data to specify spatial spillovers. Third, some studies have used spillover barrier measures to specify spillovers.

Typically, 'econometric efforts to measure the spatial spillovers of agricultural research have used knowledge stocks computed as spatial aggregations of R&D based on geopolitical boundaries, geographic proximity, or agro-ecological similarity' (Alston and Pardey, 2001). In the case of Thai rice, Pochanukul (1992) estimated a series of transferability matrices that capture the potential spillovers of varietal technology among different production environments, using experimental yields data. Her estimation accounts for three major factors: geo-climatic conditions, past development of research and the regional allocation of public infrastructure. Infrastructure like irrigation appears to play a more crucial role in determining the transferability of rice research in Thailand.

(1.3) Deflators

Besides lags and spillovers, the deflator is another issue to consider when measuring the research variable. In the Handbook of Agricultural Economics, deflators for research variables are recommended to convert research expenditure into constant currency units (Evenson, 2001). However, there is no common deflator for agricultural R&D. Choices of deflators in the literature are varied by case studies, mostly depending on data availability.

Official research expenditure (e.g., OECD and NSF data) is often deflated by the implicit GDP deflator (Pardey et al., 1987, OECD 2007).[22] However, some studies developed their own deflators because using the GDP deflator to proxy price

[22] In the OECD's main science and technology indicators manual, R&D expenditure series have been deflated using the implicit GDP deflator (OECD, 2007, p.8). OECD stands for Organization for Economic Cooperation and Development. NSF stands for National Science Foundation.

increases for R&D inputs may not be adequate. For example, Pardey et al., (1987) constructed two deflators for public agricultural research in the U.S. Huffman and Evenson (2005) used their own constructed research price index to convert the U.S. public agricultural research expenditure to constant dollar values. In the case of the UK, Thirtle and Bottomley (1989) tried using the 'implied deflator for R&D expenditure' which represents the price of scientific manpower in the UK. However, such a deflator was not available for long enough periods, causing them to change to the less preferred choice of the retail price index (p.1072).

In the Thai context, choices of deflators are varied among studies. For example, Setboonsarng and Evenson (1991) used the real research budget, but the deflator was not clearly identified. Pochanukul (1992, p.217) only mentioned that the public deflator was used to deflate the crops research budget at current prices to the real budget at 1972 prices. Kaipornsak (1995), Chandrachai et al., (2004) and Songsiengchai (2007) estimated TFP determinant models using the public R&D budget expressed as a share of GDP. Jareonsatapornkul (2007) assessed the economic impact of public rice research using the consumer price index to convert the rice budget data into 1988 constant prices.

2) Measuring the extension variable

The extension variable is easier to deal with as issues of time lag and spatial spillovers are not major concerns as in the case of the research variable. Specifying the extension services variable in some empirical studies is straightforward and only requires deflators (Evenson, 2001). The deflator is required to convert expenditure into constant currency units.

Depending on case studies and data availability, some studies do incorporate time lags in the extension variable (Evenson and Quizon, 1991, Evenson, 2001). In terms of the lag profile, extension lags are shorter than research lags. Spillover effects may be important for research but not for extension. Accordingly, the model for extension may only need to include local expenditure.

As noted earlier, research helps the development of new technology and extension helps speed up the rate of diffusion and adoption of new technology. It is common that an interaction term between research and extension is included to represent their relationship in the sense that research can have a greater impact on productivity with cooperation from extension as an agency to diffuse research knowledge to farmers. It is preferable to include separate research and extension variables and also to allow for interaction effects. In practice, multicollinearity is likely to be a problem. Some studies used a preaggregated research and extension variable to overcome the statistical problems in an econometric model (e.g., Huffman and Evenson, 1992 and Nagy, 1991).[23]

2.4.3 Statistical and Econometric Issues

Several econometric problems often arise in the regression-based analysis.[24] Common problems found in the research evaluation models are usually specification error, multicollenearity and simultaneity. These issues are mainly drawn from Alston et al. (1998b).

1) Specification error

Either primal (production function) or dual (cost or profit function) methods tend to suffer from specification errors as a result of omitted variables and mismeasurement bias. It is highly likely in empirical studies that researchers can either unintentionally or intentionally omit a variable (due to lack of data). If the omitted variable is correlated with the included variables, the estimated coefficients on the included variables will be biased. For instance, omitted private research is expected to influence production positively and to be positively correlated with public research. If so, the public research coefficient will be biased upward. Failure to incorporate sufficient lag length will also lead to omitted variable bias.

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[23] In Nagy (1991), R&E are combined to avoid multicollinearity and were assumed to follow an inverted U-shape distribution of the partial production coefficient.
[24] The commonly used estimation method is ordinary least squares (OLS).

It is possible for the included variable to be mismeasured. Any such mismeasurement will result in biased estimates. This issue deals mostly with the quality adjustment on conventional inputs and the measurement of the research variable. If an input has not been adjusted for its quality changes, such as an improvement in labour skills, and this is correlated with a research variable, the coefficient on the research variable will be biased. The research variable is also likely to be mismeasured since it usually involves aggregating across various research activities, such as different technology types, commodities, or institutions that vary in many respects and lag profiles. Therefore, a thorough understanding of each type of research data is necessary if aggregation is to be undertaken.

2) Multicollinearity

Multicollinearity is another problem, especially with time-series data. When multicollinearity is serious, only limited confidence can be placed in the estimate.[25] It is typically found that variables such as research, extension and education move together over time. The lag structure imposed on research and extension variables also often shows a strong correlation among lagged variables. This is often the case when a production function is used to evaluate agricultural research and the unit of analysis is at the country level.

One possible solution is to use more data, more prior beliefs or some other means of making less demand on the data. The dual approach can be useful as multicollinearity is likely to be less of a problem with cost, profit, or supply functions than with production functions. This is because most real input and output prices are less highly correlated than input and output quantities. However, serial correlation may be more serious (Alston et al., 1998b, p.189).

3) Simultaneity

Simultaneity is often a problem when a production function is estimated to evaluate agricultural research. This is because conventional inputs may not be exogenous. In

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[25] The symptoms are large variances on regression coefficients, and low t-statistics despite a high F-statistic for overall significance.

practice, agricultural outputs and inputs are likely to be affected by weather, pests and farmers' decisions and so estimates on input coefficients tend to be biased and inefficient since they are correlated with the error terms. In addition, future output and its profitability may depend on past research, while research expenditure may depend on past output and so cause a simultaneity problem.

For TFP decomposition, if research investment is made in response to productivity change, causality may be compounded. The dual approach seems to suffer less from this problem since many of the explanatory variables are prices. In general, price variables are viewed as exogenous and should not be correlated with error terms because prices are determined by the market, and not by farmers. However, while this is often true for farm-level data, for aggregate national or regional data output prices may be influenced to some extent by aggregate output levels.

2.5 Empirical Evidence: Agricultural Research Impact Studies

This subject has received considerable attention in empirical research from applied and agricultural economists for several decades. This section surveys the literature focusing on issues and the main findings from studies of the agricultural research impact on productivity. Empirical evidence, for both international and Thai studies, is reviewed for the productivity effects and then for the measurement of rates of return. Since there are only a few Thai studies they are reviewed together in the last subsection.

2.5.1 Empirical Studies on Agricultural Research Impacts: An Overview of Issues and Findings

A substantial number of studies have examined the agricultural research impacts on productivity, farm income, consumer welfare, export competitiveness and poverty. Among these studies, the linkage between research and productivity has received considerable attention. Numerous studies emphasize measuring the influence of agricultural research on productivity change in agriculture (Ruttan, 1987, Guindo, 1989, Evenson and Pray, 1991, Fan and Pardey, 1997, Evenson, 2001, Kelvin et al., 2005). They associate productivity growth with technical change attributed to agricultural research. Several studies have further investigated who benefits from increases in productivity growth and who should finance agricultural research (Evenson and Pray, 1991, Mundlak, 2000).

Much of the literature has examined the contribution of agricultural productivity in output growth and then explained the sources of the growth, which often include research and extension (APO, 2001, Coelli and Rao, 2003, Griliches, 1963, Alauddin et al., 2005). In particular, a number of studies have estimated TFP and examined how its growth can be explained by factors representing measures of technology, human capital and public policy (Zepeda, 2001).

Most studies have focused on the role of public research since research investment is primarily public-sector activities and the influence of private research on productivity is mostly unknown (Alston et al., 1998b, Evenson, 2001). The overwhelming conclusion of this empirical research is that investment in public research and extension has been a primary source of agricultural productivity change in many countries (Evenson, 1993, Evenson, 2001).

1) Measuring Rates of Return (ROR) on Agricultural Research

The estimation of returns to agricultural research investment has been a standard practice accompanying the agricultural research impact studies (Griliches, 1957, 1958, Norton and Davis, 1981, Evenson and Pray, 1991, Chang and Zepeda, 2001). It is interesting to compute a social rate of return on investment in research because the allocation of the government budget has other non-research funding purposes such as irrigation, education and roads. The RORs have usually been measured as internal rates of return (IRRs), which equate a present value of research benefits to that of costs. These IRRs largely refer to real (inflation adjusted), marginal (for incremental research expenditure) and ex post (for past investment). Not only are there numerous empirical studies on this issue but they have been reviewed many times.[26]

Almost all studies have found positive and significant impacts on productivity from agricultural research investment and the corresponding rates of return have also been high (Ruttan, 1987, Alston et al., 2000, Evenson, 2001). According to the World Development Report 2008, the payoff from agricultural research investment has been high, delivering an average rate of return of 43 percent in 700 development projects in developing countries (The World Bank, 2007).[27] Although many have questioned the accuracy of the high rates of return, 'a widely shared belief is that the estimated rates are robust enough to accommodate such criticisms and still be in a range that is substantially above the social rate of return on public funding' (Roseboom, 2002).

To a certain extent, several studies have tried to convey a message to the relevant government or other providers of research funding that the agricultural research benefits are large so that financial support should be raised or at least maintained (Evenson and Pray, 1991, Evenson et al., 1999, Rozelle et al., 2003). Any slowdown in the growth of public agricultural research expenditure is a reason for serious concern (Roseboom, 2002).

2) Pervasive Underinvestment in Agricultural Research

It is widely held, with the support of high rates of return on agricultural research, that there has been pervasive underinvestment in agricultural R&D, especially in developing countries (e.g., Ruttan, 1980, Chang and Zepeda, 2001, Evenson and McKinsey, 1991, Roseboom, 2002, Pardey et al., 2006a). Several studies have suggested reasons for continued public underinvestment in agricultural research (See, for example, Oehmke, 1986, Ruttan, 1987, Harris and Lloyd, 1991, Roseboom, 2002). The pervasive underinvestment reflects both lack of awareness of the potential

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[26] See, for example, Alston et al. (1998b), Evenson and Pray (1991), Evenson (2001), Griliches (1979, 1994, 1996, 1998), Alston and Pardey (2001), Huffman and Evenson (1992, 2005).

[27] More evidence of high rates of return on agricultural R&D is shown in section 2.5.3.

benefits of agricultural research and a lack of power to turn latent demand into actual demand for research or new technology (Ruttan, 1987).

The effects of new technology are frequently not apparent to the group of people who have the power to increase public spending on agricultural research. Farmers who are the major beneficiaries of agricultural research in several countries tend to have very little political influence whereas government and consumers are mainly interested in agriculture only when there is a food crisis (Ruttan, 1987, p.180). Harris and Lloyd (1991) asserted that market failure and government failure provide explanations for the persistent underinvestment in agricultural research. The market failure prevents the private sector from effectively providing research. Government also fails to undertake or fund potentially high payoff research projects because research is considered as a long-term and risky activity which is 'politically unprofitable' (Harris and Lloyd, 1991, p.24).

International spillovers of public agricultural R&D results have contributed to a global underinvestment in agricultural R&D that existing public policies have only partly succeeded in correcting (Alston 2002, Pardey et al., 2006c). Numerous studies argue that research capacity in developing countries needs to be substantially strengthened, particularly the capacity to borrow, adapt and diffuse technology from countries in comparable agro climatic regions (Ruttan, 2002, p.180). Due to high expectations for research results when resources are scarce and financial support limited, research resource allocation and research priority settings have become another important area in the literature (Alston et al., 1998b).

3) Overestimation vs. Underestimation Issues

In general, there has been scepticism that the influence of research and its corresponding rate of return might be overstated since the omission of variables (e.g., private and foreign research) and mismeasurement are still problems (Fuglie et al., 1996, Evenson, 2001, p.621, Alston, 2002, Pardey et al., 2006b).[28] In addition, the arbitrary truncation of the lag distribution for the stream of research benefits could lead to serious upward biases in the estimated rate of return (Alston et al., 1998a). As lack of data (that prevents the inclusion of some important factors and long lags in the estimation model) is often a problem in empirical studies and the commonly used procedures tend to understate research costs and overstate research benefits, the tendency to overestimate that results in an upward bias in ROR estimates has dominated the literature (Alston and Pardey, 2001).

On the other hand, the argument for underestimation concerns the implicit assumption underlying the estimation of the rates of return. Townsend and Thirtle (2001) argued that the usual assumption implies that if there were no research, there would be neither growth nor decline in output or productivity. They provided empirical support, using South African livestock research as a case study, that this assumption leads to underestimation of the ROR. By separating livestock health maintenance from improvement research, research benefits from preventing disastrous losses that would occur in the absence of health research were accounted for. Their results suggest a minimum underestimation of about 50 percent, implying the ROR estimates that implicitly assume that with no research, there would be no change in productivity are severely biased downwards. Besides excluding benefits from disease prevention, the conventional ROR estimates may exclude benefits from food safety R&D or social science research related to agriculture (some of which may not show up clearly in commodity markets and some of which are not captured in conventional productivity measures), and the spillover benefits from agricultural R&D into non-agricultural applications (Alston and Pardey, 2001).

Further, Fuglie et al., (1996, p.58-63) pointed out other sources of biases causing over- or under-estimation in the traditional ROR estimates. These include failures to account for environmental and health effects, social costs of raising funds for

[28] For example, if there was an evidence of foreign knowledge contributing to productivity growth then the rate of return to research which only includes local investment would be overestimated.

financing public research through taxation on private sector activity, government intervention in commodity programs, dislocation and adjustment costs.

4) Attribution Issues

As many sectors are involved in conducting research, it is not clear which research has actually contributed most to productivity change. As a result, more recent studies have focused on the attribution problem ignored in the earlier literature. These studies try to determine who has conducted particular research that has led to productivity improvement (Alston and Pardey, 2001, Huffman and Evenson, 2005 and 2006, Pardey et al., 2006b). Nonetheless, estimation models distinguishing among types of research expenditure place a heavy burden on the data (Fuglie and Heisey, 2007).

In a broader sense, the attribution issue not only accounts for different types of research expenditure but also addresses all important factors affecting output and productivity. Failure to account for one source of innovation may overattribute observed gains in productivity to another source (Fuglie and Heisey, 2007).

2.5.2 Empirical Evidence on Agricultural Research Impact on Productivity: International Studies

Most studies have relied on a regression-based analysis, using both time series and panel data. In general, the impact of research on productivity has been found to be positive and its benefits large. The extent varies widely across studies. Some important findings of various case studies are summarized as examples in this subsection.

Asia Pacific: Chang and Zepada (2001) review the literature on factors affecting agricultural productivity with an emphasis on the role of investment in the Asia Pacific region. Their study demonstrates the increasing importance of investment in human capital and public goods, particularly education, agricultural research and extension (R&E) and infrastructure. They also reviewed policy reforms, notably land reforms, for their fundamental impact on agricultural productivity. Although productivity was found to vary across commodities and countries, according to the stage of economic development, government policy and agronomic-ecological conditions, the crucial determinants were investment in agricultural R&E and human capital.

Chang and Zepada (2001) draw three main conclusions from their survey regarding the driving forces behind agricultural productivity growth in the Asia Pacific region. First, potential growth due to expansion of cultivated land and increased input use is limited, with the exception of machinery. Second, technological progress was recognized as the key to growth driven by agricultural R&E and improvements in human capital. Third, policy reforms were viewed as a one-shot boost to agricultural productivity compared with agricultural R&E that can provide a sustained contribution to productivity.

United States: The first regression study by Griliches (1964b) included public expenditure on agricultural research in the production function using state-level data. His study was later improved by including more complicated lag functions in the construction of research variables as well as allowing for the possibility of geographic spillovers (Griliches, 1992). A significant and positive impact of agricultural research on production and productivity was confirmed.

Since the study by Griliches (1964b), many studies have examined the data further and found positive and significant impacts from public and private agricultural research on productivity, while the evidence for public extension is mixed. Some have shown a positive impact and some have not shown any effect (Huffman and Evenson, 2005).

The treatment of spatial spillovers has received considerable attention in recent U.S. case studies.[29] For example, Alston and Pardey (2001) used U.S. wheat varieties as a case study to illustrate the importance of locational spillovers in attributing varietal improvement technology among research institutes. By using measures of agro-ecological similarity to parameterize technological spillover potential, they found substantial spillover effects among U.S. states. Hence, studies that do not allow for interstate or international spillovers will overestimate own-state research responsibility for state-level productivity growth.

White et al. (2003) studied returns to wheat research investment by focusing on research spillovers. They found research spillovers existed among various classes of wheat and explain why social rates of return are higher than private ones. Plastina and Fulginiti (2007) used spatial econometric techniques,[30] to account for stochastic spatial dependency generated by knowledge spillovers, in measuring the benefits from public agricultural R&D in 48 U.S. states during 1949-1991. Their results show failure to account for knowledge spillovers resulted in an estimated internal rate of return (IRR) to public agricultural R&D investment of 11 and 13 percent higher, for own state and social IRRs, respectively.

Chavas and Cox (1992) propose an alternative nonparametric approach to investigate the effects of research on productivity using aggregate time series data on U.S. agriculture for 1950-1982. The nonparametric approach is chosen as an alternative way to overcome unresolved issues in the parametric approach. For example, it requires no functional form and no restrictive assumption on substitution among inputs. It allows for biased technical change using disaggregated inputs and flexibility in investigating the length and shape of lag distribution between research and productivity. Technical progress is modelled as a function of lagged research expenditure and estimated using a standard linear programming algorithm. The results indicate at least 30 years of lags are necessary to capture the effects of public

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[29] The U.S. is large in size consisting of many states that are spatially diverse and so spatial heterogeneity receives considerable attention.

[30] The model and estimation method follows the spatial econometric textbook by Anselin (1988).

research while shorter lags of 23 years are required for private research. This implies private research has a stronger influence on farm productivity in the short term but a smaller influence in the longer term. The estimated internal rate of return is 28 percent for public research and 17 percent for private research.

As more disaggregated data have become available, recent studies have paid attention to the attribution issue and have investigated the composition of agricultural research in more detail. For instance, Alston and Pardey (2001) present arguments and evidence concerning the attribution issue, using the specification of research lags in econometric models to illustrate the problem of attributing aggregate productivity. The main message is to determine and identify research responsible for productivity growth. It is crucial that all important variables be included and correctly measured.

Huffman and Evenson (2005, 2006) examine the impact of agricultural R&E on agricultural TFP by focusing on the composition of public research funding. The study employs the TFP decomposition model using panel data covering 48 contiguous states over 1970-1999. It was found that funding sources matter for determining the impact of public research on state agricultural TFP. An increase in federal competitive grant funding at the expense of federal formula funding would lower the productivity of public agricultural research.

Oceania: Investment in R&D for Australia and New Zealand has long been regarded as an important source of productivity growth in agriculture (Mullen et al., 2006, Mullen, 2007). Given the flat R&D investment, Mullen (2007) uses econometric models to assess whether there has been a general slowdown in productivity growth and a decline in the returns from research in Australian broadacre agriculture during 1953-2003. Estimations were divided into two different models of 16 and 35 year lags between knowledge stock and TFP growth. The results show productivity growth has remained strong with no evidence of a decline in the returns from research. The marginal impact of research, represented by knowledge stock, is positive on TFP growth for both the 16 and 35 lagged models.

Mullen et al. (2006) study and compare research trends and productivity growth in agriculture in Australia and New Zealand. Research intensity and productivity growth in Australia are found to outperform those in New Zealand despite the fact that investment in R&D has been flat in both countries. The typical approach of TFP decomposition is employed by regressing an index of TFP against several explanatory variables, including stock of knowledge[31], investment in extension, weather, farmers' education level, terms of trade, foreign investment in research, investment in public infrastructure and the degree of regulation in factor and product markets. Besides local research, foreign research spillovers also contribute to the TFP growth. The internal rates of return were calculated using a cost stream from 1927 to 2003 and a benefit stream from 1953 to 2003. The estimated returns to investment in domestic research in both countries are in the range of 15 to 20 percent.

Hall and Scobie (2006) estimate the contribution of R&D to productivity in agriculture in New Zealand during 1927-2001. Their study accounts for both domestic (public and private research) and foreign research. The stocks of knowledge were constructed based on the current and past research expenditure using three methods; the perpetual inventory method (PIM), the Koyck transformation and the Almon polynomial lag structure.[32] The spillovers of foreign research were captured using the data on U.S. patents granted to foreign residents. The results show foreign knowledge is an important factor consistently explaining the TFP growth. The contribution of domestic research is positive and significant but the evidence is not consistent across various experimental runs. Results are sensitive to the type of model and the measurement of the variables. The rate of return on agricultural research was estimated at 17 percent.

China: Fan and Pardey (1997) use a newly constructed panel data set to study the contribution of agricultural research to output growth in Chinese agriculture during

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[31] The stock of knowledge variable is a weighted sum of past expenditure on R&D where the length and shape of the R&D lag profile are imposed.

[32] PIM needs to specify depreciation rate (using 5%, 15% for both domestic and foreign R&D) while Koyck transformation does not. Both assume the effect of R&D investment declines at a constant rate as the lag length increases.

1965-1993. The analysis is based on the aggregate production function that includes conventional inputs, research investment, regional dummies, time-specific dummies capturing the effects of two phases of the post-1978 economic reforms, and time trend as explanatory variables. The research or stock-of-knowledge variable was specified as a weighted sum of deflated past research expenditure. The study applied OLS estimation on both Cobb-Douglas and quasi-translog production specifications. The result confirms the general belief that research-induced technical change accounts for a significant share (20 percent) of the growth in agricultural output.

Rozelle et al. (2003) fill the gap in agricultural research impact studies in China by emphasizing total factor productivity. Their study uses two-stage least squares to estimate the determinants of TFP for rice, wheat and maize during 1981-1997. Technology, measured as varietal turnover, was the most important factor driving the sharp increase in TFP in the early reform period (1981-1984). On the contrary, expenditure on extension and investment in irrigation did not help TFP growth. The breakdown of the extension and irrigation system is a probable cause. In the late reform period (1984-1995), technology remained the most important source of TFP growth. Their results provide supportive evidence that investment in technology generation and diffusion have led to past TFP gains. Essentially, the study establishes a basis for policy makers and donors to invest in agricultural research.

India: Rosegrant and Evenson (1992) assess the sources of TFP growth in the crops sector, using the fixed effects approach for the district level data set during 1956-1987. Public research was shown to be the most important source of TFP, which is consistent with findings for Bangladesh and Pakistan. Foreign and domestic inventions are also included and have a large complementary impact on public research.

Evenson et al. (1999) confirm previous findings for India that an increase in agricultural productivity can be induced by public investment in R&E, and improvement in human capital and infrastructure, notably expansion of the irrigated area. The rates of return to public agricultural research are high and it appears the government is underinvesting in agricultural research.

Ananth et al. (2006) measure the impact of research investment on technology development of 8 major field crops in India covering a 25 years period. A TFP growth index was constructed to capture the productivity of selected crops and then regressed on crops research investment per hectare of area, extension, human capital, infrastructure, price policy and climate factors. The results confirm agricultural research investment had a considerable impact on the release of crop varieties and other technologies, implying an improvement in crops productivity. The increase in productivity was mainly attributable to the research effort. The study also uses the estimated elasticity of TFP with respect to research investment to quantify returns on crops research investment. The internal rate of return was quite high for crops that received higher research investment.

Indonesia: Salmon (1991) develops a set of province by province total productivity indices for rice in Indonesia between 1972 and 1977. Using a Divisia or chained factor share weighted index, he then estimates the rate of return to the investment made in rice research between 1965 and 1977. The estimation is based on a model that relates the total productivity with its determinants, in particular research in the own-province, research in adjacent provinces, the Bimas[33] participation ratio, the literacy rate and the ratio of bunded to total cultivated rice area. The research capital stocks were constructed for two types of rice, bunded and nonbunded, using budget data and accounting for the lag structure with a gamma distribution.[34] The results yield a positive and significant impact from research for bunded rice, but not for nonbunded rice. A probable cause is the high correlation between bunded and nonbunded rice research. The important role of research spillovers from IRRI is mentioned but could not be measured.

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[33] Bimas is an education and extension program for farmers in Indonesia.
[34] The study concentrates on two major zones of riceland; i) bunded riceland consisting of irrigated and nonirrigated lowlands, ii) nonbunded riceland consisting of tidal swamp and upland riceland.

Fuglie (2004) uses an index number and production function approach to measure TFP growth in Indonesian crops and livestock agriculture for the period 1961 to 2000. His findings on TFP based on the Tornqvist index, Paasche index and Cobb-Douglas index were linked to agricultural research spending.[35] All three indices indicate agricultural TFP growth accelerated in the 1970s and 1980s but stagnated in the 1990s. Agricultural growth in the 1990s relied entirely on an increase in conventional factors (land, labour, livestock, fertilizer and machinery). Fuglie (2004) does not investigate the sources of the productivity slowdown but suggests a probable cause to the decline in public and private investment in the agricultural sector. This probable cause is supported by his previous study (Fuglie, 1999) that examined the role of public and private sectors in agricultural research investment. Agricultural technology, induced by research, is recognized as one of the keys to agricultural productivity growth and development.

Philippines: Evenson and Quizon (1991) analyse the contribution of infrastructure and technology investment to Philippine agricultural productivity growth for the period 1948-1984. The duality-based profits function system of output supply and factor demand equations is employed and estimated jointly by generalized least squares. Variables characterising technology include a variable measuring change in high-yielding rice varieties (HYVs) and two research variables, national (Manila-Los Banos-based) and region-specific research. Both national and region research assume a 6-year time lag and no research spillovers among regions. The extension variable has a shorter 2-year time lag. The study finds regional research conducted outside the Manila-Los Banos centre has been more productive in raising productivity than the national research. The HYVs and irrigation show relatively low impact. The estimated internal rate of return to the combined research investment is high at 70 percent, while the rate of return on extension investment is low.

[35] The Tornqvist index uses factor shares to weight the growth in inputs and outputs. The Paasche index uses end-period prices of inputs and outputs as aggregation weights. The Cobb-Douglas index uses revenue shares to weight output growth and the production elasticities estimated from the Cobb-Douglas function to weight input growth.

2.5.3 Empirical Evidence on the Rate of Return to Agricultural Research

As one of the objectives of this thesis is to compute the rates of return on agricultural research investment, this subsection pays particular attention to some findings on the internal rates of return.

1) Empirical evidence from international studies

According to the review study by Alston et al. (2000), the earliest attempt to compute a social rate of return to public R&D appears in McMillen's (1929) book but the more recent literature has its roots in work by Schultz (1953) and Griliches (1957). Schultz (1953) estimated the amount of resources saved by the technological change in U.S. agriculture and compared it with total public investment in agricultural research (Griliches, 1992). The most well-known study in this area is the evaluation of hybrid corn research in the U.S. by Griliches (1957). He evaluated the return on public and private investment, using the economic surplus method,[36] in order to confirm quantitatively the intuitive view that returns to such investment have been high. These two pioneering studies found high rates of return on research investment regardless of the calculation methods.

Since these pioneering studies, there have been a large number of studies assessing the returns on agricultural research investment at both commodity and aggregate levels, using economic surplus and econometric approaches. As noted above, economic surplus is often employed by project evaluation or commodity-specific studies whereas the econometric or regression-based method is widely used at the aggregate level. The majority is dominated by the U.S. In 35 U.S. case studies published over 1965-2005, the median estimate of the social rate of return was 45 percent per year (Fuglie and Heisey, 2007, p.3).

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[36] Adoption of the hybrid corn varieties reduces marginal and average costs thereby shifting the supply curve to the right. Economic benefits are the change in consumer's and producer's surpluses. See Alston et al., 1998b and Evenson, 2001 for more explanation of the economic surplus method.

In the Handbook of Agricultural Economics, Evenson (2001) provides a good review of the evidence on the economic impact of agricultural R&E including a summary of computed IRRs.[37] Most are marginal internal rates of return (MIRR) as they are based on coefficients estimated for the research variable. It is almost unanimous that estimated IRRs are high, but their range is wide.[38] Alston et al., (2000) compiled a total of 289 studies including 1,821 ROR estimates over the past 40 years and found the annual rates of return averaged 80 percent for agricultural R&D.

It is particularly true for Asian agricultural research that IRRs are very high. A survey of case studies by Evenson and Pray (1991) found the rates of return to public research investment in Asia ranged from 19 to 218 percent, returns to public extension investment from 15 to 215 percent and returns to international research investment from 68 to 108 percent. Some examples of the MIRR evidence in Asian agriculture are shown in Table 2.4.

Table 2.4 Rates of Return to National Investment in Research Programs in Asia

Study classified by methods	Country	Program	Period	Commodity	MII
Imputation-accounting					
Pray (1978)	Pakistan	R&D+Ext	1906-56	Crops	34-4
	Pakistan	R&D+Ext	1948-73	Crops	23-3
Pee (1977)	Malaysia	R&D	1932-73	Rubber	24
Pray (1980)	Bangladesh	R&D	1961-77	Wheat, Rice	30-3
Nagy (1991)	Pakistan	R&D	1967-81	Wheat	58
				Maize	19
Pray and Ahmed (1991)	Bangladesh	R&D	1948-81	Crops	35
Ribeiro (1989)	India	Private R&D	1970-87	Sorghum	38
				Pearl millet	176
Metaproduction function					
Tang (1963)	Japan	R&D	1880-58	Aggregate	35
Kahlon et al. (1977)	India	R&D	1960-71	Crops	63
Salmon (1991)	Indonesia	R&D	1972-77	Rice	100+
Khan and Akbari (1986)	Pakistan	R&D	1955-81	Aggregate	36
Librero and Perez (1987)	Philippines	R&D	1956-83	Maize	27-4
				Sugarcane	51-7
Librero and Emlano (1990)	Philippines	R&D	1948-81	Poultry	154
Pray and Ahmed (1991)	Pakistan	R&D	1948-81	Aggregate	100
Byerlee (1991)	Pakistan	R&D	1965-88	Wheat	15-2

[37] See Evenson (2001) Table 6 on pages 597-604 for a summary of over 200 studies of public agricultural research impact. About half of them used the metaproduction function, one-quarter used TFP decomposition and the rest used other methods. All of these studies are based on aggregate data and the majority is time-series data.

[38] To a certain extent, the large range of IRR estimates reflects variations within groups, e.g., applied vs. basic research, or research on natural resources vs. commodities (Alston and Pardey, 2001, p.142). In general, estimates are sensitive to methods, assumptions and coverage.

TFP Decomposition					
Evenson and Jha (1973)	India	R&D	1953-71	Crops	40
Evenson and Flores (1978)	Asia, national	R&D	1950-65	Rice	32-39
	Asia, national	R&D	1966-75	Rice	73-78
Flores et al. (1978)	Tropics	R&D	1966-75	Rice	46-71
Nagy (1991)	Pakistan	R&D+Ext	1959-79	Crops & livestock	64.5
Pray and Ahmed (1991)	Bangladesh	R&D	1948-81	Crops	100+
Evenson and McKinsey (1991)	India	R&D	1956-83	Wheat	50
				Rice	155
				Jowar	117
				Bajra	107
				Maize	94
				Aggregate	218
		Private R&D	1956-83	Aggregate	95
Evenson (1991)	10 Asian LDCs	R&D	1962-82	Wheat	80+
				Rice	59
				Other cereals	80+
				Cassava	80+
				Potatoes	19
				Sweet potatoes	80+
				Groundnuts	44
				All cereals	50
				All staples	53
Profit function					
Evenson (1991)	North India	R&D+Ext	1959-75	Crops	72
Evenson and Quizon (1991)	Philippines	Regional R&D	1948-84	Crops	70
Evenson (1991)	10 Asian LDCs	R&D	1962-82	Wheat	80+
				Rice	59
				Other cereals	80+
				Cassava	80+
				Potatoes	19
				Sweet potatoes	80+
				Groundnuts	44
				All cereals	50
				All staples	53
Setboonsarng and Evenson (1991)	Thailand	Regional R&D	1967-80	Crops	42
Pochanukul (1992)	Thailand	Regional R&D	1961-87	Crops	45

Source: Evenson and Pray 1991, p.356. Note: some updates from Evenson (2001) are added to the original table. Ext is extension; LDCs is least-developed countries. Unless otherwise noted, all programs are national public-sector programs.

2) Empirical evidence from Thai studies

With regard to Thailand, studies on the agricultural research impact on productivity are still limited. As mentioned in the earlier section, most studies concentrate on measuring TFP growth and identifying sources of output growth. Agricultural research is sometimes referred to as the one factor determining TFP growth in the agricultural sector but this is often taken for granted due to the general belief that the research benefits are large.

Previous studies (Poapongsakorn, 2006, Warr, 2006, Chandrachai et al., 2004, Tinakorn and Sussangkarn, 1998, Siamwalla et al., 1987) have shown that past productivity growth in Thai agriculture was remarkably higher than in non-agricultural sectors and contributed significantly to overall economic growth through releasing resources to other sectors. Some studies maintain the relatively high rate of productivity growth in the agricultural sector and its ability to maintain output while releasing factor inputs could be a result of public investment in agricultural research and extension (Tinakorn and Sussangkarn, 1998, p. 35 and 1996, p.81). This presumption is based on the fact that Thailand is an agriculture-based economy and the government has long invested in agricultural research.

A recent study by Poapongsakorn (2006, p.65-87) found technological improvements, including genetic improvement, mechanization and resource management, were the second largest source of agricultural growth after capital accumulation during 1981-2003. These improvements could be the result of long standing investment in public research, mostly in genetic improvement, and private research, mostly in mechanization. Poapongsakorn (2006, p.54) also emphasizes that R&E is important to agricultural productivity growth in Thailand, and that there is still inadequate research planning and prioritization. This view was shared by Siamwalla et al., (1987) who advocate continued public investment in agricultural research for new technology. However, these two studies do not provide any empirical evidence on the particular impact of agricultural R&E on agricultural output and productivity growth.

Studies measuring rates of return on agricultural research in Thailand are limited. While two outstanding studies by Setboonsarng and Evenson (1991) and Pochanukul (1992) investigated the particular role of research and computed the corresponding rates of return, they were focused only on crops.[39] These two studies used a profit function approach which does not allow for factor substitution in response to relative price changes (Coxhead, 1992) and the associated productivity is the partial productivity of variable inputs holding fixed factors constant (Pochanukul, 1992). Other studies measure returns to investment in major agricultural commodities, e.g.,

[39] There are not many previous ex post studies on the impact of research and they concentrated only on production of individual crops such as rice and maize (Pochanukul, 1992, p.167).

Jaroensathapornkul (2007) for rice, Isvilanonda (2000) for jasmine rice and Adulavidhaya et al., (1987) for rice and corn.[40]

Setboonsarng and Evenson (1991) conduct a metaprofit function-based analysis of the supply of rice, corn and other crops and the demand for labour, machinery and fertilizer in Thai agriculture. A pooled time-series and cross-section data set was utilized for 19 agro-economic zones during the period 1967-1980. Output supply and factor demand equations take the normalized quadratic functional form and are estimated jointly by the seemingly unrelated regression (SUR) of Zellner. The model includes three variable inputs- labour, machinery and fertilizer, fixed factor infrastructure and technology variables. The emphasis of their study is on the role of the technology variable represented by research expenditure. Research capital is a regional stock of research constructed from regional research investment (aggregated for all crops) during 1950-1979 based on the presumed time lag structure. The study assumes no depreciation on the lag structure and no research spillovers are taken into account.

Their results show the impact of research and extension (R&E) on output supply and productivity are positive but small. The overall elasticity of output with respect to investment in R&E is approximately 0.25. The net elasticity on productivity is 0.09 implying an internal rate of return to investment in R&E of 42 percent. Their results also reveal R&E impacts on factor choice in favour of mechanization. Research programs in particular appear to have a strong bias toward mechanization and against fertilizer use.

Pochanukul (1992) also studies the economic impact of public crops research on the productivity of variable inputs, farm income, output supply and input demand. Her study uses the normalized quadratic restricted profit function applied to a pooled time-series and cross-section data during 1961-1987 for 19 agro-economic zones. The research variable is constructed, using the research budget from 1950 to 1988, as

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[40] These studies mostly used benefit/cost ratio.

national research capital weighted by the estimated transferability parameter (greater transferability implies larger interregional spillovers) for the relevant zone and the time lag for each crop group.[41] However, research spillovers within a country were only captured for varietal improvement type of rice research and the international research spillovers from international research institutes were ignored.[42]

The result shows crops research improves real farm income and the productivity of variable inputs by increasing aggregate output and reducing the utilization of aggregate variable inputs. A 1 percent increase in research can increase the productivity of variable inputs by about 0.1 percent. Agricultural research has bias effects against rice in favour of other crops. In contrast with Setboonsarng and Evenson (1991) cited above Pochanukul (1992) described this technical change as being of a 'labour-using and machinery-saving type' (p.212). The estimated marginal rate of return from research is 44.95 percent, which is comparable to the study of Setboonsarng and Evenson (1991). The high rate of return suggests additional investment in public crops research is worthwhile.

2.6 Conclusion

This last section summarizes the main findings from the literature review, bringing out important findings for filling gaps in the literature. They are listed in the following bullet points.

Main findings:

- The impact of agricultural research on agricultural TFP has been positive and significant in most studies. The magnitude of the productivity effects varies among empirical studies.

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[41] The study classifies crops into four major crop groups, i.e., rice, field crops, tree crops and vegetables.

[42] Pochanukul (1992, p.82) noted that the TFP index is a preferred measure of research output. However, at that time the index has never been estimated in Thailand and estimating this index requires considerable effort which would involve another elaborate piece of work.

- It takes an uncertain number of years for agricultural research to affect productivity. Identifying research lags is a matter of empirical study. A constrained and short lag structure is typically imposed. The arbitrary truncation of the lag distribution for the stream of research benefits could lead to serious upward biases in the rate of return. Allowing for flexible, dynamic and infinite lag structure has recently been a challenge.
- International research spillovers are largely ignored in most studies due to the lack of data. Some studies have accounted for spatial spillovers within a country using cross-section or panel data.
- The attribution issue of distinguishing among major sources of innovation or types of research expenditure has become increasingly important. All important factors affecting productivity should be taken into account.
- The rates of return on agricultural research investment have been large and their range is wide. They are sensitive to data and estimation methods.
- Existing ROR estimates, mostly public-sector research, are largely subject to the omitted variable bias mainly due to the omission of other sources of technology such as private and foreign research. They are widely perceived to be overestimated. However, losses that would have occurred in the absence of research have been ignored, possibly causing underestimated ROR.

Filling gaps in the literature for Thai agriculture:

- Despite a substantial number of studies, the linkage between research and TFP in Thai agriculture remains empirically untested.
- There has never been study that takes into account the role of private research, university research and international research spillovers.
- Long-run relationships and dynamic lag structure between measured productivity and its determinants have not been investigated.
- No study has estimated rate of return to Thai agricultural research at an aggregate level. Previous studies have only focused on crops and TFP has never been used in agricultural research impact studies.

Chapter 3

3. Background of Thai Agriculture and the Agricultural Research System

3.1 Introduction

During the 1960s and early 1970s, land abundance and labour surplus had resulted in a rapid expansion of Thai agriculture giving it a leading role in terms of GDP growth, exports and employment (Siamwalla et al., 1991, Poapongsakorn, 2006). The rapid growth was attained at the expense of forest land and degradation of natural resources. Industrialization in the 1980s also attracted resources and labour away from agriculture to manufacturing and services. As a result, the sector has relied more on tractors, agricultural machinery and new technology. Amidst the increasing scarcity of conventional inputs, the role of agricultural research as a major source of technology and innovation has become increasingly important.

This chapter aims to provide a background on Thai agriculture with an emphasis on output, productivity and agricultural research. It is divided into two parts to present a background on Thai agriculture and the agricultural research system. The first part (section 3.2) reviews the background of the Thai agricultural sector, describing its characteristics in terms of output, inputs and productivity. The basic forces driving the development of the agricultural sector and Thai agricultural policies are also discussed. The second part (section 3.3) provides the historical background of the Thai agricultural research system. Funding sources and the characteristics of major agricultural research performers are described. The problems and challenge facing the research system are also briefly reviewed.

3.2 Agriculture in the Thai Economy

Until the 1980s, when its leading role was superseded by industry, Thailand has been an agriculture-based economy and it is still critically important to the Thai economy. The agricultural sector has continued to contribute to overall economic development by being an important source of rural income and export earnings.[43] It also provides raw materials for agribusiness and ensures household food security.

The secular decline of agriculture relative to industry has been commonly observed in an open economy experiencing rapid economic growth (Johnston and Mellor, 1961, Coxhead and Plangpraphan, 1998).[44] The labour force, land and capital requirements for infrastructure and for manufacturing and other expanding sectors have been drawn from agriculture over time. Despite the declining shares of agricultural output and labour force, Thai agriculture continues to contribute to economic growth through releasing resources to more productive sectors while maintaining output. In other words, despite the declining share for agriculture, the sector continues to contribute to overall economic growth using fewer resources.[45] The Thai agricultural sector has never been stagnant and its dynamic role continues to form a basis for development in the Thai economy (Warr, 2005, 2006).

The following provides the background for Thai agriculture in general by analysing the sector's specific characteristics in terms of output, inputs and productivity. Then, the process of agricultural development and sources of changes are described. Lastly, agricultural policies are briefly reviewed.

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[43] Thailand is a major net agricultural exporter, particularly for rice, rubber, cassava, sugar and poultry products (Warr, 2008). The majority of poor people in Thailand reside in rural areas and are directly involved in agricultural production (Warr, 2004).

[44] See Martin and Warr (1994), Siamwalla (1996), Coxhead and Plangpraphan (1998) for the explanation of agriculture's relative decline in Thailand.

[45] Johnston and Mellor (1961) provide a thorough conceptual background on how agriculture contributes to economic development.

3.2.1 Outputs

The contribution of agricultural GDP in overall GDP has been declining continuously since 1970.[46] As shown in Table 3.1, the share of agricultural GDP at constant prices (1988) accounted for 15.39 percent of total GDP over the study period of 1970-2006. Despite the declining share of agricultural value added, the agricultural sector still manages to grow at an average growth rate of 3.02 percent per year (Table 3.2).[47] Agricultural outputs recorded negative growth during the economic crisis in 1997. However, both the share and the rate of growth of agricultural GDP increased after the economic crisis.

Table 3.1 Agriculture in Thai Economy during 1970-2006

	GDP All sectors	**GDP Agriculture**	**Agriculture share in GDP**	**Composition of Agriculture**				
				Crops	**Livestock**	**Fisheries**	**Forestry**	**Agricul[illegible] Servi[illegible]**
	(m. baht)	(m. baht)	(% of GDP)	(% of Agriculture GDP)				
1970-1975	551,002	132,304	24.10	63.19	8.71	13.20	10.62	4.2[illegible]
1976-1980	812,058	164,675	20.40	64.78	10.30	11.46	8.76	4.7[illegible]
1981-1985	1,078,649	192,471	17.87	68.66	10.16	10.61	5.99	4.5[illegible]
1986-1990	1,577,830	226,019	14.54	68.19	11.63	11.45	4.48	4.2[illegible]
1991-1995	2,500,010	262,522	10.61	65.72	11.76	16.99	2.07	3.4[illegible]
1996-2000	2,963,604	291,481	9.85	67.95	11.02	16.85	1.47	2.7[illegible]
2001-2006	3,562,353	344,779	9.73	69.48	11.18	16.06	1.10	2.1[illegible]
1970-2006	**1,874,078**	**231,036**	**15.39**	**66.82**	**10.64**	**13.85**	**4.98**	**3.7[illegible]**

Source: National Economic and Social Development Board (NESDB)
Note: GDP is measured as real value added at constant 1988 prices.

Within the agricultural sector, crops production has long occupied the largest share of total agricultural output, followed by fisheries, livestock, forestry and agricultural services, respectively. However, in terms of the average annual growth rate, livestock GDP growth is largest during the study period, followed by fisheries and crops. The expansion in livestock is mostly attributed to the higher demand for poultry exports, particularly from European markets (Poapongsakorn, 2006). For other sectors, as shown in Table 3.2, forestry and agricultural services are relatively insignificant and

[46] Since GDP is measured as real value added, the notion 'GDP' is used interchangeably with 'output' and 'value added' throughout this thesis. Chapter 4 provides more explanation on output and input data as well as showing the full data set.
[47] The discrete approximation to instantaneous rate of change over time is applied, percentage rate of growth of any variable X is calculated as $(\ln X_t - \ln X_{t-1}) \times 100$ or $\ln(X_t/X_{t-1}) \times 100$.

have negative annual growth rates. Since this thesis focuses on the crops and livestock sectors, the important characteristics of these major sectors are briefly reviewed in the following.

Table 3.2 Average Annual Percentage Rates of Growth of Real Outputs, 1971-2006

	GDP growth All sectors (% per year)	Agricultural GDP growth (% per year)					
		All	Crops	Livestock	Fisheries	Forestry	Agricultural Services
1971-1980	6.48	3.32	3.98	5.84	-0.28	-0.28	5.24
1981-1990	7.56	3.27	3.42	4.34	6.15	-6.67	2.01
1991-2000	4.36	2.74	2.92	1.34	5.24	-6.44	-1.93
2001-2006	4.96	2.55	2.41	3.79	3.10	1.89	-3.11
1971-2006	**5.94**	**3.02**	**3.27**	**3.83**	**3.60**	**-3.40**	**0.96**

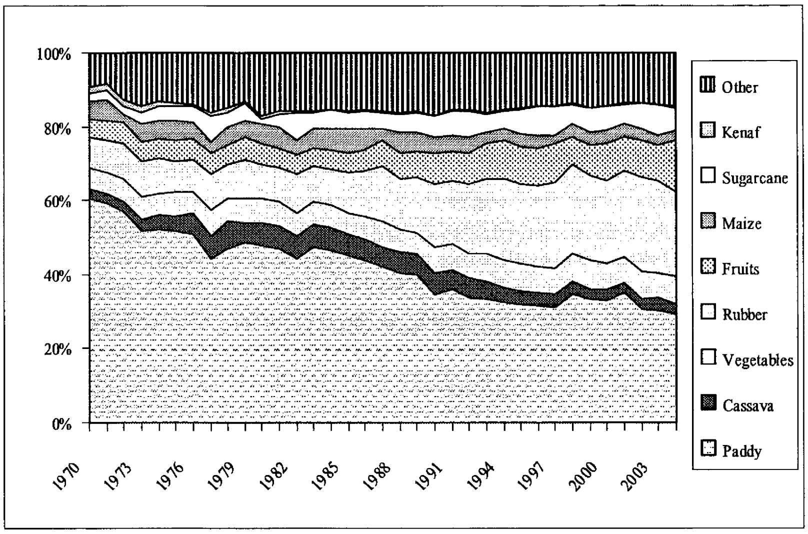
Source: National Economic and Social Development Board (NESDB)

Note: GDP at 1988 fixed-price is measured as real value added. Percentage rate of growth of GDP is calculated as $\ln(GDP_t/GDP_{t-1})\times 100$.

Crops: Within the crops sector, rice has been the dominant output but its share has been declining and there were marked changes in the composition of major crops (Figure 3.1). The sector diversified away from rice monoculture toward multiple cropping, particularly upland crops, between 1960 and 1980 and then toward high-value crops. Poapongsakorn et al. (1995) explained that the crop diversification process was driven by the changes in comparative advantage and input intensities. The change in cropping mixes is also regarded as an important factor that helps maintain the moderate growth rate in the agricultural sector.

There was a rapid expansion in traditional crops such as rice, cassava, sugarcane and maize during the 1960s to the early 1970s. This expansion was mainly due to the availability of land and public investment in infrastructure, notably roads and irrigation. From the late 1970s, in which the land frontier was exhausted, there were changes in the cropping pattern from traditional to high value crops such as rubber, soybeans, tree crops and flowers. More recently, in response to the increasing demand for biofuels, high-value crops have extended to fuel crops, e.g., oil palm and sugarcane. Table 3.3 shows the production of major crops.

Figure 3.1 Percentage Share of Crops Value Added by Type of Crops, 1970-2004



Source: Poapongsakorn (2006)
Note: the sequence in which shown in the diagram is the same as the sequence of the legend.

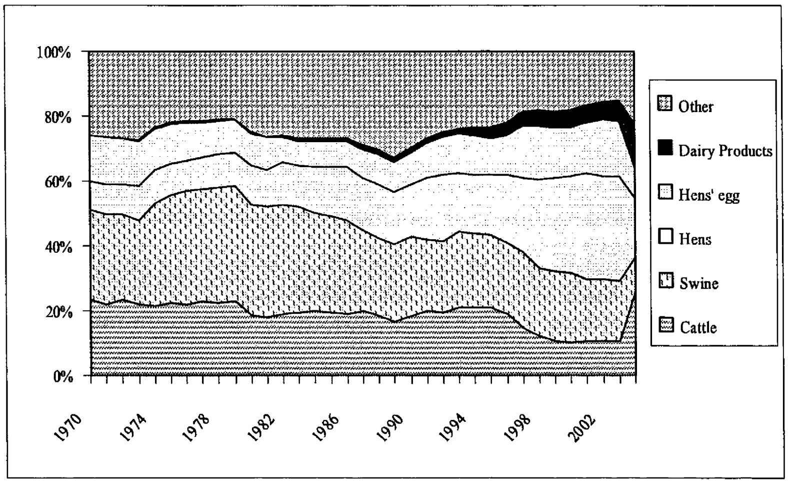
Table 3.3 Major Crops Production in Thailand, 1970-2006

	Production (1,000 tons)				Annual growth rate (% per year)
	1970-1980	1981-1990	1991-2000	2001-2006	1970-2006
Rice	15,051	18,984	22,082	28,995	1.80
Cassava	8,870	19,585	18,221	19,324	5.23
Sugarcane	13,945	27,074	47,983	57,676	6.21
Maize	2,338	3,904	4,064	4,125	2.71
Oil Palm	72	628	2,310	4,983	17.19
Soybeans	98	339	399	235	4.02
Kenaf	326	188	92	27	-13.31
Cotton	66	102	69	20	-4.02
Rubber	394	919	2,012	2,852	6.58
Pineapple	1,627	1,675	2,164	2,118	3.98

Source: Office of Agricultural Economics (OAE)
Note: Production is average quantity during the relevant period.

Livestock: As shown in Figure 3.2, livestock production has largely been dominated by poultry, swine and cattle. There was a remarkable expansion of poultry and swine industries during the 1970s. After that, the share of swine value added has continuously declined, which can be partly attributed to low farm gate prices due to the monopsonistic power of the carcass wholesalers (Poapongsakorn, 1985). This reduces the relative profitability and lowers the incentives for farmers to stay in the swine industry. In contrast, the poultry industry (broiler and laying hens in particular) is regarded as a success story of Thai livestock production. The success was driven by research and extension, which introduced modern breeds of poultry and advanced methods of raising them, together with the contract farming methods pioneered by large agri-business in the early 1970s (Siamwalla et al., 1993). On the other hand, cattle were initially raised as a cheap power source for ploughing and transport before being raised purposely for beef production in recent years.

Figure 3.2 Percentage of Livestock Value Added by Products, 1970-2004



Source: Poapongsakorn (2006)
Note: the sequence in which shown in the diagram is the same as the sequence of the legend.

Table 3.4 Number of Livestock in Thailand, 1970-2006

	Number of livestock (1,000 heads)				Annual growth rate (% per year)
	1970-1980	1981-1990	1991-2000	2001-2006	1970-2006
Layer	13,091	17,869	34,240	30,705	2.54
Broiler	893	862	1,760	2,582	0.75
Swine	683	743	1,011	1,245	1.12
Cattle	2,312	2,644	3,107	2,858	0.72
Dairy Cows	6	43	196	330	14.13
Buffalos	3,631	3,646	2,140	1,032	-3.18

Source: Office of Agricultural Economics (OAE)
Note: Number of livestock is average quantity during the relevant period.

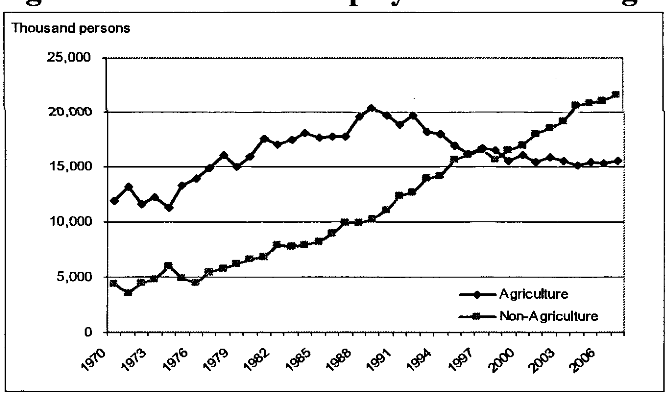
Table 3.4 summarizes the numbers of livestock and annual growth rate during 1970 to 2006. The numbers of poultry, swine, cattle and dairy cows has increased over time. The exception is buffalos, where numbers have declined as Thai farms have become more mechanized and no longer use animals as the primary source of power. On the other hand, dairy cows increased substantially with an average annual growth rate of 14.13 percent per year. This is in line with government promotion and increasing nutritional awareness in favour of milk consumption.

3.2.2 Inputs

1) Labour

Thai agriculture has long been a major source of employment generation. Over the study period, 1970-2006, agricultural employment accounted for more than half of total employment for almost three decades. However, particularly since the early 1980s, the share of agricultural employment in total employment has declined. This declining trend of agricultural employment is in line with the structural change of the Thai economy that has shifted from agricultural-based to industrialized, attracting agricultural labour towards industries and services. Figure 3.3 shows the number of agricultural workers has declined while that of non-agriculture increased. Since 1999, the number of non-agriculture workers has exceeded that of agriculture.

Figure 3.3 Number of Employed Persons in Agriculture and Non-Agriculture



Source: Labour Force Survey (LFS), National Statistical Office (NSO)

Within the agricultural sector, the largest source of employment is in the crops sector, followed by livestock and fisheries. Following the same trend found in overall agriculture, the employment share in the crops sector has also declined while the shares of livestock and fisheries have increased. In particular, the employment share of livestock sector has increased distinctly in recent years. The average annual growth rate of livestock employment over the study period is also the highest, at 8.19

percent. This is in accordance with the largest growth of livestock GDP that results mainly from the expansion of poultry production. The average growth rates in other agricultural subsectors are relatively small, notably in crops production. The average annual growth rate of employment, drawn from the Labour Force Survey (LFS), is summarized in Table 3.5.

Table 3.5 Average Annual Percentage Rates of Growth of Employment, 1971-2006

		Agricultural Employment Growth (% per year)			
	All sectors (%)	**All**	**Crops**	**Livestock**	**Fisheries &Others**
1971-1980	3.23	3.38	3.33	6.49	4.01
1981-1990	3.26	2.27	2.06	9.46	4.72
1991-2000	0.92	-1.73	-2.00	1.71	2.75
2001-2006	1.69	-0.70	-2.52	19.71	0.24
1971-2006	**2.34**	**0.97**	**0.52**	**8.19**	**3.23**

Source: Labour Force Survey (LFS), National Statistical Office (NSO) and Thailand Development Research Institute (TDRI)

It is interesting to find the highest growth in livestock employment during 2001-2006. By looking at the LFS data at a disaggregated level (Table 3.6), the data reveal that this expansion came mainly from the production of cattle and other large-scale animals. There was also employment growth in small-scale animal production, including poultry and swine, but to a lesser extent. This probably occurred because poultry and the swine industry have become more modernized and rely less on labour. Moreover, the employment growth in the large-scale animal sector coincided with the government program that promoted cattle production by giving away cattle to farm households.[48] Therefore, it is likely the remarkable growth is attributable to the government intervention.

[48] The program gives away millions of cattle to farm households through an ad-hoc agency called SPV or special purpose vehicles. The program was initiated in 2002 and became active during 2003-2005.

Table 3.6 Employment in Livestock Subsector, 2000-2006

	Large-scale animals sector (persons)	Growth rate (%)	Other livestock sector (persons)	Growth rate (%)
2000	444,847		174,916	
2001	611,035	31.74	333,048	64.40
2002	654,338	6.85	401,820	18.77
2003	929,149	35.06	378,057	-6.10
2004	1,232,742	28.27	271,249	-33.20
2005	1,701,610	32.23	296,021	8.74
2006	1,708,859	0.43	313,923	5.87

Source: National Statistical Office (NSO)

Note: The data are classified under ISIC code 0121 and 0122. Large-scale animals sector (0121) includes cattle, buffalo, sheep, goat and dairy cows. Other livestock sector (0122) includes small-scale and animal products, e.g., poultry, swine, etc.

It should be noted that migrant workers from neighbouring countries are not accounted for in the LFS data. Foreign migrants have become important to the Thai economy and the agricultural sector since 1996 (Chalamwong, 1996).[49] Most migrant workers have come from Myanmar, Laos and Cambodia. They have been concentrated in low-skilled jobs and employed in agriculture and fisheries, construction, manufacturing and services. Approximately 25 percent of migrants are in agriculture, 15 percent in fisheries, 40 percent in industry and 20 percent in services. In overall agriculture, migrants are the dominant source of employment in fisheries while Thais still dominate employment in crops and livestock (Martin, 2007).

The total number of migrant workers, both registered and unregistered, has grown rapidly from about 700,000 in 1996 to 1.8 million in 2007, accounting for about 2.2 percent and 5 percent of the Thai labour force, respectively. Since 1996, Thai migrant worker policy has permitted employers to register the migrants they employ. The number of migrants coming into Thailand for job purposes has risen and issues involving migrant workers have increasingly gained public attention. The number of workers has been estimated by several studies (Chalamwong et al., 2003, Archawanijkul, 2004, Martin, 2007, Chalamwong and Prugsamatz, 2009). Using the total number of migrant workers from 1996 to 2006 and the approximate shares of

[49] From an interview with Dr.Yongyuth Chalamwong, Research Director for Labour Development, Human Resources and Social Development Program, TDRI.

migrants in agriculture and fisheries provided in the report of the International Labour Organization (Martin, 2007), rough estimates of migrant workers in the agricultural sector are obtained as shown in Table 3.7.

Table 3.7 Foreign Migrant Workers in Thailand, 1996-2006

	Registered (persons)	Non-registered (persons)	Total (persons)	Estimates in overall agriculture (persons)
1996	293,652	406,348	700,000	280,000
1997	293,652	424,037	717,689	287,076
1998	90,911	870,556	961,467	384,587
1999	99,974	886,915	986,889	394,756
2000	99,956	563,820	663,776	265,510
2001	568,249	281,751	850,000	340,000
2002	409,339	558,910	968,249	387,300
2003	288,780	711,220	1,000,000	400,000
2004	849,552	149,848	999,400	399,760
2005	705,293	807,294	1,512,587	605,035
2006	668,576	1,104,773	1,773,349	709,340

Source: Ministry of Labour (Martin, 2007, Table 2, page 4). Note that the total number includes all types of migrants, that is, minority groups living in border provinces, refugees and illegal labour. The estimates in overall agriculture supposedly represent the maximum numbers of workers.

2) Land

During the 1970s, land abundance was considered an important contributor to agricultural growth. However, expansion of the land frontier came to an end in 1978.[50] As shown in Table 3.8, the average rates of growth of land area, both land used (land utilization) and cultivated areas, dropped significantly from the 1980s.[51] The stock of land used for crops production has continued to drop until recent years whereas the cultivated area, which includes multiple cropping, has increased slightly. This implies an increasing role of irrigation that enables the second rice and multiple crop plantations during dry seasons. However, the majority of farms still depend on rain for crops production while only about one-fourth of the total land used in Thailand was irrigated up to 2006. Table 3.9 shows the proportion of irrigated area in comparison to the total agricultural land area. The proportion of irrigated area has increased over time but at a declining rate.

[50] Thailand is unique among Asian countries in that the land under cultivation per agricultural worker actually was increasing until as late as 1977 (Siamwalla and Setboonsarng, 1991, p.238).
[51] See the definitions of land areas and full data sets in Chapter 4. There are two sets of land data. The first set is the stock of land area or land utilization. The second set is cultivated land area, which account for multiple cropping and actual planted area may fluctuate from year to year.

Table 3.8 Average Annual Percentage Rates of Growth of Land Area, 1971-2006

	Land Utilization (% per year)				Cultivated Area (% per year)		
					Planted area	Public&private	
	Crops	Pasture	Others	Total	Crops	Livestock	Total
1971-1980	3.02	4.82	-4.40	2.34	3.16	2.46	3.11
1981-1990	1.05	3.48	0.75	1.05	0.95	1.17	0.96
1991-2000	-0.14	1.34	0.77	-0.07	-0.01	-3.90	-0.22
2001-2006	-0.16	2.96	-0.05	-0.13	0.01	-0.01	0.01
1971-2006	**1.07**	**3.17**	**-0.81**	**0.90**	**1.14**	**-0.08**	**1.07**

Source: Office of Agricultural Economics (OAE), Department of Livestock Development (DLD) and Poapongsakorn (2006)

Table 3.9 Land under Irrigation, 1970-2006

	Accumulated Irrigated Area (rai)	Land Use Area (rai)	Proportion of Irrigated Area (%)	Growth rate of Irrigated Area (% per year)
1970-1980	13,977,235	109,916,079	12.62	5.75
1981-1990	23,664,053	128,085,803	18.44	3.49
1991-2000	29,065,272	131,656,808	22.08	1.39
2001-2006	32,124,641	130,644,954	24.59	1.47
1970-2006	**23,615,964**	**124,064,127**	**18.69**	**3.20**

Source: Office of Agricultural Economics (OAE)
Note: Rai is a unit used for measuring the size of land area in Thailand, 1 hectare = 6.25 rai.

Crops have accounted for the largest share of land area within agriculture and rice production, in particular, has dominated the use of agricultural land. However, its share has been declining, especially in major rice.[52] There has been a shift away from rice production in favour of other crops, especially high value crops. In recent years, there has been a remarkable expansion in the planted areas of oil palm, rubber and fruit, such as durian, mangosteen and longan. The main driving forces behind this are the rise in export demand and the increase in demand for palm oil as a source of energy.

For livestock, pasture or grass area has increased during 2001-2006, but when considering both public and private livestock area the average growth rate has decreased slightly (Table 3.8). This is due partly to the outbreak of avian influenza in 2004, resulting in a significant drop in the private area for poultry production.

[52] There are two main types of rice; major rice and second rice. Major rice is grown during the rainy season while second rice is grown during the dry season. For example, in the Central Plains region, the rainy season is from May to October and the dry season is from November to April (Office of Agricultural Economics, 2006b).

3) Capital

The NESDB's agricultural capital stock comprises both public and private capital, mainly including construction costs of the irrigation system, agricultural machinery and equipment, farm buildings and imported breeding livestock.[53] Table 3.10 presents the capital stock net of annual depreciation in the overall agricultural sector for the study period of 1970 to 2006.

Following the same pattern as agricultural output, net capital stock in agriculture has been increasing but its share in total net capital stock has been declining. The movement of the capital stock tends to follow the business cycle. Agricultural capital stock increased steadily during the 1970s and the early 1980s and growth rates were found to be high during the economic boom period of 1987-1996. Much slower growth rates were observed following the economic crisis in 1997 but capital growth began to pick up again as the economy recovered from the crisis.

Table 3.10 Net Capital Stock at Constant (1988) Prices, 1970-2006

	Net Capital Stock at 1988 prices			**Growth Rate**	
	All sectors (m. baht)	**Agriculture** (m. baht)	**Agricultural share** (%)	**All sectors** (% / year)	**Agriculture** (% / year)
1970-1975	1,303,071	245,998	18.90	4.00	3.07
1976-1980	1,722,628	277,084	16.19	6.14	0.93
1981-1985	2,434,626	297,309	12.30	6.97	1.72
1986-1990	3,512,955	335,725	9.69	8.75	2.96
1991-1995	6,176,627	442,831	7.22	11.26	7.16
1996-2000	8,931,190	613,375	6.86	3.98	5.00
2001-2006	9,827,385	734,548	7.47	2.24	3.52
1970-2006	**4,883,050**	**424,727**	**11.34**	**6.08**	**3.48**

Source: National Economic and Social Development Board (NESDB). The capital stock series were officially launched in 1998 and the calculation was dated back to 1970.

As capital plays an increasingly important role in Thai agriculture, the following briefly reviews the major components of capital stock. In particular, farm machinery and equipment are important to crop production while breeding animals are major

[53] The breeding livestock covers only those imported by the public sector, specifically the Department of Livestock Development.

capital inputs to livestock production. Public capital is also briefly mentioned as it is another important factor driving agricultural production.[54]

Farm Mechanization

Mechanization in Thai agriculture can be categorized into three forms (Krasachat, 1997): mechanization of ploughing (tractors), mechanization of irrigation (water pumps), and mechanization of threshing (threshers). The spread of tractor usage was evident from the mid-1960s to the mid-1970s. The spread was induced by the need to clear new land and replace the use of animal power (buffalo and cattle) which is less productive. It was also partly induced by the rise in crop prices and the cheaper cost of tractors (Thailand Development Research Institute, 1988).[55] Multiple-cropping that relies on an irrigation system stimulates the use of water pumps. The lack of farm labour and draft animals during the peak farming season encourages rice farmers to rely on threshing equipment (Krasachat, 1997). Farm mechanization has become increasingly important and the number of units of major equipment has been increasing continuously since 1971, as shown in Table 3.11. The rapid growth in non-agricultural labour demand and wages also provided incentives for migration thereby driving rapid farm mechanization (Coxhead and Plangpraphan, 1998, p.9).[56]

Table 3.11 Machinery and Equipment in Thai Agriculture, 1971-2006

	2-wheel tractors		Big tractors		Water pumps		Threshing equipment	
	Unit	Growth	Unit	Growth	Unit	Growth	Unit	Growth
1971-1980	126,817	22.51	18,034	23.42	292,579	14.07	5,553	30.36
1981-1990	469,480	11.13	40,065	5.78	726,137	8.27	32,929	9.42
1991-2000	1,802,233	15.89	198,681	22.56	2,338,182	13.64	76,506	11.31
2001-2006	5,387,328	13.15	886,688	18.57	6,131,592	11.79	177,337	9.89
1971-2006	**1,564,146**	**15.95**	**219,109**	**17.48**	**1,954,403**	**11.96**	**61,498**	**15.84**

Source: Office of Agricultural Economics (OAE)
Note: Unit and growth represent average numbers and average annual percentage rates of change in the corresponding period.

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[54] Some of which are not necessarily included in the NESDB's capital stock.

[55] Expansion of the local tractor industry since the mid-1960s has also lowered the cost of tractors (Thailand Development Research Institute, 1988).

[56] Coxhead and Plangpraphan (1998) showed that rapid mechanization was one response to rising wages. Agricultural mechanization grew exponentially during the rapid intersectoral labour migration as labour and machinery are short-run substitutes (p.10).

Livestock Capital

Unlike crops, livestock production does not rely heavily on farm machinery and equipment. The inventory of breeding livestock is usually considered a major capital input to livestock production (Poapongsakorn, 2006, Kompas and Che, 2004). In the past, most animal breeds were imported from the U.S., Australia and Japan. More recently, livestock breeds have increasingly been developed locally led by private companies and universities.[57]

Public Capital

Expansion of agricultural production in the past was largely attributable to heavy investment in public infrastructure, particularly roads and irrigation (Siamwalla et al., 1993). In terms of government spending on physical infrastructure, roads have always been the top priority (Fan et al., 2004). Rural roads in particular provide farmers with access to markets and technology thereby reducing the costs of production and facilitating new technology adoption. The length of rural roads has increased substantially, experiencing about a ten-fold increase over the period 1977 to 2000 (Fan et al., 2004).

Development of irrigation has been crucial in helping to overcome water shortages during the dry season. The largest expansion of irrigated area was during the 1970s. Since the 1990s the increase has been minor (Fan et al., 2004). Public investment in irrigation has been mainly devoted to rice production, which is concentrated in the Central region. This rice-oriented specificity was criticized as an obstacle to the full utilization of public capital embodied in the irrigation structure and to agricultural diversification (Siamwalla et al., 1991 and Manarangsan, 2002).

[57] Unfortunately, there are no official data on the quantity of breeding animals developed locally and the NESDB capital stock data only include imported breeding livestock by the public sector. However, the NESDB capital stock series will include private-sector breeding livestock in the near future.

4) Other Input Materials

Fertilizers

Fertilizers are important in raising agricultural production and output yield. They are a direct input to crops production and indirectly to livestock farms through animal feeds. Chemical fertilizers have been widely used and their usage has increased steadily as a result of the decline in agricultural land area and the deterioration in soil quality of cultivated land. Nevertheless, the national average rate of fertilizer application shown in Table 3.12 is still low (Budhaka, 1987, p.459 and Krasachat, 1997, p.28). Besides the vital role of chemical fertilizers, there is also a tendency to a greater use of natural and biological fertilizers due to an increasing awareness of food safety (Office of Agricultural Economics, 2004, p.57).

Table 3.12 Quantity and Price of Chemical Fertilizers Use in Agriculture, 1970-2006

	Use of fertilizers		Price of fertilizers			
	Ton	Growth rate (% per year)	Baht/ton		Growth rate (% per year)	
			Current prices	Constant prices	Current prices	Constant prices
1970-1980	556,387	10.32	3,368	13,593	7.37	-1.88
1981-1990	1,554,382	12.15	4,883	9,235	0.69	-3.62
1991-2000	3,212,001	3.22	6,281	7,600	3.84	-0.59
2001-2006	3,941,997	2.32	8,808	8,347	7.53	4.92
1970-2006	**2,092,866**	**7.52**	**5,447**	**9,945**	**4.56**	**-0.87**

Source: Office of Agricultural Economics (OAE)
Note: Number in the table is an average during the relevant period. The Consumer price index (CPI) is used as a deflator in converting prices of fertilizers into real terms. The CPI is obtained from the Bureau of Trade and Economic Indices, Ministry of Commerce.[58]

As almost all chemical fertilizers are imported, movements in fertilizer prices largely follow import prices (Office of Agricultural Economics, 2004).[59] The prices of fertilizers tend to fluctuate widely following prices in the world market and exchange rate movements. Over the study period, fertilizers at current prices have increased steadily. Inflation-adjusted prices show some fluctuations and a notable decline after

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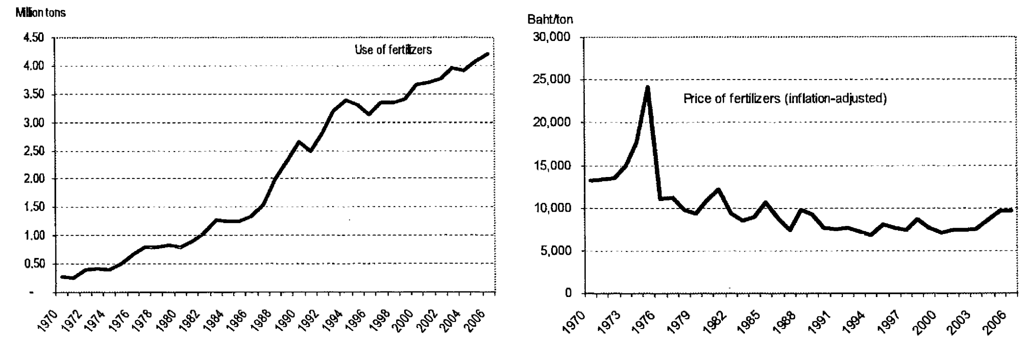
[58] Although the producer price index (PPI) is a preferred deflator, its data series are not consistently available.

[59] All chemical fertilizers were either imported or mixed with imported materials. Local producers basically import raw materials from abroad to mix with various nutrient formulas that meet domestic demand.

the peak was reached in the post-oil shock year of 1975 (Thailand Development Research Institute, 1988). In recent years, rising fertilizer prices in tandem with rising fuel costs have caused a concern and created uncertainty regarding production costs in Thai agriculture. The quantity and prices of chemical fertilizers for agriculture use are shown in Table 3.12 and Figure 3.4.

Figure 3.4 Quantity and Price of Chemical Fertilizers Use in Agriculture



Source: Office of Agricultural Economics (OAE). Note: Fertilizers consist of nitrogen, phosphorus and potassium. The OAE calculated the use of fertilizer as import + last year carry over + local manufacturing - raw materials - industrial used - next year carry over. The CPI is used as a deflator.

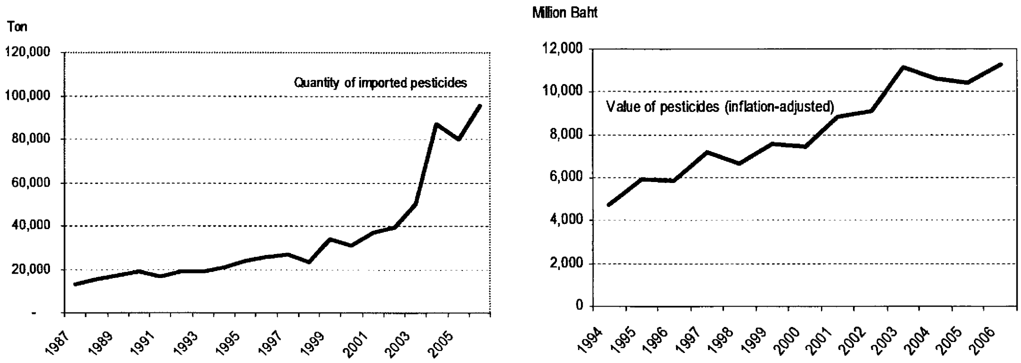
Pesticides

Pesticides are used to prevent crop losses from insects and diseases and to protect product quality. Similar to fertilizers, the use of pesticides has increased continuously and almost all pesticides used in Thailand are imported. The three most heavily applied pesticides in Thailand are insecticides, herbicides and fungicides, which account for more than 90 percent of the pesticides imported each year (Thapinta and Hudak, 2000).

According to the Office of Agricultural Economics (2004), pesticides were heavily used during the 1960s with an average annual rate of growth of 30 percent. After that, the rate of growth of pesticides used in agriculture slowed. In the 1990s the annual growth rate was only 10 percent. During 2001-2006, the amount of imported pesticides rose steeply at an average rate of 18.8 percent per year. Nevertheless, the use of chemical pesticides is expected to decline in future due to an increasing awareness of food safety and environmental problems caused by pesticide residuals

(Office of Agricultural Economics, 2004, p.57). The quantity and value of imported pesticides are shown in Figure 3.5.

Figure 3.5 Quantity and Value of Imported Pesticides, 1987-2006



Source: Department of Agriculture (DOA) and Office of Agricultural Economics (OAE).
Note: Imported pesticides consist of insecticides, fungicides, herbicides and others. The consumer price index (CPI) is used as a deflator in converting value of pesticides into real terms.

3.2.3 Agricultural Productivity

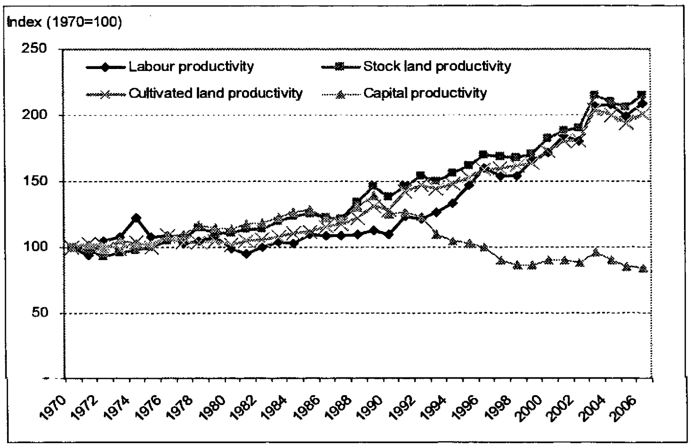
Productivity is classified into two types – partial productivity and total factor productivity (TFP). Partial productivity takes into account only one particular input, holding other inputs constant, while TFP takes into account all important inputs. Although TFP is generally preferred, partial productivity cannot be disregarded. Both are important in comparing the production performance of various outputs. Since TFP is thoroughly investigated in Chapter 4, the following discussion focuses only on partial productivity in Thai agriculture.

Partial Productivity

Conventionally, partial productivity is measured as labour productivity or output per unit of worker and land productivity or output per unit of land, often called yield. Since there are three major inputs in the agricultural sector – labour, land and capital – this section describes changes in partial productivity with respect to each of these major inputs. Particular emphasis is given to labour and land productivity which are commonly used as measures of partial productivity. In addition, changes in yields of some selected agricultural commodities are presented.

Changes of labour, land and capital productivity over the study period are summarized in Figure 3.6 using the index normalized at 100 in 1970.[60] In general, labour and land productivity share an upward trend while capital productivity has been declining since 1990. Holding other factor inputs constant, labour and land productivity has risen over time while capital productivity increased until 1989 and then began to decline. This is because capital stock has been accumulated more rapidly in recent years while agricultural workers and land area have been increasingly limited. However, inputs are not constant in practice with labour especially quite mobile. Therefore, it is important to keep in mind that partial productivity indices are subject to the constraint that other factors are held fixed.

Figure 3.6 Change of Partial Productivity (1988 fixed-prices)



Source: Calculated based on output and input data described in the previous section. Output is real value added, labour is number of employed persons, land stock is land used in agriculture, cultivated land is planted area accounted for multiple cropping plus public and private livestock area, and capital stock is net capital stock in the 1988 fixed-price. See details in Appendix 3 Table 3.24.

Labour Productivity

Labour productivity is often used as an index of production efficiency and an index of increase in income (Shintani, 2003). Labour productivity is measured as real output (at 1988 fixed-prices) divided by the number of employed workers (Table 3.13). In general, output per worker in the overall agricultural sector has increased at the rate of 2.05 percent per year between 1970 and 2006. Such a rate is quite high compared

[60] Normalization (to 100 or 1) is typical of aggregate indices presented for productivity computations (Morrison Paul, 1999, p.33).

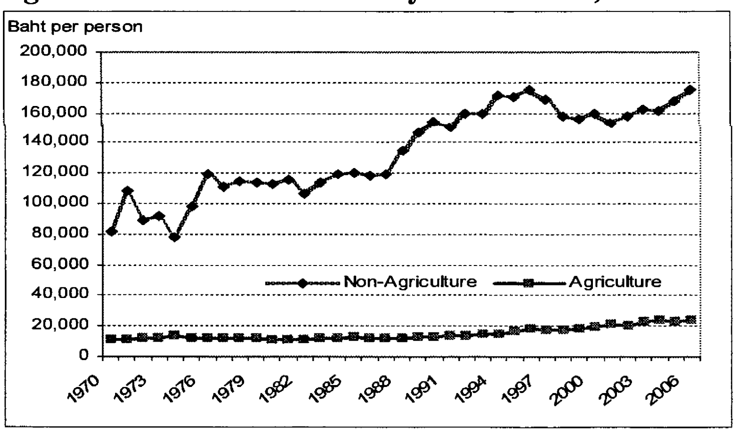
with the average annual rate of growth of labour productivity in the non-agricultural sector, estimated at 2.12 percent. Table 3.13 shows these calculations and presents labour productivity in various sub-periods. It indicates output per worker in both the agricultural and non-agricultural sectors has increased but that of agriculture has risen more rapidly particularly since the 1990s. The level of productivity in the non-agricultural sector is about nine-fold higher than in the agricultural sector. Figure 3.7 illustrates the changes in labour productivity in both the agricultural and non-agricultural sectors over the study period.

Table 3.13 Labour Productivity and Annual Growth Rate, 1970-2006

	Output per worker		Growth rate (% per year)	
	Agriculture	Non-Agriculture	Agriculture	Non-Agriculture
1970-1980	11,919.03	101,716.25	-0.05	3.22
1981-1990	11,988.10	124,776.25	1.00	3.09
1991-2000	16,450.72	162,914.11	4.47	0.37
2001-2006	22,353.52	163,148.20	3.25	1.58
1970-2006	**14,854.56**	**134,450.58**	**2.05**	**2.12**

Source: Calculated based on output data from the NESDB and employment data from the NSO

Figure 3.7 Labour Productivity in Thailand, 1970-2006



Source: Calculated based on output data from the NESDB and employment data from the NSO

Land Productivity (Yield)

Land productivity or output yield is a conventional measure of productivity, particularly for crops, because land plays such an important role in agricultural production. Land productivity in overall agriculture is measured as real value added in the 1988 fixed-price divided by the stock of land used in agriculture. As shown in Table 3.14, output yield (using land utilization data) has increased markedly at the rate of 2.12 percent per year over the period of 1970 to 2006. Output per cultivated area, accounting for multiple cropping, is higher but growing at a lower average annual growth rate of 1.95 percent.

The average annual growth rate of output yield was relatively low during the 1970s due to the rapid expansion of the cultivated land area. Since the 1980s, the growth rates have increased substantially as a result of the declining arable land. In addition, the land-labour ratio has a negative growth rate reflecting limited land area per agricultural worker.

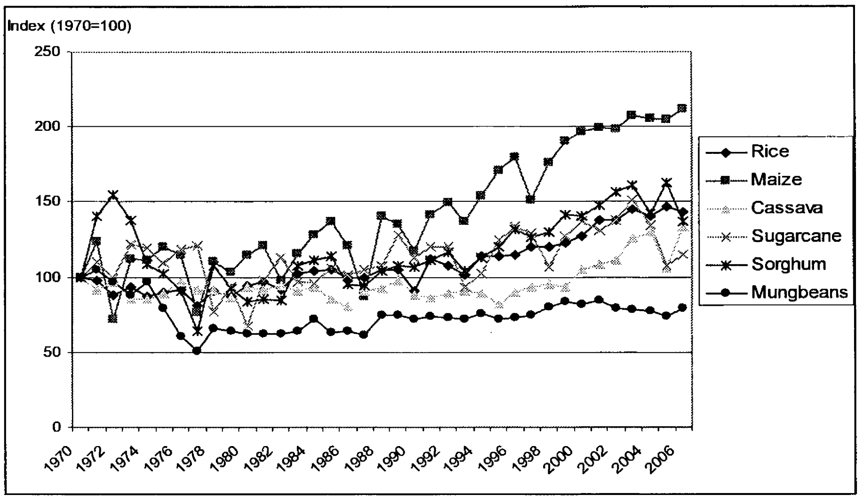
Table 3.14 Land Productivity and Land-Labour Ratio, 1970-2006

	Output yield (Baht per rai)		**Growth rate of yield** (% per year)		**Land-Labour ratio** (Rai per worker)	
	Land used	Cultivated area	Land used	Cultivated area	Land used	Cultivated area
1970-1980	1,333.44	1,556.54	0.98	0.21	8.98	7.66
1981-1990	1,630.60	1,748.12	2.23	2.31	7.37	6.88
1991-2000	2,104.40	2,346.50	2.81	2.96	7.79	6.99
2001-2006	2,640.31	2,928.02	2.68	2.54	8.46	7.63
1970-2006	**1,834.04**	**2,044.22**	**2.12**	**1.95**	**8.14**	**7.26**

Source: Calculated based on output data from the NESDB and land data from the OAE.
Note: 1 rai = 0.16 hectare or 1 hectare = 6.25 rai. Land used is stock of land. Cultivated area includes multiple cropping. See Chapter 4 for more explanation and full data set.

With regard to yield per cultivated area of major crops, Figure 3.8 presents changes of yield per rai of major food and feed crops during 1970 to 2006. With the exception of mungbeans, yields of these important crops, including rice, maize, cassava, sugarcane and sorghum have generally been increasing over time. The percentage growth rates of yields of these crops as well as other important export oriented commodities are presented in Table 3.15.

Figure 3.8 Output Yields of Food and Feed Crops in Thai Agriculture, 1970-2006



Source: Office of Agricultural Economics (OAE).
Note: Rice includes major and second rice.

Table 3.15 Average Annual Growth Rates of Yield Per Rai for Major Crops

Unit: Percent per year

	1970-1980	1981-1990	1991-2000	2001-2006	**1970-2006**
Food and Feed Crops					
Rice	-0.57	-0.39	3.36	1.98	**1.00**
Maize	1.41	0.18	5.17	1.21	**2.08**
Cassava	-0.70	-0.52	1.73	3.92	**0.80**
Sorghum	-1.79	2.43	2.76	-0.39	**0.88**
Sugarcane	-3.85	5.10	1.91	-3.02	**0.37**
Mungbeans	-4.71	1.50	1.22	-0.56	**-0.65**
Oil Crops					
Oil palm	-11.00	13.22	1.24	2.04	**4.27**
Soybeans	-0.76	4.49	1.18	1.29	**1.58**
Fibre Crops					
Kenaf	3.12	-0.10	2.86	-0.13	**1.61**
Cotton	3.79	0.34	0.51	-1.33	**1.07**
Trees and Fruit Trees					
Rubber	2.88	9.89	3.92	1.90	**4.95**
Pineapple	6.13	-1.71	-0.57	2.89	**1.55**

Source: Calculated based on yield data from the Office of Agricultural Economics (OAE)
Note: Data for oil palm are available only from 1977. Soybeans include first and second crops. See details in Appendix 3 Table 3.26.

The yield of rice, which is the major crop in Thai agriculture, had a negative growth rate during the first two decades with the rate of growth turning positive in the latter periods. Its average growth rate over the whole period is estimated at 1 percent per annum. Crops that have a noticeably high growth rate of yield per rai are rubber, oil palm and maize. Their average annual growth rates were estimated at 4.95, 4.27 and

2.08 percent, respectively. In particular, yields per cultivated area of maize and rubber have increased with positive growth rates in all sub-periods.

3.2.4 Agricultural Development: Boom Bust and Beyond

The past performance of Thai agriculture, from rapid growth to decline and recent recovery, is well demonstrated in Poapongsakorn (2006, p.5-18). Table 3.16 summarizes the development of the agricultural growth pattern with its sources of change.

Table 3.16 Thai Agricultural Growth and Sources of Change

Thai agriculture	Sources of change
Agricultural growth 1960s – 1970s	• Massive expansion into forested areas • Public investment in infrastructure, primary education • Conservative fiscal and monetary policies • World commodity boom (1972-74)
Agricultural decline 1980 – mid 1990s	• Cost-price squeeze • Exhaustion of land frontier • Depression of agricultural prices • Asset-price bubble • Dutch-disease: manufacturing boom drew resources away from agriculture
Agricultural negative growth 1996 – 1998	• Reduction in world agricultural price in 1998 • The El Nino-induced drought • The decline of some livestock subsectors and marine fisheries
Agricultural recovery 1999 – 2006	• Rapid growth of world economy • Increased world agricultural prices due to China's rising demand for commodities (e.g. rubber, cassava) and rising fuel costs

Note: This table is summarized and adapted from Poapongsakorn (2006)

The agricultural sector was the economy's "engine of growth" in the 1960s and 1970s. The main driving force was attributable to expansion of the land frontier and heavy public investment in roads and irrigation. As shown in Table 3.17, the average annual growth rate of agricultural value added was relatively high during the 1960s to mid-1980s. During 1986 to 1996, there was a rapid expansion in the manufacturing sector drawing resources away from agriculture. Agricultural growth dropped sharply during the period 1986 to 1990. The decline in agricultural growth was in line with structural change toward an industrialized economy as well as many external factors, particularly a worldwide depression in major agricultural product prices.

Table 3.17 Value Added Growth Rates of Major Sectors in Thailand

Unit: Percent per year

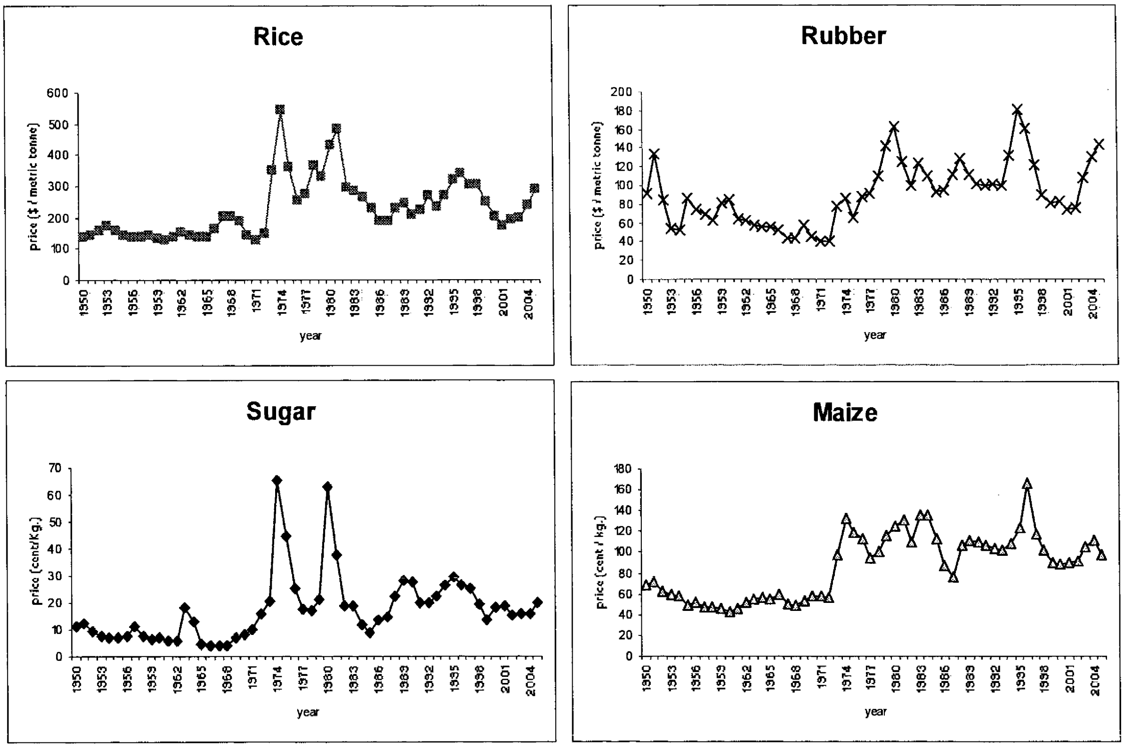
	Agriculture	Manufacturing	Services	All Sectors
1961-1980	4.35	9.33	7.47	6.99
1981-1985	4.10	4.79	7.35	5.30
1986-1990	2.45	14.04	6.61	9.81
1991-1996	3.39	10.59	4.79	7.85
1997-1998	-1.09	-5.03	1.34	-6.24
1999-2006	3.07	6.78	4.67	4.85
1961-2006	**3.53**	**8.45**	**6.26**	**6.28**

Source: Calculated from National Income data of NESDB

Floatation of the baht in the 1997 economic crisis resulted in a sharp depreciation and improved the competitiveness of agricultural exports (Poapongsakorn, 2006, p. 9). However, agricultural exports continued to decline and agricultural value added recorded negative growth during 1997 to 1998, mainly because of the decline in world agricultural prices in 1998 and the effect of the El-Nino drought in 1997-1998 (Poapongsakorn, 2006).

The influence of world agricultural prices confirms the integrated role of Thai agriculture in the world economy, especially as major producers of agricultural products such as rice, rubber, poultry and cultured shrimp. Favourable external factors also contributed to the recovery of agricultural growth in recent years, for example, the rise in the world prices of rubber, cassava and rice. World prices of major agricultural commodities are shown in Figure 3.9.

Figure 3.9 World Price of Rice, Rubber, Sugar and Maize



Source: Poapongsakorn (2006), original data are from the World Bank and International Monetary Fund

Agricultural Diversification

Crops production is still dominated by staple crops such as rice, rubber, cassava, sugar cane, maize and kenaf. Nonetheless, there has been a changing production structure in Thai agriculture in tandem with the changing comparative advantage and changing demand pattern toward high value added and safe products (Poapongsakorn et al., 1995). There has been a shift from traditional crops such as rice, maize and cassava to high value crops, particularly in horticulture.

Agricultural commodities and exports have been diversified from major crops to processed agricultural products, such as frozen chicken, shrimp and canned pineapple and high value products such as coffee, pepper, cut flowers, orchids, fruit and vegetables (Table 3.18). While rice is still the dominant crop occupying the majority of land area and labour force, its export value ranked after rubber since the 1990s and after shrimp in 1991-1995 and 2001-2002. The diversification into high value products has helped farmers cope with the cost-price squeeze problem, which is the situation where the cost of production increases through a rapid increase in the real wage rate and input prices, while world output prices decline (Poapongsakorn, 2006). In addition, the diversification of commodity production was also an important source of productivity growth as it released resources to commodities with higher value and market potential (Fuglie, 2001).

Table 3.18 Major Agricultural Exports, 1970-2006

Unit: Million baht

Commodity	1970-1980	1981-1990	1991-2000	2001-2006	**1970-2006**
Rice	8,759.90	26,843.34	52,944.51	86,164.25	38,141.16
Rubber	5,880.71	19,682.51	68,723.59	205,081.12	58,898.26
Shrimp	1,103.23	9,048.19	47,520.20	78,295.54	28,313.32
Cassava products	6,298.27	19,185.80	19,247.12	31,400.47	17,351.70
Sugar and products	3,911.60	11,164.80	25,308.70	36,578.59	16,952.28
Poultry meat	355.67	3,231.44	12,083.70	12,806.99	7,476.51
Canned Pineapple	1,432.24	3,355.11	7,374.68	10,742.79	6,414.33
Cut flowers	245.42	440.91	869.46	2,204.67	888.99

Source: Office of Agricultural Economics (OAE)
Notes: Numbers in the table are average values during sub-periods. Data for poultry meat and cut flowers (including orchids) are available from 1976.

Future Challenge

The future challenge facing Thai agriculture lies in its ability to adjust and respond to changing comparative advantage given the resource constraints that it faces. Increasing water scarcity, exhausted land frontier and a declining agricultural labour force has placed constraints on the future performance of the agricultural sector. A more liberalized trading environment, from both multilateral and bilateral agreements, also places a considerable challenge on Thai farmers to adjust production efficiently and respond quickly to changing demand. All of these constraints and challenges will shape new cropping patterns and production structures to be less reliant on input expansion and more focused on technological progress. Productivity growth, especially through technical change is recognized as a means to address these major challenges and constraints.

3.2.5 Review of Agricultural Policies

Agricultural policies are briefly reviewed in this section in accordance with national economic and social development (NESDB) plans. The review first highlights major sectoral policy issues relevant to the scope of this thesis, followed by trade policy.

In general, significant agricultural policies since the beginning of the first national development plan in 1961 up to the present have been implemented through subsidies for irrigation, rural credits, agricultural inputs and investment in rural infrastructure and agricultural research. In summarizing policy changes, it is convenient to discuss them in relation to the national development plans. These plans have emphasized the importance of agricultural research, showing its importance in the minds of policy makers. However, while the NESDB plans covered a broad range of agricultural policy proposals, the subsequent implementation of these policies has often resulted in significant variation from the initial proposal. Table 3.19 summarizes major agricultural policies highlighted in the NESDB plans.

During the first to third national plans, infrastructure development (such as roads, irrigation and electricity) has been the key focus of agricultural policies. Conservation of natural resources has also received policy attention since the second plan as the agricultural expansion during the 1960s to 1970s came with the cost of land encroachment and environmental degradation. Agricultural diversification was emphasized to reduce price risk and raise farm income thereby reducing income disparity between urban and rural areas. Agricultural research has been promoted to enhance productivity since the first plan, emphasizing on major exporting crops, such as rice and rubber. Livestock development focused on breeding, animal health protection and extension services that encouraged farmers to expand livestock farming.

Agricultural productivity and the competitiveness of agricultural commodities have received more attention since the fifth plan and the role of science and technology has been reinforced. In order to compete in world markets and raise farm income, recent policies focus more on increasing value added to agricultural products. Research and development (R&D) is recognized as a means of enhancing agricultural productivity.

Table 3.19 Summary of Agricultural Policy Proposals, as Reflected in the National Development Plans

National plan	Period	Agricultural policy proposals
1	1961-1966	Infrastructure development, agricultural research and extension, agricultural cooperatives and credits
2	1967-1971	Infrastructure development, agricultural productivity, research and extension, rural development, natural resources conservation and agricultural diversification
3	1972-1976	Infrastructure development, increase farm income, improve quality of export commodities, improve water system and land allocation
4	1977-1981	Agricultural diversification (reduce price risk and raise farm income), land reform, preserve forest as water reservoirs
5	1982-1986	Increase productivity or yield per rai, land reform and land registration, agricultural credits, science and technology
6	1987-1991	Reduce cost of production, increase competitiveness, income distribution, agricultural diversification, science and technology, biotechnology research
7	1992-1996	Income distribution, increase farmers' income and standard of living, conservation of environment and natural resources, development of agro-processing industry
8	1997-2001	Agricultural sustainability (promote natural farming, organic farming, integrated farming and agro forestry), conservation of environment and natural resources
9	2002-2006	Self-sufficiency, productivity, competitiveness, science and technology development, conservation of environment and natural resources
10	2007-2011	Agricultural restructuring: support R&D, generate value creation in products, promote agricultural sustainability, enhance productivity and efficient use of water resources and land management

Source: Summarized from the National Economic and Social Development Plans, available at http://www.nesdb.go.th/Default.aspx?tabid=62 and Tongpan (1993)

Trade policy was unfavorable to agriculture in the early periods. Before the 1960s, the Thai government imposed export taxes on principal export commodities such as rice and rubber.[61] Since 1980, taxation of agricultural commodities has been gradually eliminated and policy has become more favorable through direct public support for agriculture such as subsidies for irrigation and agricultural inputs and

[61] The rice export tax began in 1955 while a rubber export tax was imposed in 1935 (Tongpan, 1993). See Warr (2008) for a review of commodity-specific trade policy including rice, maize, cassava, soybeans, sugar, palm oil, rubber and urea fertilizer.

price support programs for agricultural commodities (Siamwalla et al., 1991, Fuglie, 2001). The rice export tax was abolished in 1986 while the export levy on rubber has been lifted since 1990 (Warr, 2008, p.268).[62] Given that Thailand is a major agricultural exporter, trade policy has primarily taken the form of direct transfers and subsidized loans to farmers, rather than intervention in agricultural commodity markets (Warr, 2008). In general, while agricultural trade policy is relatively liberal, Thailand cannot be considered a free-trading country with regard to some agricultural commodities, including soybeans, palm oil, rubber, rice and sugar (Warr, 2008).

3.3 Agricultural Research System in Thailand

This section provides some background on the Thai agricultural research system beginning with an historical summary. Agricultural research funding is then described, followed by a review of the characteristics and trends of the major types of agricultural research investment – public, university, private and foreign. Common characteristics of agricultural research activities are also described. Finally, problems and future challenges for the Thai agricultural research system are discussed.

3.3.1 Historical Development of the Agricultural Research System[63]

Agricultural research in Thailand began in 1903[64] but only became active after World War II,[65] due to the pre-war lack of personnel and the government's low priority for research investment (Pochanukul, 1992). Its historical development is closely linked with the evolution of technology application in Thai agriculture, which was summarized in a review study by the Asian Development Bank (Office of Agricultural Economics, 1998). Prior to 1955, agricultural production relied on

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[62] Warr (2008) showed that Thailand's rice exports are currently neither protected nor subsidized to any significant extent. Since 1990 the nominal rate of protection on rubber has been roughly zero.
[63] This section is mainly drawn from OAE (1998), Pochanukul (1992) and Isarangkura (1986).
[64] Historically, this began when a Thai prince who graduated in agriculture abroad returned home and set up education programs in farming as well as an agricultural breeding program (Isarangkura, 1986).
[65] The worldwide expansion of agricultural research and extension programs in the post World War II era, especially in the 1950s, 1960s, and 1970s, was heavily funded by grants and loans from international agencies (Evenson, 2001, p.615).

traditional technology. From 1955 to 1965, there was moderate application of two-wheel hand tractors and other imported technology, e.g., fertilizer, irrigation and new seeds. A more systematic introduction of production techniques took place during 1966 to 1975. In 1975-1976, the green revolution was launched with the introduction of high yielding varieties for rice, corn and soybean. Since 1977, the agricultural research focus has been extended to cover other areas particularly in developing pest resistant varieties, and natural and organic farming (Office of Agricultural Economics, 1998). More recently, research has focused on increasing agricultural productivity while preserving natural resources and protecting the environment.

Thailand's agricultural research system become more structured after 1956-59 when the National Research Council of Thailand (NRCT) was set up to look after all research activities. Its direction was set in line with the national development plan prepared by the National Economic and Social Development Board (NESDB) that was also established in the same period (Isvilanonda and Praneetvatakul, 2003). National research policy and guidance became more organized when the first research policy was set in 1977. However, there has never been a national agricultural research plan. There is only a technology and science development plan which broadly guides agricultural research activities in various institutions (Isarangkura, 1986, p.24).

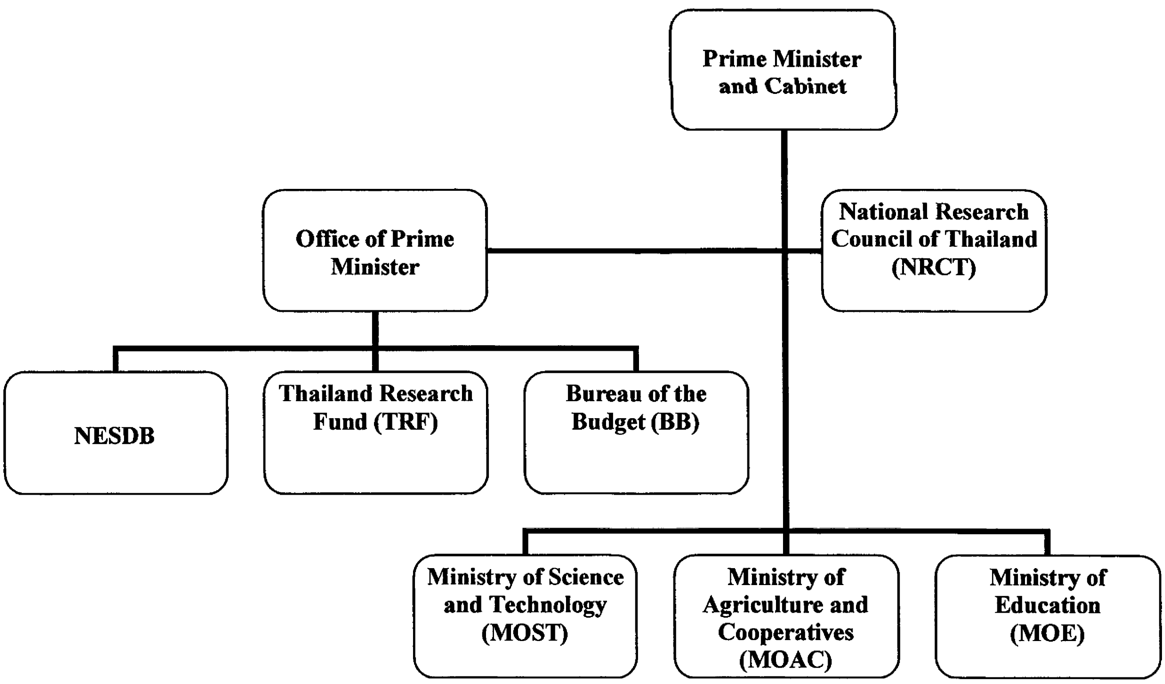
The importance of agricultural research has been realized since the first national development plan in 1961. Improvement in agricultural research was emphasized as a fundamental basis for future development in the first and second plans. Since the late 1970s, the government has reinforced the role of science and technology in raising productivity. A clear linkage between productivity and research was spelled out, emphasizing the enhancement of productivity and higher value added products through several areas including support of R&D and transfer of technology in agriculture. In the ninth development plan, the emphasis of R&D promotion was on science and technology which includes biotechnology research.

The agricultural research system in Thailand mainly consists of research in crops, livestock and fisheries, conducted by various institutions, primarily government agencies. Agricultural research institutes were initially centralized in the Bangkok area and later decentralized in regional research centres. However, research is still top-down in the sense that the involvement of farmers and other stakeholders in determining research priorities is rare. The prioritization and adaptation process are dominated by the executive boards in the Ministry of Agriculture and Cooperatives (MOAC).

3.3.2 Agricultural Research Funding

The government budget is the major source of national agricultural research funding in Thailand. The budget allocation mechanism involves the NESDB in determining general guidelines for research direction, and the NRCT in examining whether the proposed research projects are feasible and justified by the national plan. The budget allocation then has to pass final approval from Cabinet. The structure of the main funding channels is shown in Figure 3.10.

Figure 3.10 Structure of Agricultural Research Funding



Source: Adapted from Fuglie (2001).

The approved budget is mainly provided by the Bureau of the Budget under the Office of the Prime Minister to the research performing ministries. In addition, each research performing agency may apply for competitive grants from the NRCT and the Thailand Research Fund (TRF). All research projects proposed by government institutions through both funding channels have to be approved by the NRCT, an autonomous agency under the Prime Minister (Isvilanonda and Praneetvatakul, 2003).

The MOAC, MOE and MOST, shown in Figure 3.10, are the three major ministries receiving funding from the government budget. During 1992-1996, MOAC accounted for 52.4 percent of total government budget on research activities, followed by MOE (21.72 percent) and MOST (13.97 percent) (Areekul, 2000). The MOAC is the leading agricultural research performer and the largest share has been dominated by crops research with relatively small budgets for livestock, forestry and fisheries (Fan et al., 2004).

The MOAC consists of four major research performing departments: the Rice Department for rice research, the Department of Agriculture (DOA) for crops research (other than rice),[66] the Department of Livestock Development (DLD) for livestock research, and the Department of Fisheries (DOF) for fisheries research. Although there have been several changes in the MOAC organization structure these four departments remain the core research agencies. Each department consists of many research stations located in all regions. There are also public organizations attached to the MOAC including the Agricultural Research Development Agency (ARDA). The ARDA was established in 2003 providing competitive grants to accelerate commercial agricultural research.

[66] Prior to 1972, the Rice Department was separated from the DOA. It was incorporated into the DOA in 1972 and was separated out again in 2006. See Appendix Table 3.27 for the principal years of the MOAC organizational changes and their annual budget expenditure since the first national development plan in 1961.

Public universities also conduct significant agricultural research, receiving government funds through the Ministry of Education (MOE) and through grants from the TRF and the NRCT. They also receive funding from other private and international sources. The leading research institutes in agricultural research since the 1960s encompass Kasetsart University in the Central region, Khon Kaen University in the Northeast, Chiang Mai University in the North, and Prince of Songkla University in the South. Maejo University in the North is also important as it is the oldest agricultural education institution and used to serve as a research station for Kasetsart University. It was previously known as the Mae Joe Institute of Agricultural Technology and was reorganized and upgraded from an agricultural college to university level in 1975 (Isarangkura, 1986).[67]

Agricultural biotechnology research is funded mainly through the National Science and Technology Development Agency (NSTDA) which is an autonomous agency under the Ministry of Science and Technology.[68] The rest of public agricultural research funding was shared by the Ministry of Industry (for sugar and sugarcane) and the Ministry of Finance (for tobacco).

Other sources of funding are from private companies and bilateral and international organizations.[69] In addition, the government supports private investment in agricultural research by providing tax incentives and subsidized loans (Fuglie, 2001). To a large extent, agricultural research is still considered a service provided by the public sector. Table 3.20 summarizes a list of public institutions conducting agricultural research in Thailand with their main sources of funding.

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[67] Chulalongkorn University has become more involved in agricultural research in the context of rural development in later periods (Isarangkura, 1981).

[68] The Ministry of Science and Technology is former "Ministry of Science, Technology and Energy" which was established in 1979. The NSTDA was established in 1991.

[69] In the past, the government R&D departments could seek external grant assistance for research projects through the Department of Technical and Economic Cooperation (DTEC) under the Prime Minister's Office. Since 2004, Thailand International Development Cooperation Agency (TICA) under the Ministry of Foreign Affairs has been the successor of DTEC. Most of the assistance from foreign sources, e.g., USAID, The World Bank, and the International Fund for Agricultural Development (IFAD), was directed to development projects rather than to pure agricultural projects (Isarangkura, 1986).

Table 3.20 Institutions Conducting Agricultural Research and Sources of Funding

Institutions	Sources of funding	Remarks
1. Ministry of Agriculture and Cooperatives (MOAC) - Department of Agriculture - Rice Department - Department of Livestock Development	- Government budget - National Research Council of Thailand (NRCT)	All research projects require an approval from NRCT
2. Public Organization under MOAC - Agricultural Research Development Agency (ARDA) - Highland Research and Development Institute (HRDI)	- Asian Development Bank (ADB) funds - Commercial service fees - Loans and grants from donor governments and public agencies	ARDA only provides financial support to commercial research.
3. Ministry of Industry - Sugarcane and Sugar Institute	- Government budget	
4. Ministry of Finance - Tobacco Monopoly	- Government budget	
5. Ministry of Science and Technology - National Centre for Genetic Engineering and Biotechnology (BIOTEC) under the NSTDA	- Government budget - Revenue from providing services and commercial projects - Competitive grants from both national and international sources.	
6. Ministry of Education - Kasetsart University - Chiang Mai University - Khon Kaen University - Prince of Songkla University - Maejo University	- Government budget - Competitive grants from both national and international sources - Private sector funding	

Note: This table is adapted and updated from Isarangkura (1986), only crops and livestock research institutions are listed to conform to the scope of this thesis.

3.3.3 Major Agricultural Research Performers

In general, agricultural research has been carried out by several research agencies that can broadly be classified into public, private, university and foreign research. Typically for developing countries, agricultural research is largely conducted by the government. According to the survey jointly conducted by the NRCT and the NSTDA, shown in Table 3.21, the government has dominated R&D expenditure in agricultural science, followed by public universities and private enterprises. The role of public universities has become increasingly important in recent years; particularly in 2005 when its R&D spending share slightly exceeded that of the government. The private sector also conducts research, well-known in seeds and livestock research. However, the surveyed private R&D spending may be underestimated as their questionnaire responding rate is quite low compared with other sectors (NRCT, 2007).

Table 3.21 R&D Expenditure in Agricultural Science Classified By Sector of Performance

	Real R&D Expenditure (million baht, at constant 1988 prices)						
	Government	Universities		Public Enterprise	Private Enterprise	Private Non-Profit	Total
		Public	Private				
1996	**752.09**	**243.63**		**0.80**	**33.01**	**6.66**	**1,036.22**
% in total	73%	24%		0%	3%	1%	100%
1997	**723.18**	**173.38**		**8.19**	**30.51**	**0.43**	**935.71**
% in total	77%	19%		1%	3%	0%	100%
1999	**650.17**	**381.25**		**5.51**	**2.79**	**0.00**	**1,039.72**
% in total	63%	37%		1%	0%	0%	100%
2001	**1,725.93**	**263.79**	**0.68**	**14.52**	**171.41**	**0.00**	**2,176.35**
% in total	79%	12%	0%	1%	8%	0%	100%
2003	**1,127.35**	**415.10**	**0.56**	**25.47**	**278.87**	**1.15**	**1,848.49**
% in total	61%	23%	0%	15%	0%	0%	100%
2005	**627.70**	**675.38**	**0.51**	**22.81**	**363.52**	**3.96**	**1,693.88**
% in total	37%	40%	0%	1%	22%	0%	100%

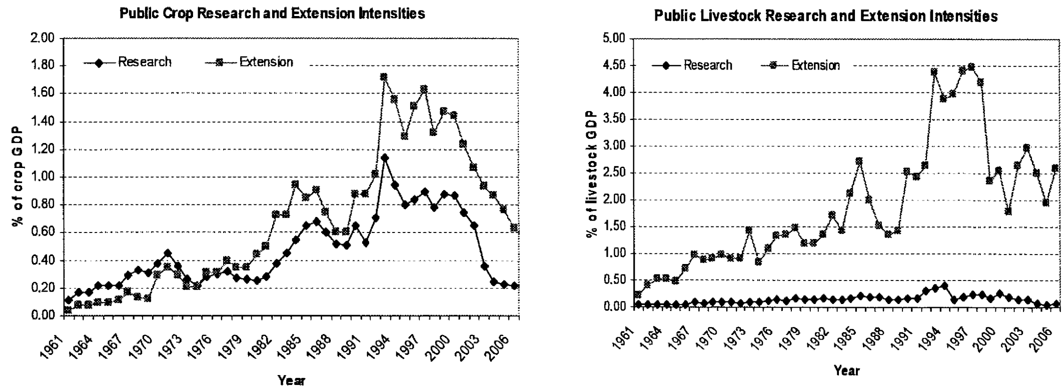
Source: National survey on R&D expenditure and personnel of Thailand, various issues, National Research Council of Thailand (NRCT). Note: Agricultural science includes crops, livestock, fisheries and forestry research. R&D expenditure at current prices was deflated to constant (1988) prices using the implicit GDP deflator.

Farmers also conduct some limited research. Their trial-and-error methods have been said to contribute to technological progress in the horticulture sector and the swine industry (Siamwalla et al., 1993, p.97). Nevertheless, their role in overall agricultural research system is regarded as minor. Major types of agricultural research investment – public, university, private and foreign are discussed in detail as follows.

1) Public Investment in Agricultural Research

Agricultural research activities have primarily been conducted by the government and agriculture has dominated public R&D expenditure in Thailand. Nonetheless, the percentage share of public agricultural research investment in agricultural GDP is still minor, at less than 1 percent, and the budget allocated to agricultural research has declined in recent years. Focusing on crops and livestock, Figure 3.11 shows that during 1961 – 2006 crops research intensity, measured as the research budget share in the crops GDP, was on average at 0.47 percent while the livestock research budget accounts for 0.14 percent of livestock GDP.[70] On average, the public agricultural research intensity is comparable to other Asian countries, although slightly higher as the data are based on budget expenditure. The public research intensity ratios of other countries are shown in Appendix Table 3.29.

Figure 3.11 Agricultural R&E Budget Relative to Agricultural 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.

Both crops and livestock research investment generally increased over three decades from 1961, but began to decline from the mid-1990s, and particularly after 2000. A slight pick-up in the agricultural research budget expenditure was observed in 2006. Crops research expenditure grew at an average annual rate of 9.6 percent in current prices during 1961 to 2006. The government budget allocated to livestock research is very modest. Livestock research expenditure grew by 8.5 percent annually in current prices over the 1961 – 2006 period.

The government plays a dominant role not only in agricultural research but also in extension (the dissemination of research results). Public agricultural research and extension (R&E) are mainly conducted by the MOAC sharing around 95 percent of the total government budget for agricultural R&E (Poapongsakorn, 2006, p.54). Table 3.22 lists major government agencies conducting agricultural R&E in Thailand.

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[70] See description of agricultural research budget data in Chapter 5.

Crops research and extension are undertaken by separate agencies while those of livestock, fisheries, land and forestry are in the same organization.[71] The DOAE was established in 1967, responsible for all crops extension activities. Prior to 1967 crops R&E were undertaken by the DOA and the Rice Department.[72]

Table 3.22 Major Government Agencies Conducting Agricultural R&E in Thailand

	Agricultural Research	Agricultural Extension
Crops	▪ Department of Agriculture (DOA) and Rice Department	▪ Department of Agricultural Extension (DOAE)
Livestock	▪ Department of Livestock Development (DLD)	▪ Department of Livestock Development (DLD)
Fisheries	▪ Department of Fisheries	▪ Department of Fisheries
Land	▪ Land Development Department	▪ Land Development Department
Forest	▪ Royal Forest Department	▪ Royal Forest Department

Note: All organizations are under the MOAC except the Royal Forest Department is now under the Ministry of Natural Resources and Environment.

More than 50 percent of the MOAC's R&E budget is dominated by crops. 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, e.g., corn, sorghum and cotton (Poapongsakorn et al., 1995, p.95). The crops research budget tends to follow demand trends rather than the introduction of new crops. This means the budget was likely expanded in profitable crops that can raise farmers' income (Siamwalla et al., 1993).

Crops research is largely commodity-specific, focusing on developing pest resistant and high yielding varieties. Farming system research to promote mixed cropping and integrated farming is minor. Other research is by discipline, e.g., plant protection, soil and fertilizer research. Adoption of new technologies by farmers depends on the effectiveness of efforts by the DOA and the DOAE and how relevant they are for the farmer.

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[71] The exception is for dairy extension activities. The Dairy Promotion Organization (DPO) was established in 1971 as a state enterprise responsible for dairy promotion in Thailand.
[72] See Appendix Table 3.27 for details.

Livestock research initially focused on veterinary (e.g., control and cure of animal diseases). Later, more emphasis was shifted to husbandry (e.g., breeding, nutrition and artificial insemination) and farm management.[73] Livestock research and extension programs conducted by the DLD mainly focus on large-scale animals, especially beef cattle, dairy cows and buffalos while small-scale animals like swine and poultry are in the hand of private companies.

As shown in Figure 3.11, trends of crops R&E expenditure as percentage shares of their GDP are in the same direction. Government spending on crops extension activities has outpaced that of research since 1975 when The World Bank began providing loans to the Thai government in order to adapt and extend its efficient extension operation.[74] In contrast, the data clearly shows the imbalance between livestock research and extension. The increased overall emphasis on livestock in the government budget allocation has been occupied by extension, which had a much higher rate of growth than research.

It should be noted that the annual government budget published by the Bureau of the Budget is commonly used as a data source of public investment in agricultural research and extension.[75] Nevertheless, it is also common to find differences in the data among different studies. This is mainly due to different classifications of agricultural research activities.[76] In addition, the reporting format of the budget under each department has changed over time, making it difficult to keep a record of consistent data series of the R&E budget. Nonetheless, the Bureau's budget data is the only long data source and should reflect an overall trend of public agricultural R&E expenditure.

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[73] See Appendix Table 3.28 for the disaggregated livestock research budget, 1961-2006. It is not possible to consistently disaggregate crops research by commodities or major research discipline because the classification of activities has changed over time.
[74] The World Bank also introduced the training and visit (T&V) system of extension in the DOAE, which required a number of extension staff to visit farms nationwide (Isarangkura, 1986). The extension budget is higher than research as more staff are hired and are available at the district level. The majority of the R&E budget goes to salaries and wages.
[75] Agricultural research is mainly conducted at the national level (Fan et al., 2004, p.27).
[76] As there are various institutions conducting agricultural research, different research activities under different agencies are included. See Isarangkura (1986, p.30) for more discussion.

2) University Investment in Agricultural Research

Universities have also been actively involved in agricultural research programs. Typically, there is research collaboration between universities, government, private companies and international research institutes. For example, Kasetsart University is the most important public-sector partner of the Thai hybrid corn industry as well as providing elite germplasm for private breeding programs (Fuglie, 2001). Universities are also important sources of skilled researchers and trained scientific staff providing training and technical services to both public and private sector research.

While the DOA focuses on rice and major crops research, universities conduct research on minor crops such as cassava and mungbeans. The most notable success story of university research was in the disease resistant varieties of maize, known as Suwan 1 and Suwan 2, developed at Kasetsart University, and funded by the Rockefeller Foundation (Office of Agricultural Economics, 1998). Universities also collaborate with the DOA in conducting crops research as well as conducting research on behalf of the private company, Charoen Pokphand (CP) Group, under a contract system (Office of Agricultural Economics, 1998).

There is no systematic database of university involvement in agricultural research and their funding sources are various. The major source of funding is from the government budget and the major players are public universities, especially Kasetsart University, Chiang Mai University and Khon Kaen University. On average, about 10 percent of the government research budget has been allocated to universities (Office of Agricultural Economics, 1998). Universities also received funding from other sources, such as international research agencies and private companies. According to the NRCT survey, university research expenditure in agricultural science increased markedly and its share in total agricultural research spending was the highest in 2005.

3) Private Investment in Agricultural Research

The role of the private sector has been important since 1970 when the Charoen Pokphand (CP) Group established a joint venture with a U.S. poultry breeding firm, Arbor Acres (Fuglie, 2001). The CP Group has played an important role in Thai livestock production, particularly in developing feed technology. Animal feed has always been its core business. Private animal research concentrates on poultry and swine, with a principal goal of improving feed efficiency.

The private sector has also played an active role in plant breeding since the late 1970s. Its research is concentrated in developing hybrid seeds for field crops, especially maize used as a main ingredient of animal feed (Fuglie, 2001). Besides developing animal feed and seeds (primarily hybrid corn, vegetables and fruit for export), there is also private research in the form of crop protection chemicals, livestock pharmaceuticals, animal breeding and farm machinery. The private research focus has been adjusted over time to serve market demands and business needs.

Although the private sector has been actively involved in agricultural research in Thailand, there is no systematic record of private investment in research. Fuglie (2001) conducted a survey of private investment in agricultural research in 1996 and estimated that the private sector was responsible for about 13 percent of total agricultural research in Thailand. This is consistent with other developing countries, where the private sector accounts for about 10 to 15 percent of the total research budget (Byerlee and Alex, 1998). Within Asia, the amount of private research investment in Thailand was ranked second after India, followed by Malaysia and China (Pray and Fuglie, 2001). It was estimated that the private research in Thailand accounted for about 0.1 percent of agricultural GDP. However, these estimates are much higher than that of the NRCT (Table 3.21).

In the review study by the ADB (Office of Agricultural Economics, 1998), the absence of a significant private sector was identified as a characteristic of the Thai agricultural research system. Recognizing the importance and limited role of the private-sector, the government encourages more of their involvement. For example, the Board of Investment (BOI) promotes investment in R&D activities through tax and non-tax incentives. The BOI package includes corporate income tax exemption, a waiver of import duty on machinery and raw materials and permission for foreign companies to own agricultural land for research purposes. This is seen by the private sector as encouraging measures especially for seed companies (Fuglie, 2001, p. 92). In 2007, the BOI announced a policy to promote R&D and manufacturing investment in biotechnology.[77] The government has also encouraged private investment in agricultural research by focusing public resources on activities to complement, rather than compete with the private sector (Fuglie, 2001).

4) Foreign Research and International Research Collaboration

Foreign research also plays an important role in transferring technology or knowledge to research agencies in Thailand. It initially came in the form of imported technology. Moderate applications of imported technology, such as fertilizer, new seeds and animal breeds, became a part of Thai agriculture in the mid-1950s and later on was extended to more advanced technology. In the early 1960s, collaborative research was initiated between Thailand and the International Rice Research Institute (IRRI)[78] which 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.[79] 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, p.21).

The most obvious example of technology transfer to Thai agriculture has been in rice, primarily irrigated rice varieties developed by IRRI. The first IRRI scientist assigned to Thailand during 1966 to 1982 brought with him a large collection of IRRI rice genetic materials, contributing to rice improvement in Thailand. The IRRI materials were crossed with Thai varieties yielding the first nonglutinous, semi-dwarf,

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[77] See 'Law and Regulations' under the BOI webpage, available at http://www.boi.go.th/english/download/law_regulations/508/Sor_2_2550.pdf.

[78] IRRI was established in 1960, located in the Philippines. IRRI receives financial support from donor countries and international agencies through the CGIAR.

[79] 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. The number of centres under the CGIAR has changed over time. As of January 2009, there were 15 centres. See their website for details at http://www.cgiar.org/centers/index.html.

photoperiod-insensitive, high-yielding varieties that were then released to Thai farmers (IRRI, 1997). Later, a number of joint research and training programs, primarily between IRRI and the MOAC, followed.

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. The CIMMYT introduced plant materials in 1963 which led to organized wheat research in Thailand. Likewise, hybrid seeds from the CIAT were introduced in 1975 for breeding purposes which formed the initial basis for cassava varietal improvement in Thailand (Isarangkura, 1986).

Furthermore, germplasm was brought in from many other countries, such as 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 very fruitful as in the case of rice varieties developed by IRRI.

The spillovers of foreign technology for livestock can be traced back to the import of the American Brahman in 1954. Foreign research also came through assistance in providing parent stocks, primarily by USAID and the Danish government. Poultry and swine industries also rely on imported breeds and materials from overseas. In contrast to crops, there does not seem to have been significant research collaboration with the CGIAR centres in the case of livestock.

3.3.4 Characteristics of Agricultural Research in Thailand

After describing the characteristics of major types of agricultural research investment in Thailand, there are some common characteristics of agricultural research worth mentioning. These are briefly described in terms of research categories, types of expenditure and research personnel.

According to the National Research Council of Thailand (NRCT), research activities in Thailand are classified into three main categories:

1. Basic research: knowledge from basic research is a theory, law or hypothesis for researchers to apply in future research.
2. Applied research: aims at producing new knowledge or technology for practical uses.
3. Experimental Development: existing knowledge or technology is developed or improved for better uses.

Agricultural research activities are mostly characterized under applied and experimental development research. In 2005, the majority of agricultural research is applied research (51.6 percent), followed by experimental development (33.9 percent) and basic research (14.5 percent) (NRCT, 2007).

With regard to types of research expenditure, current expenditure primarily covering the salaries and wages of research personnel accounts for the largest share of total agricultural research expenditure (Table 3.23). Capital expenditure, comprising the cost of tools and equipment and land and construction materials, is minor.

Table 3.23 Types of Research Expenditure in Agricultural Science (million baht)

	Current expenditure (1988 fixed prices)			**Capital expenditure** (1988 fixed prices)		
	Salaries and wages	Others	Total	Tools and Equipment	Land and Construction	Total
1996	**350.14**	**570.74**	**920.88**	**100.08**	**44.93**	**145.00**
% in total	32.85	53.55	86.40	9.39	4.22	13.60
1997	**753.92**	**389.10**	**1,141.91**	**74.38**	**117.44**	**190.23**
% in total	56.59	29.21	85.72	5.58	8.82	14.28
1999	**762.76**	**372.12**	**1,134.88**	**27.78**	**19.43**	**47.21**
% in total	64.53	31.48	96.01	2.35	1.64	3.99
2001	**1,379.23**	**755.77**	**2,135.00**	**43.66**	**12.03**	**55.69**
% in total	62.96	34.50	97.46	1.99	0.55	2.54
2003	**1,267.09**	**324.60**	**1,591.69**	**15.44**	**8.45**	**23.89**
% in total	78.43	20.09	98.52	0.96	0.52	1.48
2005	**341.96**	**970.23**	**1,312.18**	**23.84**	**14.34**	**38.17**
% in total	25.32	71.85	97.17	1.77	1.06	2.83

Source: National survey on R&D expenditure and personnel of Thailand, various issues, National Research Council of Thailand (NRCT). Note: R&D expenditure at current prices was deflated to constant (1988) prices using the implicit GDP deflator.

In terms of research personnel, there were 4,996 researchers, 3,745 technicians and 5,250 support staff in 2005. The highest number of researchers in agricultural science was in government research agencies, followed by universities, while those in other sectors were minor (Table 3.24). The share of government researchers has declined over the period of 1996 to 2005 while the share of university researchers increased. As indicated in Table 3.24, this increasing university share shows a reversal in 2005. However, as 2005 is currently the latest year for which data is available. There is no way to tell whether or not this is a continuing trend. Of these agricultural researchers, the majority were master-degree graduates, followed by bachelor-degree and PhD graduates.

Table 3.24 Researchers (headcount) in Agricultural Science Classified by Sector of Performance

	Government	Universities		Public Enterprise	Private Enterprise	Private Non-Profit	Total
		Public	Private				
1996	**3,988**	**1,015**	-	**49**	**5**	**143**	**5,200**
% in total	76.69	19.52	-	0.94	0.10	2.75	100.00
1997	**3,216**	**828**		**68**	**56**	**1**	**4,169**
% in total	77.14	19.86		1.63	1.34	0.02	100.00
1999	**2,786**	**1,654**		**32**	**16**	**0**	**4,488**
% in total	62.08	36.85		0.71	0.36	0.00	100.00
2001	**2,406**	**2,381**	**2**	**71**	**362**	**0**	**5,222**
% in total	46.07	45.60	0.04	1.36	6.93	0.00	100.00
2003	**1,889**	**1,684**	**7**	**37**	**0**	**6**	**3,623**
% in total	52.14	46.48	0.19	1.02	0.00	0.17	100.00
2005	**1,980**	**1,878**	**3**	**86**	**984**	**65**	**4,996**
% in total	39.63	37.59	0.06	1.72	19.70	1.30	100.00

Source: National survey on R&D expenditure and personnel of Thailand, various issues, National Research Council of Thailand (NRCT)

3.3.5 Problems and Challenges of Agricultural Research[80]

The main issues facing the Thai agricultural research system are inadequate research priority settings, lack of capable research personnel, underinvestment in public research and poor coordination among research institutes and the linkages with extension. The fact that the research system comprises many research institutes while research planning is unclear results in an overlap of functions and weak coordination,

[80] This section is mainly taken from Office of Agricultural Economics (1998) and Pochanukul (1992).

especially between public and private research. There is also poor coordination between research and extension. As a result, farmers' problems and needs are not properly conveyed to researchers.

Research stations often encounter problems of trained manpower shortage, inadequate budgets and equipment and lack of clear direction in research priorities. There has been insufficient investment in research and unbalanced investment between research and extension. Research is often undervalued because of its time consuming characteristics and the uncertainty of success. It cannot respond quickly to policy makers who tend to prefer short-term returns (Pochanukul, 1992). Further, the R&E programs tend to be commodity-specific and hence there is a lack of multi-disciplinary research. There has been an increasing trend for agricultural diversification requiring mixed and integrated farming research.

Lack of a systematic database of agricultural research expenditure is another shortfall, which obstructs in-depth analysis of the research impact studies. Such analysis can help determine research priorities and policy and enable the country to realize maximum returns on agricultural research investment. Although there are surveys on R&D expenditure conducted in recent years, there are still data discrepancies amongst studies and the data cannot be traced back to the past. Assessing agricultural research impact requires long and consistent data series.

The above issues are not new and some have been raised in previous studies (for example, Isarangkura, 1986, Office of Agricultural Economics, 1998, Pochanukul, 1992). Still, the problems are unresolved and overcoming them is a challenge. To meet the challenges, the agricultural research system needs to address the following points[81];

[81] Points are summarized from the previous studies.

- Increase productivity while reducing use of land and scarce inputs as well as preserving natural resources and environment
- Achieve production and export diversification
- Be more market-friendly and client-oriented
- Focus more on collaborative research and strengthen private and university research
- Strengthen research-extension-farmer linkage
- Decentralize public research funding

Appendix 3 Data for the Background on Thai Agriculture and Research System

Table 3.25 Change of Partial Productivity in Thai Agriculture (1988 fixed prices)

	Real Output	Labour	Labour productivity		Land	Land productivity		Net Capital Stock	Capital productivity	
	(mill. baht)	(mill. persons)	Output/ worker	Index (1970=100)	(mill. rai)	Yield per rai	Index (1970=100)	(mill baht)	Output/ capital	Index (1970=100)
1970	121,863.63	10.80	11,287	100.00	94.17	1,294	100.00	231,338	0.53	100.00
1971	126,532.97	11.88	10,655	94.40	99.39	1,273	98.38	236,422	0.54	101.60
1972	124,611.50	10.51	11,859	105.07	103.55	1,203	92.99	239,408	0.52	98.81
1973	135,328.92	11.07	12,220	108.27	109.35	1,238	95.63	241,756	0.56	106.26
1974	139,813.77	10.13	13,799	122.26	110.45	1,266	97.83	257,365	0.54	103.13
1975	145,672.49	11.98	12,163	107.76	112.21	1,298	100.32	269,698	0.54	102.54
1976	154,035.67	12.59	12,236	108.41	113.11	1,362	105.24	269,098	0.57	108.66
1977	156,729.03	13.47	11,638	103.11	113.80	1,377	106.43	270,896	0.58	109.83
1978	173,380.41	14.69	11,803	104.57	116.44	1,489	115.07	282,261	0.61	116.61
1979	169,309.35	13.85	12,221	108.28	117.60	1,440	111.25	280,682	0.60	114.51
1980	169,921.00	15.13	11,229	99.49	119.00	1,428	110.35	282,485	0.60	114.19
1981	179,057.00	16.64	10,764	95.37	121.29	1,476	114.08	288,052	0.62	118.00
1982	182,649.00	16.18	11,288	100.01	123.59	1,478	114.21	291,672	0.63	118.88
1983	192,003.00	16.43	11,687	103.54	124.23	1,546	119.43	298,429	0.64	122.13
1984	200,091.00	17.23	11,614	102.90	125.31	1,597	123.39	300,604	0.67	126.36
1985	208,555.00	16.79	12,418	110.03	128.60	1,622	125.32	307,789	0.68	128.63
1986	208,103.00	16.94	12,288	108.87	130.90	1,590	122.86	321,683	0.65	122.81
1987	207,075.00	16.86	12,285	108.85	131.20	1,578	121.97	325,415	0.64	120.80
1988	229,383.00	18.55	12,369	109.59	131.77	1,741	134.52	333,053	0.69	130.74
1989	249,843.00	19.59	12,753	112.99	131.83	1,895	146.45	341,623	0.73	138.83
1990	235,693.00	18.98	12,416	110.00	132.12	1,784	137.85	356,852	0.66	125.38
1991	252,354.00	18.10	13,942	123.53	133.08	1,896	146.54	380,197	0.66	126.00
1992	262,667.00	19.13	13,732	121.67	132.05	1,989	153.71	404,247	0.65	123.35
1993	255,106.00	17.84	14,300	126.69	131.27	1,943	150.18	439,632	0.58	110.16
1994	265,893.00	17.63	15,085	133.65	131.83	2,017	155.86	479,721	0.55	105.22
1995	276,590.00	16.69	16,571	146.82	132.48	2,088	161.34	510,359	0.54	102.88
1996	288,840.00	16.00	18,056	159.98	131.82	2,191	169.33	550,875	0.52	99.54
1997	286,833.00	16.54	17,337	153.60	131.11	2,188	169.06	603,389	0.48	90.24
1998	282,606.00	16.31	17,326	153.51	130.39	2,167	167.49	623,822	0.45	86.00
1999	289,178.00	15.42	18,750	166.13	131.34	2,202	170.14	633,473	0.46	86.66
2000	309,948.00	15.97	19,407	171.94	131.20	2,362	182.57	655,315	0.47	89.79
2001	320,016.00	15.35	20,854	184.76	131.06	2,442	188.69	671,987	0.48	90.40
2002	322,179.00	15.80	20,391	180.67	130.89	2,461	190.21	693,618	0.46	88.18
2003	363,033.00	15.56	23,329	206.70	130.68	2,778	214.67	716,201	0.51	96.22
2004	354,431.00	15.12	23,448	207.75	130.48	2,716	209.91	742,654	0.48	90.60
2005	347,830.00	15.45	22,515	199.48	130.28	2,670	206.33	772,718	0.45	85.45
2006	361,183.00	15.32	23,583	208.94	130.18	2,774	214.40	808,579	0.45	84.80

Source: Real output (GDP) and net capital stock from NESDB, labour from NSO and land from OAE
Note: See Chapter 4 for explanations on output and input data.

Table 3.26 Yields of Major Crops per Planted Area (kilograms per rai)

	Rice	Maize	Cassava	Sugarcane	Sorghum	Mungbean	Kenaf	Cotton	Oil Palm	Soybeans	Rubber
1970	306	291	2,446	6,904	183	149	145	139		137	36
1971	300	361	2,250	7,640	258	156	145	141		151	39
1972	270	211	2,366	6,851	283	144	145	129		138	40
1973	285	326	2,080	8,396	252	131	173	157		136	43
1974	268	323	2,080	8,254	198	145	152	148		134	43
1975	275	349	2,180	7,541	188	118	151	153		154	40
1976	281	333	2,364	8,146	166	90	182	174		179	43
1977	247	223	2,237	8,366	118	76	153	172	659	101	46
1978	279	322	2,246	5,349	197	98	169	174	618	157	50
1979	267	300	2,100	6,445	169	95	156	190	506	150	56
1980	289	335	2,281	4,698	153	93	198	203	474	127	48
1981	296	352	2,235	6,781	156	93	175	182	540	165	51
1982	281	286	2,302	7,830	154	93	159	171	897	146	58
1983	312	337	2,220	6,696	197	95	147	188	910	176	59
1984	319	372	2,276	6,618	204	107	151	196	1,027	197	73
1985	320	399	2,087	7,318	209	94	170	239	1,382	203	79
1986	306	353	1,969	6,997	174	95	162	227	1,328	198	88
1987	305	254	2,217	7,256	173	92	159	217	1,268	149	98
1988	322	408	2,258	7,422	191	112	198	270	1,462	206	106
1989	320	393	2,394	8,870	197	111	191	244	1,674	210	120
1990	278	341	2,165	7,824	195	108	196	210	1,778	199	129
1991	342	411	2,114	8,309	203	110	204	207	1,563	200	136
1992	329	435	2,183	8,282	214	109	211	205	1,487	209	154
1993	311	398	2,220	6,430	190	108	220	203	1,884	197	161
1994	348	449	2,165	7,063	207	113	227	219	1,831	194	172
1995	348	498	2,004	8,594	219	107	234	222	2,016	205	176
1996	350	523	2,205	9,233	241	109	230	223	2,024	212	180
1997	367	439	2,287	8,932	231	111	227	222	1,900	218	182
1998	367	513	2,329	7,370	238	119	248	217	1,739	219	177
1999	375	555	2,293	8,777	259	124	256	214	2,236	220	179
2000	389	572	2,574	9,466	257	122	261	221	2,014	224	191
2001	423	581	2,659	9,042	270	126	268	213	2,242	226	206
2002	421	578	2,710	9,496	286	118	270	200	2,045	230	210
2003	444	602	3,064	10,426	295	117	259	227	2,383	240	227
2004	429	599	3,173	9,269	261	115	238	215	2,154	230	232
2005	448	595	2,596	7,434	298	110	240	189	1,820	243	219
2006	438	615	3,257	7,899	251	118	259	204	2,276	242	214

Source: Office of Agricultural Economics (OAE)

Table 3.27 Annual Budget of MOAC's Departments Conducting Research and Extension

Unit: million baht (current prices)

	Department of Agriculture (DOA)	Rice Department	Department of Agricultural Extension (DOAE)	Department of Livestock Development (DLD)	Department of Fisheries (DOF)	Total
1961	26.20	21.60		21.84	8.62	78.26
1962	40.31	32.13		33.98	22.98	129.41
1963	43.29	36.11		40.64	28.67	148.70
1964	49.92	43.98		40.91	37.85	172.65
1965	56.25	50.31		45.53	30.63	182.72
1966	77.17	83.63		60.51	42.87	264.18
1967	102.02	81.34		79.20	55.91	318.47
1968	116.08	95.84		82.89	60.48	355.29
1969	92.06	52.18		86.76	70.97	301.97
1970	104.26	52.28	95.25	88.76	60.82	401.38
1971	106.38	52.37	124.00	87.40	58.32	428.46
1972	107.68	53.82	122.95	90.97	56.86	432.28
1973	173.80		143.56	118.42	68.53	504.31
1974	189.44		157.05	123.60	82.86	552.95
1975	271.21		231.78	177.02	137.73	817.74
1976	318.10		278.81	210.52	177.51	984.94
1977	342.94		402.34	264.67	179.30	1,189.26
1978	352.17		480.55	286.15	190.20	1,309.07
1979	378.22		535.65	294.19	212.60	1,420.67
1980	432.54		743.87	360.18	243.15	1,779.74
1981	515.37		917.47	438.56	300.46	2,171.87
1982	583.39		1,020.46	501.11	371.09	2,476.05
1983	719.81		1,215.85	615.70	532.92	3,084.28
1984	776.51		1,340.83	685.72	585.76	3,388.82
1985	797.31		1,627.10	784.11	658.23	3,866.74
1986	845.79		1,530.41	814.22	719.83	3,910.26
1987	849.73		1,355.87	837.41	671.93	3,714.94
1988	979.67		1,391.82	1,065.29	735.38	4,172.15
1989	1,049.67		1,494.82	1,070.58	828.45	4,443.52
1990	1,246.36		1,848.42	1,415.93	1,486.25	5,996.96
1991	1,564.20		2,526.23	1,959.90	1,946.02	7,996.35
1992	1,768.37		3,042.26	1,985.21	2,478.20	9,274.04
1993	2,197.00		4,048.26	2,735.27	2,717.08	11,697.61
1994	2,468.68		4,683.25	2,962.97	2,719.35	12,834.25
1995	2,534.26		5,460.84	3,357.54	3,091.31	14,443.96
1996	3,105.43		6,407.48	3,799.62	3,412.48	16,725.01
1997	3,301.55		6,756.41	3,698.60	3,872.63	17,629.19
1998	3,051.53		5,306.70	3,164.70	3,315.59	14,838.51
1999	3,165.09		5,280.14	2,861.06	3,368.43	14,674.71
2000	3,237.68		5,682.18	2,848.91	3,120.31	14,889.07
2001	3,190.65		5,591.09	2,832.30	3,088.54	14,702.58
2002	3,092.86		5,452.46	2,583.39	3,202.35	14,331.06
2003	2,866.99		4,962.86	2,826.63	2,443.36	13,099.84

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	Department of Agriculture (DOA)	Rice Department	Department of Agricultural Extension (DOAE)	Department of Livestock Development (DLD)	Department of Fisheries (DOF)	Total
2004	2,971.36		4,602.67	3,052.70	2,496.58	13,123
2005	2,838.73		4,339.57	3,011.26	2,664.39	12,853
2006	3,215.60		4,144.72	4,012.57	2,699.15	14,072
2007	2,946.26	815.40	4,186.14	6,445.51	2,872.85	17,266

Source: Bureau of The Budget, The Prime Minister's Office, Thailand's Budget in Brief, various issues. Budget data shown in the table are total annual budget allocated to each department.

Notes on principal years of the MOAC organizational changes

There have been several organizational restructuring and name changes since the ministry in charge of agriculture was established in 1892. The following notes focus on changes relating to the departments conducting agricultural research and extension, which took place from 1961 onwards.

Principal years	Organization changes	Remarks
1967	DOAE was established on 21 October 1967	Crops extension budget was separated in 1968 but still included with the DOA until 1969
1972	Rice department merged with the DOA	Rice department budget was combined with the DOA in 1973
2006	Rice department was officially separated from the DOA on 16 March 2006	Rice department budget was separated in 2007

Source: official websites of MOAC (www.moac.go.th), DOA (www.doa.go.th), DOAE (www.doae.go.th), Rice Department (www.ricethailand.go.th)

Table 3.28 Agricultural Research Expenditure in Livestock Classified by Major Discipline (current prices)

	Health[1] (Baht)	Husbandry[2] (Baht)	Share of husbandry (%)		Health[1] (Baht)	Husbandry[2] (Baht)	Share of husbandry (%)
1961	1,024,010	n.a.	n.a.	1984	21,804,100	9,009,000	29.24
1962	1,250,000	n.a.	n.a.	1985	24,143,400	8,898,100	26.93
1963	1,425,900	n.a.	n.a.	1986	29,628,200	9,635,900	24.54
1964	n.a.	n.a.	n.a.	1987	33,378,100	11,229,200	25.17
1965	1,566,800	n.a.	n.a.	1988	25,378,600	11,417,600	31.03
1966	1,782,500	n.a.	n.a.	1989	26,957,200	12,260,800	31.26
1967	2,204,700	1,539,300	41.11	1990	34,171,100	18,683,900	35.35
1968	2,481,500	1,363,700	35.46	1991	40,559,500	21,181,800	34.31
1969	2,689,600	1,413,000	34.44	1992	50,468,700	54,283,300	51.82
1970	n.a.	n.a.	n.a.	1993	61,327,100	52,896,000	46.31
1971	2,868,200	1,055,300	26.90	1994	90,342,800	53,769,000	37.31
1972	2,875,700	963,100	25.09	1995	14,516,800	50,957,100	77.83
1973	3,007,100	1,494,200	33.19	1996	22,014,500	64,646,900	74.60
1974	3,663,900	3,300,200	47.39	1997	32,512,600	73,473,000	69.32
1975	6,897,200	3,650,700	34.61	1998	22,531,900	78,669,100	77.74
1976	7,484,200	6,367,000	45.97	1999	16,882,900	71,190,100	80.83
1977	7,056,200	7,305,200	50.87	2000	32,694,400	74,044,500	69.37
1978	8,572,500	9,115,700	51.54	2001	28,244,500	77,025,000	73.17
1979	9,833,000	9,025,100	47.86	2002	19,329,400	59,695,000	75.54
1980	11,587,900	12,272,500	51.43	2003	20,364,000	72,622,200	78.10
1981	15,155,700	14,124,400	48.24	2004	15,354,600	19,665,600	56.16
1982	16,651,300	6,916,200	29.35	2005	15,992,700	41,022,800	71.95
1983	20,709,900	8,612,000	29.37	2006	16,903,900	33,221,800	66.28

Source: Bureau of the Budget, Budget Document, various issues.

Notes: 1 Veterinary science
2 Breed and feed improvement
n.a. = Data not available

Table 3.29 Public Agricultural R&D Intensity in Various Countries

(1) Global trend:

Intensity ratios of public agricultural research expenditure, 1981, 1991, 2000

	Agricultural R&D spending as a share of AgGDP (%)		
Country group	**1981**	**1991**	**2000**
Low&middle income:	**0.56**	**0.56**	**0.55**
Sub-Saharan African	0.86	0.76	0.65
Asia-Pacific	0.33	0.37	0.39
Latin America & the Caribbean	0.91	1.08	1.19
West Asia & North Africa	0.60	0.60	0.74
High income	**1.51**	**2.08**	**2.35**
Global total	**0.91**	**1.00**	**0.98**

Source: Nienke M. Beintema and Gert-Jan Stads (2008), 'Measuring agricultural research investments: a revised global picture', available at http://www.asti.cgiar.org/pdf/global_revision.pdf. The data are calculated based on Agricultural Science & Technology Indicators (ASTI) datasets (various years), OECD (various years), and Pardey et al. (2006e).

(2) Selected countries:

Public agricultural research intensity (%)

Year	China	India	Indonesia	Philippines	Thailand	U.S.
1971	0.34	0.08			0.39	1.64
1972	0.44	0.10			0.31	1.53
1973	0.39	0.07			0.24	1.39
1974	0.37	0.09			0.20	1.37
1975	0.42	0.12			0.27	1.59
1976	0.41	0.13			0.29	1.75
1977	0.45	0.16			0.29	1.94
1978	0.54	0.16			0.26	1.89
1979	0.51	0.20			0.25	1.96
1980	0.49	0.19			0.24	1.96
1981	0.41	0.19	0.36	0.20	0.27	2.18
1982	0.37	0.21	0.37	0.22	0.35	2.41
1983	0.42	0.19	0.43	0.24	0.41	2.50
1984	0.43	0.21	0.42	0.25	0.49	2.55
1985	0.42	0.23	0.39	0.28	0.59	2.52
1986	0.41	0.24	0.42	0.33	0.59	2.63
1987	0.35	0.24	0.39	0.31	0.54	2.72
1988	0.39	0.21	0.33	0.29	0.47	2.68
1989	0.40	0.23	0.26	0.27	0.46	2.68
1990	0.32	0.24	0.31	0.26	0.57	2.79
1991	0.35	0.26	0.30	0.26	0.47	2.90
1992	0.41	0.25	0.31	0.26	0.65	3.05
1993	0.41	0.25	0.27	0.33	0.92	2.95
1994	0.38	0.24	0.30	0.32	0.86	3.19
1995	0.34	0.25	0.30	0.32	0.71	3.03
1996	0.32	0.23	0.27	0.34	0.75	2.98
1997	0.29	0.25	0.26	0.40	0.81	2.96
1998	0.33	0.27	0.18	0.45	0.72	3.36

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Public agricultural research intensity (%)						
Year	China	India	Indonesia	Philippines	Thailand	U.S.
1999	0.34	0.30	0.18	0.39	0.77	3.74
2000	0.38	0.35	0.18	0.41	0.79	4.02
2001	0.39	0.34	0.16	0.41	0.66	4.26
2002	0.48	0.37	0.18	0.44	0.58	4.27
2003	0.48	0.36	0.20		0.33	3.93
2004	0.39				0.23	3.76
2005	0.40				0.21	
2006					0.20	
1971-2006	**0.40**	**0.31**	**0.29**	**0.32**	**0.47**	**2.68**

Source: data for China, India, Indonesia and the Philippines are from Agricultural Science and Technology Indicators (ASTI) datasets under the International Food Policy Research Institute (IFPRI), available at http://www.asti.cgiar.org/timeseries.aspx and updated series are obtained from Nienke Beintema (IFPRI), data for Thailand are from the Bureau of the Budget (BB) as described in Chapter 5, data for the U.S. are from Fuglie and Heisey (2007).
Note: ASTI data for Thailand are available only from 1975-1984 and they are about three-fold higher than the data from the BB reported in the above table. However, these two data sources are compiled from a different basis and may not be directly comparable.

Chapter 4

4. TFP Measurement and Sources of Growth in Thai Agriculture

4.1 Introduction

This chapter examines sources of growth in Thai agriculture with the emphasis on total factor productivity (TFP) growth. Conventional growth accounting is employed to measure TFP growth as a residual of output growth that cannot be explained by factor input growth. This allows decomposition of output growth into growth from each factor input and growth from TFP. The TFP estimates will be used to examine the determinants of productivity growth and to calculate the social rate of return on agricultural research in the following chapters.

TFP growth is computed for the overall agricultural sector and also for the crops and livestock subsectors. The output and input data are time-series at an aggregate level, covering 37 years from 1970 to 2006. As the measurement of TFP growth attempts to approximate pure technological change, adjustments of factor inputs are also undertaken to separate out the effects of changes in input quality.

The chapter comprises five sections. Section 4.2 provides a brief review of TFP measurement methods. Section 4.3 explains TFP estimation and the adjustment methods employed in this study. Definitions and sources of the data are described in section 4.4. Sources of agricultural growth are examined and results from factor input adjustment are discussed in section 4.5. The estimates of TFP growth with and without adjustments are highlighted. Section 4.6 draws conclusions.

4.2 Review of TFP Measurement Methods[82]

In general, the TFP measurement methods that have been used in empirical productivity studies can be grouped into two main approaches: conventional or non-frontier methods and frontier analysis. The first approach assumes outputs are efficiently produced on the production frontier while the second approach allows for outputs being produced off the frontier. Both the conventional and frontier approaches can be classified into parametric and nonparametric methods. The nonparametric method does not impose a specific functional form, whereas the parametric method imposes a functional form and employs econometric techniques in estimating a production or a cost or a profit function. Important assumptions and applications of the two main approaches are summarized as follows.

4.2.1 Conventional or Non-Frontier Approach

The conventional approach begins productivity analysis by assuming all producers are technically efficient and producing at the best-practice level. The observed outputs can be produced at their maximum level on the production possibility frontier. Therefore, TFP change is theoretically represented by a shift of the production frontier. TFP growth is measured as a residual that cannot be explained by the weighted average of input growth. It is often used to measure aggregate TFP growth for the entire economy, sectors or industry level analysis. The conventional approach can be classified into nonparametric and parametric methods. The main difference between the two methods is in the weight given to the growth of each factor input.

1) Nonparametric method

The nonparametric method assumes perfect competition in input and output markets, thereby using factor income shares to weigh the contributions of each factor input. By taking the producer equilibrium conditions, each input is employed up to the point

[82] This subject has been reviewed and discussed repeatedly in a huge number of studies over fifty years. See, for example, Kaipornsak (1995), Aswicahyono (1997), Chen (1997), Felipe (1997), Griliches (1994, 1996), Hulten (2000), Mahadevan (2002, 2003), Coelli, et al. (2005).

that its marginal product equals its real input price. As a result, the factor income share can be used to replace the output elasticity with respect to each input.[83] An assumption of constant returns to scale is often made such that all factor income shares sum to one. By assuming perfect competition and constant returns to scale, TFP growth theoretically represents the effect of technical change that shifts the production function.[84] Examples of this method are the growth accounting (GA) technique and index numbers such as the Laspeyres index, Divisia index (continuous-time) and Tornqvist (discrete-time) index.

The most commonly used method is national income based growth accounting.[85] It is often applied to macro-level analysis. The growth accounting approach is popular, mainly because it provides a simple yet elegant framework that well suits studies subject to limited data availability.[86] However, the perfect competition assumption is inappropriate in some applications such as regulated industries (Cowing and Stevenson, 1981). The TFP index, measured as output index over input index, has also been widely used. The disadvantage is that it requires both price and quantity data. Since TFP growth is measured as a residual, it is crucial that output and inputs are correctly measured. Data reliability is often a concern in empirical studies, particularly for price data in developing countries.

2) Parametric method

The parametric method does not impose perfect competition conditions. It directly estimates output elasticity with respect to each input using econometric techniques, often by the least squares (LS) method. A functional form must be specified when estimating a production function, a cost or a profit function. An advantage of this technique is that the output elasticity with respect to individual input can be estimated

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[83] This is true for any production function that is homogeneous of degree one, without an assumption of constant returns to scale.

[84] If these assumptions are not satisfied, conventional TFP growth includes not only the effect of technical change but also other factors such as the effect of non-constant returns to scale and market imperfections. See Cowing and Stevenson (1981) for TFP measurement in regulated industries.

[85] See Jorgenson and Griliches (1967, 1972) and Denison (1967) for issues in growth accounting.

[86] Almost all countries in the Asia-Pacific region have used this method including Thailand (see, for example, Oguchi (2001, 2004), Poapongsakorn (2006) and Warr (2006).

econometrically and its significance can be tested. Input price data, often unreliable in developing countries, are not required for computing factor income shares as in the case of the nonparametric method.

However, this method is not as popular as the nonparametric approach due to econometric difficulties, such as endogeneity and multicollinearity. The TFP residual is highly likely to be correlated with input variables, thereby causing biased and inefficient estimators. In most cases of growth analysis, multicollinearity results from the upward trends of nearly all the key time series variables. Even without trend, input coefficients often seem totally implausible to most economists (Harberger, 1996, p.385). An application to the Cobb-Douglas functional form also places the unrealistic assumption of constant and unitary elasticity of substitution among all pairs of inputs. The number of observations should be large enough for reliable statistical tests. Apart from using different techniques in deriving the weights of input growth, parametric and nonparametric methods are fundamentally the same under perfect competition. Both methods can be used under the growth accounting framework.

4.2.2 Frontier Approach

The frontier approach does not assume all producers are technically efficient. Observed outputs are therefore not necessarily produced on the production frontier. This approach allows the decomposition of TFP growth into technical change and technical efficiency. Technical change is a shift of the production frontier. A change in the technical efficiency refers to a shift toward the production frontier. The sources of technical inefficiency can also be examined. This approach often aims at measuring firm-level inefficiency. Hence, it is particularly popular with micro-productivity analysis using cross-sectional or panel data. Frontier analysis can also be classified into nonparametric and parametric methods. As reviewed by Lovell (1993), although there are many different methods, two are emphasised. These are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The main difference between the two methods is in interpreting why firms do not perform at their best-practice level.

1) Nonparametric method

The nonparametric method uses linear programming to construct a production frontier and then to measure efficiency relative to this linear frontier. The principal method that has been used is data envelopment analysis (DEA). The DEA method designates all deviations from the frontier as being due to technical inefficiency, assuming no measurement errors or other statistical errors. It is useful when there are multiple outputs, prices and behavioural assumptions such as cost-minimization or profit-maximization are difficult to define, and measurement errors are not a big issue. The DEA-based Malmqvist TFP index is a well-known example of this method. It is popular when input price data are either not available or could be distorted due to government intervention.[87]

2) Parametric method

This method computes the unknown production frontier econometrically. The observed output is then compared with this frontier. The most commonly used method is the stochastic frontier approach (SFA). The SFA attributes the deviations of observed outputs from the maximum level on the frontier to farm-specific technical inefficiency and uncontrollable random error. Most statistical frontier analysis emphasises estimating the inefficiency effects (Coelli et al., 2005, p.244). The random error represents statistical noise arising from omission of relevant variables and measurement errors. The SFA has an advantage over the DEA when data noise is a problem. This is often the case with agriculture where data are most likely influenced by measurement errors and uncontrollable factors such as weather and disease (Coelli, et al., 2005).[88]

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[87] See Ruttan (2002), Coelli and Rao (2003) and Coelli et al. (2005, Chapters 6 to 7) for more details and applications.

[88] See Kumbhakar and Lovell (2000) and Coelli, et al. (2005, Chapters 9 to 10) for more details and applications.

In sum, both frontier and non-frontier approaches analyse TFP in different contexts, as to whether a producer can produce at best-practice level or not. As a result, they offer TFP measurement methods with different emphasis and require different types of data. The frontier analysis is often applied to cross-sectional or panel data, whereas the conventional approach is mainly applied to macro-productivity data sets. Table 4.1 summarizes the principal methods used in measuring TFP and the corresponding data requirements.

Table 4.1 Summary of TFP Measurement Methods and Data Requirements

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

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

4.3 TFP Measurement Method used in this Study

Although there are several approaches for measuring TFP, a suitable approach depends on the objectives of the study and data availability. Since this chapter aims to examine sources of agricultural growth at an aggregate level, the growth accounting framework is the most appropriate. Growth accounting allows a distinction of growth in real factor input from growth in TFP (Jorgenson, 1995). In addition, one of the research questions this thesis addresses is testing the role of agricultural research on productivity and measuring its corresponding rate of return. The assessment of research impact involves lag length and requires time series data. As shown in Table

4.1, time series data are not applicable to the frontier approach so that the non-frontier approach is the only feasible option.[89]

Moreover, the competitive equilibrium conditions which are the underlying assumptions of the growth accounting approach are reasonable for the case of Thai agriculture. The agricultural sector is well characterised by a perfect competitive market in the sense that there are a large number of farmers who maximise profit (or minimise cost) and take prices as given. It is generally recognized that Thai farmers are price takers in input and output markets (Pochanukul, 1992, p.168). Compared with other industries, such as manufacturing and services, the agricultural sector is considered a suitable case study for applying the growth accounting method.

Under the growth accounting framework, the discrete-time Tornqvist approximation to the continuous-time Divisia index is employed. The method implicitly specifies a translog form of the production function but does not explicitly estimate the function. The transcendental logarithmic (or translog) production function developed by Christensen, Jorgenson and Lau (1973) is a flexible functional form that does not impose constant elasticity of substitution and allows the output elasticity with respect to each input to vary with time. The translog specification serves as a potential function for the Tornqvist index (Hulten, 2000).

Constant returns to scale (CRS) is assumed such that all factor income shares sum to one.[90] This translog-based growth accounting formula and the CRS assumption have been widely used in previous studies using country-level data. For example, Jorgenson (1995) uses growth accounting and CRS to compare economic growth among countries, and a number of empirical case studies using this approach were reviewed in a recent publication series of Asian Productivity Organization (Oguchi,

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[89] To employ a frontier approach, a panel data set is needed so that a frontier surface in each year can be calculated.

[90] The use of CRS technology is sensible when dealing with aggregate country-level data (Coelli and Rao, 2003, p.7). For Thailand and the agricultural sector, the CRS technology is applied in all nonparametric growth accounting studies, for example, Budhaka (1987), Kaipornsak (1998, 1999), Tinakorn and Sussangkarn (1996), Chockpisansin (2002), Chandrachai et al. (2004), Warr (2005) and NESDB (2006).

2001, 2004). It is national income based growth accounting in the sense that most output and input data are obtained from the national accounts.

There are three primary inputs included in the production function - labour, land and capital. Labour and land inputs are adjusted following the methods developed by Tinakorn and Sussangkarn (1996, 1998). The adjustment methods are explained following the TFPG measurement method.

4.3.1 TFP Growth Measurement Method

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

$$Q_t = A_t F(L_t, N_t, K_t) \tag{4.1}$$

where Q_t = real output at time t

L_t = labour quantity at time t

N_t = land quantity at time t

K_t = capital quantity at time t

A_t = level of efficiency at time t

Totally differentiating equation (4.1) with respect to time gives:

$$\frac{dQ_t}{dt} = \frac{dA_t}{dt} F(L_t, N_t, K_t) + A_t \frac{\partial F}{\partial L_t}\frac{dL_t}{dt} + A_t \frac{\partial F}{\partial N_t}\frac{dN_t}{dt} + A_t \frac{\partial F}{\partial K_t}\frac{dK_t}{dt} \tag{4.2}$$

Dividing both sides by Q_t gives:

$$\frac{dQ_t}{dt}\frac{1}{Q_t}=\frac{dA_t}{dt}\frac{1}{A_t}+\frac{\partial F}{\partial L_t}\frac{dL_t}{dt}\frac{1}{F(L_t,N_t,K_t)}+\frac{\partial F}{\partial N_t}\frac{dN_t}{dt}\frac{1}{F(L_t,N_t,K_t)}+\frac{\partial F}{\partial K_t}\frac{dK_t}{dt}\frac{1}{F(L_t,N_t,K_t)} \tag{4.3}$$

Rearranging equation (4.3) gives:

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

or $$\hat{Q}_t=\hat{A}_t+MP_L\left(\frac{L_t}{Q_t}\right)\hat{L}_t+MP_N\left(\frac{N_t}{Q_t}\right)\hat{N}_t+MP_K\left(\frac{K_t}{Q_t}\right)\hat{K}_t \tag{4.4}$$

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

In a perfectly competitive market, producers maximize profit and will employ each input where its marginal product equals its real factor price. That is, the real wage rate (w) equals the marginal product of labour (MP_L); the real rate of land rent (r) equals the marginal product of land (MP_N) and the real rate of return (i) equals the marginal product of capital (MP_K). Hence, replacing marginal products with factor prices, equation (4.4) can be rewritten as:

$$\hat{Q}_t=\hat{A}_t+S_L\hat{L}_t+S_N\hat{N}_t+S_K\hat{K}_t \tag{4.5}$$

where $S_L = wL/Q$ = proportional share of labour income in the value of total output

$S_N = rN/Q$ = proportional share of land income in the value of total output

$S_K = iK/Q$ = proportional share of capital income in the value of total output

Note that when the competitive equilibrium condition is not assumed, the coefficients of the instantaneous growth rate of inputs are simply the output elasticities with respect to each input. By taking the producer equilibrium assumption, the unobservable output elasticities are equivalent to the observed factor income shares. This is an underlying assumption of the nonparametric method using the growth accounting framework.

Equation (4.5) indicates output growth can be decomposed into the growth rate of the efficiency level and the growth rate of labour, land and capital, weighted by their output elasticities or factor income shares. The first component is the shift in the production function (representing technical change) and the latter is the movement along the production function (representing input substitution).

Rearranging equation (4.5), the estimation of TFP growth $(TFPG_t)$ can be expressed as the residual part of output growth that cannot be explained by the combined growth of physical inputs:

$$\hat{A}_t = TFPG_t = \hat{Q}_t - S_L\hat{L}_t - S_N\hat{N}_t - S_K\hat{K}_t \tag{4.6}$$

Since the differentiation is applicable only to continuous variables, the growth rate terms in the above equations are for an instantaneous rate of change. However, in practice, annual data are discrete in nature. Hence, the discrete annual data can be applied to estimate equation (4.6) by taking the average of two consecutive periods:

$$\begin{aligned} TFPG_t &= \ln TFP_t - \ln TFP_{t-1} \\ &= (\ln Q_t - \ln Q_{t-1}) - \frac{1}{2}(S_{Lt} + S_{Lt-1})(\ln L_t - \ln L_{t-1}) \\ &- \frac{1}{2}(S_{Nt} + S_{Nt-1})(\ln N_t - \ln N_{t-1}) - \frac{1}{2}(S_{Kt} + S_{Kt-1})(\ln K_t - \ln K_{t-1}) \end{aligned} \tag{4.7}$$

Equation (4.7) is the growth accounting formula used to measure TFP growth in this study. It is similar to finding the growth of TFP measured by a Tornqvist index.[91] The Tornqvist index has been shown to be an exact and superlative index and a suitable discrete-time approximation to the continuous-time Divisia index (Diewert, 1976). The constant return to scale assumption requires that all factor income shares sum to unity.

Notes on units of measurement[92]:

Ideally, all variables in the production function should be measured in real physical units. However, it is difficult to aggregate outputs and inputs at different physical units. At an aggregate level, it is well-known that real output is measured as value added at constant prices. It is also preferable to measure inputs on a flow basis in order to reflect their actual contribution to production. Specifically, labour should be measured in person-hours; capital should be measured in machine-hours and land should be measured in intensity of land usage. However, in practice, inputs are usually measured as stocks due to lack of data. Adjustment on each input stock variable can be undertaken to better reflect its actual contribution.

For national income based growth accounting analysis, aggregate output is measured in terms of real gross domestic product or real value-added.[93] Labour is measured as working hours or numbers of employed persons. Land is measured as cultivated area. Capital is measured as real capital stock based on the national accounts. This approach to the measurement of output and inputs has been widely used in previous studies, for example, Oguchi (2004), Harberger (1996), Tinakorn and Sussangkarn (1996) and Poapongsakorn (2006).

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[91] Tornqvist index is the most common chain-index method, originating with Tornqvist (1936) and developed by Diewert (1976) and Caves, Christensen and Diewert (1982).

[92] This is mainly taken from Tinakorn and Sussangkarn (1996, p.9-10), Jorgenson and Griliches (1967) and Denison (1967).

[93] To avoid recognizing substitution among factor inputs (e.g., labour, capital) and intermediate inputs, the TFP measure is often based on a value-added framework (Morrison Paul, 1999, Chapter2).

Notes of CRS assumption:

The return to scale property of the production function is important in TFP measurement. It is worth mentioning why this study assumes constant returns to scale (CRS). A production function with CRS means a unit proportional change in all inputs results in a unit proportional change in output. Under CRS, the sum of output elasticities with respect to all inputs is equal to unity. Therefore, the value shares of each input also sum to one, if inputs are paid according to their value marginal product. This study considers that the CRS property is sensible for Thai agriculture for two main reasons – technical (due to the use of aggregate data) and practical (due to a lack of reliable data).

First, the use of CRS is suitable for an aggregate level study. The average farm size in Thai agriculture is neither large-scale nor tiny, due to fragmentation. It is also sensible for international comparison purposes since farm sizes are heterogeneous across countries (Coelli and Rao, 2003, p.7).[94]

Second, a departure from CRS is difficult in practice, mostly due to a lack of reliable data on capital prices. If CRS is not assumed, a reliable capital price series is required to calculate the value share of capital income. Due to data limitation, all the previous studies in the Thailand context have assumed CRS technology in the growth accounting analysis, and have derived the capital share as a residual.

4.3.2 Adjustment Methods of Factor Inputs

Theoretically, the TFP growth derived in the previous section should represent technological change. However, in practice, the residual measure of TFP embodies the impact of many aspects, mainly resulting from imperfect measurement of factor inputs. To obtain the TFP growth that more closely represents pure technological change, the productivity growth arising from the improvement in input quality should be separated out. Although it is impossible to get to the pure technological change in

[94] A departure from CRS is sensible when the data are expressed on average per farm basis (See Coelli and Rao, 2003 for more details).

practice, as the TFP residual is recognized as a measure of our ignorance (Abramoviz, 1956), other factors such as economies of scale and irregular factors (e.g., weather and epidemic) will be taken care of in the TFP determinants model.

The adjustment of quality changes is undertaken on labour and land. Capital is not adjusted for quality changes for two main reasons. First, the quality changes in capital are not easily measurable and are often impeded by lack of detailed data.[95] Disaggregated data on the marginal productivity of each type of capital at each point of time are required (Jorgenson and Griliches, 1967). Second, an improvement in capital, such as new models of agricultural machinery, could result from research and capital is thereby left unadjusted for assessing the impact of agricultural research. Adjustment for capital quality may remove some of the contributions of research from the TFP measure (Evenson, 2001). On the other hand, adjustment for labour quality may improve prospects for estimating the technology impact on TFP because education effects can be dropped from the TFP decomposition function (Evenson, 2001).

Capital stock is sometimes adjusted for its cyclical fluctuation in the recent literature (Oguchi, 2004). The capital adjustment for business fluctuation is not included here as this chapter only focuses on the effect of input quality changes that are more relevant to the agriculture context.[96] Note that output quality is not a concern because agricultural commodities are stable through time.

1) Labour quality adjustment

As detailed data are more available it has become conventional in recent studies to adjust for the change in labour quality under the growth accounting framework (Harberger, 1996, Oguchi, 2004). However, there have been contrasting views on the

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[95] Denison (1967) considers it neither desirable nor possible to measure the quality changes in capital. The quality changes embodied in capital are commonly left unadjusted in empirical works (Tinakorn and Sussangkarn, 1996, p.27); especially in the Thailand context where detailed data on capital are not available.

[96] The capital adjustment for business fluctuation was initially tested using the Wharton or capacity utilization method (Oguchi, 2004) but it was not supported by the data.

inclusion of labour improvement in the measurement of TFP growth. Before proceeding to make an adjustment on labour quality changes, it is worth considering different views regarding the adjustment of labour quality changes.

Should labour quality changes be adjusted?

The pioneering studies on quality-adjusted TFP growth by Jorgenson and Griliches (1967, 1972), Denison (1961, 1967) and Griliches (1970) consider improvement in the quality of inputs as part of input growth, and hence should be subtracted from the calculation of TFP growth.[97] On the contrary, Chen (1997) is of the opinion that quality improvement is technical change embodied in inputs, and therefore it should be regarded as part of TFP growth.

According to Jorgenson and Griliches (1967), "quality change" is regarded as an error in measurement of factor inputs. The measurement errors result from aggregating inputs of different quality and marginal productivity. Incorrect aggregation from summing various types of input at constant prices often overestimates TFP growth. By eliminating these errors the contribution of factor input increases while TFP reduces. Therefore, an adjustment for labour quality change in the sense of an aggregation bias should be removed from the residual TFP. As stated in their subsequent paper (Jorgenson and Griliches, 1972, p.67), 'returns to labour of comparable quality may also differ by age, race, sex, or occupation and these differences should be reflected in the measurement of labour input'.

In contrast, Chen has argued that TFP growth (TFPG) should represent embodied technological change, and should include both input quality improvement and disembodied technological change. He also argues that it is not meaningful to examine the role of technological change if it is confined to disembodied technological change. The reason is that TFPG estimates are sensitive to input measurement and relevant quality adjustment. The more quality adjustments are made to the factor inputs, the less will be left for the residual TFPG. If there is over-

[97] In detail, there were great differences in the measurement of inputs and output and explanation of the residual TFP between Jorgenson and Griliches (1967, 1972) and Denison (1967, 1969).

adjustment in quality change, which Chen claims is often the case, TFPG will be smaller. However, if the quality change is considered as part of TFP, any adjustment error will not affect its estimated value (Chen, 1997, p.24).

It is posited here that despite the contrasting views, it is preferable to make an adjustment on labour quality. This is because labour quality adjustment can quantify the contribution of labour quality changes to output growth. This helps in distinguishing between labour quality changes and technological change.

One of the purposes of this thesis is to assess the agricultural research impact on TFPG. This impact operates through advances in technology (such as better quality seeds, machinery and disembodied technical change) rather than labour quality change that is often caused by non-farm factors. Labour quality improvement is more likely to be related to education and irrelevant to technological progress in agriculture. Chen's argument is not applicable to this study, although his point may make sense for other research purposes.

Given the objective of this study, the residual TFPG should reflect changes in technology as closely as possible. Distinguishing the effect of quality changes gives a clearer picture of the residual TFPG. Although there is a possibility that over-adjustment may occur resulting in very small TFPG, an unadjusted TFPG can also be investigated and compared with the adjusted one.

In the context of Thai agriculture, the composition of the labour force has changed over time. Labour quality changes are mainly affected by structural change in the economy that shifts labour from agriculture to the non-agricultural sectors. The shift of labour away from farms, particularly males and young workers, changes the composition of workers in terms of age, sex and education. In turn, this affects labour quality and productivity in the agricultural sector. Hence, it is appropriate to adjust for labour quality changes. In doing so, productivity growth arising from improved labour quality can be separated out from the residual TFP growth that more closely reflects pure technological change.

In sum, it is sensible to make an adjustment on labour quality. The adjustment is also common in the Thai literature, for example, Tinakorn and Sussangkarn (1996), Chandrachai et al. (2004) and Poapongsakorn (2006). An adjustment helps reveal the extent to which labour quality has changed and how this qualitative change is attributable to growth. For comparison purposes, in reporting the results from growth accounting, both adjusted and unadjusted TFP are presented and in examining TFP determinants, both are employed.

Labour quality adjustment method

To adjust for the qualitative change of labour in Thai agriculture, this study adopts the labour quality-adjusted index computed by the Thailand Research Development Institute (TDRI). The index computation follows the method developed by Tinakorn and Sussangkarn (1994, 1996). This method modifies Denison's (1967) pioneering study on labour quality adjustment, to suit the nature of data in Thailand. The rationale is that changes in age, sex and the education levels of workers over time should have an impact on output if the marginal products of different groups are not the same. For example, as long as workers of younger age and those of lower education earn less, the shifting of worker composition away from these groups indicates an improved contribution to output (Tinakorn and Sussangkarn, 1996, p.30-35). The constant growth in the number of workers may increase or decrease output due to the changing composition of workers' age, sex and education. Therefore, adjusting for changes in labour quality gives a clearer picture on the contribution of labour input to output growth quantitatively and qualitatively.

The adjustment method computes the age-sex-education index or quality-adjusted labour index based on the wage differentials of workers classified according to their age, sex and education level. In the LFS, the male and female labour force was categorized into five age groups, 15-19, 20-29, 30-39, 40-49 and 50-Over. They are then grouped according to levels of education attainment. There are five educational classes: 1) no formal education, elementary education or lower 2) upper and lower secondary education 3) vocational education 4) university education of high level technical vocational education and 5) teacher training education.

The qualitative changes in age, sex and education are measured simultaneously because the average wage of male and female workers at different age groups is influenced by education levels and vice versa. This method is widely applied in the Thai literature, for example, Poapongsakorn (2006), Chandrachai et al. (2004), Chockpisansin (2002). It is summarized as follows.[98]

1. Tabulate the average wage of private employees in each year by age (i), sex (j) and education levels (k) from the LFS.
2. Calculate the average wage differential index ($W_{i,j,k}$) by using the average wage of male workers, age 30-39; attaining elementary education as a reference point (that is, their wage is set equal to 1).
3. Compute the share of employment ($S_{i,j,k}$) or the percentage of workers, categorised by age, sex and education levels.
4. The index is computed as the weighted average of wage differential using employment share as weights. The index formula is $I = \sum S_{i,j,k} \cdot W_{i,j,k}$
5. This index is used to adjust labour input.

2) Land quality adjustment

With the same rationale as explained in the labour quality adjustment, productivity arising from land quality changes can be separated out from the residual TFPG. As agricultural land is quite limited, the same amount of land may contribute to output growth more than its quantity shows. Thus, this study makes an adjustment on the stock of land in order to distinguish the effect of land quality changes over time.

Land and irrigation are important in agriculture. Access to irrigation can improve the quality of land and enables farmers to grow rice and multiple crops during the dry season. An expansion in irrigated area is expected to increase agricultural output and productivity (Tinakorn and Sussangkarn, 1994, p. 41). Thus, accounting for changes in land quality can be done by adjusting land input with the effect of irrigation.

[98] See details in Tinakorn and Sussangkarn (1996).

To account for the impact of irrigation on land quality, it is important to consider which source of land input data is being used. The two sets of land data used in this study are stock and flow. If available data relate to the stock of land area, which does not take into account second rice[99] or multiple cropping, it is appropriate to adjust the land input with its access to irrigation. On the other hand, if available data cover land area that already includes multiple cropping it is not necessary to adjust it to allow for the effect of irrigation.

Following Tinakorn and Sussangkarn (1996, p. 28-29), the adjustment method of land input quality uses an index of irrigated area to adjust the index of cultivated area. Numbers are converted into simple indices in order to compare their changes with the base year. It simply adjusts the stock of land series with an irrigated area series.[100] This method is also used in Poapongsakorn (2006). The steps undertaken are as follows:

1. Tabulate accumulated irrigation area and land area that needs to be adjusted.
2. Find the proportion of irrigated area in land area.
3. Calculate an index of proportion of irrigated area and an index of land area by using 1988 as a reference or base year.
4. The proportion of irrigated area index is used to adjust land input by multiplying it with the index of land area.

To measure TFP growth using adjusted factor inputs, equations (4.6) and (4.7) are revised by replacing unadjusted factor inputs and relevant factor income shares with adjusted ones. Let (*) denote an adjusted variable. The continuous time formula in equation (4.6) is expressed as:

$$TFPG_t^* = \hat{Q}_t^* - S_L^* \hat{L}_t^* - S_N^* \hat{N}_t^* - S_K \hat{K}_t \qquad (4.8)$$

[99] Second rice refers to rice grown during dry seasons, relying mainly on the irrigation system.
[100] Similar to the splicing technique, the pattern of land growth is converted to follow that of irrigated area. See Appendix 4B for details.

where $TFPG_t^*$ = adjusted TFP growth

$\hat{L}_t^*$ = quality-adjusted labour growth

$\hat{N}_t^*$ = quality-adjusted land growth

$\hat{K}_t$ = capital growth

S_L^*, S_N^* = factor income shares using adjusted labour and land, respectively

S_K = capital income share

By applying discrete annual data, equation (4.8) is specified as:

$$\begin{aligned} TFPG_t^* &= (\ln Q_t - \ln Q_{t-1}) - \frac{1}{2}(S_{Lt}^* + S_{Lt-1}^*)(\ln L_t^* - \ln L_{t-1}^*) \\ &- \frac{1}{2}(S_{Nt}^* + S_{Nt-1}^*)(\ln N_t^* - \ln N_{t-1}^*) - \frac{1}{2}(S_{Kt} + S_{Kt-1})(\ln K_t - \ln K_{t-1}) \end{aligned} \quad (4.9)$$

4.4 Output and Input Measurements and Data Sources

This study employs aggregate annual time series data of agricultural outputs and inputs at the national level for Thailand, covering 1970-2006. The choice of the starting period was constrained by the availability of the data. The agriculture sector is broadly defined to cover crops, livestock, fisheries, forestry and agricultural services. Then agriculture with only crops and livestock is considered. This is divided into two subsectors, crops and livestock.

Altogether, the analysis consists of four cases.[101] First is a broad definition of overall agriculture including crops, livestock, fisheries, forestry and agricultural services (subsequently Ag1). Second is a narrowed definition of traditional agriculture comprising crops and livestock only (subsequently Ag2).[102] The third sector is crops

[101] The classification is set to serve one of the objectives of this thesis to assess the agricultural research impacts on productivity emphasizing the crops and livestock sectors. The overall agriculture is included because it has been a standard practice in empirical studies of Thai agriculture (See Table 2.1 in Chapter 2 for a summary of the previous Thai studies).

[102] It is referred to as traditional agriculture because crops and livestock have long been two important sectors in Thai agriculture, in terms of GDP, employment and export.

and the fourth is livestock. Within each sector, primary inputs are divided into unadjusted inputs and inputs adjusted for quality changes.

4.4.1 Output

Output is represented by Gross Domestic Product (GDP) at constant market prices in the agricultural sector. GDP at constant (1988=100) market prices has been widely used for the case of Thailand and is also used in this study. It is measured as total value added in which all intermediate costs are taken out of the value of production or gross output.[103] The data are obtained from the Office of the National Economic and Social Development Board (NESDB).

It is important to note that agricultural GDP in this study does not include simple agricultural processing products, as in the past.[104] This is in accordance with the Thailand Standard Industrial Classification 2001 (TSIC-2001)[105] that classifies simple processing activities as components of the manufacturing sector. Due to the change in sectoral classification, the agricultural GDP series since 2001 no longer include simple processing activities and it is impossible to separate these processing activities from manufacturing GDP. However, the GDP series prior to 2001 are reported at a disaggregated level, which separates the value of simple processing products. To obtain consistent output data, agricultural simple processing is excluded from the GDP series prior to 2001.[106]

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[103] The value added output measure is best used for primary production (Mahadevan, 2002, p.3).

[104] Prior to 2001, simple agricultural processing products were treated as part of agricultural GDP. Simple agricultural processing involves manual activities like sorting vegetables or processing agricultural products such that they can be stored or transported conveniently. It is different from food processing that involves machinery and equipment. Food processing, such as canned fruit and fruit juices, has long been included in the manufacturing industry. It has nothing to do with the agricultural GDP data.

[105] TSIC is in line with the International Standard Industrial Classification (ISIC).

[106] See Appendix 4A table 4.18.

4.4.2 Inputs

As output is measured as value added, three primary agricultural inputs are considered in this study - labour, land and capital. Fertilizers, feed, and pesticides are components of the intermediate costs that have been subtracted from output in calculating value added. Hence, there is no need to include fertilizers or other intermediate inputs.

1) Labour

Labour input is represented by the number of employed persons in the agricultural sector.[107] It is obtained from the Labour Force Survey (LFS) conducted by the National Statistical Office (NSO). Labour input includes those of age 15 and over working in the fields during the survey period in the rainy season. This comprises both self-employed (farm owner-operator, family labour employees) and private workers (contract or hired labour).

The availability of consistent time-series data of the LFS began in 1971. From 1971 onwards, there have been changes in the number of rounds and the timing when surveys were conducted. The second round LFS (July-September during 1971-1983) and the third round LFS (August during 1984 to the present) are commonly chosen to form a time series of the data in the literature.[108] They are also employed in this study. The main reason is that such surveys were conducted during July-September which is the rainy season when the agricultural population is most active in the fields. The rainy season series should represent the total number of the labour force that actually contribute to agricultural production in each year. More importantly, a consistent data series on the labour force can only be obtained from these rounds of surveys.

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[107] Although the total working hours is a preferable flow measure of labour input, the number of workers employed is used instead because it was found that hours reported in agriculture were a mixture of both on- and off-farm work, which includes non-agricultural activities (Tinakorn and Sussangkarn, 1996, p.55).

[108] For example, Tinakorn and Sussangkarn (1996, 1998), Coxhead and Plangpraphan (1999), Chandrachai et al. (2004) and Poapongsakorn (2006).

It is important to note that there have been changes in the definition of employed persons in the LFS. The age of the labour force has been changed in accordance with the International Labour Organization (ILO) definition. During 1970-1988, the employment data covered those aged 11 and over. During 1989-2000, the definition of employed persons changed to age 13 and over. From 2001 to the present, the definition has changed to age 15 and over.

To obtain a consistent time series, this study follows Poapongsakorn (2006) and uses his employment series, from 1977 to 2003, that adjusted the data prior to 2001 to cover only those aged 15 and over. His data set also provides disaggregated employment in the crops and livestock sectors. The employment series at a disaggregated level during 2004-2006 were obtained by request from the NSO. The employment series for 1970-1976 was estimated based on the data obtained from Coxhead and Plangpraphan (1999) and the available LFS data.

Specifically, for overall agriculture (Ag1), the 1970-1976 LFS data set is combined with the data set from Poapongsakorn (2006) using the splicing technique.[109] Traditional agriculture (Ag2) also follows the same technique used in the overall agriculture, combining the 1970-1976 data series with the 1977-2006 series. The 1977-2006 series is the summation of crops and livestock employment obtained from Poapongsakorn (2006) and LFS.

There are no separate data available on employment for the crops and livestock sectors prior to 1977. However, it was observed that from 1977 to 1981 the employment shares of crops and livestock in traditional agriculture hardly changed, although these shares did change later.[110] Therefore, it is assumed the employment structure within agriculture did not change in the period before 1977 and that the shares of employment of crops and livestock during 1970-1976 were the same as

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[109] The adjuster is computed by dividing the 1977 Poapongsakorn data with the 1977 LFS data. Then, this ratio is used to multiply all numbers of LFS data. Note that the Coxhead and Plangpraphan data set is actually the same as the LFS data but has more data on 1970. See Appendix 4A Table 4.19.
[110] See Appendix 4A Table 4.20

during 1977 to 1981. As a result, the employment numbers for crops and livestock during 1970-1976 are estimated using the percentage share of each sector during 1977 to 1981.

In terms of labour quality adjustment, the calculation of the age-sex-education index requires the distribution of average wage data by age, sex and education. The LFS does not report such detailed data. Hence, the labour quality-adjusted index is obtained from the Thailand Development Research Institute (TDRI) for the period 1977-2004.[111] The computation method of the age-sex-education index also follows Tinakorn and Sussangkarn (1996), based on the LFS raw data. However, the LFS wage data needed to calculate the index are only available from 1977 onwards. Due to data limitations, the structure of workers' age, sex and education for the period before 1977 is assumed to remain the same as in 1977 and after 2004 is assumed to be the same as in 2004.

2) Land

Land input is obtained from the Office of Agricultural Economics (OAE) and the Department of Livestock Development (DLD) under the Ministry of Agriculture and Cooperatives (MOAC). This study employs two sources of agricultural land data, stock and flow data sets. The first data set is stock of land area. It is the utilization of land in agriculture or total farm holding area. It represents a stock because the recorded land area is fixed regardless of how many times the area is cultivated. Land utilization consists of eight categories according to the purpose of land use. They are areas for housing, paddy, field crops, fruit trees, perennial crops, vegetables and flowers, grass or pasture, idle land and others. These data are obtained from the land utilization surveys conducted by the OAE.

The second data set is the cultivated area consisting of total planted area for crops and total livestock area. It represents a flow because land area is counted per cultivation. These data are obtained from both the OAE and the DLD. Total planted area includes

[111] The data are the updated version used in Poapongsakorn (2006).

both major and second rice as well as other crops selected from six major crop groups.[112] They are food and feed crops, oil crops, fibre crops, vegetables, fruit trees and perennial trees, e.g., maize, cassava, soybean, oil palm, cotton, kenaf, garlic, banana, rubber, etc. The selection is based on the importance of each crop to the Thai economy and the availability of a complete data set from 1970 to 2006. The data on planted areas for each crop are from the Centre for Agricultural Information, OAE.

The land input for livestock includes grass or pasture area and privately owned areas. Since there are no complete time series data on public and private livestock areas, this study combines data from three sources, using the splicing technique. The main data source is Poapongsakorn (2006),[113] combined with the data set from the survey of livestock area by the DLD and the land utilization survey report by the OAE. Prior to 1975, there is no grass area available in the OAE survey. Therefore, grass area during 1970-1974 is estimated based on the proportion of grass area in 1975.[114]

3) Capital

Capital input is represented by net capital stock at constant prices (1988=100) in the agricultural sector, obtained from the NESDB.[115] It is defined as the value of public and private fixed assets (construction and equipment) after deducting depreciation, or gross capital stock minus annual depreciation. Net capital stock is employed because depreciation, which is lost capital during the production process, does not subsequently contribute to productivity.

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[112] Major crop groups are classified according to Thailand Standard Industrial Classification (TSIC). Altogether the total planted areas include cultivated areas under 39 crops.

[113] His data set is available from 1980-2003 and based on official data sources of the OAE and the DLD.

[114] See Appendix 4A Table 4.21. Land area in livestock refers to total livestock land comprising grass and privately owned areas.

[115] The NESDB officially published capital stock data in May 1998. The data are dated back to 1970. They are computed based on the perpetual inventory method or PIM (NESDB, 2006). As the data became available in 1998, previous studies often constructed capital stock based on selected agricultural machinery and equipments (e.g., tractors, water pumps, buffalos), for example, Budhaka (1987), Patamasiriwat and Suewattana (1990), Coxhead and Plangpraphand (1998), Krasachat (1997).

The NESDB only constructs the net capital stock for the overall agricultural sector. Disaggregated capital stock data are not available. Hence, the capital stocks for crops and livestock sectors are estimated as follows. First, the imputed return to capital is estimated as GDP at factor cost minus the return to land and labour, as described in equation (4.10). Then the sector shares of this imputed return to capital are used to divide the capital stock among sectors. That is, imputed income flows to capital by sector are used to divide the value of the total capital stock. This can be expressed as:

$$RK = gdp_{FC} - wL - rN \tag{4.10}$$

where RK = imputed return to capital

gdp_{FC} = real GDP at factor cost

wL = real return to labour

rN = real return to land

The real values of GDP at factor cost, return to labour and land are derived by deflating nominal values with the implicit GDP deflator. The GDP deflator is calculated by dividing GDP at current prices by GDP at constant (1988) prices, multiplied by 100.

Equation (4.10) is used to find the imputed return to capital for crops, livestock and total agriculture. Then the capital shares of crops and livestock to total agriculture are used to separate the NESDB agricultural net capital stock at constant prices. The real capital stock for the traditional agriculture (Ag2) is a summation of crops and livestock capital stock series. The calculation steps are summarized in the following list:[116]

1. Calculate imputed return to capital, based on equation (4.10) for crops, livestock and total agriculture (Ag1).
2. Find the percentage share of crops and livestock in Ag1, denoted as %crops and %livestock, respectively.

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[116] See Appendix 4A Table 4.22.

3. Use the percentage shares to separate crops and livestock capital from the NESDB agricultural net capital stock series at constant prices (K_Ag1):
    - Crops capital stock = %crops × K_Ag1 and
    - Livestock capital stock = %livestock × K_Ag1.

It is worth mentioning why this technique is used to estimate capital stock for crops and livestock. The NESDB capital stock series is regarded as a reliable source of data with broad coverage of public and private capital input. Breaking up the NESDB capital data should give more reliable results than constructing the capital based on alternative data sources.[117]

Constructing the capital stock using the accumulated number of agricultural machinery and an inventory of livestock breeds can partially approximate capital stock for crops and livestock. However, the total numbers from partial approximation are different from the NESDB's country-wide coverage capital data. The main reasons are different data sources and partial coverage of capital input. In particular, the prices of capital are most likely to be unreliable and not available. Estimating prices of capital could give biased results. The method used in this study can overcome these data difficulties. It also provides comparable capital stock series for crops and livestock to total agricultural capital stock, provided by the NESDB.

4) Factor income share

Factor income shares are calculated by dividing the value of factor income of each input by the total value of output or GDP at current factor cost. By following the growth-accounting formula shown in Equations (4.7) and (4.9), the factor income shares of the two consecutive periods are averaged.

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[117] Poapongsakorn (2006) is apparently the first study that estimated TFP and capital stock for crops and livestock in Thailand. His study used selected agricultural machinery and 1995 household equipment prices to derive crop capital and computed livestock capital using the inventory of breeding livestock valued at average investment cost. The data source is mainly from the OAE and the DLD.

Because the NESDB has changed the way it reports the GDP series, GDP at factor cost of crops and livestock is no longer available after 2001. As a result, the shares of crops and livestock GDP in agricultural GDP (without fisheries) at current market prices during 2002-2006 are used, ignoring the role of government. The shares of crops and livestock GDP at current prices are multiplied with the agricultural GDP (without fisheries) at factor cost to obtain crops and livestock GDP at factor cost for the years 2002 to 2006. Then, traditional agricultural GDP at factor cost (Ag2) is derived by summing relevant crops and livestock GDP.[118]

For labour income, the average wage rate reported by the LFS includes only those of private or hired workers. Since it does not incorporate the wage rate of self-employed, own-account workers or unpaid family workers, which are all important sources of labour in Thai agriculture, the LFS wage rate is too high. Following Tinakorn and Sussangkarn (1996) and Poapongsakorn (2006), the LFS average yearly wage is adjusted down by the wage payment of all workers, obtained from the social accounting matrix (SAM). This adjusted wage is called imputed wage based on SAM taking into account self-employed and unpaid labour.

The imputed wage is based on the wage payment of all agricultural workers, from the 1995 social accounting matrix (SAM) developed by TDRI. Specifically, the ratio of the SAM wage and the LFS wage in 1995 is used to adjust the remaining LFS wage.[119] The adjusted wage rate is then multiplied with the number of workers. Finally, the labour income share is derived by dividing the labour income with GDP at factor cost. This is expressed as:

$$S_L = (W \cdot L) / GDP_{FC} \tag{4.11}$$

[118] See Appendix 4A Table 4.23. GDP at factor cost equals GDP at current market prices minus net indirect taxes (taxes – subsidies). It represents the total output valued at factor costs, separating out the role of government via net taxes.

[119] The ratios for agriculture, crops and livestock are obtained by courtesy from the TDRI. Note that the SAM is developed for TDRI internal uses. This thesis does not have access to the SAM database, and only the adjusters are provided. See Appendix 4A Table 4.24.

where S_L = labour income share

W = average wage rate

L = number of employed persons

GDP_{FC} = GDP at current factor cost

The main source of wage data comes from the LFS by the NSO. As this study follows Poapongsakorn (2006) in terms of the definition of the labour force, the wage data from 1977-2004 is also obtained from Poapongsakorn (2006) and TDRI, which also calculated their data based on the LFS raw data tapes. However, the NSO surveys of wage data became available only from 1977 onwards. Owing to this data constraint, this study employs the wage data prior to 1977 from an alternative source that also based estimation of wage rate on the LFS wage (Coxhead and Plangpraphan 1998, 1999). The recent wage data after 2004 is taken from the LFS. The LFS wage rate for traditional agriculture (Ag2) is an average of the crops and livestock wage rate.

For land income, the rent for the agricultural sector, crops and livestock is estimated based on average rent per rai, derived by dividing total rent (actual and imputed) in the national accounts by the corresponding land area. The rent per rai is assumed to be the same for both crops and livestock. Total land rent and land area data are obtained from the NESDB. It comprises the actual rent and the rent imputed for owner-occupied land.[120] This is specified as:

$$S_N = (R \cdot N) / GDP_{FC} \tag{4.12}$$

where S_N = land income share

R = average land rent

N = land area

GDP_{FC} = GDP at current factor cost

[120] See Appendix 4A Table 4.25. Note that the data from this table are used to derive rent per rai. The total land area data used in the growth accounting are drawn mainly from the OAE (Table 4.29).

After computing the factor income shares for labour and land, the share for capital is computed as a residual. That is $S_K = 1 - S_L - S_N$, where S_K is capital income share.

Table 4.2 Summary of the Data by Definition and Source (1970-2006)

Variables[121]	Definitions	Sources
Agricultural output	GDP at 1988 prices (value added)	National Income of Thailand, NESDB (1970-2006)
Agricultural labour	Number of employed persons age 15 and above	Labour Force Survey, NSO (1971-2006) Poapongsakorn, 2006 and TDRI (1977-2003) Coxhead and Plangpraphan, 1999 (1970-1971)
Agricultural land - Crop land - Livestock land	Farm holding area or land utilization for overall agriculture - Land utilization (stock) and cultivated area (flow) - Grass and privately own area for livestock	Land Use in the Agriculture of Thailand and Agricultural Statistics of Thailand, OAE (1970-2006) Livestock statistics, DLD (1999-2006) Poapongsakorn, 2006 (1980-2003)
Agricultural capital	Net capital stock at 1988 prices	National Income of Thailand, NESDB (1970-2006)
Agricultural wage	Imputed wage of all workers, measured as private workers' wage adjusted by 1995 SAM wage to account for self employed and unpaid family labour	Labour Force Survey, NSO (1977-2006) Poapongsakorn, 2006 and TDRI (1977-2004) Coxhead and Plangpraphan, 1999 (1970-1976)
Land rent	Actual and imputed rent (rai)	NESDB
Labour quality-adjusted index	Qualitative changes in age, sex and education attainment of agricultural workers	TDRI (based on Labour Force Survey, NSO)
Irrigation	Accumulated irrigation area (rai), including small, medium and large scale irrigation projects	OAE
Factor income share	Value of factor income divided by GDP at factor cost	NESDB (GDP at factor cost)

[121] Output, input and relevant data are shown in Appendix 4A and 4B.

4.5 Results and Discussion

This section discusses sources of agricultural growth with an emphasis on TFP growth (TFPG). The first sub-section provides general findings on TFPG estimates before and after adjusting for quality changes. The second sub-section examines sources of growth for each agricultural sector; overall agriculture (Ag1), traditional agriculture (Ag2), the crops and livestock sectors. The effects of factor input adjustment are also explained.

4.5.1 General Findings

One pattern that can be observed for all agricultural sectors from the growth accounting analysis is that TFP makes an important contribution to its own sector's output growth. Over the period 1971-2006, the average annual growth rates of TFP are positive and relatively high, compared with the three factor inputs. Tables 4.3 and 4.4 summarize the decomposition of output growth in Thai agriculture using unadjusted and adjusted factor inputs, respectively.

In overall agriculture (Ag1), capital accumulation is the largest source of growth, followed by TFP, labour and land, respectively. After adjusting for labour and land quality improvement, their percentage contribution to output growth increases while that of TFP decreases. The overall ranking of the contribution of each input and TFP remains unchanged.

The relative importance of factor inputs and TFP in the overall agriculture is also shared by the traditional agriculture and the crops sector. Capital accumulation is the major source of output growth in most sectors, except for the livestock in which employment is the largest source of output growth. TFPG has generally been the second most important source of growth in all sectors. The percentage contribution of adjusted and unadjusted TFPG is relatively high in the traditional agriculture (Ag2).

These findings are qualitatively consistent with those of Poapongsakorn (2006), although different in magnitude.[122] Despite the differences in study period, measurement of capital stock and growth calculation, the relative importance of factor inputs and TFPG for overall agriculture, crops and livestock are comparable, as shown in Appendix Table 4.38.

Table 4.3 Decomposition of Agricultural Growth Using Unadjusted Inputs, 1971-2006

	Output growth	Input Growth			Unadjusted TFPG	% Contribution to output growth			
		Labour $s_L\hat{L}$	Land $s_N\hat{N}$	Capital $s_K\hat{K}$		Labour	Land	Capital	TFPG
Agl	3.02	0.45	0.07	1.65	0.85	15.00	2.19	54.73	28.08
Ag2	3.34	0.30	0.09	1.61	1.35	9.01	2.56	48.11	40.32
Crops	3.27	0.20	0.10	2.09	0.88	6.22	2.98	63.95	26.86
Livestock	3.83	2.80	-0.01	0.17	0.88	72.97	-0.38	4.53	22.88

Notes: TFPG estimation is based on equation (4.7). See Appendix 4C for details.
Land is based on the stock of land area data set. Agl includes crops, livestock, fisheries, forestry and agricultural services. Ag2 includes crops and livestock only.

Table 4.4 Decomposition of Agricultural Growth Using Adjusted Inputs, 1971-2006

	Output growth	Input Growth			Adjusted TFPG*	% Contribution to output growth			
		Labour $s_L^*\hat{L}^*$	Land $s_N^*\hat{N}^*$	Capital $s_K\hat{K}$		Labour	Land	Capital	TFPG*
Agl	3.02	0.57	0.19	1.65	0.61	18.79	6.13	54.73	20.35
Ag2	3.34	0.45	0.22	1.61	1.06	13.59	6.51	48.11	31.78
Crops	3.27	0.25	0.25	2.09	0.68	7.60	7.63	63.95	20.82
Livestock	3.83	3.00	-0.01	0.17	0.67	78.35	-0.38	4.53	17.49

Note: TFPG estimation is based on equation (4.9). See Appendix 4C for details.
Land is based on the stock of land area data set. Livestock land is not adjusted. Agl includes crops, livestock, fisheries, forestry and agricultural services. Ag2 includes crops and livestock only.

It should be noted that the results in this study do not account for the role of migrant workers from Thailand's neighbouring countries due to lack of data. As pointed out in Chapter 3, migrant workers have become increasingly important, particularly from 1996 onwards. This omission could produce some bias in the TFP estimation. An increase in the number of migrant workers should increase the contribution of labour

[122] Poapongsakorn (2006) is apparently the only study that estimated TFP growth for agricultural subsectors. His study employed the growth accounting method but did not apply Tornqvist discrete approximation to continuous time data in calculating rates of growth as in this thesis. His covered period is 1980-2003. Capital stock for overall agriculture is based on the NESDB capital stock at 1988 prices and capital stock for crops and livestock are constructed based on other sources of data. Labour and land are also adjusted for their quality changes.

growth to overall growth. As TFP is measured as a residual, its contribution should decrease. From rough estimations using the number of migrants during 1996-2006 described in Chapter 3, the inclusion of migrant workers in the growth accounting increases the labour growth contribution and hence reduces that of TFP in overall agriculture, on average, by 0.043 percentage points. That is, TFPG is reduced by an average of 0.614 to 0.571. The direction of TFPG remains unchanged. There are only slight differences between the quality-adjusted TFPG and the TFPG taking into account migrant workers in the overall and traditional agriculture.[123]

For crops and livestock individually, since there is no disaggregated data available on each of these sectors it is best to leave the estimation of TFPG incorporating the role of migrant workers for future study. In addition, Thai workers are shown to be the dominant source of crop agriculture (Martin, 2007), omitting migrants should not cause a significant bias, as shown by the rough estimates above. The majority of migrants are seasonal workers and are concentrated in labour-intensive crop farms of border provinces (Chalamwong et al., 2009). Rice production, particularly in the Central Plain, has become mechanized and now requires less labour. Future study can help clarify this issue further.

4.5.2 Sources of Agricultural Growth

This sub-section explains the sources of growth in each agricultural sector. It begins with interpreting results from the adjustments made on factor inputs. As a similar interpretation applies to all subsectors, the discussion focuses only on overall agriculture. This should give a clearer picture on the contribution of factor inputs as well as on adjusted TFPG. Then sources of growth, both adjusted and unadjusted, are discussed for each sector with an emphasis on TFP.

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[123] The econometric estimation of TFP determinants over the entire study period, which is conducted in Chapter 6, is not significantly affected by these slight changes of TFP estimates.

1) Factor input adjustments: how important are they to growth?

The effect of changes in labour quality

Over the 37-year sample period, there has been a slight improvement in the labour quality for overall agriculture. As shown in Table 4.5, the average number of employed persons accounting for quality improvement is higher than the unadjusted number reported in the Labour Force Survey. The average annual growth rate of quality-adjusted employment is 1.46 percent while the unadjusted growth rate is 1.17 percent. The slight change in labour quality is also consistent with previous studies. For instance, Chandrachai et al. (2004) found there was not much improvement in the quality of labour. The improved quality of labour in agriculture was the lowest, compared to manufacturing and services (Tinakorn and Sussangkarn, 1996).

Table 4.5 Labour Input with and without Quality Adjustment

Agl	Total Employment (million persons)		Growth rate (%)	
Period	Unadjusted	Adjusted for quality	Unadjusted	Adjusted for quality
1971-1975	11.06	10.83	2.71	2.71
1976-1980	13.95	13.68	4.94	5.03
1981-1985	16.65	16.47	2.22	2.45
1986-1990	18.18	18.21	2.59	2.81
1991-1995	17.88	18.13	-2.44	-2.14
1996-2000	16.05	16.70	-0.81	-0.17
2001-2006	15.43	16.70	-0.66	-0.13
1971-2006	**15.47**	**15.71**	**1.17**	**1.46**

Although agricultural labour quality was generally improved, there were slight drops in labour quality in 1986, 1988 and 2002.[124] This could be a result of labour migration to the industrial sector, notably from 1986 which was the beginning year of an economic and industrial boom in Thailand. There is no difference between unadjusted and adjusted employment growth during 1971-1977 because the structure of the labour force and its quality is assumed to remain unchanged due to data limitations.

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[124] See labour quality index in Appendix 4B Table 4.28.

Table 4.6 Effect of Changes in Labour Quality in Overall Agriculture

Agl Period	Output Growth	Unadjusted Labour	Adjusted Labour	Unadjusted TFPG	Adjusted TFPG(L)	Effect of quality* TFPG - TFPG(L)
1971-1975	3.57	0.98	0.96	1.00	1.02	-0.02
1976-1980	3.08	2.29	2.28	0.30	0.31	-0.01
1981-1985	4.10	0.90	0.99	2.32	2.22	0.10
1986-1990	2.45	1.08	1.18	-0.01	-0.12	0.11
1991-1995	3.39	-1.41	-1.28	1.59	1.46	0.13
1996-2000	2.28	-0.35	-0.07	0.34	0.05	0.29
2001-2006	2.55	-0.26	-0.07	0.66	0.47	0.19
1997-1998	-1.09	0.47	0.93	-4.34	-4.80	**0.46**
1971-2006	**3.02**	**0.45**	**0.57**	**0.85**	**0.73**	**0.11**

Note: *Effect of labour quality improvement equals TFPG minus TFPG(L) or adjusted L minus unadjusted L. TFPG is unadjusted TFP growth. TFPG(L) is TFP growth adjusted for changes in labour quality.

Under growth accounting, there is also a slight difference between unadjusted and quality-adjusted labour growth. As shown in Table 4.6, after adjusting for changes in labour quality, the contribution of labour input to agricultural growth increases slightly from 0.45 to 0.57 percent. Since TFP is measured as a residual, the improvement in labour quality raises labour input growth and thereby lowers TFPG from 0.85 to 0.73 percent. When productivity growth arising from labour quality improvement is separated out, the TFPG that better reflects pure technological change becomes smaller.

The effect of labour quality changes is indicated by the difference between unadjusted TFPG and labour-quality adjusted TFPG, which is equivalent to the difference between unadjusted and adjusted labour growth. From Table 4.6, labour quality improvement contributes to agricultural growth at an annual rate of 0.11 percent. Although the effect is quite small, it tends to increase over time. In particular, there was a considerable improvement in labour quality during the crisis period of 1997-1998. The probable cause could have been the return of high skill labour from non-agricultural sectors as there were layoffs in the manufacturing sector during the crisis.

As shown in Table 4.7, the improvement of labour quality is also evident at the subsector level. In particular, the effect of labour quality is notably high in the livestock sector. The rising share of livestock employment in the total agricultural labour force implies a movement of labour toward the livestock sector. It is likely that higher quality labour, in terms of age, sex and education, has moved to this sector. As a result, TFPG was adjusted down according to the magnitude of labour quality improvement.

Table 4.7 Effect of Changes in Labour Quality in Each Sector, 1971-2006

	Output Growth	Unadjusted Labour	Adjusted Labour	Unadjusted TFPG	Adjusted TFPG(L)	Effect of quality* TFPG - TFPG(L)
Ag1	3.02	0.45	0.57	0.85	0.73	0.11
Ag2	3.34	0.30	0.45	1.35	1.19	0.15
Crops	3.27	0.20	0.25	0.88	0.83	0.04
Livestock	3.83	2.80	3.00	0.88	0.67	0.20

Note: *Effect of labour quality improvement equals TFPG minus TFPG(L).
TFPG is unadjusted TFP growth. TFPG(L) is TFP growth adjusted for changes in labour quality.

The effect of changes in land quality

The contribution of land expansion to output growth is relatively small compared with other inputs. By adjusting land inputs with access to irrigation, the contribution of land expansion has increased as expected. This implies that there has been an improvement in land quality due to the irrigation system.[125]

There are two sets of land data; cultivated area and land stock. The cultivated areas are not adjusted with the access to irrigation because the effect of irrigation is already taken into account for the areas under the second rice and multiple crops.[126] However, the cultivated areas are not the same as the adjusted land stock due to different definitions and coverage between the cultivated area and the land utilization data sets. In general, only slight differences are found in the growth rates of land areas using the land utilization (stock basis) and the cultivated areas (flow basis). More difference is found between the unadjusted and adjusted land, using the land utilization data set.

[125] The irrigated area and land adjustment index are shown in Appendix 4B Table 4.30.

[126] In Appendix 4C, growth accounting for Ag2 (Table 4.35) and crops (Table 4.36) report two sets of TFP growth; TFPG(1) using cultivated or planted land area, TFPG(2) using land utilization or stock of land area. Only the stock of land is presented here because a comparison can be made between unadjusted and adjusted land.

By taking into account the effect of improved land quality, the land contribution to output growth increases, and thereby the contribution of adjusted TFPG is lower. As shown in Table 4.8, the average annual growth rate of unadjusted land for overall agriculture during 1971-2006 is 0.07 percent while that of adjusted land is 0.19 percent. The effect of improved land quality that contributes to productivity growth is 0.12 percent on average. When this component of productivity growth is separated out, the TFP growth declines from 0.85 to 0.73 percent.

Table 4.8 Effect of Changes in Land Quality in Overall Agriculture

Agl Period	Output growth	Unadjusted Land	Adjusted Land	Unadjusted TFPG	Adjusted TFPG(N)	Effect of Quality* TFPG-TFPG(N)
1971-1975	3.57	0.26	0.17	1.00	1.09	-0.09
1976-1980	3.08	0.07	0.32	0.30	0.06	0.25
1981-1985	4.10	0.12	0.33	2.32	2.11	0.21
1986-1990	2.45	0.04	0.14	-0.01	-0.11	0.10
1991-1995	3.39	0.00	0.11	1.59	1.48	0.12
1996-2000	2.28	-0.02	0.10	0.34	0.22	0.11
2001-2006	2.55	-0.01	0.14	0.66	0.51	0.15
1997-1998	-1.09	-0.05	0.08	-4.34	-4.46	0.12
1971-2006	**3.02**	**0.07**	**0.19**	**0.85**	**0.73**	**0.12**

Note: *Effect of labour quality improvement equals TFPG minus TFPG(N).
TFPG is unadjusted TFP growth. TFPG(N) is TFP growth adjusted for irrigation.

Table 4.9 Effect of Changes in Land Quality in Each Sector, 1971-2006

	Output Growth	Unadjusted Land	Adjusted Land	Unadjusted TFPG	Adjusted TFPG(N)	Effect of quality TFPG – TFPG(N)
Agl	3.02	0.07	0.19	0.85	0.73	0.12
Ag2	3.34	0.10	0.25	1.35	1.22	0.13
Crops	3.27	0.10	0.25	0.88	0.73	0.15

Note: *Effect of land quality improvement equals TFPG minus TFPG(N).
TFPG is unadjusted TFP growth. TFPG(N) is TFP growth adjusted for irrigation.

As shown in Table 4.9, the same pattern is also found in traditional agriculture (Ag2) and in crops. Effective irrigation has improved agricultural land, particularly in the crops sector. As irrigation is generally targeted at paddy rice production, the crops sector captured most of the benefit in terms of land quality improvement. Second rice and other crops planted during the dry season contribute to output growth.

2) Sources of growth in overall agriculture (Ag1)

The growth accounting exercise decomposes agricultural growth into growth of land, labour, capital and TFP. As was argued earlier, adjustment of input quality changes leads to a more accurate estimation of the TFP. Discussion of the results therefore focuses on the adjusted TFP series. The sources of growth, both adjusted and unadjusted, are shown to compare the effect of the adjustment. Tables 4.10 and 4.11 summarize the results in sub-periods, which indicate a changing composition of sources of growth over time.

Table 4.10 Average Percentage Rates of Growth of Unadjusted TFP in Overall Agriculture

	GDP	Input Growth			Unadjusted	% Contribution to GDP growth			
Period	growth	Labour	Land	Capital	TFPG	Labour	Land	Capital	TFPG
1971-1975	3.57	0.98	0.26	1.33	1.00	27.56	7.39	37.16	27.88
1976-1980	3.08	2.29	0.07	0.42	0.30	74.22	2.28	13.67	9.84
1981-1985	4.10	0.90	0.12	0.76	2.32	21.89	2.97	18.50	56.63
1986-1990	2.45	1.08	0.04	1.34	-0.01	43.98	1.67	54.94	-0.59
1991-1995	3.39	-1.41	0.00	3.21	1.59	-41.73	-0.03	94.71	47.06
1996-2000	2.28	-0.35	-0.02	2.31	0.34	-15.43	-0.72	101.35	14.79
2001-2006	2.55	-0.26	-0.01	2.16	0.66	-10.31	-0.39	84.81	25.89
1971-2006	**3.02**	**0.45**	**0.07**	**1.65**	**0.85**	**15.00**	**2.19**	**54.73**	**28.08**

Note: TFPG estimation is based on equation (4.7). Land is the stock of land use. See Appendix 4C Table 4.34.

Table 4.11 Average Percentage Rates of Growth of Adjusted TFP in Overall Agriculture

	GDP	Adjusted Input Growth			Adjusted	% Contribution to GDP growth			
Period	growth	Labour	Land	Capital	TFPG*	Labour	Land	Capital	TFPG*
1971-1975	3.57	0.96	0.17	1.33	1.11	26.98	4.82	37.16	31.03
1976-1980	3.08	2.28	0.32	0.42	0.07	73.89	10.27	13.67	2.18
1981-1985	4.10	0.99	0.33	0.76	2.01	24.24	8.16	18.50	49.09
1986-1990	2.45	1.18	0.14	1.34	-0.22	48.37	5.60	54.94	-8.92
1991-1995	3.39	-1.28	0.11	3.21	1.35	-37.83	3.39	94.71	39.73
1996-2000	2.28	-0.07	0.10	2.31	-0.06	-2.90	4.20	101.35	-2.65
2001-2006	2.55	-0.07	0.14	2.16	0.32	-2.81	5.53	84.81	12.47
1971-2006	**3.02**	**0.57**	**0.19**	**1.65**	**0.61**	**18.79**	**6.13**	**54.73**	**20.35**

Notes: TFPG estimation is based on equation (4.9). Land is the stock of land use. See Appendix 4C Table 4.34.

In general, the contribution of the adjusted TFPG is slightly lower than for the unadjusted one. The relative importance of major sources of output growth is the same whether or not the factor inputs are adjusted for their quality changes. For the whole period, agricultural output growth shows an average annual rate of 3.02

percent, of which 55 percent is due to the contribution of capital accumulation. Adjusted TFPG is the second contributing factor (20 percent), followed by quality-adjusted labour (19 percent) and land adjusted for irrigation (6 percent).

It was observed that most of the labour growth was from the early sub-periods. The contribution of labour during the first two decades was quite high. In particular, labour was the largest source of growth during 1976-1980. However, labour growth declined sharply during 1991-1995 and continued to decline up to 2006. Although labour quality has gradually improved since 1981, adjusted labour growth was still negative over the last two decades. The main reason is the migration of workers to non-agricultural sectors.

Land shares a similar story to labour input. It contributed significantly to agricultural growth during the early periods. After Thailand reached its land frontier in 1978 (Krasachat, 2002, p.4), unadjusted land growth was minor and eventually turned negative. While effective irrigation has raised land's contribution to agricultural growth its contribution is still relatively small and declining.

Capital growth is positive in every sub-period. This is consistent with the increasingly important role of farm mechanization since 1970 (Siamwalla et al., 1991 and Krasachat, 1997, p.21).

Residual TFPG is also important. Although its average annual growth rate is small, it has been shown to steadily contribute to output growth over time. Both adjusted and unadjusted TFP growth is mostly positive over the study period. TFP growth is noticeably high in the latter half period. This implies that technological development has become increasingly important.

Comparing adjusted and unadjusted TFPG, it is obvious that their movements are roughly the same. Figure 4.1 illustrates the adjusted TFPG with the solid line and the unadjusted TFPG with the dashed line.

Figure 4.1 TFP Growth in Overall Agriculture

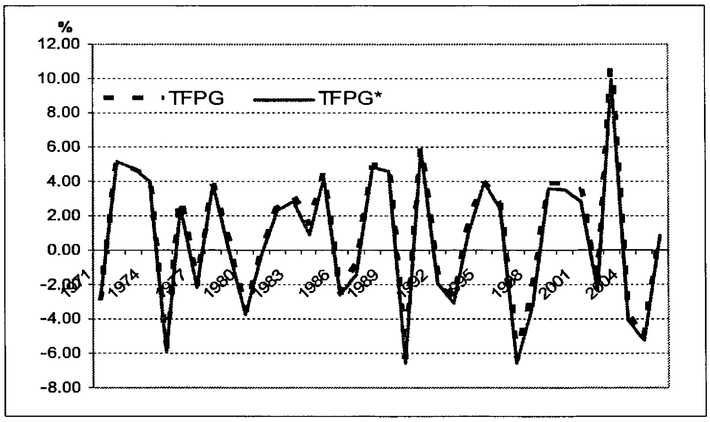
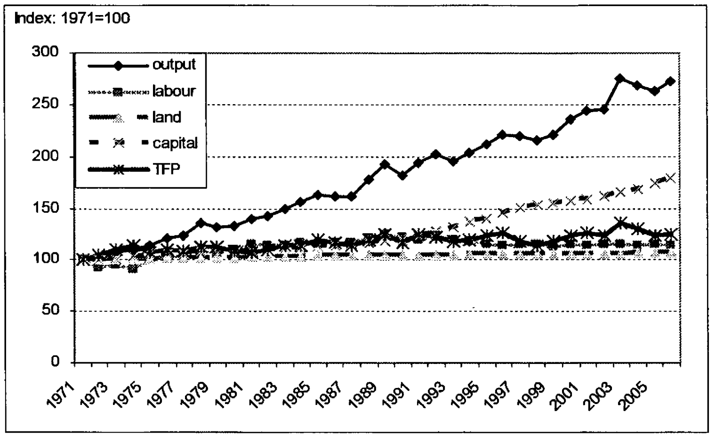


Figure 4.2 Thai Agricultural Output, Inputs and TFP since 1971



To present the output decomposition in terms of level, growth is converted into an index with 1971 as a base year. Figure 4.2 gives a picture of the changing patterns of agricultural output, inputs adjusted for quality changes and TFP level over time. Since 1971, the contributions of capital and TFP are rising while those of labour and land are declining. TFP has become increasingly important notably since it overtook the contribution of labour in the mid-1990s.

Over time, the growth accounting suggests the growth of output in Thai agriculture has relied more heavily on the growth of capital than on the growth of labour or land. The latter two factors have become increasingly limited mainly due to competitive uses by non-agricultural sectors. Specifically, an increasing number of workers have left low pay and hard work in agriculture for higher paid jobs in other sectors, as shown by the declining share of total agricultural employment.[127] To compensate for the declining manpower, agricultural production has relied more on farm machinery and equipment. TFPG, as a crude proxy for technological development, has also become increasingly important. As factor inputs are subjected to diminishing returns and have become more limited, the role of TFPG is expected to rise in the future.

The above findings are consistent with previous studies, for example, Poapongsakorn and Anuchitworawong (2006), Chandrachai et al. (2004) and Tinakorn and Sussangkarn (1996). Despite the smaller magnitude of TFPG estimates in this thesis compared with these earlier studies, it is still positive.[128] These findings support the previous literature that TFPG, including technological development, is an important source of agricultural growth.

3) Traditional agriculture (Ag2)

Focusing on traditional agriculture or combined crops and livestock sectors,[129] capital accumulation is still the largest source of growth, followed by TFP, labour and land. The same ranking applies for both adjusted and unadjusted sources of output growth. Tables 4.12 and 4.13 show the estimated results from the growth accounting. Similar to the overall agriculture, the sector has relied less on labour and land and more on capital as a source of growth. The contribution of land is relatively small although the effective irrigation raised its contribution.

TFP has been shown to be an important source of growth whether the factor inputs are adjusted for quality or not. It makes the second largest contribution to growth and its percentage contribution to GDP growth is close to that of capital. The average annual growth rate of TFP is much higher than TFP growth in overall agriculture.

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[127] Poapongsakorn et al. (1995, p.32) showed that the widening differentials in sectoral GDP growth rates (comparing agriculture with industry and services) and urban-rural wages are the most important forces attracting resources away from the agricultural sector.

[128] This study covers the longest period among growth accounting studies. It is dated back to 1970 when the role of technology may not have been as evident as in recent years. Note that data definitions are also different.

[129] The reason for combining crops and livestock is to test the overall significance of agricultural research that has long been concentrating on these two major sectors.

As shown in Figure 4.3, the pattern of both TFPG series fluctuates over time. Differences between the unadjusted TFPG (dash line) and adjusted TFPG (solid line) are trivial. Overall, the improvement of labour quality and irrigation raise the contribution of input factors thereby lowering TFP growth from 1.35 to 1.06 percent.

Table 4.12 Average Percentage Rates of Growth of Unadjusted TFP in Traditional Agriculture

Period	GDP growth	Input Growth			Unadjusted TFPG	% Contribution to GDP growth			
		Labour	Land	Capital		Labour	Land	Capital	TFPG
1971-1975	4.00	0.68	0.35	5.24	-2.27	16.94	8.81	131.00	-56.75
1976-1980	4.45	2.09	0.11	-1.21	3.45	46.99	2.53	-27.17	77.65
1981-1985	4.67	0.93	0.14	0.10	3.50	19.93	3.00	2.19	74.88
1986-1990	2.44	1.26	0.05	1.30	-0.17	51.46	2.13	53.18	-6.77
1991-1995	2.84	-1.98	0.00	1.60	3.22	-69.77	-0.12	56.34	113.55
1996-2000	3.16	-0.48	-0.04	0.70	2.98	-15.29	-1.14	22.14	94.30
2001-2006	2.60	-0.44	-0.01	3.54	-0.49	-16.79	-0.48	136.14	-18.87
1971-2006	**3.34**	**0.30**	**0.09**	**1.61**	**1.35**	**9.01**	**2.56**	**48.11**	**40.32**

Notes: TFPG estimation is based on equation (4.7). Land is the stock of land use. See Appendix 4C Table 4.35.

Table 4.13 Average Percentage Rates of Growth of Adjusted TFP in Traditional Agriculture

Period	GDP growth	Input Growth			Adjusted TFPG*	% Contribution to GDP growth			
		Labour	Land	Capital		Labour	Land	Capital	TFPG
1971-1975	4.00	0.66	0.20	5.24	-2.10	16.58	4.93	131.00	-52.52
1976-1980	4.45	2.09	0.36	-1.21	3.21	46.90	8.10	-27.17	72.17
1981-1985	4.67	1.05	0.38	0.10	3.14	22.43	8.21	2.19	67.17
1986-1990	2.44	1.38	0.16	1.30	-0.40	56.42	6.63	53.18	-16.23
1991-1995	2.84	-1.82	0.15	1.60	2.92	-64.14	5.13	56.34	102.67
1996-2000	3.16	-0.09	0.12	0.70	2.43	-2.94	3.87	22.14	76.94
2001-2006	2.60	-0.16	0.17	3.54	-0.95	-6.18	6.58	136.14	-36.54
1971-2006	**3.34**	**0.45**	**0.22**	**1.61**	**1.06**	**13.59**	**6.51**	**48.11**	**31.78**

Notes: TFPG estimation is based on equation (4.9). Land is the stock of land use. See Appendix 4C Table 4.35.

Figure 4.3 TFP Growth in Traditional Agriculture

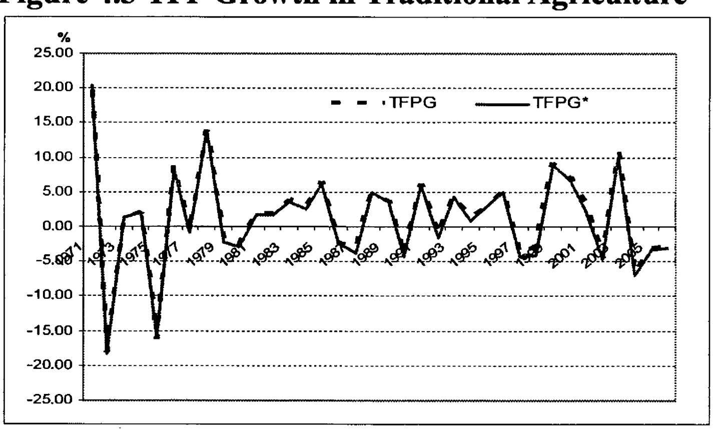


Figure 4.4 Traditional Agricultural Output, Inputs and TFP since 1971

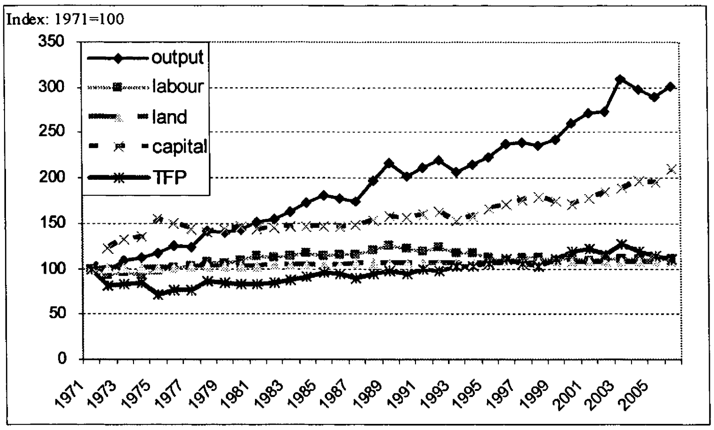


Figure 4.4 gives a picture of a changing pattern of output, inputs and TFP indices over time. The trends of factor inputs (adjusted for quality changes) are declining while TFP has tended to rise, especially from the early 1980s to 2003. As conventional inputs are scarce, agricultural production has relied more on technology inputs such as fertilizer, high yielding seed varieties, and nutritious animal feed.

If the TFPG estimates were able to closely capture the 'pure technological change' the improvement in agricultural technology would be quite impressive. Whether or not longstanding public investment in agricultural research contributes to the rising TFP will be explored in the next chapter.

4) Crops sector

For the crops sector, capital accumulation is still the largest source of growth, followed by TFP, land and labour. The relative importance of factor inputs and TFP holds for both adjusted and unadjusted growth accounting, except for the switching rank between land and labour.

Comparing between unadjusted (Table 4.14) and adjusted factor inputs (Table 4.15), the improvement of labour quality has a minor effect on labour contribution to growth. Over the study period, it accounts for only 0.05 percent per year. The labour quality index has been rising but the declining share of workers in this sector has pushed labour growth down.[130] Irrigation contributes the most as it is directly beneficial to crops, especially for rice. It raises land quality and contributes to GDP growth at 0.15 percent per year.

Table 4.14 Average Percentage Rates of Growth of Unadjusted TFP in Crops Sector

Period	GDP growth	Input Growth			Unadjusted	% Contribution to GDP growth			
		Labour	Land	Capital	TFPG	Labour	Land	Capital	TFPG
1971-1975	3.98	0.79	0.40	5.24	-2.45	19.74	10.16	131.78	-61.67
1976-1980	3.98	2.08	0.13	-1.43	3.20	52.22	3.24	-35.99	80.53
1981-1985	5.12	0.73	0.16	-0.27	4.50	14.23	3.07	-5.33	88.04
1986-1990	1.73	1.14	0.06	1.23	-0.70	65.91	3.65	70.92	-40.47
1991-1995	3.03	-1.83	0.00	2.17	2.69	-60.33	-0.13	71.61	88.85
1996-2000	3.52	-0.48	-0.04	1.38	2.66	-13.68	-1.23	39.19	75.73
2001-2006	2.41	-0.90	-0.02	6.22	-2.91	-37.25	-0.70	258.74	-120.78
1971-2006	**3.27**	**0.20**	**0.10**	**2.09**	**0.88**	**6.22**	**2.98**	**63.95**	**26.86**

Notes: TFPG estimation is based on equation (4.7). Land is the stock of land use. See Appendix 4C Table 4.36.

Table 4.15 Average Percentage Rates of Growth of Adjusted TFP in Crops Sector

Period	GDP growth	Input Growth			Adjusted	% Contribution to GDP growth			
		Labour	Land	Capital	TFPG*	Labour	Land	Capital	TFPG*
1971-1975	3.98	0.77	0.22	5.24	-2.26	19.44	5.65	131.78	-56.87
1976-1980	3.98	2.08	0.41	-1.43	2.92	52.39	10.31	-35.99	73.30
1981-1985	5.12	0.78	0.44	-0.27	4.17	15.21	8.58	-5.33	81.55
1986-1990	1.73	1.18	0.19	1.23	-0.87	68.30	11.12	70.92	-50.34
1991-1995	3.03	-1.74	0.17	2.17	2.43	-57.54	5.67	71.61	80.27
1996-2000	3.52	-0.34	0.14	1.38	2.34	-9.65	3.93	39.19	66.54
2001-2006	2.41	-0.88	0.19	6.22	-3.13	-36.55	7.95	258.74	-130.13
1971-2006	**3.27**	**0.25**	**0.25**	**2.09**	**0.68**	**7.60**	**7.63**	**63.95**	**20.82**

Notes: TFPG estimation is based on equation (4.9). Land is the stock of land use. See Appendix 4C Table 4.36.

The pattern of unadjusted (TFPG) and adjusted TFP growth (TFPG*) over time is illustrated in Figure 4.5. The overall picture of output decomposition is depicted in Figure 4.6. Capital accumulation has increased steadily and plays a dominant role, particularly in ploughing and harvesting. Labour and land (adjusted for quality changes) have played relatively diminishing roles, particularly since the sub-period of 1991-1995. This implies crops production has relied less on labour and land inputs.

[130] See Appendix 4B Table 4.27 and 4.28 for details of employment share and labour quality index.

The level of TFP index (technological factor and other unconventional factors) has increased markedly during 1991-2000 but declined in recent years.

Figure 4.5 TFP Growth in Crops Sector

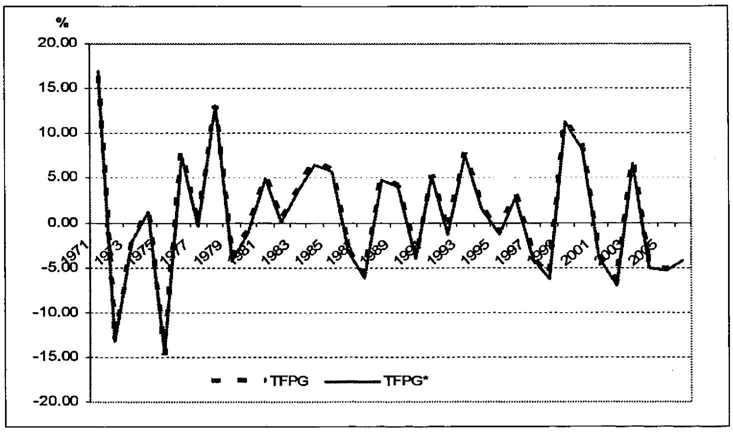
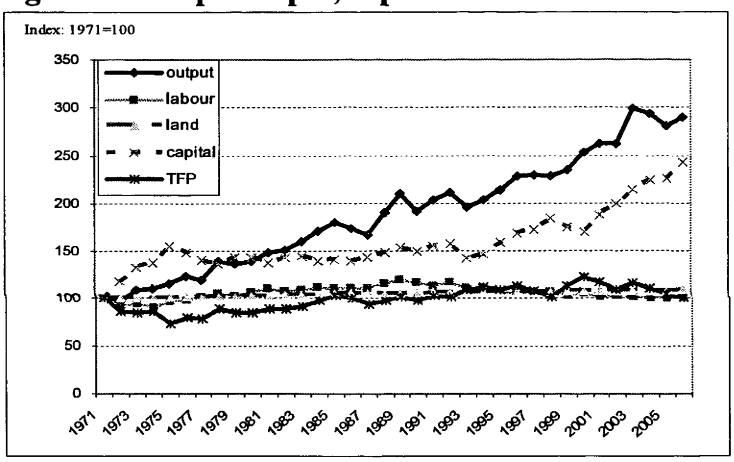


Figure 4.6 Crops Output, Inputs and TFP since 1971



5) Livestock sector

The growth accounting of the livestock sector presents different results in two aspects. First, unlike the other sectors, labour is found to be the largest source of output growth. Expansion of livestock output, more or less, is due to expansion of labour through expansion of new farm entering into livestock industry. Second, the contribution of capital is decreasing. However, TFP still manages to contribute significantly to livestock expansion and is the second most important source of growth. The negative land growth reflects the fact that the land input declines. This must be qualified by the fact that the measure of land input is imperfect and the fact that the composition of livestock land is changing and the data did not reflect the changes.[131] Nevertheless, the results are comparable and seem more reasonable than Poapongsakorn (2006) as shown in appendix Table 4.38. The contribution of capital is positive, the contribution of TFP is less, the contribution of labour is the largest and that of land is insignificant as in Poapongsakorn (2006). Tables 4.16 and 4.17 present the empirical findings and the two surprising findings are explained as follows.

Table 4.16 Average Percentage Rates of Growth of Unadjusted TFP in Livestock Sector

Period	GDP growth	Input Growth			Unadjusted TFPG	% Contribution to GDP growth			
		Labour	Land	Capital		Labour	Land	Capital	TFPG
1971-1975	4.15	0.08	0.14	3.40	0.53	1.98	3.45	81.87	12.69
1976-1980	7.54	0.77	0.02	0.04	6.71	10.21	0.26	0.56	88.97
1981-1985	1.77	1.75	0.14	2.63	-2.75	99.01	8.08	148.25	-155.34
1986-1990	6.90	0.92	-0.03	3.29	2.73	13.35	-0.49	47.60	39.54
1991-1995	1.76	-0.70	0.02	1.10	1.34	-39.79	1.23	62.59	75.97
1996-2000	0.97	0.99	-0.38	-0.33	0.70	101.58	-39.37	-34.25	72.03
2001-2006	3.79	13.11	-0.01	-7.56	-1.75	345.80	-0.25	-199.27	-46.27
1971-2006	**3.83**	**2.80**	**-0.01**	**0.17**	**0.88**	**72.97**	**-0.38**	**4.53**	**22.88**

Notes: TFPG estimation is based on equation (4.7). See Appendix 4C Table 4.37 for details.

Table 4.17 Average Percentage Rates of Growth of Adjusted TFP in Livestock Sector

Period	GDP growth	Input Growth			Adjusted TFPG*	% Contribution to GDP growth			
		Labour	Land	Capital		Labour	Land	Capital	TFPG*
1971-1975	4.15	0.08	0.14	3.40	0.53	2.00	3.45	81.87	12.67
1976-1980	7.54	0.61	0.02	0.04	6.87	8.04	0.26	0.56	91.14
1981-1985	1.77	1.65	0.14	2.63	-2.65	93.15	8.08	148.25	-149.4
1986-1990	6.90	1.33	-0.03	3.29	2.32	19.32	-0.49	47.60	33.56
1991-1995	1.76	-0.71	0.02	1.10	1.34	-40.05	1.23	62.59	76.24
1996-2000	0.97	1.47	-0.38	-0.33	0.22	151.17	-39.37	-34.25	22.44
2001-2006	3.79	13.64	-0.01	-7.56	-2.28	359.69	-0.25	-199.27	-60.16
1971-2006	**3.83**	**3.00**	**-0.01**	**0.17**	**0.67**	**78.35**	**-0.38**	**4.53**	**17.49**

Notes: TFPG estimation is based on equation (4.9). Land is not adjusted for irrigation. See Appendix 4C Table 4.37 for details.

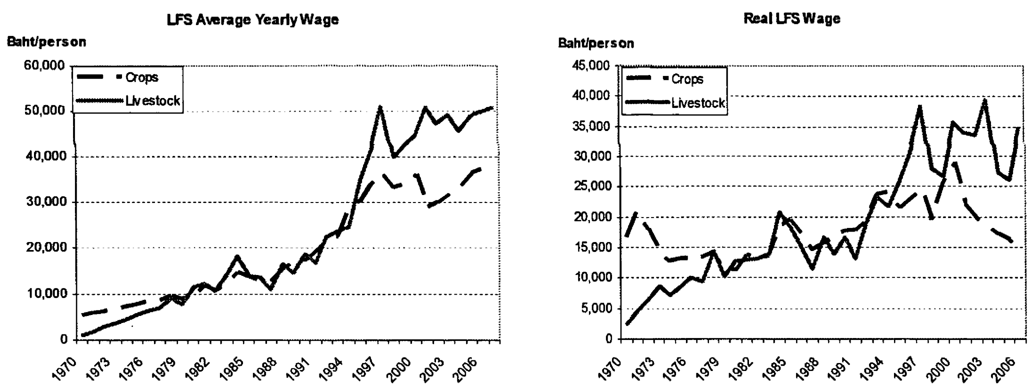
First, it is surprising to find labour as the leading factor because the share of total agricultural employment has been declining and the contribution of labour has reduced in the overall agriculture and crops sector. Tables 4.16 and 4.17 indicate most of the labour growth occurred during 2001-2006. This is in accordance with the

[131] Livestock includes mainly cattle, swine and poultry. They require different combination of inputs and techniques of production.

increasing share of livestock employment in total agricultural employment. Since 2001, there has been a remarkable rise in employment in the livestock sector. Rising employment in the livestock sector is also consistent with an increasing wage rate in the sector. In contrast, real wage in the crops sector has declined since 2000 (Figure 4.7). A relatively higher wage attracting labour to the livestock sector is one probable cause.[132] Increases in both employment and the nominal wage rate (LFS average yearly wage) also raise the labour income shares, resulting in outstanding growth in the labour input.

It is likely that better educated and more productive workers have moved to the livestock sector as labour quality improvement is outstanding. Comparing the employment growth between Tables 4.16 and 4.17, labour quality improvement raises the contribution of labour to GDP growth by 0.2 percent per year. This is the largest contribution, compared with the overall agriculture and crops sector.

Figure 4.7 Nominal and Real Wages in Crops and Livestock Sectors



Second, the relatively small and decreasing role of capital stock is likely to be explained by the nature of livestock farming, by its measurement and by the assumption of constant returns to scale.[133] Since both capital stock and its income share are measured as a residual after deducting the contribution of labour and land,

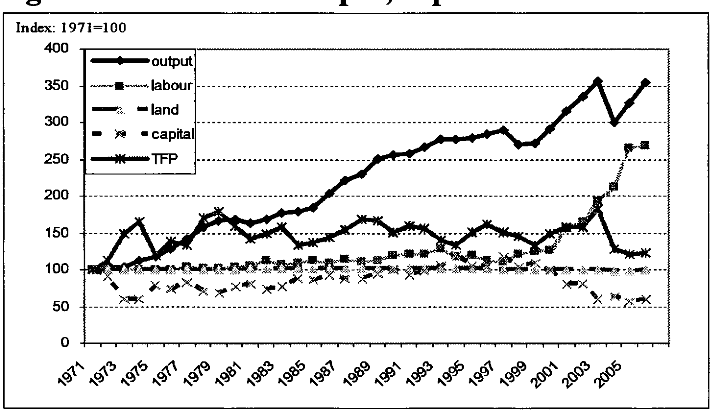
[132] See Appendix Table 4.27 for total employment in Thai agriculture and Table 4.24 for the average yearly wage.
[133] Under CRS, all factor income shares sum to unity thereby capital income share is computed as a residual after subtracting labour and land income shares from one. Given the tiny value share of land, a larger labour income share implies a smaller capital income share.

larger employment growth (and labour income shares) implies smaller growth of capital stock. For example, corresponding to the highest labour growth, the largest negative growth of capital is also presented during 2001-2006. However, in constructing livestock capital based on the number of breeds valued at investment cost Poapongsakorn (2006, p.83) obtained negative growth of capital and capital stock contributed the least to livestock growth.[134] As two studies measuring the capital stock differently yield similar results, measurement errors should not be a big issue. The overall contribution of capital is possibly declining.

As for the nature of livestock farming, the decreasing role of capital may be due to the less important role of machinery in livestock production. Compared with crops, livestock farming relies less on machinery and equipment, such as tractors and water pumps. Livestock farming still relies heavily on labour, for instance, in feeding animals and in milking cows.

In addition, the inventory of breeding animals is generally recognized as a major capital input to livestock production (Poapongsakorn, 2006, p.69). The role of capital may be underestimated by the fact that only breeds imported by the public sector are included in the capital stock (NESDB, 2006). Livestock breeds imported by the private sector and produced domestically have not been taken into account and this is captured as technological development in the residual TFP.

Figure 4.8 Livestock Output, Inputs and TFP since 1971



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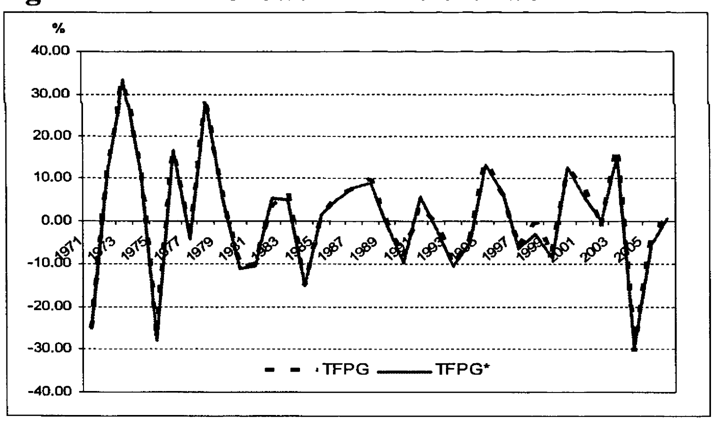
[134] His average rate of growth of livestock capital was estimated at -0.23 percent during 1981-2003.

Figure 4.8 captures the whole picture of output, adjusted inputs and TFP at the index level basis. It confirms an increasing trend of labour input and a decreasing role of capital. The contribution of land is trivial. This is not surprising because Thai animal farms are mostly small-scale, raising animals in a confined area rather than on grazing land. TFP contributes positively to growth. The average annual growth rate of TFP, adjusted for labour quality, is estimated at 0.67 percent.

Nonetheless, TFP growth during 2004-2005 dropped considerably (Figure 4.9). This coincides with the significant drop of livestock GDP in 2004, which is the year the poultry sector was severely affected by the Avian Influenza (Bird Flu) outbreak. Negative GDP growth (-15.66 percent) was recorded in that year, which is the largest decline of GDP growth in the past four decades. It is highly likely that the recent decline in TFPG was partly caused by the Bird Flu outbreak though this causal link cannot be confirmed without further evidence. What actually drives TFP growth in the livestock sector will be investigated empirically in the next chapter.

Figure 4.9 TFP Growth in Livestock Sector



4.6 Conclusion

This chapter decomposes agricultural growth into input growth and total factor productivity growth during 1971-2006, using the conventional growth accounting framework. It also distinguishes between qualitative changes in factor inputs and technological change.

Labour input is adjusted for the changing composition of age, sex and education level in the agricultural workforce. This adjustment indicates the small improvement in labour quality, due to a more educated agricultural workforce is offset owning to male workers in economically active age groups leaving farms to work in non-agricultural sectors. Land quality has also been improved by the irrigation system, which is accessed mainly in rice production. The factor input adjustments reduce the contribution of TFPG in all studied sectors. Nonetheless, differences between unadjusted and adjusted TFP growth are minor.

The estimation results, for both the adjusted and unadjusted growth accounting, generally show that real factor inputs combined are still the dominant source of growth. Even so, TFPG has been positive and has contributed significantly in the overall agriculture and major subsectors. Although the magnitude of adjusted and unadjusted TFPG is not large and fluctuates noticeably, the levels of TFP index have generally increased. Among factor inputs, capital accumulation is the most important source of growth. Labour is also important, particularly in the livestock sector, although its role has diminished. Land plays a relatively minor role in explaining agricultural growth, which is in accordance with the closing of the land frontier.

As TFP growth is measured as a residual, there are many candidates that can explain the residual. These include both technology factors, such as agricultural research and extension, and other factors, such as infrastructure, resources reallocation and weather-related factors. To make deeper progress in explaining productivity change, further investigation on the residual TFP is required. Decomposition of TFPG will be undertaken in the next chapter.

Appendix 4 Data and Growth Accounting Results

Appendix 4A: Data Estimation as Described in Text

Table 4.18 Agricultural GDP (1988 fixed prices) with and without Simple Processing Products (million baht)

	Agricultural GDP with simple processing products	Simple agricultural processing products	Agricultural GDP without simple processing products
1970	130,702	8,838	121,864
1971	136,171	9,638	126,533
1972	134,105	9,494	124,611
1973	145,311	9,982	135,329
1974	149,889	10,075	139,814
1975	156,094	10,422	145,672
1976	164,885	10,849	154,036
1977	169,319	12,590	156,729
1978	187,355	13,975	173,380
1979	183,106	13,797	169,309
1980	184,576	14,655	169,921
1981	194,023	14,966	179,057
1982	198,825	16,176	182,649
1983	208,312	16,309	192,003
1984	217,518	17,427	200,091
1985	227,324	18,769	208,555
1986	228,191	20,088	208,103
1987	228,346	21,271	207,075
1988	252,346	22,963	229,383
1989	276,569	26,726	249,843
1990	263,607	27,914	235,693
1991	282,740	30,386	252,354
1992	296,277	33,610	262,667
1993	289,065	33,959	255,106
1994	303,376	37,483	265,893
1995	313,855	37,265	276,590
1996	326,836	37,996	288,840
1997	323,884	37,051	286,833
1998	318,953	36,347	282,606
1999	325,877	36,699	289,178
2000	346,856	36,908	309,948
2001	356,138	36,122	320,016
2002	n.a.	n.a.	322,179
2003	n.a.	n.a.	363,033
2004	n.a.	n.a.	354,431
2005	n.a.	n.a.	347,830
2006	n.a.	n.a.	361,183

Source: NESDB (n.a. = data not available). As described in text.

Table 4.19 Employment Data Set for the Overall Agricultural Sector (persons)

	Initial data set (all sources are based on LFS)			Combined data set*
	1. Employment (age 11 and over)	2. Employment (age 15 and over)	3. Employment (age 15 and over)	Employment (age 15 and over)
	From Coxhead & Plangpraphan (1999) and LFS	From Poapongsakorn (2006)	Directly from LFS, NSO	Combine 1 – 3 LFS, NSO
1970	11,963,072			10,797,058
1971	13,157,680			11,875,230
1972	11,642,150			10,507,415
1973	12,270,571			11,074,586
1974	11,226,280			10,132,079
1975	13,270,080			11,976,675
1976	13,948,530			12,588,998
1977	14,921,900	13,467,495		13,467,495
1978		14,690,020		14,690,020
1979		13,853,934		13,853,934
1980		15,132,099		15,132,099
1981		16,635,311		16,635,311
1982		16,181,176		16,181,176
1983		16,429,399		16,429,399
1984		17,228,061		17,228,061
1985		16,794,224		16,794,224
1986		16,935,613		16,935,613
1987		16,855,366		16,855,366
1988		18,545,313		18,545,313
1989		19,591,623		19,591,623
1990		18,983,166		18,983,166
1991		18,099,884		18,099,884
1992		19,127,757		19,127,757
1993		17,840,189		17,840,189
1994		17,626,374		17,626,374
1995		16,690,722		16,690,722
1996		15,996,575		15,996,575
1997		16,544,557		16,544,557
1998		16,310,993		16,310,993
1999		15,422,459		15,422,459
2000		15,971,136		15,971,136
2001		15,345,659		15,345,659
2002		15,799,842		15,799,842
2003		15,561,301		15,561,301
2004			15,115,349	15,115,349
2005			15,448,618	15,448,618
2006			15,315,350	15,315,350

Source: NSO, Poapongsakorn (2006) and Coxhead and Plangpraphan (1999).

* Using splicing technique, adjuster is computed by dividing 1977 Poapongsakorn's data with 1977 LFS data (=13,467,495/14,921,900 =0.90). Then, use this ratio to multiply all numbers in the first column and combine with Poapongsakorn's series.

Table 4.20 Employment in Crops and Livestock Sectors, Age 15 and Over (persons)

	Traditional Agriculture	Initial data set from Poapongsakorn (2006) and LFS, NSO				Estimated data based on % in Ag2	
	Ag2	Crops	%crop in Ag2	Livestock	%livestock in Ag2	Crops =0.99×Ag2	Livestock =0.01×Ag2
1970	10,596,194					10,490,232	105,962
1971	11,654,308					11,537,765	116,543
1972	10,311,940					10,208,820	103,119
1973	10,868,559					10,759,873	108,686
1974	9,943,586					9,844,150	99,436
1975	11,753,866					11,636,327	117,539
1976	12,354,797					12,231,249	123,548
1977	13,216,952	13,022,267	0.99	194,685	0.01		
1978	14,395,017	14,235,628	0.99	159,389	0.01		
1979	13,579,203	13,398,778	0.99	180,426	0.01		
1980	14,832,020	14,629,236	0.99	202,784	0.01		
1981	16,242,147	16,010,509	0.99	231,637	0.01		
1982	15,802,176	15,394,407	0.97	407,769	0.03		
1983	16,072,547	15,789,377	0.98	283,170	0.02		
1984	16,849,602	16,532,815	0.98	316,787	0.02		
1985	16,311,471	15,945,958	0.98	365,513	0.02		
1986	16,506,505	16,208,417	0.98	298,088	0.02		
1987	16,395,312	15,920,089	0.97	475,222	0.03		
1988	18,105,812	17,751,031	0.98	354,780	0.02		
1989	19,158,347	18,754,443	0.98	403,904	0.02		
1990	18,502,246	17,979,979	0.97	522,267	0.03		
1991	17,624,678	16,986,992	0.96	637,686	0.04		
1992	18,681,582	18,062,134	0.97	619,448	0.03		
1993	17,313,450	16,567,017	0.96	746,433	0.04		
1994	17,005,943	16,452,519	0.97	553,425	0.03		
1995	16,132,036	15,587,653	0.97	544,383	0.03		
1996	15,343,540	14,861,514	0.97	482,026	0.03		
1997	15,935,833	15,488,610	0.97	447,223	0.03		
1998	15,687,893	15,150,261	0.97	537,632	0.03		
1999	14,689,726	14,094,287	0.96	595,439	0.04		
2000	15,337,915	14,718,151	0.96	619,764	0.04		
2001	14,551,246	13,607,162	0.94	944,084	0.06		
2002	15,002,654	13,946,495	0.93	1,056,159	0.07		
2003	14,790,670	13,483,463	0.91	1,307,207	0.09		
2004	14,484,318	12,980,326	0.90	1,503,992	0.10		
2005	14,752,707	12,755,075	0.86	1,997,632	0.14		
2006	14,673,010	12,650,227	0.86	2,022,783	0.14		

Source: NSO, Poapongsakorn (2006) and Coxhead and Plangpraphan (1999).
As explained in text.

Table 4.21 Livestock Area (Rai)

	Land Use				**Cultivated Area**		**Combined**
	OAE land utilization survey			Estimated	Poapongsakorn	DLD	**livestock**
	Total area	Grass Area	%Grass Area	Grass Area[1/]	(2006)	survey	**area[2/]**
1970	94,172,689			409,063			5,461,235
1971	99,390,862			431,729			5,763,846
1972	103,551,564			449,802			6,005,132
1973	109,353,297			475,004			6,341,584
1974	110,445,657			479,748			6,404,932
1975	112,211,305	487,418	**0.43**	487,418			6,507,325
1976	113,112,010	410,623	0.36				5,482,066
1977	113,796,436	323,978	0.28				4,325,302
1978	116,441,234	349,027	0.30				4,659,722
1979	117,602,875	517,363	0.44				6,907,109
1980	118,998,940	**523,014**	0.44		**6,982,553**		**6,982,553**
1981	121,293,839	761,284	0.63		7,895,704		7,895,704
1982	123,586,793	766,312	0.62		8,173,044		8,173,044
1983	124,230,250	765,705	0.62		8,299,002		8,299,002
1984	125,313,764	752,590	0.60		8,220,563		8,220,563
1985	128,603,472	847,535	0.66		8,307,618		8,307,618
1986	130,898,940	833,285	0.64		8,405,036		8,405,036
1987	131,202,622	837,416	0.64		8,220,223		8,220,223
1988	131,772,759	768,461	0.58		8,023,309		8,023,309
1989	131,831,185	750,235	0.57		7,966,954		7,966,954
1990	132,124,409	740,435	0.56		7,852,196		7,852,196
1991					7,928,058		7,928,058
1992					8,025,909		8,025,909
1993					8,210,520		8,210,520
1994					8,460,296		8,460,296
1995					8,221,710		8,221,710
1996					8,277,473		8,277,473
1997					5,962,367		5,962,367
1998					5,513,351		5,513,351
1999					6,109,009	6,982,389	6,109,009
2000					5,317,571	4,081,585	5,317,571
2001					5,504,109	5,424,182	5,504,109
2002					5,622,680	6,766,779	5,622,680
2003					**5,853,719**	**5,535,390**	**5,853,719**
2004						4,304,001	4,551,515
2005						4,665,046	4,933,322
2006						5,026,090	5,315,129

Source: OAE, DLD and Poapongsakorn (2006).

1/ Estimated area during 1971-1974 is based on % of grass area in 1975 (= 0.43×Total area).

2/ Data are combined using splicing technique; bold numbers are used in computing adjusters. The first adjuster in 1980 is the ratio of Poapongsakorn (2006) to OAE and the second adjuster in 2003 is the ratio of Poapongsakorn (2006) to DLD.

Table 4.22 Net Capital Stock at Constant Prices in Crops and Livestock Sectors (million baht)

	Estimated imputed return to capital: (RK)			% Crops in Agl	% Live-stock in Agl	NESDB Agri Net Capital Stock (K_Agl)	Crops Capital (= %crop ×K_Agl)	Livestock Capital (=%livesotck ×K_Agl)
	Crops	Live-stock	Agl					
1970	21,551	8,943	47,410	0.45	0.19	231,338	105,157	43,639
1971	4,950	9,173	36,572	0.14	0.25	236,422	31,999	59,297
1972	18,662	9,347	41,161	0.45	0.23	239,408	108,545	54,367
1973	37,297	8,926	58,044	0.64	0.15	241,756	155,343	37,177
1974	47,311	10,172	71,991	0.66	0.14	257,365	169,135	36,364
1975	43,802	10,563	54,896	0.80	0.19	269,698	215,195	51,897
1976	47,835	11,627	65,033	0.74	0.18	269,098	197,936	48,111
1977	40,618	12,726	62,930	0.65	0.20	270,896	174,847	54,781
1978	50,327	14,097	85,053	0.59	0.17	282,261	167,018	46,784
1979	60,191	14,987	92,568	0.65	0.16	280,682	182,509	45,443
1980	57,889	16,510	89,651	0.65	0.18	282,485	182,404	52,023
1981	47,437	15,530	80,724	0.59	0.19	288,052	169,271	55,418
1982	52,923	14,332	84,432	0.63	0.17	291,672	182,824	49,509
1983	59,029	16,450	94,110	0.63	0.17	298,429	187,187	52,164
1984	40,476	14,778	71,282	0.57	0.21	300,604	170,693	62,320
1985	44,070	15,154	76,252	0.58	0.20	307,789	177,887	61,168
1986	47,200	19,101	89,621	0.53	0.21	321,683	169,419	68,561
1987	58,476	20,386	104,001	0.56	0.20	325,415	182,967	63,786
1988	67,656	21,180	111,895	0.60	0.19	333,053	201,378	63,041
1989	75,419	23,900	118,024	0.64	0.20	341,623	218,303	69,179
1990	61,759	22,783	108,249	0.57	0.21	356,852	203,593	75,104
1991	75,178	23,253	128,508	0.59	0.18	380,197	222,417	68,796
1992	69,090	21,754	120,665	0.57	0.18	404,247	231,463	72,880
1993	38,120	18,963	100,295	0.38	0.19	439,632	167,093	83,123
1994	40,993	22,124	104,530	0.39	0.21	479,721	188,129	101,535
1995	63,218	20,745	125,711	0.50	0.17	510,359	256,651	84,218
1996	74,836	21,015	137,225	0.55	0.15	550,875	300,422	84,361
1997	64,028	20,467	120,613	0.53	0.17	603,389	320,312	102,390
1998	88,941	19,739	146,902	0.61	0.13	623,822	377,688	83,822
1999	71,968	19,604	136,343	0.53	0.14	633,473	334,377	91,083
2000	65,940	17,370	140,447	0.47	0.12	655,315	307,671	81,046
2001	108,137	13,934	179,957	0.60	0.08	671,987	403,799	52,031
2002	118,845	13,893	182,214	0.65	0.08	693,618	452,396	52,887
2003	161,446	5,899	224,080	0.72	0.03	716,201	516,012	18,854
2004	166,993	7,384	233,622	0.71	0.03	742,654	552,338	24,423
2005	161,437	3,438	233,189	0.69	0.01	773,396	559,781	11,922
2006	179,877	5,998	243,583	0.74	0.02	809,433	624,408	20,820

Source: NESDB, NSO, OAE. As described in text.

Table 4.23 GDP at Current Factor Cost for Crops and Livestock Sectors (million baht)

	GDP at current factor cost			GDP at market prices		Combined GDP factor cost		
	Ag (no fishery)	Crops	Livestock	% Crops	% Livestock	Crops*	Livestock*	Ag2 (crops + livestock)
1970	31,553	24,322	3,899			24,322	3,899	28,221
1971	29,617	21,854	4,193			21,854	4,193	26,047
1972	35,112	26,653	4,436			26,653	4,436	31,089
1973	51,611	41,559	4,374			41,559	4,374	45,933
1974	65,025	50,847	7,238			50,847	7,238	58,085
1975	70,034	55,306	7,556			55,306	7,556	62,862
1976	79,314	62,383	8,271			62,383	8,271	70,654
1977	82,762	62,759	10,521			62,759	10,521	73,280
1978	98,760	77,318	9,961			77,318	9,961	87,279
1979	111,619	86,023	12,394			86,023	12,394	98,417
1980	131,697	100,486	17,025			100,486	17,025	117,511
1981	137,777	104,024	17,413			104,024	17,413	121,437
1982	129,479	98,452	15,224			98,452	15,224	113,676
1983	156,334	119,379	20,120			119,379	20,120	139,499
1984	145,265	110,152	17,641			110,152	17,641	127,793
1985	136,980	103,235	15,866			103,235	15,866	119,101
1986	142,913	103,917	20,682			103,917	20,682	124,599
1987	163,545	120,372	23,628			120,372	23,628	144,000
1988	203,395	157,372	25,922			157,372	25,922	183,294
1989	223,465	174,809	29,797			174,809	29,797	204,606
1990	208,320	157,482	32,764			157,482	32,764	190,246
1991	236,819	181,494	37,348			181,494	37,348	218,842
1992	249,655	196,669	34,921			196,669	34,921	231,590
1993	206,618	156,944	32,103			156,944	32,103	189,047
1994	252,940	199,110	35,586			199,110	35,586	234,696
1995	312,891	250,090	42,382			250,090	42,382	292,472
1996	349,146	283,956	43,862			283,956	43,862	327,818
1997	351,124	287,347	43,841			287,347	43,841	331,188
1998	390,107	326,779	43,816			326,779	43,816	370,595
1999	331,862	263,308	49,636			263,308	49,636	312,944
2000	325,762	266,737	41,319			266,737	41,319	308,056
2001	357,838	283,842	53,750			283,842	53,750	337,592
2002	405,967			**0.82**	**0.16**	**333,712**	**53,815**	387,527
2003	505,993			**0.86**	**0.12**	**437,083**	**51,316**	488,399
2004	561,654			**0.87**	**0.12**	**486,869**	**58,645**	545,514
2005	622,428			**0.86**	**0.13**	**535,891**	**71,837**	607,728
2006	726,169			**0.90**	**0.09**	**651,963**	**59,829**	711,793

Source: NESDB. As described in text. *For 2002-2006, GDP at factor cost for crops and livestock equal % of crops and livestock GDP at current prices multiplied with the agricultural GDP (without fisheries) at factor cost.

Table 4.24 Average Yearly Wage and Imputed Wage Based on SAM 1995 (Baht/person)

	LFS Average Yearly Wage				Imputed Wage based on SAM 1995*			
	Ag1	Ag2	Crops	Livestock	Ag1	Ag2	Crops	Livestock
1970	5,010.44	3,134.21	5,276.24	992.18	1,673.49	1,046.83	1,454.66	644.92
1971	5,163.63	3,838.52	5,768.55	1,908.49	1,724.65	1,282.07	1,590.39	1,240.52
1972	6,474.50	4,542.83	6,260.87	2,824.79	2,162.48	1,517.30	1,726.12	1,836.11
1973	7,349.30	5,247.13	6,753.18	3,741.09	2,454.67	1,752.54	1,861.85	2,431.71
1974	8,321.70	5,951.44	7,245.49	4,657.39	2,779.45	1,987.78	1,997.58	3,027.30
1975	10,333.60	6,655.75	7,737.80	5,573.69	3,451.42	2,223.02	2,133.31	3,622.90
1976	10,318.30	7,360.05	8,230.11	6,489.99	3,446.31	2,458.26	2,269.04	4,218.50
1977	10,628.58	7,853.50	8,692.03	7,014.96	3,549.95	2,623.07	2,396.39	4,559.72
1978	9,972.20	9,287.69	9,597.28	8,978.10	3,330.71	3,102.09	2,645.97	5,835.76
1979	10,154.19	8,321.91	8,965.49	7,678.34	3,391.50	2,779.52	2,471.78	4,990.92
1980	11,188.69	10,815.91	10,060.62	11,571.20	3,737.02	3,612.51	2,773.71	7,521.28
1981	12,503.56	12,035.75	11,815.65	12,255.86	4,176.19	4,019.94	3,257.57	7,966.31
1982	11,702.12	10,636.00	10,588.17	10,683.84	3,908.51	3,552.43	2,919.16	6,944.49
1983	13,396.30	13,281.58	12,445.76	14,117.40	4,474.37	4,436.05	3,431.30	9,176.31
1984	15,413.58	16,466.00	14,628.36	18,303.64	5,148.14	5,499.64	4,033.04	11,897.37
1985	14,697.99	13,916.53	13,771.49	14,061.58	4,909.13	4,648.12	3,796.80	9,140.03
1986	13,672.11	13,261.79	12,862.17	13,661.40	4,566.48	4,429.44	3,546.10	8,879.91
1987	13,874.58	11,970.73	12,915.92	11,025.53	4,634.11	3,998.22	3,560.92	7,166.60
1988	16,475.06	16,113.73	15,540.87	16,686.60	5,502.67	5,381.99	4,284.62	10,846.29
1989	18,143.92	15,803.52	16,819.31	14,787.73	6,060.07	5,278.38	4,637.08	9,612.03
1990	18,751.65	18,138.61	17,443.41	18,833.80	6,263.05	6,058.29	4,809.15	12,241.97
1991	20,650.01	18,010.12	19,170.54	16,849.70	6,897.10	6,015.38	5,285.32	10,952.30
1992	23,773.78	22,000.13	21,623.11	22,377.15	7,940.44	7,348.04	5,961.49	14,545.15
1993	24,823.41	23,236.03	22,633.35	23,838.70	8,291.02	7,760.83	6,240.02	15,495.15
1994	29,549.88	26,368.58	28,126.73	24,610.44	9,869.66	8,807.11	7,754.54	15,996.78
1995	32,540.71	32,599.97	30,152.87	35,047.06	10,868.60	10,888.39	8,313.15	22,780.59
1996	36,042.95	37,742.55	33,970.50	41,514.59	12,038.35	12,606.01	9,365.67	26,984.49
1997	39,907.82	43,966.17	36,699.55	51,232.78	13,329.21	14,684.70	10,118.07	33,301.31
1998	36,647.78	36,642.19	33,324.56	39,959.83	12,240.36	12,238.49	9,187.58	25,973.89
1999	36,966.31	38,167.51	33,790.60	42,544.43	12,346.75	12,747.95	9,316.07	27,653.88
2000	37,860.82	40,437.82	36,182.03	44,693.62	12,645.51	13,506.23	9,975.39	29,050.85
2001	32,036.08	39,732.66	28,548.33	50,916.99	10,700.05	13,270.71	7,870.78	33,096.04
2002	34,076.40	38,679.36	30,029.97	47,328.76	11,381.52	12,918.91	8,279.26	30,763.69
2003	36,572.72	40,569.78	31,810.41	49,329.15	12,215.29	13,550.31	8,770.13	32,063.95
2004	35,767.43	39,503.77	33,332.43	45,675.10	11,946.32	13,194.26	9,189.75	29,688.82
2005	37,012.17	42,662.60	36,416.95	48,908.26	12,362.07	14,249.31	10,040.15	31,790.37
2006	43,168.07	43,621.56	37,278.30	49,964.82	14,418.14	14,569.60	10,277.63	32,477.13

Source: NSO, Poapongsakorn (2006) and TDRI

*The ratios of SAM wage to LFS wage for agriculture, crops and livestock are obtained from TDRI. The imputed wage is derived by multiplying these ratios with the relevant LFS series.

Table 4.25 Land Rent

	Total land rent million baht	Total agricultural land area million rai	Land rental rate Baht/rai
1970	2,556	94.17	27.14
1971	2,428	99.39	24.43
1972	2,904	103.55	28.04
1973	4,498	109.35	41.13
1974	4,885	110.45	44.23
1975	5,077	112.21	45.24
1976	5,208	113.11	46.04
1977	5,737	113.80	50.41
1978	5,843	116.44	50.18
1979	6,864	117.60	58.37
1980	9,382	119.92	78.24
1981	11,915	122.16	97.54
1982	12,044	124.43	96.79
1983	12,281	125.07	98.19
1984	12,314	126.24	97.54
1985	12,630	129.62	97.44
1986	12,632	131.09	96.36
1987	13,077	133.06	98.28
1988	13,745	123.34	111.44
1989	12,412	123.45	100.55
1990	10,184	123.83	82.25
1991	11,452	124.50	91.99
1992	12,152	124.11	97.91
1993	17,230	123.24	139.81
1994	23,886	123.78	192.97
1995	32,659	124.34	262.66
1996	34,444	124.54	276.58
1997	36,050	124.67	289.16
1998	37,570	124.81	301.03
1999	37,636	124.94	301.23
2000	38,876	125.06	310.85
2001	39,009	124.69	312.86
2002	40,610	124.32	326.64
2003	42,754	124.21	344.21
2004	44,956	124.39	361.42
2005	47,075	124.13	379.23
2006	49,456	124.25	398.02

Source: NESDB

Appendix 4B: Output and Input Data

Table 4.26 Growth Rate and Share of GDP at 1988 Prices in Thai Agriculture

	Share							Growth						
	GDP All sectors	Agriculture*	Crops	Livestock	Fisheries	Forestry	Agricultural Services	GDP All sectors	Agriculture*					
	(m. baht)	(% of GDP)	(% of Agricultural GDP)						All	Crops	Livestock	Fisheries	Forestry	Agricultural Services
1970	478,041	25.49	62.71	8.62	13.71	11.15	3.81							
1971	501,203	25.25	62.60	8.64	13.56	11.30	3.91	4.73	3.76	3.59	3.94	2.66	5.09	6.22
1972	522,344	23.86	61.47	9.06	14.65	10.60	4.22	4.13	-1.53	-3.35	3.21	6.22	-7.92	6.25
1973	574,414	23.56	64.70	8.31	12.70	9.80	4.49	9.50	8.25	13.37	-0.43	-6.01	0.38	14.50
1974	600,154	23.30	63.66	8.76	12.20	10.80	4.58	4.38	3.26	1.64	8.55	-0.75	12.98	5.21
1975	629,858	23.13	64.01	8.88	12.38	10.07	4.66	4.83	4.10	4.65	5.48	5.57	-2.82	5.72
1976	687,608	22.40	64.54	9.22	11.49	10.12	4.63	8.77	5.58	6.40	9.32	-1.85	6.03	5.08
1977	755,415	20.75	61.70	10.04	14.01	9.32	4.93	9.40	1.73	-2.76	10.31	21.50	-6.51	8.02
1978	830,025	20.89	65.25	10.20	12.07	7.63	4.85	9.42	10.10	15.70	11.66	-4.80	-9.87	8.29
1979	873,508	19.38	65.44	10.95	10.18	8.95	4.48	5.11	-2.38	-2.10	4.73	-19.42	13.58	-10.14
1980	913,733	18.60	66.95	11.10	9.56	7.78	4.62	4.50	0.36	2.65	1.68	-5.93	-13.69	3.28
1981	967,706	18.50	67.55	10.24	10.76	6.70	4.75	5.74	5.24	6.12	-2.82	17.15	-9.73	8.10
1982	1,019,501	17.92	67.45	10.34	11.41	6.16	4.64	5.21	1.99	1.83	2.95	7.84	-6.35	-0.35
1983	1,076,432	17.84	68.29	10.35	10.96	5.85	4.55	5.43	4.99	6.24	5.10	0.90	-0.12	3.03
1984	1,138,353	17.58	69.55	10.00	10.21	5.75	4.49	5.59	4.13	5.96	0.70	-2.93	2.30	2.75
1985	1,191,255	17.51	70.45	9.88	9.68	5.48	4.51	4.54	4.14	5.43	2.92	-1.16	-0.69	4.60
1986	1,257,177	16.55	68.13	11.06	10.48	5.90	4.43	5.39	-0.22	-3.57	11.07	7.73	7.18	-1.91
1987	1,376,847	15.04	66.01	12.03	11.86	5.67	4.43	9.09	-0.50	-3.65	7.93	11.84	-4.41	-0.66
1988	1,559,804	14.71	68.79	11.34	11.01	4.57	4.29	12.48	10.23	14.35	4.36	2.79	-11.31	7.07
1989	1,749,952	14.28	70.06	11.38	11.18	3.40	3.99	11.50	8.54	10.37	8.86	10.09	-21.18	1.23
1990	1,945,372	12.12	67.97	12.34	12.74	2.88	4.07	10.59	-5.83	-8.86	2.30	7.23	-22.41	-3.73
1991	2,111,862	11.95	67.48	11.64	14.78	2.34	3.77	8.21	6.83	6.10	0.95	21.69	-14.07	-0.87
1992	2,282,572	11.51	67.39	11.54	15.32	2.16	3.59	7.77	4.01	3.88	3.13	7.60	-3.84	-0.88
1993	2,470,908	10.32	64.32	12.34	17.85	2.04	3.45	7.93	-2.92	-7.58	3.81	12.36	-8.75	-6.96
1994	2,692,973	9.87	64.37	11.83	18.69	1.71	3.40	8.61	4.14	4.22	-0.12	8.73	-13.28	2.67
1995	2,941,736	9.40	65.04	11.45	18.32	2.11	3.08	8.84	3.94	4.98	0.72	1.91	24.81	-5.75
1996	3,115,338	9.27	66.51	11.20	17.35	1.99	2.96	5.73	4.33	6.57	2.08	-1.12	-1.61	0.26
1997	3,072,615	9.34	67.35	11.51	16.66	1.63	2.85	-1.38	-0.70	0.56	2.10	-4.75	-20.51	-4.54
1998	2,749,684	10.28	68.05	10.88	17.15	1.32	2.59	-11.10	-1.48	-0.45	-7.14	1.45	-22.45	-10.84
1999	2,871,980	10.07	68.61	10.76	16.74	1.27	2.62	4.35	2.30	3.12	1.21	-0.13	-1.76	3.24
2000	3,008,401	10.30	69.20	10.73	16.37	1.15	2.55	4.64	6.94	7.79	6.63	4.70	-2.99	4.33
2001	3,073,601	10.41	69.42	11.35	15.58	1.10	2.55	2.14	3.20	3.51	8.84	-1.75	-1.56	3.27
2002	3,237,042	9.95	69.02	11.93	15.45	1.10	2.50	5.18	0.67	0.09	5.67	-0.18	1.08	-1.39
2003	3,468,166	10.47	70.20	11.30	15.26	1.06	2.18	6.90	11.94	13.63	6.50	10.74	8.39	-1.98
2004	3,688,189	9.61	70.82	9.90	16.20	1.08	2.00	6.15	-2.40	-1.51	-15.66	3.58	-0.60	-11.01
2005	3,855,111	9.02	68.83	11.02	16.96	1.17	2.03	4.43	-1.88	-4.74	8.82	2.70	5.66	-0.23
2006	4,052,006	8.91	68.61	11.56	16.91	1.10	1.82	4.98	3.77	3.45	8.58	3.48	-1.64	-7.30

Source: National Economic and Social Development Board (NESDB). *Exclude Simple Agricultural Processing.

To be consistent with the growth accounting formula discussed in text, GDP growth formula is $\ln(GDP_t/GDP_{t-1})\times 100$.

Table 4.27 Total Employment with at least 15 Years of Age in Thai Agriculture

	Total Employment (in millions of persons)					Share (%of all sectors)	(% of agriculture)			Growth				
		Agriculture									Agriculture			
	All sectors	All	Crops	Livestock	Fisheries &Others	All	Crops	Livestock	Fisheries &Others	All sectors	All	Crops	Livestock	Fisheries &Others
1970	15.66	10.80	10.49	0.11	0.20	68.96	97.16	0.98	1.86					
1971	15.95	11.88	11.54	0.12	0.22	74.46	97.16	0.98	1.86	1.85	9.52	9.52	9.52	9.52
1972	15.48	10.51	10.21	0.10	0.20	67.88	97.16	0.98	1.86	-2.99	-12.24	-12.24	-12.24	-12.24
1973	16.36	11.07	10.76	0.11	0.21	67.71	97.16	0.98	1.86	5.51	5.26	5.26	5.26	5.26
1974	16.47	10.13	9.84	0.10	0.19	61.53	97.16	0.98	1.86	0.68	-8.89	-8.89	-8.89	-8.89
1975	17.45	11.98	11.64	0.12	0.22	68.64	97.16	0.98	1.86	5.79	16.73	16.73	16.73	16.73
1976	17.67	12.59	12.23	0.12	0.23	71.25	97.16	0.98	1.86	1.25	4.99	4.99	4.99	4.99
1977	19.49	13.47	13.02	0.19	0.25	69.10	96.69	1.45	1.86	9.81	6.75	6.27	45.48	6.75
1978	20.86	14.69	14.24	0.16	0.30	70.41	96.91	1.09	2.01	6.81	8.69	8.91	-20.00	16.34
1979	20.37	13.85	13.40	0.18	0.27	68.00	96.71	1.30	1.98	-2.37	-5.86	-6.06	12.40	-7.12
1980	21.62	15.13	14.63	0.20	0.30	70.00	96.68	1.34	1.98	5.92	8.82	8.79	11.68	8.83
1981	23.38	16.64	16.01	0.23	0.39	71.16	96.24	1.39	2.36	7.83	9.47	9.02	13.30	27.02
1982	23.92	16.18	15.39	0.41	0.38	67.66	95.14	2.52	2.34	2.28	-2.77	-3.92	56.55	-3.67
1983	24.08	16.43	15.79	0.28	0.36	68.22	96.10	1.72	2.17	0.70	1.52	2.53	-36.47	-6.02
1984	24.98	17.23	16.53	0.32	0.38	68.96	95.96	1.84	2.20	3.67	4.75	4.60	11.22	5.88
1985	24.84	16.79	15.95	0.37	0.48	67.62	94.95	2.18	2.87	-0.59	-2.55	-3.61	14.31	24.34
1986	25.67	16.94	16.21	0.30	0.43	65.97	95.71	1.76	2.53	3.30	0.84	1.63	-20.39	-11.78
1987	26.56	16.86	15.92	0.48	0.46	63.47	94.45	2.82	2.73	3.39	-0.47	-1.79	46.64	6.96
1988	28.28	18.55	17.75	0.35	0.44	65.57	95.72	1.91	2.37	6.30	9.55	10.89	-29.23	-4.57
1989	29.67	19.59	18.75	0.40	0.43	66.02	95.73	2.06	2.21	4.80	5.49	5.50	12.97	-1.43
1990	29.96	18.98	17.98	0.52	0.48	63.37	94.72	2.75	2.53	0.95	-3.15	-4.22	25.70	10.43
1991	30.29	18.10	16.99	0.64	0.48	59.75	93.85	3.52	2.63	1.11	-4.76	-5.68	19.97	-1.20
1992	31.68	19.13	18.06	0.62	0.45	60.39	94.43	3.24	2.33	4.47	5.52	6.14	-2.90	-6.30
1993	31.63	17.84	16.57	0.75	0.53	56.40	92.86	4.18	2.95	-0.13	-6.97	-8.64	18.65	16.60
1994	31.66	17.63	16.45	0.55	0.62	55.68	93.34	3.14	3.52	0.08	-1.21	-0.69	-29.92	16.37
1995	32.26	16.69	15.59	0.54	0.56	51.74	93.39	3.26	3.35	1.88	-5.45	-5.40	-1.65	-10.48
1996	32.03	16.00	14.86	0.48	0.65	49.94	92.90	3.01	4.08	-0.70	-4.25	-4.77	-12.17	15.60
1997	32.94	16.54	15.49	0.45	0.61	50.22	93.62	2.70	3.68	2.80	3.37	4.13	-7.49	-7.03
1998	31.93	16.31	15.15	0.54	0.62	51.08	92.88	3.30	3.82	-3.11	-1.42	-2.21	18.41	2.33
1999	31.90	15.42	14.09	0.60	0.73	48.34	91.39	3.86	4.75	-0.10	-5.60	-7.22	10.21	16.21
2000	32.83	15.97	14.72	0.62	0.63	48.64	92.15	3.88	3.96	2.87	3.50	4.33	4.00	-14.60
2001	33.38	15.35	13.61	0.94	0.79	45.97	88.67	6.15	5.18	1.67	-4.00	-7.85	42.09	22.68
2002	34.26	15.80	13.95	1.06	0.80	46.11	88.27	6.68	5.05	2.60	2.92	2.46	11.22	0.35
2003	34.68	15.56	13.48	1.31	0.77	44.88	86.65	8.40	4.95	1.20	-1.52	-3.38	21.33	-3.39
2004	35.71	15.12	12.98	1.50	0.63	42.33	85.88	9.95	4.17	2.94	-2.91	-3.80	14.02	-19.99
2005	36.30	15.45	12.76	2.00	0.70	42.56	82.56	12.93	4.50	1.64	2.18	-1.75	28.38	9.79
2006	36.34	15.32	12.65	2.02	0.64	42.14	82.60	13.21	4.19	0.12	-0.87	-0.83	1.25	-8.01

Source: Labour Force Survey (Round 2) for 1970-1983, Labour Force Survey (Round 3) for 1984-2006, National Statistical Office (NSO), Poapongsakorn (2006) and Thailand Development Research Institute (TDRI). Growth is calculated as $\ln(L_t/L_{t-1})\times 100$.

Table 4.28 Labour Quality Adjusted Index

	Employment Index				Labour Quality Index Index of Age-Sex-Education			Quality Adjusted Employment Index			
	Ag1	Ag2	Crops	Livestock	Agriculture	Crops	Livestock	Ag1	Ag2	Crops	Livestock
1970	58.22	58.52	59.10	29.87	97.90	98.48	100.89	56.99	57.29	58.20	30.13
1971	64.03	64.37	65.00	32.85	97.90	98.48	100.89	62.69	63.01	64.01	33.14
1972	56.66	56.95	57.51	29.07	97.90	98.48	100.89	55.47	55.76	56.63	29.33
1973	59.72	60.03	60.62	30.63	97.90	98.48	100.89	58.46	58.76	59.69	30.91
1974	54.63	54.92	55.46	28.03	97.90	98.48	100.89	53.48	53.76	54.61	28.28
1975	64.58	64.92	65.55	33.13	97.90	98.48	100.89	63.22	63.55	64.55	33.43
1976	67.88	68.24	68.90	34.82	97.90	98.48	100.89	66.45	66.80	67.85	35.14
1977	72.62	73.00	73.36	54.87	97.90	98.48	100.89	71.09	71.46	72.24	55.37
1978	79.21	79.50	80.20	44.93	97.99	98.47	92.51	77.62	77.91	78.97	41.56
1979	74.70	75.00	75.48	50.86	98.21	98.37	93.37	73.37	73.66	74.25	47.48
1980	81.60	81.92	82.41	57.16	98.32	99.16	92.17	80.22	80.54	81.72	52.68
1981	89.70	89.71	90.19	65.29	98.54	99.25	97.50	88.39	88.40	89.52	63.66
1982	87.25	87.28	86.72	114.94	98.58	99.29	89.36	86.02	86.04	86.11	102.71
1983	88.59	88.77	88.95	79.82	98.75	99.36	95.64	87.48	87.66	88.38	76.34
1984	92.90	93.06	93.14	89.29	99.08	99.50	95.52	92.04	92.20	92.67	85.29
1985	90.56	90.09	89.83	103.03	99.43	99.76	93.88	90.04	89.58	89.61	96.72
1986	91.32	91.17	91.31	84.02	99.37	99.68	94.92	90.75	90.59	91.02	79.75
1987	90.89	90.55	89.69	133.95	100.32	100.14	95.35	91.18	90.84	89.82	127.72
1988	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1989	105.64	105.81	105.65	113.85	100.34	100.23	99.00	106.00	106.17	105.90	112.70
1990	102.36	102.19	101.29	147.21	100.58	100.30	106.14	102.96	102.78	101.59	156.24
1991	97.60	97.34	95.70	179.74	100.63	100.43	97.29	98.21	97.96	96.10	174.87
1992	103.14	103.18	101.75	174.60	101.12	100.73	101.89	104.30	104.34	102.49	177.91
1993	96.20	95.62	93.33	210.39	101.40	100.82	101.36	97.54	96.96	94.10	213.25
1994	95.04	93.93	92.68	155.99	101.99	101.11	104.94	96.94	95.79	93.72	163.70
1995	90.00	89.10	87.81	153.44	102.12	101.17	108.60	91.91	90.99	88.84	166.64
1996	86.26	84.74	83.72	135.87	102.48	101.54	105.56	88.40	86.85	85.01	143.42
1997	89.21	88.02	87.25	126.06	102.80	101.65	106.12	91.71	90.48	88.70	133.77
1998	87.95	86.65	85.35	151.54	104.47	102.44	113.00	91.88	90.52	87.43	171.23
1999	83.16	81.13	79.40	167.83	105.21	102.92	114.03	87.49	85.36	81.72	191.37
2000	86.12	84.71	82.91	174.69	105.47	102.98	113.25	90.83	89.34	85.38	197.83
2001	82.75	80.37	76.66	266.10	107.08	103.34	111.73	88.60	86.06	79.22	297.31
2002	85.20	82.86	78.57	297.69	107.01	103.62	107.68	91.17	88.67	81.41	320.57
2003	83.91	81.69	75.96	368.46	108.16	103.89	109.08	90.76	88.36	78.91	401.91
2004	81.50	80.00	73.12	423.92	109.03	104.29	106.81	88.86	87.22	76.26	452.79
2005	83.30	81.48	71.86	563.06	109.03	104.29	106.81	90.82	88.83	74.94	601.40
2006	82.58	81.04	71.26	570.15	109.03	104.29	106.81	90.04	88.35	74.32	608.97

Source: National Statistical Office (NSO) and Thailand Development Research Institute (TDRI).

Table 4.29 Land used in Thai Agriculture

	Land Use/ Farm Holding Area (rai)						Cultivated Area (rai)					
							Planted Area					
	Rice	Other crops	Pasture	Others1/	Total	% Growth	Rice2/	Other crops3/	Total	% Growth	Livestock Area (public&private)	% Growth
1970	58,682,255	23,216,783	323,112	11,950,539	94,172,689		50,603,440	24,498,174	75,101,614		5,461,235	
1971	63,804,868	23,805,613	338,062	11,442,319	99,390,862	5.39	48,353,000	27,120,403	75,473,403	0.49	5,763,846	5.39
1972	65,485,340	25,535,403	353,012	12,177,809	103,551,564	4.10	45,930,000	28,769,400	74,699,400	-1.03	6,005,132	4.10
1973	67,162,293	28,062,339	367,962	13,760,703	109,353,297	5.45	52,269,582	31,365,152	83,634,734	11.30	6,341,584	5.45
1974	68,050,389	29,004,501	382,912	13,007,855	110,445,657	0.99	49,889,000	33,047,345	82,936,345	-0.84	6,404,932	0.99
1975	71,239,242	30,723,251	487,418	9,761,394	112,211,305	1.59	55,601,914	34,228,076	89,829,990	7.98	6,507,325	1.59
1976	71,316,929	32,008,096	410,623	9,376,362	113,112,010	0.80	53,594,718	34,535,885	88,130,603	-1.91	5,482,066	-17.14
1977	71,497,303	33,732,759	323,978	8,242,396	113,796,436	0.60	56,447,453	38,716,703	95,164,156	7.68	4,325,302	-23.70
1978	73,270,474	34,531,525	349,027	8,290,208	116,441,234	2.30	62,666,614	42,719,002	105,385,616	10.20	4,659,722	7.45
1979	72,857,034	36,614,848	517,363	7,613,630	117,602,875	0.99	58,971,380	40,914,318	99,885,698	-5.36	6,907,109	39.36
1980	73,562,985	37,214,620	523,014	7,698,321	118,998,940	1.18	60,109,890	42,896,657	103,006,547	3.08	6,982,553	1.09
1981	73,523,312	39,096,589	761,284	7,912,654	121,293,839	1.91	59,970,299	45,438,003	105,408,302	2.30	7,895,704	12.29
1982	73,222,199	41,499,686	766,312	8,098,596	123,586,793	1.87	60,133,792	46,122,902	106,256,694	0.80	8,173,044	3.45
1983	73,634,692	41,677,617	765,705	8,152,236	124,230,250	0.52	62,595,983	47,331,246	109,927,229	3.40	8,299,002	1.53
1984	73,909,386	42,502,215	752,590	8,149,573	125,313,764	0.87	62,329,326	49,209,819	111,539,145	1.46	8,220,563	-0.95
1985	73,902,435	45,541,938	847,535	8,311,564	128,603,472	2.59	63,416,440	51,859,282	115,275,722	3.30	8,307,618	1.05
1986	74,223,803	47,586,993	833,285	8,254,859	130,898,940	1.77	61,571,082	49,196,264	110,767,346	-3.99	8,405,036	1.17
1987	72,169,171	50,210,530	837,416	7,985,505	131,202,622	0.23	59,147,321	48,734,282	107,881,603	-2.64	8,220,223	-2.22
1988	70,827,661	51,746,769	768,461	8,429,868	131,772,759	0.43	64,587,931	51,211,605	115,799,536	7.08	8,023,309	-2.42
1989	70,189,879	52,506,685	750,235	8,384,386	131,831,185	0.04	64,438,576	52,919,396	117,357,972	1.34	7,966,954	-0.70
1990	69,436,107	53,649,844	740,435	8,298,023	132,124,409	0.22	61,910,147	51,328,004	113,238,151	-3.57	7,852,196	-1.45
1991	69,253,120	54,624,978	742,268	8,455,822	133,076,188	0.72	59,670,860	49,809,181	109,480,041	-3.38	7,928,058	0.96
1992	68,835,616	54,526,207	749,713	7,939,673	132,051,209	-0.77	60,452,711	49,674,209	110,126,920	0.59	8,025,909	1.23
1993	68,336,567	54,158,189	743,604	8,032,533	131,270,893	-0.59	59,251,261	49,898,475	109,149,736	-0.89	8,210,520	2.27
1994	68,320,651	54,706,728	751,710	8,054,199	131,833,288	0.43	60,677,143	49,592,801	110,269,944	1.02	8,460,296	3.00
1995	68,292,753	55,288,110	760,940	8,136,767	132,478,570	0.49	63,353,003	48,024,541	111,377,544	1.00	8,221,710	-2.86
1996	67,547,556	55,210,671	741,965	8,319,314	131,819,506	-0.50	63,727,679	48,442,660	112,170,339	0.71	8,277,473	0.68
1997	66,695,947	55,194,415	718,642	8,498,604	131,107,608	-0.54	64,189,196	48,165,024	112,354,220	0.16	5,962,367	-32.81
1998	65,914,065	55,093,164	693,143	8,693,153	130,393,525	-0.55	62,698,177	46,991,650	109,689,827	-2.40	5,513,351	-7.83
1999	65,686,993	55,887,803	802,414	8,964,174	131,341,384	0.72	64,443,551	46,337,355	110,780,906	0.99	6,109,009	10.26
2000	65,412,560	55,977,317	846,891	8,959,145	131,195,913	-0.11	66,492,130	46,612,831	113,104,961	2.08	5,317,571	-13.87
2001	65,220,587	55,978,705	885,625	8,975,057	131,059,974	-0.10	66,272,072	45,817,362	112,089,434	-0.90	5,504,109	3.45
2002	65,124,470	55,860,371	889,008	9,018,164	130,892,013	-0.13	66,440,247	45,399,581	111,839,828	-0.22	5,622,680	2.13
2003	64,892,332	55,916,186	919,047	8,954,462	130,682,027	-0.16	66,404,157	45,254,799	111,658,956	-0.16	5,853,719	4.03
2004	64,658,948	55,860,665	1,012,798	8,947,872	130,480,283	-0.15	66,565,421	45,932,855	112,498,276	0.75	4,551,515	-25.16
2005	63,861,066	56,418,202	1,103,271	8,893,454	130,275,993	-0.16	67,676,629	45,735,345	113,411,974	0.81	4,933,322	8.06
2006	63,257,356	56,982,384	1,011,705	8,931,929	130,183,375	-0.07	67,615,973	45,588,343	113,204,316	-0.18	5,315,129	7.45

Source: Office of Agricultural Economics, Department of Livestock Development and Poapongsakorn (2006). Notes: 1 hectare = 6.25 rai.

1/ Others include housing area, idle and unclassified areas. 2/ Rice includes major rice and second rice. 3/ Other major crops include food&feed crops (e.g., maize, sorghum, cassava), oil crops (e.g., castor bean, oil palm, coconut), fibre crops (e.g., kenaf, cotton), vegetables (e.g., garlic, shallot, dried chilli), fruit trees (e.g., banana, mangosteen, pineapple) and perennial trees (e.g., coffee, para rubber).

Table 4.30 Irrigated Area and Index of Adjusted Land Input

	Accumulated Irrigated Area (rai)	Land Use Area (rai)	Proportion of Irrigated Area (%)	In dex of Proportion of Irrigated Area	Index of Land Use Area	Index of Adjusted Land Input
1970	10,515,500	94,172,689	11.17	57.13	71.47	40.83
1971	10,765,500	99,390,862	10.83	55.42	75.43	41.80
1972	11,268,400	103,551,564	10.88	55.68	78.58	43.75
1973	12,208,700	109,353,297	11.16	57.12	82.99	47.40
1974	12,573,450	110,445,657	11.38	58.25	83.82	48.82
1975	12,861,050	112,211,305	11.46	58.64	85.16	49.94
1976	14,968,520	113,112,010	13.23	67.71	85.84	58.12
1977	15,668,690	113,796,436	13.77	70.45	86.36	60.84
1978	16,504,840	116,441,234	14.17	72.52	88.37	64.08
1979	17,724,568	117,602,875	15.07	77.11	89.25	68.82
1980	18,690,370	118,998,940	15.71	80.36	90.31	72.57
1981	19,821,560	121,293,839	16.34	83.61	92.05	76.96
1982	20,752,290	123,586,793	16.79	85.91	93.79	80.57
1983	21,656,124	124,230,250	17.43	89.19	94.28	84.08
1984	22,866,122	125,313,764	18.25	93.36	95.10	88.78
1985	23,889,148	128,603,472	18.58	95.04	97.59	92.75
1986	24,447,077	130,898,940	18.68	95.55	99.34	94.92
1987	24,975,732	131,202,622	19.04	97.39	99.57	96.97
1988	25,755,531	131,772,759	19.55	100.00	100.00	100.00
1989	25,989,010	131,831,185	19.71	100.86	100.04	100.91
1990	26,487,934	132,124,409	20.05	102.57	100.27	102.84
1991	27,182,473	133,076,188	20.43	104.51	100.99	105.54
1992	27,703,850	132,051,209	20.98	107.34	100.21	107.56
1993	28,356,114	131,270,893	21.60	110.52	99.62	110.10
1994	28,685,480	131,833,288	21.76	111.32	100.05	111.38
1995	29,013,021	132,478,570	21.90	112.05	100.54	112.65
1996	29,460,862	131,819,506	22.35	114.35	100.04	114.39
1997	29,679,838	131,107,608	22.64	115.82	99.50	115.24
1998	29,931,635	130,393,525	22.95	117.44	98.95	116.21
1999	30,190,362	131,341,384	22.99	117.60	99.67	117.22
2000	30,449,088	131,195,913	23.21	118.74	99.56	118.22
2001	30,776,649	131,059,974	23.48	120.15	99.46	119.50
2002	31,247,425	130,892,013	23.87	122.14	99.33	121.32
2003	32,246,840	130,682,027	24.68	126.25	99.17	125.20
2004	32,486,165	130,480,283	24.90	127.38	99.02	126.13
2005	32,725,490	130,275,993	25.12	128.52	98.86	127.06
2006	33,265,275	130,479,434	25.49	130.44	99.02	129.16

Source: Agricultural Statistics of Thailand (various years), Office of Agricultural Economics.
Note: Irrigated area includes large, medium and small scale irrigation projects.

Table 4.31 Net Capital Stock in Thai Agriculture

	Net capital stock of Thailand at 1988 prices								
	All sectors	Agriculture		Crops	Livestock	Growth			
	(m. baht)	(m. baht)	(% share)	(m. baht)	(m. baht)	All sectors	Agriculture	Crops	Livestock
1970	1,179,194	231,338	19.62	105,157	43,639				
1971	1,222,847	236,422	19.33	31,999	59,297	3.64	2.17	-118.98	30.66
1972	1,270,792	239,408	18.84	108,545	54,367	3.85	1.26	122.15	-8.68
1973	1,325,061	241,756	18.24	155,343	37,177	4.18	0.98	35.85	-38.01
1974	1,380,156	257,365	18.65	169,135	36,364	4.07	6.26	8.51	-2.21
1975	1,440,375	269,698	18.72	215,195	51,897	4.27	4.68	24.08	35.57
1976	1,515,868	269,098	17.75	197,936	48,111	5.11	-0.22	-8.36	-7.57
1977	1,610,680	270,896	16.82	174,847	54,781	6.07	0.67	-12.40	12.98
1978	1,708,864	282,261	16.52	167,018	46,784	5.92	4.11	-4.58	-15.78
1979	1,819,386	280,682	15.43	182,509	45,443	6.27	-0.56	8.87	-2.91
1980	1,958,342	282,485	14.42	182,404	52,023	7.36	0.64	-0.06	13.52
1981	2,109,620	288,052	13.65	169,271	55,418	7.44	1.95	-7.47	6.32
1982	2,251,264	291,672	12.96	182,824	49,509	6.50	1.25	7.70	-11.27
1983	2,425,614	298,429	12.30	187,187	52,164	7.46	2.29	2.36	5.22
1984	2,611,594	300,604	11.51	170,693	62,320	7.39	0.73	-9.22	17.79
1985	2,775,039	307,789	11.09	177,887	61,168	6.07	2.36	4.13	-1.87
1986	2,930,305	321,683	10.98	169,419	68,561	5.44	4.42	-4.88	11.41
1987	3,134,639	325,415	10.38	182,967	63,786	6.74	1.15	7.69	-7.22
1988	3,415,707	333,053	9.75	201,378	63,041	8.59	2.32	9.59	-1.17
1989	3,785,324	341,623	9.02	218,303	69,179	10.27	2.54	8.07	9.29
1990	4,298,800	356,852	8.30	203,593	75,104	12.72	4.36	-6.98	8.22
1991	4,877,760	380,197	7.79	222,417	68,796	12.64	6.34	8.84	-8.77
1992	5,480,415	404,247	7.38	231,463	72,880	11.65	6.13	3.99	5.77
1993	6,127,058	439,632	7.18	167,093	83,123	11.15	8.39	-32.59	13.15
1994	6,848,472	479,721	7.00	188,129	101,535	11.13	8.73	11.86	20.01
1995	7,549,430	510,359	6.76	256,651	84,218	9.74	6.19	31.06	-18.70
1996	8,389,886	550,875	6.57	300,422	84,361	10.56	7.64	15.75	0.17
1997	8,930,490	603,389	6.76	320,312	102,390	6.24	9.11	6.41	19.37
1998	9,019,444	623,822	6.92	377,688	83,822	0.99	3.33	16.48	-20.01
1999	9,102,169	633,473	6.96	334,377	91,083	0.91	1.54	-12.18	8.31
2000	9,213,961	655,315	7.11	307,671	81,046	1.22	3.39	-8.32	-11.68
2001	9,305,348	671,987	7.22	403,799	52,031	0.99	2.51	27.19	-44.32
2002	9,435,260	693,618	7.35	452,396	52,887	1.39	3.17	11.36	1.63
2003	9,620,468	716,201	7.44	516,012	18,854	1.94	3.20	13.16	-103.14
2004	9,883,430	742,654	7.51	552,338	24,423	2.70	3.63	6.80	25.88
2005	10,183,005	773,396	7.59	559,781	11,922	2.99	4.06	1.34	-71.72
2006	10,536,796	809,433	7.68	624,408	20,820	3.42	4.55	10.93	55.75

Source: National Economic and Social Development Board (NESDB). Crops and livestock capital are estimated as described in text.

Table 4.32 GDP Deflators in Thai Agriculture

	Ag1	Ag2	Crops	Livestock
1970	28.55	32.88	31.74	41.18
1971	26.28	29.38	27.56	42.60
1972	31.62	35.86	34.72	43.63
1973	41.83	46.75	47.21	43.12
1974	50.13	57.87	56.84	65.41
1975	52.37	59.75	59.06	64.71
1976	56.01	62.70	62.45	64.48
1977	58.91	65.93	64.62	73.98
1978	63.88	67.28	68.04	62.40
1979	72.62	76.81	77.28	74.00
1980	82.74	88.81	88.52	90.57
1981	83.23	87.38	86.19	95.28
1982	77.23	80.24	80.13	80.95
1983	88.22	92.63	91.27	101.56
1984	78.84	80.50	79.35	88.44
1985	72.28	71.30	70.46	77.31
1986	76.53	75.85	73.52	90.18
1987	89.08	89.40	88.33	95.24
1988	100.00	100.00	100.00	100.00
1989	100.77	100.81	100.12	105.08
1990	102.33	100.79	98.59	112.91
1991	111.18	109.87	106.84	127.44
1992	116.52	111.93	111.32	115.50
1993	107.43	96.66	95.59	102.25
1994	124.05	116.09	116.57	113.45
1995	143.87	138.50	139.28	134.11
1996	151.68	146.33	148.08	135.93
1997	155.90	146.65	148.98	133.01
1998	176.42	166.21	169.95	142.82
1999	150.60	136.23	132.53	159.81
2000	143.31	124.64	124.63	124.71
2001	146.53	131.30	128.38	149.15
2002	159.62	148.89	150.39	140.26
2003	169.64	165.28	171.73	125.23
2004	188.70	190.75	194.03	167.23
2005	210.81	219.34	224.37	187.92
2006	232.88	246.26	263.56	143.56

Source: Calculated as described in text. Note: Ag1 is overall agriculture without simple processing (crops, livestock, fisheries, forestry and agricultural services). Ag2 is traditional agriculture of crops and livestock only.

Appendix 4C: Growth Accounting Results

Table 4.33 Contribution of Inputs and TFP to Growth in Thai Agriculture

	Output growth	Labour		Land		Net Capital Stock	Unadjusted TFPG	Adjusted TFPG*
		Unadjusted	Adjusted for quality	Unadjusted	Adjusted for irrigation			
a) Agriculture1 (Crops, Livestock, Fisheries, Forestry, Agricultural Services)								
1971-1980	3.32	1.63	1.62	0.17	0.24	0.87	0.65	0.59
1981-1990	4.28	1.27	1.37	0.09	0.25	0.94	1.99	1.72
1991-2000	2.74	-0.83	-0.62	0.00	0.10	2.72	0.85	0.54
2001-2006	2.55	-0.26	-0.07	-0.01	0.14	2.16	0.66	0.32
1971-2006	3.02	0.45	0.57	0.07	0.19	1.65	0.85	0.61
	(100.00)	(15.00)	(18.79)	(2.19)	(6.13)	(54.73)	(28.08)	(20.35)
b) Agriculture2 (Crops and Livestock)								
1971-1980	4.22	1.38	1.37	0.23	0.28	2.02	0.59	0.55
1981-1990	4.76	1.43	1.54	0.10	0.29	0.92	2.31	2.00
1991-2000	2.69	-1.13	-0.86	-0.01	0.13	0.95	2.89	2.47
2001-2006	2.60	-0.44	-0.16	-0.01	0.17	3.54	-0.49	-0.95
1971-2006	3.34	0.30	0.45	0.09	0.22	1.61	1.35	1.06
	(100.00)	(9.01)	(13.59)	(2.56)	(6.51)	(48.11)	(40.32)	(31.78)
c) Crops								
1971-1980	3.98	1.43	1.43	0.27	0.32	1.91	0.37	0.33
1981-1990	4.79	1.28	1.33	0.12	0.34	0.85	2.54	2.27
1991-2000	2.92	-1.10	-0.99	-0.02	0.15	1.41	2.62	2.35
2001-2006	2.41	-0.90	-0.88	-0.02	0.19	6.22	(2.91)	(3.13)
1971-2006	3.27	0.20	0.25	0.10	0.25	2.09	0.88	0.68
	(100.00)	(6.22)	(7.60)	(2.98)	(7.63)	(63.95)	(26.86)	(20.82)
d) Livestock								
1971-1980	5.84	0.43	0.34	0.08		1.72	3.62	3.70
1981-1990	4.56	1.02	1.05	0.06		2.54	0.94	0.91
1991-2000	1.34	0.43	0.79	-0.18		0.48	0.60	0.25
2001-2006	3.79	13.11	13.64	-0.01		-7.56	-1.75	-2.28
1971-2006	3.83	2.80	3.00	-0.01		0.17	0.88	0.67
	(100.00)	(72.97)	(78.35)	(-0.38)		(4.53)	(22.88)	(17.49)

Note: numbers in parentheses are % contribution to output growth.

Table 4.34 Growth Accounting of Overall Agriculture (Ag1)

	Agricultural Sector (Ag1)							
	Output (Q)	Labour ($S_L \times L$)		Land ($S_N \times N$)		Capital ($S_K \times K$)	TFP	
	GDP growth	Unadjusted Labour	Adjusted for quality	Unadjusted Land	Adjusted for irrigation	Net Capital Stock	Unadjusted TFPG	Adjusted TFPG*
1971	3.76	5.51	5.40	0.40	0.10	0.75	-2.91	-2.49
1972	-1.53	-7.04	-6.89	0.31	0.19	0.44	4.76	5.18
1973	8.25	2.79	2.73	0.41	0.34	0.38	4.66	4.76
1974	3.26	-4.33	-4.24	0.07	0.13	2.74	4.78	4.03
1975	4.10	8.11	7.94	0.11	0.09	2.08	-6.20	-5.94
1976	5.58	2.54	2.49	0.05	0.63	-0.09	3.09	2.47
1977	1.73	3.46	3.38	0.04	0.19	0.28	-2.04	-2.17
1978	10.10	4.13	4.09	0.13	0.22	1.92	3.92	3.82
1979	-2.38	-2.54	-2.40	0.06	0.31	-0.28	0.39	-0.06
1980	0.36	3.68	3.66	0.07	0.27	0.33	-3.72	-3.72
1981	5.24	4.08	4.11	0.14	0.35	0.97	0.05	-0.24
1982	1.99	-1.23	-1.20	0.15	0.30	0.59	2.48	2.33
1983	4.99	0.71	0.78	0.04	0.29	1.04	3.20	2.87
1984	4.13	2.37	2.51	0.07	0.39	0.31	1.38	0.93
1985	4.14	-1.34	-1.14	0.20	0.32	0.93	4.34	4.17
1986	-0.22	0.43	0.40	0.14	0.17	1.81	-2.60	-2.56
1987	-0.50	-0.22	0.22	0.02	0.15	0.52	-0.81	-1.41
1988	10.23	4.31	4.16	0.03	0.20	1.12	4.78	4.84
1989	8.54	2.52	2.69	0.00	0.05	1.22	4.79	4.58
1990	-5.83	-1.49	-1.38	0.01	0.10	2.09	-6.44	-6.55
1991	6.83	-2.26	-2.26	0.03	0.12	3.04	6.02	5.87
1992	4.01	2.69	2.95	-0.04	0.10	2.86	-1.50	-1.92
1993	-2.92	-3.54	-3.45	-0.03	0.14	3.65	-3.00	-3.12
1994	4.14	-0.62	-0.33	0.03	0.09	3.62	1.11	0.95
1995	3.94	-2.68	-2.67	0.04	0.10	2.65	3.94	3.89
1996	4.33	-1.99	-1.87	-0.04	0.15	3.41	2.96	2.42
1997	-0.70	1.53	1.72	-0.05	0.07	4.20	-6.39	-6.62
1998	-1.48	-0.63	0.09	-0.05	0.08	1.57	-2.38	-3.22
1999	2.30	-2.45	-2.24	0.06	0.09	0.73	3.96	3.60
2000	6.94	1.48	1.67	-0.01	0.09	1.66	3.81	3.52
2001	3.20	-1.60	-1.05	-0.01	0.11	1.29	3.52	2.87
2002	0.67	1.05	1.10	-0.01	0.16	1.76	-2.13	-2.34
2003	11.94	-0.49	-0.16	-0.01	0.31	1.92	10.53	9.90
2004	-2.40	-0.86	-0.68	-0.01	0.07	2.29	-3.82	-4.12
2005	-1.88	0.59	0.65	-0.01	0.06	2.67	-5.14	-5.22
2006	3.77	-0.23	-0.25	0.00	0.14	3.05	0.95	0.82

Source: author's calculation.

Table 4.35 Growth Accounting of Traditional Agriculture (Ag2)

	Agricultural Sector (Ag2: crops and livestock only)									
	Output (Q)	Labour ($S_L \times L$)		Land ($S_N \times N$)			Capital ($S_K \times K$)	TFP		
	GDP growth	Unadjusted Labour	Adjusted for quality	Cultivated Areas (1)	Unadjusted Land (2)	Adjusted for irrigation	Net Capital Stock	Cultivated area TFPG (1)	Unadjusted TFPG (2)	Adjusted TFPG* (2)
1971	3.63	4.60	4.50	0.07	0.54	0.11	-21.29	20.25	19.78	20.30
1972	-2.53	-6.04	-5.91	-0.05	0.31	0.22	21.95	-17.84	-18.21	-18.25
1973	11.70	2.41	2.36	0.89	0.37	0.40	7.63	0.74	1.28	1.30
1974	2.45	-3.60	-3.52	-0.06	0.15	0.14	3.54	2.32	2.11	2.05
1975	4.75	6.57	6.43	0.56	0.38	0.11	14.37	-16.50	-16.31	-15.91
1976	6.76	2.08	2.04	-0.21	0.09	0.71	-4.16	9.02	8.72	8.17
1977	-1.03	3.07	3.01	0.42	0.12	0.22	-3.30	-1.20	-0.90	-0.93
1978	15.14	3.96	3.92	0.68	0.16	0.25	-3.14	13.40	13.92	13.87
1979	-1.15	-2.64	-2.49	-0.20	0.11	0.36	3.13	-1.48	-1.77	-2.16
1980	2.51	4.01	3.99	0.21	0.09	0.30	1.43	-2.83	-2.70	-2.89
1981	4.90	4.34	4.38	0.24	0.15	0.40	-1.78	1.93	2.02	1.73
1982	1.98	-1.39	-1.35	0.09	0.16	0.35	1.30	2.00	1.92	1.68
1983	6.09	0.93	1.00	0.29	0.05	0.34	1.21	3.73	3.98	3.61
1984	5.28	2.84	3.00	0.12	0.08	0.45	-0.80	3.05	3.08	2.56
1985	5.12	-2.07	-1.83	0.29	0.24	0.38	0.58	6.45	6.50	6.11
1986	-1.65	0.72	0.68	-0.34	0.18	0.21	-0.13	-1.90	-2.44	-2.42
1987	-1.95	-0.37	0.15	-0.23	0.04	0.18	1.41	-2.77	-3.05	-3.69
1988	12.87	5.05	4.89	0.51	0.01	0.24	2.95	4.51	5.01	4.93
1989	10.16	2.92	3.10	0.08	0.01	0.06	3.51	3.67	3.75	3.52
1990	-7.22	-1.85	-1.73	-0.20	0.02	0.11	-1.24	-3.89	-4.11	-4.32
1991	5.33	-2.62	-2.61	-0.17	0.03	0.15	1.80	6.30	6.10	5.98
1992	3.77	3.35	3.67	0.04	-0.02	0.12	1.80	-1.20	-1.15	-1.57
1993	-5.83	-4.73	-4.62	-0.05	-0.05	0.19	-5.41	4.58	4.59	4.24
1994	3.54	-1.16	-0.80	0.11	0.04	0.12	3.35	1.28	1.35	0.89
1995	4.33	-3.32	-3.30	0.08	0.05	0.13	4.46	3.06	3.09	2.99
1996	5.91	-3.11	-2.96	0.08	-0.07	0.19	3.60	5.22	5.37	4.97
1997	0.78	2.34	2.61	-0.19	-0.08	0.09	2.31	-3.80	-3.91	-4.35
1998	-1.40	-0.95	0.03	-0.28	-0.08	0.10	2.50	-2.67	-2.86	-4.03
1999	2.85	-3.96	-3.69	0.16	0.06	0.11	-2.71	9.08	9.18	8.89
2000	7.64	2.61	2.91	0.15	-0.01	0.12	-2.20	6.94	7.11	6.67
2001	4.24	-3.15	-2.38	-0.08	-0.01	0.15	4.13	3.47	3.40	2.44
2002	0.90	1.64	1.72	-0.01	-0.02	0.20	3.67	-4.40	-4.39	-4.69
2003	12.61	-0.65	-0.17	0.00	-0.01	0.37	2.56	10.69	10.71	9.85
2004	-3.36	-0.83	-0.56	-0.03	-0.01	0.08	4.05	-6.58	-6.60	-6.95
2005	-2.97	0.64	0.70	0.09	-0.01	0.07	-0.51	-3.19	-3.10	-3.24
2006	4.17	-0.18	-0.20	0.01	-0.01	0.16	7.32	-2.99	-2.97	-3.11

Source: author's calculation. Note: (1) Since cultivated area already includes multiple cropping, there is no need to adjust for the effect of irrigation. (2) Unadjusted land means farm holding area or fixed supply of land, not accounted for multiple cropping. Therefore, it is adjusted for irrigation.

Table 4.36 Growth Accounting of Crops Sector

	Crops									
	Output (Q)	Labour ($S_L \times L$)		Land ($S_N \times N$)			Capital ($S_K \times K$)	TFP		
	GDP growth	Unadjusted Labour	Adjusted for quality	Planted Area (1)	Unadjusted Land (2)	Adjusted for irrigation	Net Capital Stock	Cultivated area TFPG (1)	Unadjusted TFPG (2)	Adjusted TFPG* (2)
1971	3.59	6.98	6.88	0.05	0.64	0.13	-20.44	17.00	16.41	17.02
1972	-3.35	-8.38	-8.26	-0.10	0.36	0.26	18.66	-12.72	-13.19	-13.22
1973	13.37	3.08	3.03	1.06	0.42	0.45	11.95	-2.66	-2.01	-2.00
1974	1.64	-4.22	-4.16	-0.07	0.17	0.16	4.05	1.53	1.28	1.23
1975	4.65	7.24	7.13	0.67	0.42	0.11	12.00	-15.01	-14.75	-14.35
1976	6.40	2.22	2.19	-0.16	0.11	0.81	-3.96	8.28	8.03	7.38
1977	-2.76	2.95	2.90	0.61	0.14	0.25	-5.56	-0.77	-0.30	-0.37
1978	15.70	4.16	4.14	0.78	0.18	0.29	-1.97	12.50	13.10	13.01
1979	-2.10	-2.67	-2.58	-0.41	0.12	0.40	4.36	-3.43	-3.93	-4.28
1980	2.65	3.76	3.80	0.25	0.10	0.35	-0.03	-1.03	-0.88	-1.16
1981	6.12	3.99	3.97	0.22	0.16	0.44	-3.37	5.19	5.26	4.98
1982	1.83	-1.81	-1.79	0.08	0.19	0.40	3.17	0.45	0.34	0.09
1983	6.24	1.24	1.26	0.35	0.05	0.39	1.04	3.69	3.99	3.63
1984	5.96	2.42	2.47	0.15	0.10	0.51	-3.43	6.80	6.85	6.41
1985	5.43	-2.04	-1.89	0.35	0.27	0.43	1.22	6.00	6.08	5.76
1986	-3.57	0.91	0.85	-0.44	0.21	0.24	-1.55	-2.51	-3.18	-3.15
1987	-3.65	-0.93	-0.69	-0.28	0.05	0.22	2.94	-5.38	-5.71	-6.12
1988	14.35	5.37	5.29	0.66	0.01	0.29	4.12	4.37	5.02	4.82
1989	10.37	2.73	2.81	0.11	0.01	0.07	3.48	4.09	4.19	4.05
1990	-8.86	-2.16	-2.14	-0.25	0.02	0.14	-2.86	-3.55	-3.82	-3.95
1991	6.10	-2.97	-2.91	-0.22	0.04	0.17	3.67	5.62	5.36	5.17
1992	3.88	3.37	3.52	0.04	-0.03	0.14	1.66	-1.02	-0.95	-1.25
1993	-7.58	-5.11	-5.07	-0.08	-0.06	0.22	-10.16	7.86	7.84	7.53
1994	4.22	-0.42	-0.32	0.11	0.05	0.14	2.80	1.76	1.82	1.62
1995	4.98	-3.12	-3.09	0.12	0.05	0.15	9.19	-1.21	-1.14	-1.27
1996	6.57	-2.55	-2.41	0.09	-0.08	0.22	5.84	3.04	3.22	2.79
1997	0.56	2.08	2.17	0.02	-0.09	0.10	2.31	-3.92	-3.81	-4.09
1998	-0.45	-1.08	-0.79	-0.29	-0.09	0.12	6.55	-5.64	-5.84	-6.33
1999	3.12	-3.55	-3.40	0.13	0.06	0.12	-5.02	11.36	11.42	11.23
2000	7.79	2.09	2.16	0.28	-0.02	0.13	-2.79	8.02	8.33	8.10
2001	3.51	-3.53	-3.51	-0.12	-0.02	0.17	10.84	-3.56	-3.66	-3.88
2002	0.09	0.93	1.06	-0.03	-0.02	0.23	5.82	-6.59	-6.60	-6.97
2003	13.63	-1.04	-1.02	-0.02	-0.02	0.42	7.70	6.99	6.99	6.54
2004	-1.51	-1.02	-1.07	0.07	-0.02	0.08	4.42	-5.02	-4.93	-4.99
2005	-4.74	-0.42	-0.44	0.07	-0.02	0.07	0.90	-5.28	-5.19	-5.27
2006	3.45	-0.19	-0.20	-0.02	0.00	0.18	7.66	-4.02	-4.03	-4.21

Source: author's calculation. Note: (1) Since cultivated area already includes multiple cropping, there is no need to adjust for the effect of irrigation. (2) Unadjusted land means farm holding area or fixed supply of land, not accounted for multiple cropping. Therefore, it is adjusted for irrigation.

Table 4.37 Growth Accounting of Livestock Sector

	Livestock						
	Output (Q)	Labour ($S_L \times L$)		Land ($S_N \times N$)	Capital ($S_K \times K$)	TFP	
	GDP growth	Unadjusted Labour	Adjusted for quality	Cultivated Area	Net Capital Stock	Unadjusted TFPG	Adjusted TFPG*
1971	3.94	0.25	0.25	0.19	28.77	-25.27	-25.27
1972	3.21	-0.47	-0.48	0.15	-8.03	11.57	11.57
1973	-0.43	0.25	0.25	0.27	-34.19	33.23	33.23
1974	8.55	-0.45	-0.45	0.05	-1.99	10.94	10.95
1975	5.48	0.89	0.90	0.06	32.44	-27.84	-27.84
1976	9.32	0.30	0.31	-0.60	-6.86	16.48	16.48
1977	10.31	3.37	3.34	-0.61	11.69	-4.13	-4.16
1978	11.66	-1.64	-2.27	0.16	-14.03	27.30	27.98
1979	4.73	1.05	1.06	1.10	-2.58	5.18	5.19
1980	1.68	1.02	0.85	0.04	11.99	-11.30	-11.13
1981	-2.82	1.44	1.91	0.47	5.46	-10.05	-10.51
1982	2.95	7.57	5.94	0.17	-9.09	3.62	5.42
1983	5.10	-5.77	-4.39	0.07	4.16	6.62	5.17
1984	0.70	2.02	1.88	-0.04	13.98	-15.16	-15.05
1985	2.92	2.64	2.20	0.05	-1.38	1.22	1.72
1986	11.07	-3.52	-3.15	0.05	8.96	5.50	5.13
1987	7.93	7.02	6.78	-0.08	-5.97	7.64	7.89
1988	4.36	-4.11	-3.35	-0.08	-0.96	9.68	8.90
1989	8.86	1.94	1.79	-0.02	7.71	-0.64	-0.49
1990	2.30	4.22	5.46	-0.03	6.69	-8.54	-9.85
1991	0.95	3.84	2.20	0.02	-6.93	4.04	5.66
1992	3.13	-0.70	0.42	0.03	4.36	-0.61	-1.64
1993	3.81	5.20	5.13	0.07	8.70	-10.72	-10.65
1994	-0.12	-8.82	-8.08	0.12	13.10	-4.23	-5.06
1995	0.72	-0.48	0.55	-0.14	-12.73	14.03	13.07
1996	2.08	-3.58	-4.71	0.03	0.11	5.52	6.67
1997	2.10	-2.35	-2.35	-1.50	12.32	-6.34	-6.37
1998	-7.14	5.97	8.78	-0.30	-12.65	-0.25	-3.09
1999	1.21	3.53	4.32	0.38	5.29	-7.79	-8.58
2000	6.63	1.62	1.52	-0.53	-6.75	12.37	12.46
2001	8.84	20.83	22.50	0.12	-20.18	7.50	5.62
2002	5.67	6.77	5.00	0.07	0.61	-1.65	0.10
2003	6.50	14.87	17.13	0.15	-26.10	17.31	15.03
2004	-15.66	10.85	9.94	-0.85	4.59	-30.47	-29.56
2005	8.82	23.31	25.02	0.22	-10.78	-3.98	-5.57
2006	8.58	1.05	1.12	0.23	6.52	0.77	0.69

Source: author's calculation.

Table 4.38 Comparison with previous study

% Contribution to output growth	Overall Agriculture		Crops		Livestock	
	Poapongsakorn (2006): 1980-2003	This study: 1970-2006	Poapongsakorn (2006): 1980-2003	This study: 1970-2006	Poapongsakorn (2006): 1980-2003	This study: 1970-2006
Labour growth	6.81	15.00	-3.03	6.22	-0.42	-0.38
Land growth	4.64	2.19	6.52	2.98	76.12	78.35
Capital growth	59.90	54.73	37.68	63.95	-7.89	4.53
TFP growth	28.65	28.08	58.66	26.86	32.20	17.49

Note: Both studies use the growth accounting method.

Chapter 5

5. Determinants of TFP Growth: Analytical Framework, Data and Estimation Methods

5.1 Introduction

The previous chapter used the growth accounting framework to decompose agricultural growth into real factor input growth and total factor productivity growth (TFPG). This decomposition was also undertaken for crops, livestock and the two sectors combined (traditional agriculture). Over the period 1970-2006, TFP was shown (in Chapter 4) to be an important source of value added growth in all sectors but the driving forces behind this residual TFP were left unexplained. An extension from the conventional growth accounts to productivity accounts is required.

This chapter outlines the analytical framework and estimation methods to be used for investigating the determinants of TFPG in Thai agriculture and the results will be presented in the following chapter. The analysis covers the four sectors of overall agriculture, traditional agriculture, crops and livestock. The chapter examines the standard determinants of TFPG suggested in the literature along with factors usually ignored in most studies, namely international research spillovers, private research and non-economic factors such as climate and epidemic. Emphasis is given to the longstanding public investment in agricultural research using a newly compiled data set. The empirical specifications, based on two different methods, allow for finite and infinite lag structure in the productivity accounts. This will be applied in the next chapter.

The rest of the chapter is organised into five sections. Section 5.2 provides the analytical framework for identifying key TFP determinants, with empirical support from the literature. The variables definitions and data sources are described in section 5.3, along with the reasons why each variable has been chosen. Two main econometric models are described with the underlying objectives for each model in section 5.4. Section 5.5 explains the estimation procedures and indicates empirical specifications for the estimation models. Finally, section 5.6 summarizes all the estimation cases in order to provide an overview for the analysis and for ease of understanding the results in the following chapter.

5.2 Analytical Framework: Key Factors Affecting TFP

As TFP is measured based on the economic theory of production function (Jorgenson and Griliches, 1967), factors affecting a change in TFP can also be identified by the production function.

For a simple production function: $Q = f(X, Z)$

where Q = output

X = conventional inputs - labour, land and capital

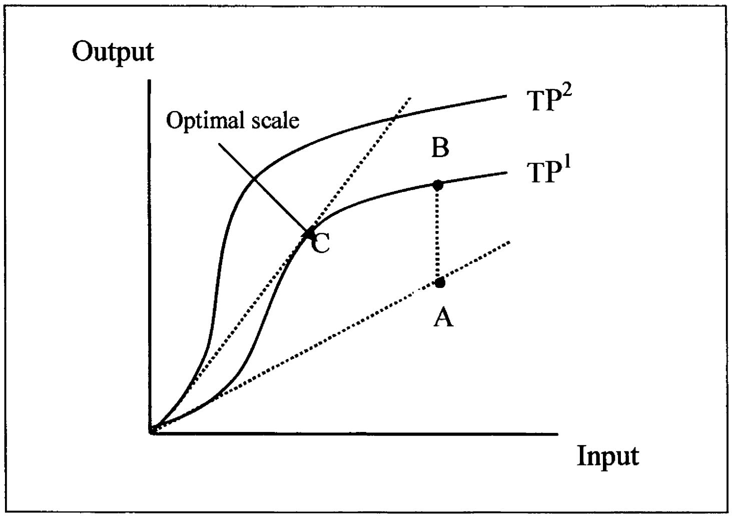
Z = unconventional inputs, such as research, extension, infrastructure, weather, etc.

By definition, TFP is viewed as an index of aggregate output relative to an index of aggregate conventional input, $TFP = Q/X$. Hence, $TFP = g(Z)$ and TFP growth is also a function of growth in the unconventional inputs.

In the usual growth accounting framework, TFPG is measured as a residual after accounting for the weighted average of conventional input growth. Hence, there are several factors captured in the unconventional inputs (Z) besides the technology factor that is of interest in this thesis. For simplicity, Z can be categorized into 3 main groups: 1) pure technical change 2) efficiency gain 3) economies of scale (Coelli et al., 2005, Chapter 1).

The three main categories of productivity change can be illustrated by Figure 5.1. Pure technical change is identified with a shift in a production function. An advance in technology is depicted by an upward shift in the production function from TP^1 to TP^2. Efficiency gain is a movement toward the production function, from point A to the technically efficient point B. Economies of scale refer to a movement along the production function toward the optimal scale at point C where maximum productivity can be achieved.

Figure 5.1 Technical Change, Efficiency Gain and Scale Economies



Source: Coelli et al. (2005, p.5-6)

Pure Technical Change

Conceptually, explaining technical change is based on endogenous growth theory or new growth theory (Romer, 1990, Aghion, 1998). In new growth theory, productivity growth representing technological progress can be explained endogenously. Innovation is recognized as an endogenous process that has systematic and predictable effects on output and productivity growth.[135] Therefore, factors affecting technological change can have an impact on growth. For instance, policy measures enhancing technology innovation through subsidies on research and development can affect output and productivity growth (Romer, 1990, Aghion, 1998).

[135] This is a more plausible approach compared to neoclassical growth theory where technological innovation is considered as an exogenous process. This implies investment in research and development has no effect on output growth (Hulten, 2000, p.34).

Efficiency Gain and Economies of Scale

Explaining the second and third category is associated with the assumptions underlying TFP measurement. TFP growth is measured based on the conditions of producer equilibrium and constant returns to scale. Producers are assumed to be technically efficient and employ each input up to the point that its marginal product equals real factor price. This means any deviation between input price and true marginal product is thrown into the residual (Harberger, 1996). Factors affecting the deviation such as market distortions and real cost reductions can explain efficiency improvement and an exploitation of scale economies.

Other Case-Specific and Natural Factors

Explaining the unexplained part of output growth is also a matter of empirical analysis. Besides the three main components discussed above, non-economic variables potentially affecting the residual TFP can also be examined, such as weather, environmental degradation, epidemics and natural disasters (Alston et al., 1998b and 1994). In addition, case-specific or ad hoc factors may well be included to control for sharp variations in output or productivity measures (Evenson and Pray, 1991, Morrison Paul, 1999).

There have been numerous studies investigating the sources of productivity growth.[136] There is still no consensus on the theoretical framework to guide empirical work on the determinants of TFP (Aswicahyono, 1998, p.24). Determining what factors influence the residual 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. In practice, while a theoretical framework alone cannot be totally relied upon, it does provide guidance on an interpretation of empirical findings.

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[136] See, for example, Griliches (1963, 1996), Evenson and Pray (1991), Mahadevan (2002, 2003), Mundlak (1992), Mundlak et al. (2002) and Huffman and Evenson (2005).

5.2.1 Identifying Potential Determinants for Agriculture

In the context of agriculture, typical factors influencing TFP through the pure technical change component are agricultural research, extension services and technology transfer from abroad. Factors affecting efficiency improvement are education of farmers, infrastructure investment and resource reallocation. Major factor affecting economies of scale is trade openness.[137]

These potential factors cannot be separately identified under the three main components of TFPG as they are closely linked and in some cases jointly determine TFPG. For example, agricultural extension can increase both technical change and production efficiency. Its main function is conveying research results to farmers thereby enabling the adoption of new technology and technological improvement. It can also raise efficiency by providing training and disseminating information to enable farmers to use inputs more efficiently. Trade openness enhances both economies of scale through expanding market size and efficiency gains through induced competition.

Moreover, there are several empirical options to identify factors determining TFP. With regard to agricultural economic studies, a number of previous studies have adopted the TFP decomposition framework (e.g., Nagy, 1991, Alston et al., 1994, Huffman and Evenson, 2006). This is a more focused approach directly specifying factors determining TFP and often used to study the economic impact of agricultural research and extension (R&E) on productivity. As described in the Handbook of Agricultural Economics (Evenson, 2001), TFP decomposition is specified as:

$$Q/X = TFP = h(C, E, T, I, S)$$

where Q is a vector of output

X is a vector of variable factors

[137] The mentioned factors are drawn from previous studies, see, for example, Evenson and Pray (1991), Mundluk (1992), Kaipornsak (1995), Chockpisansin (2002), Chandrachai et al. (2004), Huffman and Evenson (2005), Warr (2006) and Songsiengchai (2007).

C is a vector of climate factors

E is a vector of soil quality factors

T is a vector of technology or inventions

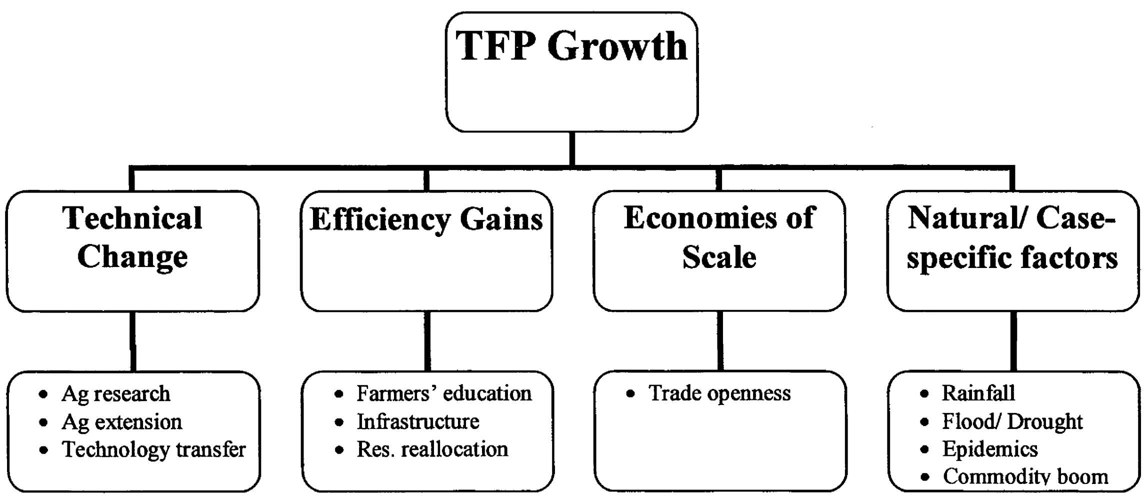
I is a vector of infrastructure

S is a vector of farmer skills

The specification entails similar factors affecting the three main categories described earlier, except that it also includes additional factors, that is, climate and soil quality. These factors are specifically important to agriculture as mentioned in the case-specific and natural factors. Besides, changes in TFP can also be due to unmeasured or imperfectly measured inputs (Zepada, 2001). These measurement errors should be captured in the error term.

This study combines key factors from the literature and classifies them into four main groups. Figure 5.2 broadly illustrates the key factors determining TFP growth in the context of agriculture. Factors are grouped into four main components according to their main functions. As mentioned, each factor can directly and indirectly affect more than one component. They are grouped for ease of illustration.

Figure 5.2 Key Factors Determining Agricultural Productivity Growth



5.2.2 Explaining Factors Determining Agricultural Productivity

The key factors affecting agricultural productivity indicated in Figure 5.2 are discussed below. Their conceptual relationships with productivity are also explained with empirical support from the literature.

1) Agricultural research

As mentioned in the literature review, agricultural research is generally recognized as a prime source of technical change that improves productivity and sustains output growth (Ruttan, 1987, Chang and Zepeda, 2001). It increases the stock of knowledge, which either facilitates the use of existing knowledge or generates new technology.

In growth accounting, pioneering studies have incorporated research and development (R&D) in explaining productivity (Jorgenson and Griliches, 1972, p.90, Denison, 1967, Chapter 20). It is well-known that residual TFP includes, but is not confined to, advances of knowledge or technological progress (Denison, 1967, Griliches, 1996). Nonetheless, since the invention of TFP the contribution of agricultural research has received considerable attention in the literature, for example, Ruttan (1987), Evenson and Pray (1991), Fan and Pardey (1997), Alston et al. (1998b) and Mullen (2007). As concluded by Hulten (2002), 'a complete explanation of productivity growth (the Jorgenson-Griliches goal) is not possible without a better understanding of the R&D-productivity linkage'.

Major issues involved in estimating the impact of research on productivity are time lags, research spillovers and attribution (Fuglie and Heisey, 2007). Lags and research spillovers should be properly taken into account. Attribution identifies which research in particular contributes to productivity gains, for instance, identifying the relative importance of research by source of funds or research types. To address the attribution issue among types of research, other factors affecting TFP also have to be properly accounted for.

Empirical studies often use agricultural research expenditure as a proxy for agricultural technology. As noted by Huffman and Evenson (2005), 'over forty years Griliches (1958, 1979) established a tradition of using real public agricultural research expenditure to proxy the "true" measure of agricultural research discoveries that impact productivity'. R&D spending is an indicator of the rate of development of innovation, on the assumption that there is positive link between resources spent and discoveries (Mahadevan, 2002, p.51). A number of studies found positive and significant linkage between agriculture research expenditure and relevant TFP growth, for example, Griliches (1964b), Pardey and Craig (1989), Evenson et al. (1999), Huffman and Evenson (2005), Kelvin et al. (2005) and Ananth et al. (2006).

In the Thai agriculture context, the government has been actively involved in R&D activities, especially at the farm level (Kohpaiboon, 2006, p.171). Longstanding public investment in agricultural research is often recognized as the main driving force of TFP growth in the agricultural sector (Tinakorn and Sussangkarn, 1996, Poapongsakorn, 2006). Poapongsakorn and Anuchitworawong (2006) found relatively high TFP growth in the crops and livestock sectors. They maintained that the higher TFP growth in the crops and livestock sectors during 1981-2003 may have been caused by research and extension (R&E) during the 1980s to the early 1990s. The reasons given are the increased proportion of government budget allocated for R&E and the improvement in production technology and advances in resource management.

2) Agricultural extension

Agricultural extension involves a dissemination of research results to farmers for adoption. It generally facilitates knowledge diffusion through information dissemination, training and demonstration. Cooperative extension can also indirectly influence the agricultural research process by conveying feedback from farmers to researchers that may improve future research. Therefore, effective agricultural extension should improve productivity.

In practice, extension is sometimes treated as a component of research activities (Alston et al., 1998b, p. 173). However, a number of empirical studies distinguish extension from research in order to examine its impact on agricultural productivity (Evenson and Pray, 1991, Evenson et al., 1999, Huffman and Evenson, 2005). Extension is often measured as public expenditure on extension services or the number of extension workers. Compared with research, the time lag is expected to be shorter (Evenson, 2001). Nonetheless, several studies argued that agricultural extension can have an immediate impact on agricultural productivity thereby lags were not imposed on the extension variable (Hall and Scobie, 2006, Yee et al., 2002, Thirtle and Bottomley, 1989).

It is also common for inclusion of an interaction term between extension and research to be used to represent the hypothesis that research can have a greater effect on productivity with cooperation from extension as an agency to diffuse research knowledge to farmers (Evenson and Pray, 1991). In the case of agricultural extension, there are no spatial spillovers as with agricultural research.

3) Technology transfer and spillovers[138]

Productivity growth can result from technology developed in other countries. Many developing countries have relied on agricultural research and technology primarily conducted by a small group of developed countries, especially the United States, France, Germany and Japan (Pardey et al., 2006c). Access to foreign technology can be gained directly through imports and foreign direct investment (FDI) or indirectly through international cooperation.

[138] Emphasis on agricultural research spillovers is given in an international dimension rather than an intra-national one because Thailand is a relatively small country. Spillovers among regions or provinces may not be as significant as in large and diversified countries like the U.S., China and Indonesia. These countries are cases that spatial econometrics (Anselin, 1988) are commonly applied. In their study of Thai agriculture Setboonsarng and Evenson (1991) did not account for intra-national spillovers. In a subsequent study which did incorporate them Pochanukul (1992) showed only slight differences from Setboonsarng and Evenson (1991) in the returns on crop research (see Chapter 2, section 2.5.3 for details).

Foreign agricultural technology can be directly imported in the form of capital goods and raw materials, such as machinery, livestock breeds, seeds and fertilizers. Alternatively, FDI is another important channel bringing in new technology and know-how that can improve production efficiency and productivity in host countries. FDI also expands market channels and encourages market competition, which is beneficial to productivity growth. For instance, FDI could bring in new planting techniques, farm management and expand the agricultural export market. An indirect channel of technology transfer is through the system of International Agricultural Research Centres (IARCs) including the centres under the support of the Consultative Group on International Agricultural Research (CGIAR) (Pardey et al., 2006c).

In most cases, the presence of FDI in the agricultural sector is small. As a result, there are limited empirical studies on the role of FDI in agricultural growth and productivity (Furtan and Holzman, 2004, Sattaphon, 2006). In the Thailand context, technology transfer to agriculture occurs mostly through non-FDI channels (Kohpaiboon, 2006). Private companies have played an important role in transferring technology to farmers, particularly the Charoen Pokphand (CP) Group. Direct import of foreign technology and capital goods has been used to proxy the technology transfer variable in explaining TFPG in the Thai literature, for example, Kaipornsak (1998, 1999), Chockpisansin (2002) and Songsiengchai (2007).

The direct import usually comes in a package that is readily available for use. On the other hand, new technology developed by international research centres is available for all users in many countries. They are not used promptly, often requiring local research to develop the technology to fit local conditions. In addition, technology from the international research centres may come in a form of knowledge sharing or training provided to local researchers.

4) Education

Education is generally considered a close and obvious measure of human capital that helps bring about innovations in production technology (Romer, 1989). In particular, education is well recognized as a mean of improving labour quality. The skills of workers were shown to be significant in causing productivity differences among countries (Acemoglu and Zilbotti, 1999). An improvement in labour skills can increase efficiency in the use of physical capital and adoption of technology. Better educated workers should therefore contribute positively to productivity.

Many empirical studies deal with the role of education in growth accounting. Some studies account for education in the growth accounting framework through the adjustment of labour quality (Denison, 1967, Tinakorn and Sussangkarn, 1996, Poapongsakorn, 2006). Some investigate the role of education as a separate variable in either the production function or productivity model (Griliches, 1964b, Lau et al., 1991, Jamison and Lau, 1982). Education is measured differently in various studies. It is often measured in terms of years of schooling, level of literacy and the population share with higher education in the total population.

The strongest evidence is the general finding that agricultural output and productivity is positively correlated with the level of education of the farmer (Griliches, 1964b, 1963, Jamison and Lau, 1982, Lau and Yotopoulos, 1989, Romer, 1989, p.30, Lau et al., 1991). However, the educational effect on productivity varies considerably across countries and case studies. A negative effect was found in some countries (Lau et al., 1991). The effect of education is also frequently found to be statistically insignificant for individual countries due to multicollinearity among input data (Lau et al., 1991).

5) Infrastructure

Infrastructure refers to public investment in physical infrastructure that is necessary for agricultural production such as irrigation, roads and electricity. Infrastructure is generally considered a fixed factor that contributes positively to agricultural growth and productivity (Evenson and Pray, 1991, Evenson, 2001). Infrastructure is typically not included in conventional inputs in growth accounting; thereby its effect on agricultural growth is captured in the residual TFP. Better public infrastructure can improve production efficiency (Mahadevan, 2002, p.28) as well as facilitate the development and transfer of technology (Zepada, 2001). For instance, irrigation and roads are required to implement technology or adopt new research results.

The impact of infrastructure varies with case studies. In developing countries, the agricultural expenditure that contributes strongly to growth is irrigation and roads (Fan and Rao, 2003). Irrigation and water systems play a crucial role in agriculture. Irrigation enables crops planting during dry seasons thereby raising the quality of land and the yield per hectare. It also facilitates the adoption of new technology. For instance, the adoption of modern rice varieties in Thailand was found to be heavily concentrated in irrigated areas (Isvilanonda and Hossain, 2000). Livestock farms also benefit from irrigation. As most animal feed is from plants, livestock farms can raise efficiency by locating near irrigated areas in order to reap the benefits of lower costs and better quality fodder and forage. Rural roads facilitate farmers' access to better and cheaper inputs and to new technology that in turn benefits agricultural productivity.

6) Trade openness

The connection between trade openness and productivity growth has generally been linked through two main channels. First, trade openness or liberalization helps in achieving economies of scale by expanding market size through export. Economies of scale bring about real cost reductions thereby increasing productivity. The exploitation of economies of scale refers to a movement along the production frontier to the point where optimal scale or maximum possible productivity can be achieved (Coelli et al., 2005, Chapter 1). Empirically, there is evidence that economies of scale play an important role in TFP growth (Harberger, 1996, Kwon, 1986).

Second, commodity trade enhances market competition through import and export. Competition influences technological development thereby increasing TFP growth. Imports increase local competition at end user markets that in turn affects production efficiency at the farm level. Export-oriented sectors have to adjust to remain competitive in world markets by adopting new technology, marketing know-how and improving production efficiency. More open economies and international trade are generally found to be favourable to TFP growth (Edwards, 1998, Urata and Yokota, 1994, Acemoglu and Zilbotti, 1999, p.34, Wilson, 2006).

Opponents of trade liberalization argue that trade openness can impede productivity growth by reducing the sales of domestic firms thereby lowering the incentives for technological development (Mahadevan, 2002, p.54). A study by Mahadevan (2002) indicates the empirical evidence on the relationship between productivity growth and openness is rather mixed. From her study, when countries do not gain much from opening up, it is most likely due to their economies not being internationally competitive, along with some internal factors such as politics and macroeconomic policy being not favourable to trade reform.

7) Resource reallocation

Resource reallocation can raise TFP growth at the aggregate level by allowing factors to move from lower marginal productivity (or real input price) to higher productivity sectors. Even though there is no TFP growth in any individual sector, aggregate TFP growth may still be observed. For instance, movement of labour from the agricultural sector to a higher productivity sector like manufacturing or services can increase TFP growth in an overall economy. Within a sector, productivity growth can result from reallocation of resources among subsectors and among commodities.

The effect of resource reallocation on productivity growth was emphasised in a number of studies, for example, Jorgenson (1988), Harberger (1996), Tinakorn and Sassangkarn (1996, p.81-83) and Aswicahyono (1998). There is also empirical evidence confirming the effect of resource reallocation is crucial for aggregate TFP growth (Warr, 2006).

In the Thailand context, previous studies have used the growth of labour's share in the non-agricultural sector to represent the impact of resource reallocation in determining TFPG in the overall economy (Tinakorn and Sussangkarn, 1996). Some recent studies refer to the effect of resource reallocation as structural change. They use labour migration among sectors as a proxy of structural change (Chockpisansin, 2002, Chandrachai et al., 2004). The general finding is that resource reallocation contributes significantly to TFP growth.

8) Natural and case-specific factors

Natural and case-specific factors refer to non-economic and irregular factors that may explain the variation of the residual TFP. Amongst the natural factors, weather is crucial for agricultural production. In particular, weather often affects farmers' decisions in harvesting; how many workers and machines should be used, and other inputs such as pest control and fertilizer use. Under the conventional TFP decomposition framework, climate is considered as a component explaining changes in TFP (Evenson, 2001). Other natural factors, such as floods, droughts and epidemics can also explain abnormal variations in TFP and so can be considered as potential determinants.

In empirical studies, weather is often ignored as an input in the production function (Alston et al., 1998b, p.165). Productivity is measured as output per unit of total inputs combined. In other words, TFP growth is a residual of output growth not explained by input growth so that weather is left in as a part of the residual. Measuring the weather variable is difficult in practice because it is commodity and location specific. Ideally, aggregate weather indices should be constructed by weighting the indices for individual locations according to corresponding regional production and aggregated across agricultural commodities (Alston et al., 1998b, p.166).

For case-specific factors that may cause irregular variations in agricultural output and productivity, the world agricultural commodity boom during 1972-1974 is a relevant example. The commodity boom raised the real price of internationally traded food commodities, thereby inducing more production. This may have affected TFP growth, without being reflected in input growth, especially when inputs are measured on a stock basis. During a boom period, farmers tend to utilize existing inputs more intensively, which does not show up in measured input growth. The commodity boom was shown to be one of the main driving forces behind the rapid agricultural growth in Thailand during the early 1970s (Poapongsakorn, 2006).

9) Economic policy and government farm programs

Some studies have included agricultural policy and government farm programs, such as commodity export tax and country-specific policy shift factors, as determinants of output and productivity (Mundlak et al. 2004, Mundlak 1992, 1997, Setboonsarng and Evenson, 1991). Inclusion of policy proxies can be problematic because the effects of policies are mostly reflected in the measures of prices and quantities of inputs and outputs. It can cause a double counting problem if the policy proxies try to measure what other variables have already accounted for (Alston, et al., 1998b, p.166).

There has seemingly been no explicit policy shift in the Thailand context that has greatly influenced agricultural productivity during the study period. The effects of government policies are reflected in the provision of infrastructure in the form of public goods such as rural roads, education, irrigation and agricultural research and extension. These factors have already been mentioned. Agricultural credit, subsidies and other government farm programs enable farmers to have access to inputs and raw materials and their effect is thereby captured in the inputs themselves.

5.3 Variables and Data Sources

This section begins with a brief description of the dependent variables and explains why both adjusted and unadjusted TFP is employed in the analysis. Each potential explanatory variable is summarized in Table 5.1 and described in detail afterwards.

Table 5.1 Summary of Variables and Data Sources

Variables	Abbreviation	Data Sources	Years
Dependent variables:			
1. Total factor productivity growth (unadjusted)	TFPGu	Author's calculation based on the growth accounting method	1971-2006
2. Total factor productivity growth (adjusted for input quality changes)	TFPGa		
Explanatory variables:			
1. Agricultural research			
Public research = real public research budget	PUBR	- Bureau of the Budget, Office of Prime	1961-2006

		Minister - National Economic and Social Development Board	
Private research = real private research expenditure (for crops and livestock only)	PRIR	- Charoen Pokphand Group	1979-2006
University research = real university research budget allocated by the government (for Ag1: overall agriculture only)	UNIR	Bureau of the Budget, Office of Prime Minister	1981-2006
Foreign research spillovers For Ag1, Ag2 and crops: = CGIAR funding to IRRI, CIAT and CIMMYT in US dollar For livestock: = import values of animal breeds as percentage share in livestock output	SPILL BREED	- CGIAR financial statements - Office of Agricultural Economics, Ministry of Agriculture and Cooperatives	1972-2006 1970-2006
2. Agricultural extension			
Extension services = real public extension budget	EXT	Bureau of the Budget, Office of Prime Minister	1961-2006
3. Technology transfer (TT)			
Capital imports = import values of machinery, equipment, fertilizers and pesticides as percentage share in total agricultural capital stock **Foreign direct investment** = net flows of FDI as percentage share in agricultural output	KM FDI	- Office of Agricultural Economics, Ministry of Agriculture and Cooperatives - Bank of Thailand	1970-2006
4. Education			
Farmers' education = agricultural labour with upper secondary education level as percentage share of total agricultural labour force	EDU	Labour Force Survey, National Statistical Office	1970-2006
5. Infrastructure			
Irrigation = percentage share of irrigated area in total agricultural land area **Road** = length of rural roads, unpaved roads and asphalt (km)	IRRIGAT ROAD	- Office of Agricultural Economics, Ministry of Agriculture and Cooperatives - Fan et al. (2004)	1970-2006
6. Trade openness			
Trade openness = agricultural export and import as percentage share in total agricultural output	TO	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives	1970-2006
7. Resource reallocation (RR)			
For Ag1 and Ag2:		- Labour Force Survey,	1970-2006

Non-crops employment share = non-crops labour as percentage share of total agricultural labour force For crops: **Non-rice employment share** = non-rice household as percentage share of total agricultural households	NC NR	National Statistical Office - Poapongsakorn (2006) - Office of Agricultural Economics, Ministry of Agriculture and Cooperatives	
8. Natural/Case-specific factors			
Rainfall = amount of rainfall in millimetre **Rainy day** = number of rainy days **Weather: drought or flooding** = rice harvested as share in total rice planted area **Bird flu outbreak** = dummy variable takes value 1 from 2004 and 0 otherwise **Agricultural commodity boom** = dummy variable takes value 1 from 1972 to 1974	RAIN RAIN2 WEATHER BIRD BOOM	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives	1970-2006

Note: The data are shown in Appendix 5

5.3.1 Dependent Variables: TFP Growth

The estimation of TFP is based on the growth accounting approach using the three primary inputs –labour, land and capital– described in the previous chapter. The factor inputs are also adjusted for quality changes. TFP as the dependent variable is expressed in both rate of change and level terms. The TFP data are initially expressed in the rate of change terms, denoted as TFP growth or TFPG. In order to express them in level terms, they are converted into indices using 1971 as a base year.

Both unadjusted and adjusted TFPG are used as dependent variables mainly for comparison purposes. Since there are contrasting views on factor input adjustment – the inclusion of quality changes in TFPG and the possibility of over-adjustment – it is better to use both sets of TFPG estimates. Although the adjusted TFPG was measured with an attempt to approximate pure technological change, it is possible that the quality changes may relate to technological development. For instance, better educated farmers may adopt new technology faster than less educated ones thereby affecting the rate of adoption of research discoveries. It therefore seems worth investigating both adjusted and unadjusted TFPG. The unadjusted TFPG is denoted as TFPGu while the TFPG adjusted for labour and land quality is denoted as TFPGa.

5.3.2 Explanatory Variables

For explanatory variables, eight major factors are investigated and some have alternative sources of data to choose from. They are described as follows.

1) Agricultural research

Agricultural research is represented by annual research budget expenditure, which is a close approximation to actual expenditure.[139] Research variables can be classified into four types – public, private, university and foreign research.

Public research data are based on the budget expenditure allocated to major agricultural research agencies under the Ministry of Agriculture and Cooperatives (MOAC).[140] The data are compiled mainly from the Bureau of the Budget under the office of the Prime Minister, from 1961 to 2006. University research is also taken from the Bureau of the Budget. Private research expenditure is obtained from subsidiaries of the Charoen Pokphand Group (CP Group), the largest agribusiness conglomerate in Thailand. Unfortunately, the data on private and university research are not completely available and so can only be compiled for the last two decades.[141] Foreign research data come from the CGIAR research funding to the main agricultural research centres that have close collaborations with Thailand.

As mentioned in the literature review, the research variable should be deflated in order to convert research expenditure into constant currency units (Evenson, 2001).

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[139] 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.
[140] Public agricultural research and extension are mainly conducted by the MOAC (Poapongsakorn, 2006). For the government budget spent on R&D activities, the MOAC also received the highest share compared with other ministries (Areekul, 2000). The majority of R&D activities in Thailand have been devoted to agriculture.
[141] The National Research Council of Thailand has recently conducted a bi-annual survey of research expenditure in Thailand, which includes data on private and university research. However, the survey data are available only from 1996 and that is too short for an econometric estimation. These data are discussed in Chapter 3 under the background of the agricultural research system in Thailand.

The nominal research expenditure series in the Thai currency unit (baht) were converted into real values in constant 1988 prices using the implicit GDP deflators. The values of GDP in agriculture, crops and livestock are taken from the National Economic and Social Development Board (NESDB).[142]

Public research - PUBR

Public research is measured as real agricultural research budget. For the overall agricultural sector, the definition of agricultural research follows the international standard of classification described in a manual on Government Finance Statistics (GFSM 1986) by the International Monetary Fund (IMF, 1986). According to the GFSM 1986, agricultural research consists of research conducted mainly by the Department of Agriculture (DOA), and animal health research conducted by the Department of Livestock Development (DLD). It also includes fertilizer and productivity-enhancing research. The budget excludes plant protection and agricultural regulation research. The data are compiled from various issues of Thailand's Budget in Brief during 1961-2006.[143] Extra years are compiled to allow for lag distribution.

For traditional agriculture, research is defined only for crops and livestock research undertaken by the DOA and the DLD, the main government agencies responsible for crops and livestock research, respectively. The budget data are compiled from budget expenditure documents for 1961-2006.[144] However, prior to 1968, the budgets for crops research and extension were not clearly separated. As a result, the research budget for the period 1961-1967 was estimated based on the proportion of research in the total budget in 1968.[145] This research budget series does not follow the IMF

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[142] GDP deflators in Thai agriculture are shown in Appendix 4B Table 4.35.

[143] Thailand's Budget in Brief is a summary of the government budget allocation. It is an annual publication of the Bureau of the Budget, Office of Prime Minister.

[144] The documents provide budget details classified by plans and activities. Only research related activities undertaken by the DOA and the DLD are collected. From 1961-1972, crops research included the budget allocated to the DOA and the Rice Department. The Rice Department was incorporated into the DOA in 1972 and then separated out again in 2006.

[145] According to an interview with Mr. Jaroen Suknantapong, a retired senior official from the MOAC who has extensive experience with the agricultural R&E budget system, the budget allocation in the 1960s was quite conservative in the sense that the portions allocated to R&E each year were hardly

definition. It includes all research related activities shown in the budget expenditure documents. The research budget includes the salaries and allowances of researchers and staff, investment capital, costs of raw materials and other research related expenses.

For crops and livestock individually, budget data are compiled in accordance with traditional agriculture. Crops research is defined as all research activities conducted by the DOA. Crops research for the period 1961-1972 includes research activities undertaken by the DOA and the Rice Department. In 1972, the Rice Department was incorporated into the DOA and the data (1973-2006) are therefore drawn only from the DOA budget. Livestock research is defined as all research activities carried out by the DLD. There was one missing document for the year 1964 so it was estimated as a simple average between 1963 and 1965.

It should be noted that the government budget expenditure is a close enough approximation to actual expenditure at the aggregate level. Although there may be changes in actual spending on some research activities, the total research budget is generally unchanged.[146] The budget expenditure also provides the most complete and consistent time series for agricultural research. In practice, the budget is planned well ahead annually by the relevant agencies and the allocated budget is usually spent. If the budget is left unspent it has to be returned to the Bureau of the Budget and the following year's budget may be cut according to the unspent amount. That is why the research budget data closely reflects actual expenditure in the Thailand context.

However, the Bureau of the Budget has changed the way they report the research budget through time. Despite several changes in the reporting format, it is still possible to compile the research budget expenditure prior to 2004. Since 2004, the new budget system does not show the detailed activities under the allocated budget.

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changed and were strictly based on the amount of the previous year. Using the share of R&E in 1968 to separate the budget amount for earlier years should be appropriate in this case.

[146] The shortfalls of budget data are noted in Isarangkura (1986) that they may be overestimated as they were for commitments rather than actual expenditure. They included the wages and salaries of all researchers, some of whom might be working on non-research activities.

Therefore, the research budget data during 2004-2006 were obtained by direct request from the DOA and the DLD. The compiled data were also double checked with the numbers reported by the Bureau of Agricultural Development Policy and Planning under the Office of Agricultural Economics.[147]

Private research - PRIR

Private research is measured as real research expenditure. Private research expenditure data can only be compiled from 1979 onwards. It is collected specifically for crops and livestock. In rate of change terms, only 1980-2006 are available. Although the private sector has been conducting agricultural research for a long time, there is no systematic reporting of their research expenditure data.[148] As a result, this study uses the research spending by two subsidiaries of the Charoen Pokphand (CP) Group to proxy crops and livestock research.

Private crops research is estimated based on the research expenditure obtained from the Crop Integration Business CP Group. The approximate expenditure data are available for 1979 to 2006 but are not complete for the whole period. The missing data are estimated using linear interpolation.[149] The data mainly include research on corn, rice, machinery, fruit, rubber and oil palm. The Crop Integration Business Group is the leading seeds company in Thailand. The emphasis of their research and development is in the area of field crops, horticulture, rice and agricultural machinery. Products such as hybrid corn, high yielding rice varieties, fertilizers, tropical fruit, orchids, tea, wine, disease-free planting materials and food processing machinery are all examples of the company's achievements.

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[147] This refers to the Bureau of Agricultural Development Policy and Planning (1996) and various issues of the MOAC's budget in brief by the OAE.

[148] Fuglie (2001) conducted a survey on private investment in agricultural research in 1996 and estimated that the private sector was responsible for about 13 percent of total agricultural research in Thailand.

[149] The estimation is also based on the interview conducted on 10th March, 2008 with Mr. Montree Kongtrakultien, the CEO and President of the Crop Integration Business Group. Company profile and agricultural research background are available at http://www.cpcrop.com.

Private livestock research expenditure is obtained from the Feed Research Centre, Bangkok Food Products Co., Ltd. It is a local subsidiary of the Charoen Pokphand Food Public Company Ltd (CPF). Animal feed is the initial core business of the CPF thereby the research expenses data are the most continuous and longest series this study can find.[150] The data, from 1979-2006, include R&D spending in the area of swine, poultry, ducks, beef cattle, incubation houses and slaughtering. Some missing data are estimated using linear interpolation.[151] The company's research aims at improving feed quality, animal breeds, and farm management systems in order to reduce production costs while satisfying customer demand.

University research - UNIR

University research is measured as real research budget. University research is confined to agricultural research programs supported by the government budget. The data comprise the government budget allocated to the four leading universities, under the Ministry of Education, well-known for conducting agricultural research in Thailand (Isarangkura, 1981). These are Kasetsart University, Chiang Mai University, Kon Kaen University and Majoe University.[152]

The budget data are compiled from the budget documents of the Bureau of the Budget. However, the longest and most consistent data series this study could find are only available from 1981 to 2007. For the two years, 2005-2006, research activities were not specified. The missing data are interpolated using linear interpolations. Unfortunately, the data cannot be disaggregated into crops and livestock activities thus only aggregate data for overall agriculture is considered.

It should be noted that external sources of funds are also important for university research, especially in the last decade, but complete data are not available. However,

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[150] Fuglie (2001) also indicated that the main objective of private livestock research in Thailand is improving feed efficiency; and feed milling technology has been a central focus.

[151] The estimation is also supplemented by a discussion with Mr. Wutthi Suphannachart, senior Vice President of the CP Group, who has been working with the livestock research team since 1976. The CPF profile and corporate research are available at http://www.cpfworldwide.com.

[152] These institutions are in line with the list of agricultural research performers in a comprehensive survey of the Thai agricultural research system by Isarangkura (1981).

ignoring the amount of external funds should not have a significant impact on the results as financial support in the 1980s to the 1990s was mainly from the government. For example, the oldest and largest university in the agricultural research field, Kasetsart University mainly received research funding (in the field of agricultural science) from the government with external funds only becoming significant from 2002 onwards.[153]

Foreign research spillovers - SPILL

International research spillovers are measured as total research funding by three major centres under the CGIAR. They are the International Rice Research Institute (IRRI), the International Maize and Wheat Improvement Centre (CIMMYT) and the International Centre for Tropical Agriculture (CIAT). These three centres are the international research centres with which Thailand has collaborated the most (Isarangkura, 1986), therefore, their research contribution is used as a proxy for foreign research spillovers. The data are obtained from the CGIAR financial reports. Since the CGIAR was established in 1971, the data are available from 1972 onwards. The funding data are classified by centres including IRRI (rice research), CIMMYT (maize and wheat research) and CIAT (cassava research).

Since it is not possible to disaggregate the research funding that contributes to Thailand in particular, the total amount of funding is used.[154] According to the CGIAR financial reports, the percentage contribution to Asia has hardly changed over time.[155] Thus, it is assumed that the proportional contribution to Thailand has remained stable over time and therefore the total contribution followed the trend of the total CGIAR expenditure (comprising IRRI, CIMMYT and CIAT).

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[153] Based on Kasetsart University budget documents, 1995-2006, and Kasetsart University Research and Development Institute (KURDI)'s source of funds available at http://www.rdi.ku.ac.th.

[154] Most of the research results undertaken by the international research agencies are commodity-specific available to all countries, making it difficult to measure the aggregate benefits of the research and associated budget spent on a particular country.

[155] See Appendix 5 Table 5.5, the data are only available from 1993-2003. The contribution to Asia should be a close enough approximation since most research results do not directly benefit an individual country, but it can be applied in several countries with similar soil and weather conditions.

The CGIAR funding data are used to represent international research spillovers in overall agriculture, traditional agriculture and the crops sector. However, it does not apply to the livestock sector because these research agencies are not relevant for livestock production. Instead, the imports of livestock breeds, expressed as a percentage share in livestock value added, are used as a proxy. The import data are described more under the technology transfer variable.

2) Agricultural extension

Agricultural extension is measured as a real public extension budget. The extension budget is 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). Livestock extension is based on the budget allocated to cooperative extension under the Department of Livestock Development (DLD).

It should be noted that from 1967 up to the present crops research and extension have been undertaken by two separate agencies, the DOA and the DOAE. Before 1967, extension services for crops other than rice were conducted by the DOA whereas extension for rice was carried out by the Rice Department. The DOAE was established in 1967 to look after extension services for all types of crops, including rice. On the contrary, livestock research and extension have been under the same agency (the DLD) for the whole period. All mentioned agencies are under the MOAC.

Data collection and estimation technique is similar to that described in public research. The extension budget is also compiled for the same period of 1961 to 2006. Since the DOAE was set up in 1967, a separate budget document is available from 1971 onwards. Prior to 1971, the data are compiled from budgets allocated to extension activities under the DOA and the Rice Department. Complete budget data on agricultural extension are only available for the public sector and only from the DOAE and the DLD. The extension data cover only crops and livestock extension.

3) Technology transfer

Technology transfer from abroad is represented by two alternative sources of data, foreign direct investment (FDI) and agricultural capital import. They both represent channels where foreign technology could be translated into productivity gains.

FDI is defined as the net flow of foreign direct investment into the agricultural sector, obtained from the Bank of Thailand. FDI comprises equity capital (with at least 10 percent foreign shareholding), loans from affiliates and reinvested earnings.[156] It is measured as its percentage share in agricultural GDP. The definition of FDI does not directly reflect technology transfer in terms of physical capital. In addition, the presence of FDI in Thai agriculture is restricted by the Foreign Business Act (1999).[157] Most agricultural activities are reserved for Thai natives, namely rice farming, farming or gardening, animal husbandry, forestry, and fishery for marine animals. As the role of FDI is relatively minor in the primary agricultural sector,[158] another source of data is also considered.

Agricultural capital import is regarded as a more specific proxy for technology transfer from abroad. It can also partly capture foreign research results embodied in imported capital. Agricultural capital import is measured as a percentage share of import values to total agricultural capital stock at current prices. Capital import includes machinery and appliances for agricultural purposes, chemical fertilizers and pesticides. Fertilizers and pesticides are included, even though they were separated out of the agricultural value added, because they are considered part of foreign research results that may contribute to local agricultural productivity. Local research has also developed based on imported fertilizers and pesticides. The data are taken from the OAE agricultural statistics. Total agricultural capital is net capital stock, obtained from the NESDB.

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156 Reinvested earning is defined as investment earnings neither distributed as dividend nor remitted to direct investors. The definition of FDI statistics is in accordance with the IMF's Balance of Payment manual, which provides an international standard of classification.

157 Foreign investment in Thailand is governed by the Foreign Business Act (1999), Alien Employment Act (1978) and Investment Promotion Act (1977).

158 Instead, technology transfer is mainly from local companies under the CP Group, through contract farming. Technology and marketing knowhow occur through non-FDI sources.

For crops and livestock in particular, imports of plant breeds and animal breeds, expressed as a percentage share in relevant GDP, are also used as proxies for the access to foreign technology. The import statistics are good enough proxies that are available at an aggregate level and consistent over the study period. The data are collected from the imports statistics through the Customs Department, reported in the OAE agricultural statistics yearbook.

It is also worth noting the distinction between the foreign research and the technology transfer variables. The foreign research represents technology spillovers mainly from the international research centres. Its broad coverage includes not only physical inputs but also know-how or training of local researchers. It also relates to research collaborations between local and foreign research that influence productivity. On the other hand, technology transfer captures a package of readily available technology directly imported into the country. This represents the foreign research results that have been used in the agricultural sector.

4) Education

Education is measured as the percentage share of the agricultural labour force with upper secondary education in the total agricultural labour force. Agricultural workers with at least upper secondary education are considered higher educated groups of workers thereby representing human capital in the agricultural sector. The numbers of agricultural labour classified by education attainment during 1970-2006 are obtained from the Labour Force Survey, National Statistical Office.

5) Infrastructure

There are two public infrastructure factors, irrigation and rural roads. Irrigation is represented by the percentage share of irrigated area in total agricultural land. The data from 1970-2006 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).[159] The data prior to 1977

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

are estimated using exponential growth trend. The missing data after 2000 is extrapolated using the Holt-Winter exponential smoothing method in Eviews (2004).

6) Trade openness

Trade openness is measured as the percentage share of agricultural imports and exports in total agricultural output. All data are expressed in nominal terms. Import and export values of agricultural commodities are obtained from the OAE. The statistics are originally drawn from the Customs Department. Agricultural output at current market prices is taken from the NESDB. The measure implies the degree of openness of the agricultural sector to world trade. A higher degree of openness is expected to expand market size through exports, increase local competition through imports and bring about real cost reduction from economies of scale.

7) Resource reallocation

Resource reallocation is measured as a percentage share of the labour force working in the higher productivity sector. For overall and traditional agriculture, it is the share of non-crops employment in the total agricultural workforce. Non-crops employment is the number of employed persons working in agricultural subsectors other than crops. Since the average wage rate of crops workers is lower than for those of the livestock and fisheries sectors, it is considered a lower productivity sector within agriculture.[160] The numbers of agricultural workers are obtained from the Labour Force Survey, National Statistical Office.[161]

For the crops sector, resource reallocation is represented by the share of non-rice households in total agricultural households. In the same manner, rice production is considered a traditional subsector with a lower wage rate. The share of non-rice households is used to represent the reallocation of agricultural workers to higher value crops production. Since there is no employment data in the rice sector, the number of households is used instead. The number of households is taken from the

[160] Under perfect competition, the real wage rate is equal to the marginal productivity of that particular input.

[161] See Chapter 4 for more description on the agricultural labour force data.

socio economic household surveys conducted by the OAE. Since the surveys were not conducted every year, missing data are interpolated using linear interpolations. Note that due to lack of data the ratio of non-rice households during 1970-1974 is assumed to be the same as in 1975.

There is no employment data at the subsector level for the livestock sector. Therefore, the effect of resource reallocation is not considered in the livestock model.

8) Natural and case-specific factors

Natural and case-specific factors include weather, epidemic and ad hoc factors potentially influencing the residual TFP measure during 1970-2006. Natural factors consist of the amount of rainfall, weather conditions and animal disease. Due to lack of data at the regional and commodity level, weather indices cannot be measured and crude proxies are used instead. The amount of rainfall can be represented by two alternative sources of data. The first source is annual average rainfall measured in millimetres. The second is the average number of rainy days within a year. The data are obtained from the OAE.

Weather condition is measured as a share of the harvested rice area in the planted area.[162] Since rice is the most important crop for the Thai economy and its planted area dominates total agricultural land, the share of the rice harvested area is considered a crude proxy for drought or flooding. A reduction in the ratio of the harvested to planted area implies an occurrence of flooding, drought or bad weather conditions. An increase in the ratio implies good weather conditions or no natural disasters. The harvested and planted area includes major and second rice, obtained from the OAE.

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

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[162] This weather measure is also adopted by Setboonsarng and Evenson (1991) and Pochanukul (1992).

The world agricultural commodity boom which took place during 1972-1974 is an important event that increased agricultural growth in Thailand (Poapongsakorn, 2006, p.5). During the boom, the prices of major crops surged inducing more production and hence productivity. As this is not well captured by the input data, the dummy variable representing the boom period is included in the productivity function.

5.4 Estimation Models: TFP Determinant Models

This section describes estimation models in search of major factors determining TFP growth in the agricultural sector. The models employ potential factors affecting TFP described in the analytical framework section.

To serve the objective of this thesis in examining the agricultural research impact on TFPG, the estimation models are specified incorporating the three main aspects of the research-productivity nexus emphasized in the literature (Fuglie and Heisey, 2007 and Alston et al., 1998b). Specifically, lags, international research spillovers and attribution issues are included in the models.

The estimations are divided into two main models. First is a general model addressing the issues of time lag and international research spillovers. It is meant to provide an explanation for the measured TFP growth (Chapter 4), covering the longest period among existing studies for Thai agriculture and disaggregated into crops and livestock.[163] Second is an attribution model addressing the attribution issue by identifying which types of research spending – public, university, private and foreign– contribute more to TFPG. The data employed in the general model are available from 1971-2006 while those in the attribution model are from 1980-2006. Lags are incorporated in both models. The forms of lag structure are described in the estimation methods section.

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[163] Existing studies using the conventional growth accounting method are summarized in Table 2.1 and Table 2.2 in Chapter 2.

5.4.1 General Model (GM)

The role of international research spillovers has often been ignored in the literature, resulting in omitted variable bias. With this in mind, the general model incorporates the public-sector and foreign research variables. The model is also specified to apportion the TFPG between that due to agricultural research expenditure and that due to other sources of productivity change for the whole study period of 1971-2006. Other explanatory variables (Xs) are explored in accordance with their potential connections with TFP. The general model of TFP growth determinants is expressed as (expected signs in parentheses):

$$TFPG_t = f(PUBR_t, EXT_t, SPILL_t, PUBSPILL_t, PUBRE_t, X_t) \qquad (5.1)$$

(+) (+) (+) (+) (+) (+/–)

where $TFPG$ = total factor productivity growth

$PUBR$ = real public agricultural research expenditure

EXT = real public agricultural extension expenditure

$SPILL$ = international research spillovers (= $BREED$ in the livestock sector)

$PUBSPILL$ = interaction term of public and international research spillovers

$PUBRE$ = interaction term of public research and extension

X = other explanatory variables, which include the following:

TT = technology transfer factor (FDI and imports of technology)

EDU = farmers' education

$INFRA$ = infrastructure factor (irrigation and roads)

RR = resource reallocation (non-crops and non-rice employment share)

TO = trade openness

W = natural and case-specific factors

t = time

Public and international research are considered in the general model since the data are available for comparable periods of 1971 to 2006 whereas, private research and university research data are only available from 1980, and so are examined in a separate model focusing on the attribution issue.

International research spillovers (SPILL) are interacted with the public research variable (PUBR), because foreign research results are generally tested and adapted by local researchers to fit local conditions. International research spillovers are expected to have a greater effect on TFP when they occur in conjunction with public research expenditure. The SPILL variable, measured as the CGIAR research spending, is employed in overall agriculture (Ag1), traditional agriculture (Ag2) and the crops sector. In the case of livestock, foreign research spillovers are represented by imports of livestock breeds (BREED).

The interaction term between public research (PUBR) and agricultural extension (EXT) is also included to capture their cooperation. Extension can facilitate the adoption of inventions by farmers as well as conveying feedback from farmers to researchers that may improve future research (Evenson, 2001). Strong cooperation between research and extension is expected to enhance TFP growth.

The model is used to find the determinants of TFPG, both adjusted and unadjusted, in overall agriculture (Ag1), traditional agriculture (Ag2), crops and livestock sectors.

5.4.2 Attribution Model (AM)

To address the attribution issue, the research variable is classified according to major sources of research expenditure – public, private, university and foreign. Due to limited data availability, identifying the relative contribution of public, private, university and foreign research to productivity growth can be determined over the period 1980-2006. This applies to estimation models of overall agriculture (Ag1), traditional agriculture (Ag2), crops and livestock sectors. The model for individual research attribution is expressed as (expected signs in parentheses):

$$TFPG_t = h(PUBR_t, PRIR_t, UNIR_t, EXT_t, SPILL_t, PUBSPILL_t, PUBRE_t, X_t) \quad (5.2)$$

$$(+) \quad (+) \quad (+) \quad (+) \quad (+) \quad (+) \quad (+) \quad (+/-)$$

where $TFPG$ = total factor productivity growth

$PUBR$ = real public agricultural research expenditure

$PRIR$ = real private agricultural research expenditure

$UNIR$ = real university agricultural research expenditure

EXT = real public agricultural extension expenditure

$SPILL$ = international research spillovers (= $BREED$ in the livestock sector)

$PUBSPILL$ = interaction term of public and international research spillovers

$PUBRE$ = interaction term of public research and extension

Ideally, productivity growth can be attributed to current and past expenditure on agricultural research and extension by the public sector, private sector and universities plus technology spillovers from overseas, setting aside measurement problems. Due to the limited number of observations (1980/82-2006), past expenditure of private sector and university research can only be explored and included for a short time period. Other explanatory variables (Xs) in the general model are also tested but only a significant variable is included.[164] University research can only be tested in the overall agriculture (Ag1) model while private research comprises only crops and livestock research.

5.5 Model Specification and Estimation Methods

This section explains the empirical specifications and estimation methods undertaken. The first method is applying the standard ordinary least squares (OLS) technique to find the relationship between variables expressed in rate of change term. The usual practice in incorporating lag length and shape is also described. The second method is

[164] The only exception is the dummy variable capturing the world agricultural commodity boom. It is excluded from the attribution model because the boom took place during 1972-1974 which is prior to the covered period of the attribution model.

the Error Correction Model (ECM) that includes both rate of change and level terms and does not impose any strong structure on lag shape.

5.5.1 Growth-Rate Specification and Lags Incorporation

Investigation of TFPG determinants begins with estimating the growth-rate model, in which all variables are measured in rate of growth terms, using the standard OLS technique. The dependent variable $(TFPG)$ is measured as rate of change based on the growth accounting formula. To be consistent, all explanatory variables (denoted by Z) are also expressed in rate of change. That is, growth rate of $Z_t = \ln Z_t - \ln Z_{t-1}$, which is equivalent to taking log and first differencing on the data series. This is the conventional formation of the growth-rate model[165] commonly applied in finding the determinants of TFPG in previous Thai studies (for example, Tinakorn and Sussangkarn, 1996, Chandrachai et al., 2004 and Songseingchai, 2007).

The general model, expressing all variables in rate of change terms is:

$$\begin{aligned} TFPG_t &= \beta_0 + \beta_1 PUBR_t + \beta_2 EXT_t + \beta_3 SPILL_t + \beta_4 PUBSPILL_t \\ &+ \beta_5 PUBRE_t + \beta_6 X_t + \varepsilon_t \end{aligned} \tag{5.3}$$

Similarly, the attribution model is specified as:

$$\begin{aligned} TFPG_t &= \gamma_0 + \gamma_1 PUBR_t + \gamma_2 PRIR_t + \gamma_3 UNIR_t + \gamma_4 EXT_t \\ &+ \gamma_5 SPILL_t + \gamma_6 PUBSPILL_t + \gamma_7 PUBRE_t + \gamma_8 X_t + \varepsilon_t \end{aligned} \tag{5.4}$$

1) Time lags

Because it takes an uncertain number of years for a new discovery to be broadly applied, previous studies agree that there are lags involved between agricultural research spending and its effect on productivity growth (e.g. Alston et al., 1998b,

[165] Growth-rate model or differenced-data model arose early in the history of econometrics (Hooker, 1901 and Tintner, 1944; cited in Hendry, 1995) and has been used to remove common trends in non-stationary data (Hendry, 1995).

Evenson, 2001, Evenson and Pray, 1991, Fuglie and Heisey, 2007). Choosing the number and distribution of lags is largely a matter of empirical case study.

Most agricultural research in Thailand is applied and experimental development research (NRCT, 2007) which, on average, takes no more than five years to complete.[166] Nonetheless, to allow for time lag testing, the data for public research were collected for ten additional years, 1961-2006. Since this study is undertaken at an aggregate level, an average time lag is chosen to represent the whole sector.

Criteria for choosing the number of lags

The number of lags can be roughly determined from the theory and the literature. However, in the case of agricultural research impact on productivity, neither the theory nor previous studies clearly indicate how many lags to include in a productivity model. Hence, choosing lag length depends on the data. Two basic criteria are employed, that is, the Schwartz criterion[167] and the adjusted R^2 (Pindyck and Rubinfeld, 1998, p.238-239). The Schwartz criterion selects the number of lags by increasing the number of lags up to the point where it reaches a minimum value. The adjusted R^2 approach simply adds additional lags until it stops increasing.

Two approaches of lag incorporation

Including a number of lagged values of research expenditure can run into problems of multicollinarity. This also uses up too many degrees of freedom as many coefficients must be estimated. As a result, free-form lags tend to give estimated coefficients that oscillate between positive and negative values (Evenson, 2001, p.588). To avoid this problem, it is necessary to impose some structure on the nature of lags. Following the commonly used method, this study adopts two approaches. First, a polynomial lag structure is imposed on the research variables. Second, a stock of research spending or stock of knowledge is estimated using the Perpetual Inventory Method (PIM).

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

[167] Since the sample size is quite small, the Schwartz criterion is used as a guide for the appropriate lag selection rather than the Akaike information criterion (AIC) as it tends to overpredict the number of lags.

Polynomial distributed lag structure

The shape of the lag distribution displays the time period between research investment and its impact on productivity. The lag structure depends on the type of research and the stage of development and is expected to change through time (Pochanukul, 1992, p.114). The commonly used technique imposes the forms of lag that reflect the gestation, blossoming and obsolescence stages of the research impact. Imposing a polynomial or Almon lag structure has been the most popular means of forming an aggregate of research expenditure (Alston et al., 1998b, Chapter 3). The majority of studies use a second-degree polynomial (Lu et al., 1979, Evenson, 1982, Thirtle and Bottomley, 1989). The pioneering study by Griliches (1958, 1979) established this tradition by arguing that as there are many types of R&D, 'aggregation of many lag structures should lead to a rather flat but somewhat bell-shaped lag structure' (Griliches, 1979, p.101). A previous study by Pochanukul (1992) also found a lag structure similar to a bell-shape (inverted V and trapezoid) in Thai crops production. This makes imposing the second-degree polynomial lag structure sensible in the case of Thai agriculture.[168]

The polynomial distributed lags (PDL) can be incorporated into the general and attribution models by imposing the bell-shape lag weights on the current and past values of agricultural research expenditure and can be applied to all types of research. For ease of illustration, let R denote a research variable, ignoring its source, and Y denotes other explanatory variables. The PDL model can be expressed as:

$$TFPG_t = \alpha + w_0 R_t + w_1 R_{t-1} + w_2 R_{t-2} + \ldots + w_n R_{t-n} + Y_t + \varepsilon_t \qquad (5.5)$$

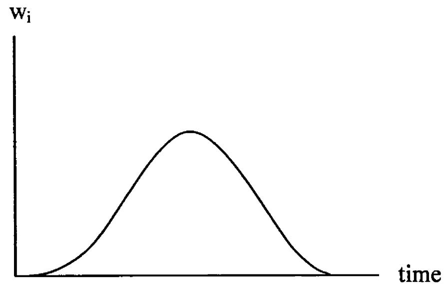
and $$w_i = \gamma_0 + \gamma_1 i + \gamma_2 i^2 \qquad i = 0,1,2,\ldots,n \qquad (5.6)$$

where w_i is timing lag weights and i is the number of lags from period 0 to n. The lag weight is assumed to follow a second-degree polynomial as shown in Figure 5.3.

168 However, under this method, lag length must be arbitrarily truncated in order to ensure certain degree of freedom. This produces upward biased estimates of returns to research (Esposti and Pierani, 2003, Alston and Pardey, 2001).

To impose a standard bell-shaped lag structure, the PDL model is estimated by imposing constraints on both ends of the lagged variables.

Figure 5.3 Shape of 2nd-degree Polynomial Distributed Lags



Imposing (5.6) in (5.5) gives (suppose n =4 for simplicity)

$$TFPG_t = \alpha + \gamma_0 R_t + (\gamma_0 + \gamma_1 + \gamma_2) R_{t-1} + (\gamma_0 + 2\gamma_1 + 4\gamma_2) R_{t-2} + (\gamma_0 + 3\gamma_1 + 9\gamma_2) R_{t-3} + (\gamma_0 + 4\gamma_1 + 16\gamma_2) R_{t-4} + Y_t + \varepsilon_t \tag{5.7}$$

Rearranging (5.7) obtains

$$TFPG_t = \alpha + \gamma_0 (R_t + R_{t-1} + R_{t-2} + R_{t-3} + R_{t-4}) + \gamma_1 (R_{t-1} + 2R_{t-2} + 3R_{t-3} + 4R_{t-4}) + \gamma_2 (R_{t-1} + 4R_{t-2} + 9R_{t-3} + 16R_{t-4}) + Y_t + \varepsilon_t \tag{5.8}$$

Denote $Z_{1t} = R_t + R_{t-1} + R_{t-2} + R_{t-3} + R_{t-4}$

$Z_{2t} = R_{t-1} + 2R_{t-2} + 3R_{t-3} + 4R_{t-4}$

$Z_{3t} = R_{t-1} + 4R_{t-2} + 9R_{t-3} + 16R_{t-4}$

Rearranging the estimation model ends up with fewer variables which increases the degree of freedom:

$$TFPG_t = \alpha + \gamma_0 Z_{1t} + \gamma_1 Z_{2t} + \gamma_2 Z_{3t} + Y_t + \varepsilon_t \tag{5.9}$$

Equation (5.9) is estimated using ordinary least squares (OLS). The estimates can be used to deduce the lag coefficients specified in equation (5.5). The first lagged coefficient (w_0) indicates the immediate impact of agricultural research on TFPG. The sum of lagged coefficients ($\sum w_i$) indicates a long-run multiplier or long-run change in TFPG given a permanent increase in agricultural research spending.

Estimating research stocks using the Perpetual Inventory Method (PIM)

Due to the cumulative nature of the research process, a new finding is partially a result of previous findings. Constructing a research stock from past research expenditure has been a common practice. Creating a research stock has been adopted in many studies using various techniques to maintain a sufficient degree of freedom and mitigate multicollinearity (e.g., Evenson and Pray, 1991, Alston et al., 1994, Huffman and Evenson, 1992, 2005, Hall and Scobie, 2006).

The Perpetual Inventory Method (PIM) is used to create a research stock from a flow of investment. This is a commonly used technique in calculating the capital stock in many countries including Thailand (NESDB, 2006). As today's innovation is partially built on past research, agricultural research can be considered as knowledge capital stock whose effects can diminish over time but potentially can last infinitely (Alston et al., 1998a, Griliches, 1998b). The PIM formula is as follows:

$$RS_t = R_t + (1-\delta)RS_{t-1} \tag{5.10}$$

where RS_t is the research stock in year t, R_t is agricultural research expenditure in year t and δ is the depreciation rate. The initial stock (RS_0) is calculated as:

$$RS_0 = \frac{R_0}{g+\delta} \tag{5.11}$$

where R_0 is agricultural research expenditure in the first year available and g is the average geometric growth rate of the research expenditure series between the first 20 years.[169] The difficult part is determining the depreciation rate. Previous studies have often assumed an annual depreciation rate of 5% (Coe and Helpman, 1995 and Johnson et al., 2005) and 15% (Hall and Scobie, 2006). This study employs three depreciation rates, 0%, 5% and 15%.[170] Using backward substitution, the research stock in equation (5.10) can be expressed as an infinite weighted sum of current and past research expenditure:

$$RS_t = R_t + (1-\delta)R_{t-1} + (1-\delta)^2 R_{t-2} + ... \tag{5.12}$$

Incorporating the research stock into the general model, equation (5.3) becomes

$$\begin{aligned} TFPG_t = \beta_0 + \beta_1 RS_t^{pub} + \beta_2 EXT_t + \beta_3 RS_t^f + \beta_4 RS_t^{pub} RS_t^f \\ + \beta_5 RS_t^{pub} EXT_t + \beta_6 X_t + \varepsilon_t \end{aligned} \tag{5.13}$$

where RS_t^{pub} is public research stock derived from the PIM, and

RS_t^f is foreign research stock derived from the PIM

Similarly, incorporating the research stock into the attribution model, equation (5.4) becomes:

$$\begin{aligned} TFPG_t = \gamma_0 + \gamma_1 RS_t^{pub} + \gamma_2 RS_t^{pri} + \gamma_3 RS_t^{uni} + \gamma_4 EXT_t \\ + \gamma_5 RS_t^f + \gamma_6 RS_t^{pub} RS_t^f + \gamma_7 RS_t^{pub} EXT_t + \gamma_8 X_t + \varepsilon_t \end{aligned} \tag{5.14}$$

where RS_t^{pri} is private research stock derived from the PIM, and

RS_t^{uni} is university research stock derived from the PIM

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[169] 20 years was chosen following Hall and Scobie (2006) and Caselli (2003).

[170] No depreciation (0%) is added because today's research is always built up from past research, research stock may not depreciate. A constant δ implies geometric decay of the stock of research knowledge.

2) Estimation technique

An investigation of TFPG determinants is more in a spirit of explanatory data analysis than hypothesis testing. All potential factors affecting TFP growth in Thai agriculture are tested econometrically. However, due to the limited numbers of observations the most insignificant variable (X) is dropped out of the model at every estimation. The joint variable deletion tests are conducted to ensure the specification choice is statistically acceptable. As some major determinants have a few proxy variables, only variables with a high explanatory power are chosen. An interpretation of the empirical finding is based on the theoretical framework. Multiple regression analysis is undertaken using Eviews.

5.5.2 Error Correction Model Specification

Expressing the variables in rate-of-change terms, as in the previous section, ensures a stationary data series and thus directly addresses the spurious regression problem (Hendry, 1995, Athukorala and Sen, 2002). However, the problem with this approach is that some meaningful level information is lost. Expressing variables in level terms can help capture the level relationship but the data series are often non-stationary. Applying the standard OLS method to non-stationary data series tends to produce 'nonsense correlation' or 'spurious regression'.[171] 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 independent variables when in fact they are completely unrelated.

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 modelling (ECM) or the London School of Economics method developed by Hendry and his co-researchers (e.g., Davidson et al., 1978, Hendry et al., 1984 and Hendry, 1995). Second is the co-integration approach pioneered by Engle and Granger (1987) and later improved by several studies such as Johansen

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

(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 or I(1).[172] On the other hand, the ECM method developed by Hendry (1995) can be applied to data series that are integrated of different orders (Athukorala and Sen, 2002).

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 (5.15) and (5.16) 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.

$$\Delta X_t = \gamma_0 + \gamma_1 X_{t-1} + \sum_{i=1}^{p} \beta_i \Delta X_{t-i} + \mu_t \qquad \text{(without time trend)} \qquad (5.15)$$

$$\Delta X_t = \gamma_0 + \gamma_1 X_{t-1} + \sum_{i=1}^{p} \beta_i \Delta X_{t-i} + \gamma_2 T + \mu_t \qquad \text{(with time trend)} \qquad (5.16)$$

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 the residual whiteness.

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[172] Engle and Granger (1987) observed that while an individual variable may be non-stationary, two non-stationary variables may form a co-integrating vector that yield a stationary residual. They proposed a two stage approach that begins with modelling the long-run or co-integrating relationship. Given that all variables are integrated of the same order, the first stage can be estimated by the OLS method. If the residual of the regression is found to be stationary, then the coefficients of the regression represent long-run or steady-state relationships. In the second stage, the short-run relationship is modelled with an error-correction mechanism. That is, the model includes first differences of all variables and the lagged residual of the first stage regression representing the disequilibrium error.

Table 5.2 Augmented Dickey-Fuller Test for Unit Roots, 1970-2006

Variables	t-statistics for level without time trend	t-statistics for level with time trend	t-statistics for first difference without time trend	t-statistics for first difference with time trend
TFPu_Ag1	-1.967(0)	-4.403(0)*	-5.891(1)*	-5.793(1)*
TFPa_Ag1	-2.690(0)**	-4.455(0)*	-6.017(1)*	-5.931(1)*
TFPu_Ag2	-0.790(0)	-5.968(0)*	-8.301(0)*	-8.085(0)*
TFPa_Ag2	-1.170(0)	-6.029(0)*	-8.353(0)*	-8.125(0)*
TFPu_Crop	-1.227(0)	-3.601(0)*	-4.968(1)*	-4.869(1)*
TFPa_Crop	-1.476(0)	-3.531(0)**	-5.036(1)*	-4.950(1)*
TFPu_Livestock	-4.570(0)*	-4.283(0)*	-6.440(0)*	-6.556(0)*
TFPa_Livestock	-4.370(0)*	-4.720(1)*	-6.245(0)*	-6.397(0)*
PUBR_Ag1	-1.840(0)	-2.229(0)	-5.796(0)*	-5.719(0)*
EXT_Ag1	-1.667(0)	-0.239(0)	-4.963(0)*	-5.220(0)*
PUBR_Ag2	-1.339(0)	-0.086(2)	-3.923(0)*	-4.228(1)*
EXT_Ag2	-1.667(0)	-0.239(0)	-4.963(0)*	-5.220(0)*
PUBR_Crop	-1.296(1)	0.240(0)	-3.887(0)*	-4.135(1)*
EXT_Crop	-1.655(0)	-0.145(0)	-4.784(0)*	-5.003(0)*
PUBR_Livestock	-2.018(0)	-1.612(0)	-5.737(0)*	-6.010(0)*
EXT_Livestock	-1.477(0)	-2.215(0)	-6.676(0)*	-6.732(0)*
SPILL	-6.505(1)*	-4.252(1)*	-4.149(0)*	-6.382(0)*
BREED	-3.032(1)*	-2.999(1)	-5.100(1)*	-5.038(1)*
TO	-2.030(0)	-1.496(0)	-7.998(0)*	-8.617(0)*
KM	-2.874(0)**	-1.952(0)	-5.723(0)*	-6.651(0)*
EDU	-1.820(0)	-1.590(0)	-6.749(0)*	-7.224(0)*
IRRIGAT	-1.688(0)	-0.645(0)	-5.220(0)*	-5.936(0)*
ROAD	-0.992(1)	-3.829(5)*	-3.351(0)*	-3.386(0)*
NC	-1.096(0)	-2.695(0)	-6.227(1)*	-6.253(1)*
NR	-1.532(0)	-1.674(0)	-5.187(0)*	-5.602(0)*
WEATHER	-6.198(0)*	-6.158(0)*	-10.070(0)*	-9.914(0)*
RAIN	-2.454(0)	-2.083(0)	-8.379(0)*	-8.717(0)*

Notes: 1. All variables are measured in natural logarithms.
2. * 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 (5.15) and (5.16).
3. Numbers in parentheses indicate the order of augmentation selected on the basis of the Schwarz criterion.

The test results, reported in Table 5.2, show the variables under consideration do not have the same order of integration. The dependent variables (TFP indices) are a mixture of stationary series or I(0) and non-stationary series that are integrated of order 1 or I(1). Most of the explanatory variables are I(1). The exceptions are international research spillovers (SPILL and BREED), roads and weather, which are I(0).[173] Since the data series are integrated of different orders, the error correction

[173] Similarly, for a shorter period 1980-2006, the variables are a mixture of I(1) and I(0).

modelling (ECM) procedure of Hendry (1995) is used in this study.[174] 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 a precise estimate 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.

$$Y_t = \alpha + \sum_{i=1}^{m} A_i Y_{t-i} + \sum_{i=0}^{m} B_i X_{t-i} + \mu_t \tag{5.17}$$

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 is allowed up to four periods. The two-year lag is the established practice in modelling with annual data (Athukorala and Tsai, 2003).

Equation (5.17) can be rearranged by subtracting Y_{t-1} on 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.

$$\Delta Y_t = \alpha + \sum_{i=1}^{m-1} A_i^* \Delta Y_{t-1} + \sum_{i=0}^{m-1} B_i^* \Delta X_{t-i} + C_0 Y_{t-m} + C_1 X_{t-m} + \mu_t \tag{5.18}$$

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 $C_0^{-1} C_1$.

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[174] This method is also used in several time-series studies, see, for example, Athukorala and Sen (2002), Athukorala and Tsai (2003), Jongwanich and Kohpaiboon (2008).

Equation (5.18) is known as the error correction mechanism (ECM) representation of the model. Under the ECM, the long-run relationship is embedded within a sufficiently complex dynamic specification, including both lagged dependent and independent variables, which helps minimize the possibility of estimating spurious regression. The short- and long-run parameters in an ECM can be separately identified. The ECM can be estimated by OLS. It is applied to the general model (GM) covering the whole study period 1971-2006 and the attribution model (AM) covering a shorter period 1980-2006 with more research variables. Equation (5.18) 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 has to satisfy standard diagnostic tests. The tests include the Breush-Godfrey LM test for serial correlation in the regression residual, the Ramsey test for functional form mis-specification (RESET), the Jarque-Bera test of normality of the residual (JBN), Engle's autoregressive conditional heteroskedasticity test (ARCH) and the Augmented Dickey-Fuller test for residual stationarity (ADF).

5.6 Summary of Empirical Estimation

The empirical investigation of the determinants of TFP growth described in this chapter employs two methods, two models, four sectors and two dependent variables. The empirical implementation of this framework is contained in Chapter 6. The two methods consist of growth-rate modelling (GRM), which is a commonly used technique in Thai studies, and unrestricted error correction modelling (ECM), which is a new attempt in this thesis to study TFP determinants. The GRM incorporates the most popular form of second degree polynomial distributed lag structure whereas the ECM does not impose any form of lag on the research variables. The research variable measured as a stock using the perpetual inventory method (PIM) can be tested in both GRM and ECM.

The estimation models are divided into two periods due to the data availability. The first is referred to as the general model (GM) and the second is the attribution model (AM). The general model is designed to explain the movements of TFPG for the whole study period of 1971-2006 and accounts for both public and foreign research. The attribution model attempts to find out which type of research spending contributes most to TFP growth by accounting for public, private, university and foreign research. Since the data on private and university research are limited the attribution model covers the period 1980-2006. As the ECM is not meant for short time periods it is preferable to use the general model as the main model and the attribution model as the supplement that helps address the research attribution issue, which has become increasingly important in the literature.

The four sectors of analysis include overall agriculture (Ag1), traditional agriculture (Ag2), crops and livestock. The dependent variables consist of the unadjusted TFP growth and the TFP growth adjusted for labour and land quality changes. Altogether there are 32 cases of empirical estimations, and they are summarized in Table 5.3.

Table 5.3 An Overview of TFP Determinants Estimation

	Methods	GRM-PDL		ECM	
	Models	**GM**	**AM**	**GM**	**AM**
Sectors	Dependent Variables				
Ag1	TFPGu	1	9	17	25
	TFPGa	2	10	18	26
Ag2	TFPGu	3	11	19	27
	TFPGa	4	12	20	28
Crops	TFPGu	5	13	21	29
	TFPGa	6	14	22	30
Livestock	TFPGu	7	15	23	31
	TFPGa	8	16	24	32

Notes: GRM-PDL = Growth-rate model incorporating polynomial distributed lags
ECM = Error correction model
GM = General model (1971-2006 and includes public and foreign research)
AM = Attribution model (1980-2006 and includes public, private, university and foreign research)
Ag1 = Overall agriculture (crops, livestock, fisheries, forestry and agricultural services)
Ag2 = Traditional agriculture (crops and livestock only)
TFPGu = Unadjusted total factor productivity growth
TFPGa = Total factor productivity growth adjusted for input quality changes
Numbers in the table indicate the sequence of estimation equations to be presented in the following chapter.

Appendix 5 Data Set for TFP Determinants

Table 5.4 Public Agricultural Research Budget (million baht)

	Real public research budget (million baht)				Growth rate (%)			
Year	Ag1	Ag2	Crops	Livestock	Ag1	Ag2	Crops	Livestock
1965	21.24	138.53	136.27	4.19	-55.62	2.49	1.35	-0.76
1966	44.05	162.97	158.55	4.74	72.96	16.25	15.14	12.33
1967	61.59	206.99	200.47	9.31	33.51	23.91	23.46	67.41
1968	155.15	241.48	242.49	8.25	92.38	15.41	19.03	-12.01
1969	130.80	249.51	247.53	9.00	-17.07	3.27	2.06	8.69
1970	157.96	289.35	287.11	9.75	18.87	14.81	14.83	7.92
1971	210.80	349.07	357.94	9.21	25.10	15.14	18.46	-9.60
1972	174.27	274.22	272.21	8.80	-17.50	-21.60	-24.03	-7.78
1973	143.19	241.97	230.05	10.44	-27.89	-24.22	-30.20	17.52
1974	172.53	202.48	193.92	10.65	15.38	-20.27	-18.72	-6.57
1975	270.20	281.89	267.32	16.30	40.75	28.34	27.45	37.10
1976	386.69	324.50	303.64	21.48	30.27	7.31	6.34	18.28
1977	263.79	322.57	306.89	19.41	-39.98	0.44	3.83	-20.44
1978	252.83	339.24	309.45	28.35	-14.34	-10.10	-14.87	26.20
1979	322.77	318.53	292.19	25.48	26.80	-5.15	-3.64	-15.37
1980	372.60	314.91	288.99	26.34	13.99	-3.66	-3.75	1.65
1981	433.26	373.18	344.39	30.73	9.85	12.08	11.41	18.22
1982	530.61	490.22	461.47	29.11	18.28	25.30	27.43	-8.35
1983	507.03	614.48	591.47	28.87	-9.54	16.51	18.58	-5.94
1984	86.75	785.51	757.99	34.84	-180.67	19.27	18.85	18.08
1985	106.95	996.31	961.33	42.74	16.79	18.66	18.34	17.52
1986	61.41	979.70	957.29	43.54	-55.26	-0.03	3.15	-9.21
1987	218.70	864.61	823.24	48.02	127.50	-10.55	-11.44	1.87
1988	245.70	860.38	822.78	37.60	1.41	-13.36	-14.40	-28.83
1989	281.63	930.11	897.38	37.32	5.10	-2.37	-1.70	-9.60
1990	408.39	1069.83	1040.11	46.81	43.00	21.22	23.62	20.34
1991	673.98	932.08	900.74	48.45	43.27	-19.11	-20.49	2.50
1992	849.74	1339.73	1253.08	90.60	19.17	32.51	29.13	59.46
1993	1130.40	1966.85	1869.40	111.71	31.46	44.23	47.58	17.14
1994	1295.59	1748.27	1617.38	127.02	9.50	-15.32	-18.70	12.96
1995	1018.21	1492.01	1436.72	48.82	-28.04	-20.18	-16.82	-96.34
1996	1059.52	1685.00	1606.63	63.68	-0.36	6.25	4.61	24.50
1997	1155.28	1825.56	1725.86	79.68	9.35	7.23	6.60	20.31
1998	817.40	1609.96	1514.99	70.86	-33.11	-11.17	-12.58	-4.59
1999	802.65	1757.78	1740.38	55.11	-4.12	5.93	10.75	-26.34
2000	964.90	1946.83	1861.34	85.59	11.48	2.58	-1.07	37.40
2001	2041.76	1701.30	1657.99	70.58	71.76	-17.72	-15.08	-28.12
2002	1790.46	1505.96	1438.41	56.41	-13.81	-13.09	-14.30	-28.08
2003	1031.82	989.55	911.76	55.73	-67.05	-54.61	-59.22	-7.72
2004	639.85	652.59	620.99	23.84	-45.39	-38.27	-36.89	-69.25
2005	581.84	572.69	545.89	16.67	-7.62	-10.09	-8.15	-44.61
2006	598.20	584.17	527.82	33.03	-0.99	-2.19	-6.81	59.81

Source: The Bureau of the Budget, Office of the Prime Minister. Note: As described in text, the research budgets for the overall agriculture (Ag1) and traditional agriculture (Ag2) are based on different basis. The nominal budget data were deflated into real terms using the GDP deflators.

Table 5.5 CGIAR Research Expenditures to Centres relating to Thai Agriculture (million US dollar)

Year	Research Expenditures (million USD)				Total CGIAR	Expenditures
	CIAT	CIMMYT	IRRI	Total (SPILL)	Expenditure (million USD)	in Asia (%)
1972	4.30	5.00	3.00	12.30	20.00	n.a.
1973	6.10	6.30	3.10	15.50	26.00	n.a.
1974	5.50	6.10	6.00	17.60	32.00	n.a.
1975	6.00	7.60	8.50	22.10	44.00	n.a.
1976	6.30	8.70	9.70	24.70	58.00	n.a.
1977	9.50	10.10	12.00	31.60	78.00	n.a.
1978	11.70	12.70	12.40	36.80	98.00	n.a.
1979	13.40	14.90	13.80	42.10	109.00	n.a.
1980	15.00	16.60	15.90	47.50	123.00	n.a.
1981	16.20	18.40	17.20	51.80	131.00	n.a.
1982	18.60	18.30	19.50	56.40	144.00	n.a.
1983	21.70	17.50	20.20	59.40	165.00	n.a.
1984	21.40	20.30	20.50	62.20	158.00	n.a.
1985	20.60	21.00	21.60	63.20	163.00	n.a.
1986	21.30	21.40	23.60	66.30	175.00	n.a.
1987	22.70	21.80	24.80	69.30	188.00	n.a.
1988	23.10	25.00	26.70	74.80	204.00	n.a.
1989	26.60	25.10	27.50	79.20	224.00	n.a.
1990	26.30	24.70	27.80	78.80	232.00	n.a.
1991	29.00	27.70	30.40	87.10	248.00	n.a.
1992	27.10	28.40	28.80	84.30	259.00	33.00
1993	29.00	27.20	29.90	86.10	254.00	34.00
1994	30.40	25.00	28.40	83.80	265.00	32.00
1995	30.20	22.30	31.70	84.20	286.00	32.00
1996	36.80	28.70	30.40	95.90	325.00	33.00
1997	33.30	30.40	28.20	91.90	333.00	31.00
1998	33.50	32.20	35.00	100.70	337.00	32.00
1999	30.70	37.40	35.10	103.20	347.00	32.00
2000	29.60	38.90	32.60	101.10	338.00	32.00
2001	29.70	40.70	32.60	103.00	355.00	31.00
2002	32.30	41.30	33.40	107.00	381.00	33.00
2003	32.90	37.50	28.80	99.20	395.00	32.00
2004	36.70	41.10	32.90	110.70	425.00	n.a.
2005	42.40	38.80	33.40	114.60	452.00	n.a.
2006	41.80	37.40	33.30	112.50	458.00	n.a.

Source: Consultative Group on International Agricultural Research (CGIAR)
Note: The CGIAR budget was officially launched in 1972. As of 2009, there are 15 centres under the CGIAR. Three centres relating to Thailand are CIAT, CIMMYT and IRRI which provide research assistance on cassava, maize and rice, respectively. All numbers are in nominal terms. n.a. = data not available.

Table 5.6 Real Private and University Research Budget (million baht)

	Real private research expenditure (PRIR)			**Growth rate (%)**			**Real university research budget (UNIR)**	**Growth rate (%)**
Year	Ag2	Crops	Livestock	Ag2	Crops	Livestock	Ag1	Ag1
1979	23.48	12.94	10.54				n.a.	
1980	21.15	12.43	8.72	-10.46	-4.05	-18.93	n.a.	
1981	21.74	13.34	8.40	2.75	7.11	-3.81	35.17	
1982	24.98	14.97	10.01	13.90	11.54	17.54	43.61	21.51
1983	21.77	13.70	8.07	-13.76	-8.93	-21.46	46.43	6.27
1984	25.77	16.38	9.38	16.86	17.92	15.04	45.35	-2.36
1985	30.73	19.87	10.87	17.63	19.30	14.65	74.97	50.26
1986	29.83	20.40	9.43	-2.99	2.65	-14.21	73.66	-1.76
1987	31.67	22.64	9.03	6.00	10.41	-4.29	62.10	-17.08
1988	29.80	21.00	8.80	-6.09	-7.52	-2.58	66.96	7.54
1989	30.44	21.97	8.47	2.14	4.54	-3.82	70.03	4.48
1990	32.27	23.33	8.94	5.83	5.98	5.46	88.03	22.88
1991	31.02	22.46	8.55	-3.97	-3.77	-4.48	106.77	19.30
1992	31.64	22.46	9.18	1.97	-0.03	7.05	131.81	21.06
1993	38.94	27.20	11.74	20.76	19.16	24.59	179.51	30.88
1994	33.30	23.16	10.14	-15.64	-16.07	-14.66	152.31	-16.43
1995	28.98	20.10	8.87	-13.90	-14.16	-13.31	142.53	-6.64
1996	28.85	19.58	9.27	-0.43	-2.62	4.37	157.16	9.77
1997	30.37	20.14	10.24	5.13	2.79	9.91	222.30	34.67
1998	27.00	18.24	8.76	-11.76	-9.89	-15.52	154.90	-36.12
1999	34.49	26.41	8.08	24.47	37.00	-8.11	183.99	17.21
2000	43.33	32.09	11.23	22.82	19.50	32.95	205.66	11.13
2001	44.33	35.05	9.28	2.28	8.82	-19.15	228.28	10.44
2002	42.11	33.25	8.86	-5.14	-5.29	-4.59	268.57	16.25
2003	48.91	30.57	18.34	14.98	-8.39	72.75	367.98	31.49
2004	43.59	28.35	15.25	-11.51	-7.56	-18.46	367.90	-0.02
2005	42.21	28.97	13.24	-3.23	2.18	-14.12	336.48	-8.93
2006	44.82	28.46	16.36	6.00	-1.79	21.19	311.10	-7.84

Source: CP Group and the Bureau of the Budget, Office of the Prime Minister.
Note: The nominal research expenditure data were deflated into real terms using the GDP deflators.

Table 5.7 Agricultural Research Stock (RS) using PIM (million baht)

	Ag1_Public RS			Ag2_Public RS			Crops_Public RS		
Year	δ = 0%	δ = 5%	δ = 15%	δ = 0%	δ = 5%	δ = 15%	δ = 0%	δ = 5%	δ = 15%
1965	801.54	670.58	460.23	1,061.01	922.02	695.31	1,032.41	897.97	678.55
1966	845.59	681.11	435.25	1,223.99	1,038.89	753.99	1,190.96	1,011.62	735.31
1967	907.18	708.64	431.56	1,430.98	1,193.94	847.88	1,391.43	1,161.51	825.49
1968	1,062.33	828.36	521.98	1,672.46	1,375.72	962.18	1,633.92	1,345.92	944.16
1969	1,193.13	917.74	574.48	1,921.97	1,556.44	1,067.36	1,881.45	1,526.16	1,050.06
1970	1,351.09	1,029.82	646.27	2,211.31	1,767.97	1,196.60	2,168.56	1,736.95	1,179.66
1971	1,561.89	1,189.12	760.13	2,560.39	2,028.64	1,366.19	2,526.50	2,008.05	1,360.65
1972	1,736.17	1,303.94	820.38	2,834.61	2,201.43	1,435.48	2,798.71	2,179.86	1,428.76
1973	1,879.36	1,381.94	840.52	3,076.58	2,333.33	1,462.13	3,028.75	2,300.91	1,444.50
1974	2,051.89	1,485.38	886.97	3,279.05	2,419.14	1,445.28	3,222.67	2,379.78	1,421.74
1975	2,322.09	1,681.30	1,024.12	3,560.94	2,580.07	1,510.38	3,489.99	2,528.11	1,475.79
1976	2,708.78	1,983.93	1,257.20	3,885.44	2,775.56	1,608.32	3,793.62	2,705.34	1,558.06
1977	2,972.57	2,148.53	1,332.41	4,208.01	2,959.36	1,689.65	4,100.52	2,876.97	1,631.24
1978	3,225.41	2,293.93	1,385.38	4,547.26	3,150.64	1,775.44	4,409.96	3,042.57	1,696.01
1979	3,548.18	2,502.01	1,500.35	4,865.79	3,311.63	1,827.66	4,702.15	3,182.63	1,733.79
1980	3,920.78	2,749.51	1,647.89	5,180.69	3,460.96	1,868.41	4,991.14	3,312.48	1,762.71
1981	4,354.04	3,045.29	1,833.97	5,553.87	3,661.09	1,961.33	5,335.53	3,491.25	1,842.69
1982	4,884.65	3,423.63	2,089.48	6,044.09	3,968.25	2,157.35	5,797.00	3,778.15	2,027.76
1983	5,391.67	3,759.48	2,283.08	6,658.57	4,384.32	2,448.23	6,388.47	4,180.72	2,315.07
1984	5,478.43	3,658.26	2,027.38	7,444.08	4,950.62	2,866.50	7,146.46	4,729.68	2,725.80
1985	5,585.38	3,582.30	1,830.22	8,440.40	5,699.40	3,432.84	8,107.80	5,454.52	3,278.26
1986	5,646.79	3,464.59	1,617.10	9,420.09	6,394.13	3,897.61	9,065.08	6,139.09	3,743.81
1987	5,865.49	3,510.06	1,593.23	10,284.70	6,939.03	4,177.58	9,888.33	6,655.38	4,005.48
1988	6,111.19	3,580.26	1,599.95	11,145.08	7,452.46	4,411.32	10,711.11	7,145.39	4,227.44
1989	6,392.82	3,682.88	1,641.58	12,075.19	8,009.94	4,679.73	11,608.49	7,685.50	4,490.70
1990	6,801.21	3,907.13	1,803.74	13,145.02	8,679.27	5,047.60	12,648.60	8,341.33	4,857.21
1991	7,475.19	4,385.75	2,207.16	14,077.10	9,177.39	5,222.55	13,549.34	8,825.00	5,029.37
1992	8,324.94	5,016.21	2,725.83	15,416.83	10,058.25	5,778.89	14,802.41	9,636.83	5,528.04
1993	9,455.34	5,895.80	3,447.36	17,383.69	11,522.20	6,878.91	16,671.81	11,024.39	6,568.23
1994	10,750.93	6,896.60	4,225.84	19,131.96	12,694.36	7,595.35	18,289.20	12,090.55	7,200.38
1995	11,769.14	7,569.98	4,610.18	20,623.97	13,551.65	7,948.06	19,725.92	12,922.75	7,557.05
1996	12,828.66	8,251.00	4,978.17	22,308.98	14,559.07	8,440.85	21,332.55	13,883.24	8,030.12
1997	13,983.94	8,993.73	5,386.73	24,134.54	15,656.68	9,000.29	23,058.42	14,914.95	8,551.47
1998	14,801.34	9,361.45	5,396.12	25,744.49	16,483.80	9,260.20	24,573.40	15,684.18	8,783.73
1999	15,603.99	9,696.02	5,389.35	27,502.27	17,417.39	9,628.95	26,313.79	16,640.36	9,206.56
2000	16,568.90	10,176.13	5,545.85	29,449.10	18,493.35	10,131.44	28,175.13	17,669.68	9,686.91
2001	18,610.66	11,709.08	6,755.74	31,150.41	19,269.99	10,313.03	29,833.12	18,444.19	9,891.87
2002	20,401.11	12,914.09	7,532.83	32,656.37	19,812.45	10,272.04	31,271.53	18,960.39	9,846.50
2003	21,432.94	13,300.20	7,434.73	33,645.93	19,811.39	9,720.78	32,183.29	18,924.13	9,281.28
2004	22,072.79	13,275.05	6,959.38	34,298.52	19,473.41	8,915.26	32,804.27	18,598.91	8,510.08
2005	22,654.63	13,193.14	6,497.31	34,871.21	19,072.43	8,150.66	33,350.17	18,214.86	7,779.46
2006	23,252.83	13,131.68	6,120.91	35,455.38	18,702.98	7,512.23	33,877.99	17,831.94	7,140.37

Source: author's calculation (as described in text).
Note: PIM = Perpetual Inventory Method. δ = depreciation rate.

Table 5.8 Agricultural Research Stock (RS) using PIM (continued)

	Livestock_Public RS			Foreign RS: SPILL			Foreign RS: BREED		
Year	δ = 0%	δ = 5%	δ = 15%	δ = 0%	δ = 5%	δ = 15%	δ = 0%	δ = 5%	δ = 15%
1965	36.99	31.99	23.85						
1966	41.73	35.14	25.02						
1967	51.04	42.69	30.57						
1968	59.29	48.81	34.24						
1969	68.30	55.37	38.11						
1970	78.04	62.35	42.14				99.38	99.38	99.38
1971	87.25	68.44	45.03				129.15	124.18	114.24
1972	96.05	73.82	47.07	118.18	118.18	118.18	156.05	144.88	124.01
1973	106.49	80.57	50.45	133.68	127.77	115.96	197.00	178.58	146.35
1974	117.14	87.19	53.53	151.28	138.98	116.16	226.45	199.10	153.85
1975	133.44	99.13	61.80	173.38	154.14	120.84	271.15	233.85	175.48
1976	154.92	115.65	74.01	198.08	171.13	127.41	311.82	262.82	189.82
1977	174.33	129.28	82.32	229.68	194.17	139.90	371.51	309.37	221.04
1978	202.68	151.16	98.32	266.48	221.26	155.72	495.64	418.04	312.02
1979	228.16	169.09	109.05	308.58	252.30	174.46	612.15	513.65	381.73
1980	254.51	186.98	119.04	356.08	287.19	195.79	718.66	594.47	430.98
1981	285.24	208.36	131.92	407.88	324.63	218.22	796.02	642.11	443.69
1982	314.35	227.05	141.24	464.28	364.79	241.89	944.29	758.27	525.41
1983	343.22	244.57	148.93	523.68	405.96	265.00	1045.26	821.32	547.56
1984	378.06	267.18	161.42	585.88	447.86	287.45	1210.52	945.52	630.69
1985	420.79	296.56	179.95	649.08	488.66	307.54	1388.15	1075.88	713.72
1986	464.33	325.27	196.50	715.38	530.53	327.71	1673.91	1307.84	892.41
1987	512.36	357.03	215.05	784.68	573.30	347.85	2314.84	1883.37	1399.48
1988	549.96	376.78	220.39	859.48	619.44	370.47	3029.04	2503.41	1903.76
1989	587.28	395.26	224.65	938.68	667.67	394.10	3481.70	2830.90	2070.86
1990	634.09	422.31	237.76	1,017.48	713.08	413.79	4077.19	3284.85	2355.72
1991	682.53	449.64	250.54	1,104.58	764.53	438.82	4858.07	3901.49	2783.25
1992	773.13	517.75	303.56	1,188.88	810.60	457.30	5466.32	4314.66	2974.01
1993	884.84	603.58	369.74	1,274.98	856.17	474.80	5923.49	4556.09	2985.07
1994	1,011.87	700.42	441.30	1,358.78	897.16	487.38	6330.73	4735.53	2944.55
1995	1,060.69	714.22	423.92	1,442.98	936.51	498.47	6692.47	4860.50	2864.61
1996	1,124.37	742.19	424.02	1,538.88	985.58	519.60	7055.26	4980.26	2797.71
1997	1,204.05	784.76	440.10	1,630.78	1,028.20	533.56	7372.14	5048.13	2694.93
1998	1,274.90	816.38	444.94	1,731.48	1,077.49	554.23	7851.34	5274.92	2769.90
1999	1,330.01	830.67	433.31	1,834.68	1,126.82	574.29	8186.84	5346.67	2689.91
2000	1,415.60	874.73	453.90	1,935.78	1,171.58	589.25	8262.74	5155.24	2362.33
2001	1,486.18	901.57	456.39	2,038.78	1,216.00	603.86	8275.15	4909.88	2020.38
2002	1,542.59	912.90	444.35	2,145.78	1,262.20	620.28	8291.51	4680.75	1733.68
2003	1,598.32	922.98	433.42	2,244.98	1,298.29	626.44	8695.80	4851.01	1877.92
2004	1,622.16	900.67	392.25	2,355.68	1,344.07	643.17	9043.48	4956.14	1943.91
2005	1,638.83	872.31	350.08	2,470.28	1,391.47	661.30	9465.19	5130.04	2074.04
2006	1,671.86	861.72	330.60	2,582.78	1,434.40	674.60	9872.01	5280.35	2169.75

Source: author's calculation (as described in text).
Note: PIM = Perpetual Inventory Method. δ = depreciation rate.

Table 5.9 Real Agricultural Extension Budget (million baht)

Year	Real extension budget (EXT)			Growth rate (%)		
	Ag2	Crops	Livestock	Ag2	Crops	Livestock
1970	346.38	224.44	103.58			
1971	404.28	278.52	98.67	11.83	18.00	-8.79
1972	343.79	226.24	102.56	-13.68	-17.44	0.66
1973	331.61	182.05	160.17	-15.31	-35.10	45.01
1974	296.80	186.20	100.81	-13.54	0.61	-54.85
1975	441.94	291.92	141.61	35.06	40.32	28.51
1976	503.42	310.13	189.17	6.26	-0.35	19.64
1977	619.56	387.10	214.02	21.79	24.93	2.03
1978	636.59	391.27	259.71	-12.43	-14.63	7.69
1979	595.74	382.70	218.69	-5.49	-0.12	-21.92
1980	730.37	504.42	223.18	17.86	24.96	0.36
1981	868.28	605.49	248.61	12.39	12.14	13.61
1982	1,218.17	894.02	322.52	31.88	37.13	23.08
1983	1,244.06	947.59	283.02	-3.98	-0.42	-18.16
1984	1,757.54	1,310.05	424.21	29.27	26.43	39.77
1985	1,843.94	1,253.54	558.18	-0.32	-9.84	24.53
1986	1,786.02	1,279.97	458.64	-1.54	5.66	-30.71
1987	1,416.23	1,023.53	380.07	-21.25	-18.71	-26.72
1988	1,310.06	955.36	354.70	-20.66	-21.24	-11.27
1989	1,474.22	1,056.43	407.79	1.65	-0.32	5.09
1990	2,194.66	1,399.67	736.95	47.01	36.99	56.88
1991	2,277.22	1,488.25	715.56	-1.64	0.03	-3.89
1992	2,614.01	1,796.26	802.00	10.02	14.93	8.27
1993	4,240.66	2,816.91	1,375.53	54.22	52.58	50.14
1994	3,864.89	2,657.63	1,223.98	-12.81	-10.04	-11.56
1995	3,552.25	2,319.15	1,260.11	-12.76	-18.60	2.19
1996	4,258.30	2,903.44	1,421.11	12.22	15.90	9.94
1997	4,538.65	3,145.04	1,481.35	5.59	7.43	2.05
1998	3,702.43	2,537.21	1,289.62	-18.96	-21.03	-6.72
1999	3,704.53	2,925.48	731.80	-2.80	11.12	-57.87
2000	3,946.48	3,097.68	848.62	-1.31	-2.07	8.18
2001	3,423.35	2,752.40	644.51	-18.46	-15.33	-36.35
2002	3,363.97	2,380.27	1,018.92	-2.65	-14.62	40.13
2003	3,405.18	2,388.63	1,218.69	-11.39	-13.28	11.40
2004	2,978.07	2,173.44	875.09	-10.04	-7.93	-17.46
2005	2,502.12	1,821.79	745.33	-14.44	-12.91	-24.87
2006	2,296.28	1,555.11	1,083.98	-12.76	-19.27	28.88

Source: The Bureau of the Budget, Office of the Prime Minister. Note: The nominal extension budget data were deflated into real terms using the GDP deflators.

Table 5.10 Agricultural Imports, Exports and Trade Openness

Year	Ag Import Value (mill baht)	Ag Export Value (mill baht)	Ag GDP at current prices (mill baht)	TO **Trade Openness**	Livestock import for breeding	Livestock GDP	BREED **Livestock breeds import as share of GDP**
	(A)	(B)	(C)	(A+B)/C	mill baht	mill baht	
1970	3,884.40	11,109.00	34,794	**0.43**	10.43	4,327.69	**0.24**
1971	3,856.40	12,614.60	33,254	**0.50**	12.68	4,657.36	**0.27**
1972	4,364.30	15,415.50	39,398	**0.50**	11.74	4,925.29	**0.24**
1973	5,444.60	23,088.10	56,610	**0.50**	17.66	4,847.01	**0.36**
1974	7,546.80	36,846.10	70,096	**0.63**	19.27	8,009.25	**0.24**
1975	8,737.60	33,750.40	76,288	**0.56**	28.93	8,369.80	**0.35**
1976	9,391.90	46,135.50	86,281	**0.64**	26.22	9,154.85	**0.29**
1977	12,984.80	51,821.20	92,329	**0.70**	44.16	11,644.51	**0.38**
1978	17,255.40	56,340.50	110,749	**0.66**	77.47	11,035.88	**0.70**
1979	21,067.00	72,045.80	122,953	**0.76**	86.22	13,720.70	**0.63**
1980	21,565.40	81,454.00	140,598	**0.73**	96.47	17,077.00	**0.56**
1981	24,914.30	100,270.60	149,028	**0.84**	73.71	17,466.00	**0.42**
1982	24,796.30	107,820.00	141,064	**0.94**	120.02	15,283.00	**0.79**
1983	29,930.00	96,351.00	169,386	**0.75**	102.54	20,178.00	**0.51**
1984	33,504.00	113,397.00	157,759	**0.93**	146.16	17,696.00	**0.83**
1985	38,254.20	115,974.00	150,734	**1.02**	137.33	15,927.00	**0.86**
1986	42,134.70	134,416.00	159,267	**1.11**	257.69	20,752.00	**1.24**
1987	53,556.10	153,991.00	184,459	**1.13**	610.39	23,725.00	**2.57**
1988	78,218.30	194,198.00	229,383	**1.19**	714.20	26,022.00	**2.74**
1989	102,244.30	230,537.00	251,767	**1.32**	475.65	29,876.00	**1.59**
1990	125,710.50	224,168.00	241,179	**1.45**	672.39	32,850.00	**2.05**
1991	142,869.30	256,036.00	280,555	**1.42**	995.18	37,430.00	**2.66**
1992	158,454.40	284,980.00	306,053	**1.45**	702.50	35,001.00	**2.01**
1993	159,889.00	279,651.00	274,063	**1.60**	467.43	32,189.00	**1.45**
1994	179,674.60	336,141.00	329,844	**1.56**	462.02	35,675.00	**1.30**
1995	213,537.60	407,037.00	397,929	**1.56**	485.15	42,475.00	**1.14**
1996	216,832.00	412,490.00	438,119	**1.44**	493.14	43,956.00	**1.12**
1997	228,830.50	484,847.00	447,176	**1.60**	421.50	43,925.00	**0.96**
1998	226,827.00	591,062.00	498,587	**1.64**	684.42	43,914.00	**1.56**
1999	228,098.00	555,783.00	435,507	**1.80**	536.17	49,734.00	**1.08**
2000	275,459.00	626,286.00	444,185	**2.03**	94.66	41,469.00	**0.23**
2001	323,122.50	685,148.35	468,905	**2.15**	18.50	54,181.00	**0.03**
2002	325,961.32	694,402.74	514,257	**1.98**	22.95	53,927.00	**0.04**
2003	363,373.57	804,349.20	615,854	**1.90**	506.28	51,380.00	**0.99**
2004	398,356.13	883,177.36	668,808	**1.92**	581.41	58,666.00	**0.99**
2005	437,576.17	936,519.41	733,276	**1.87**	792.49	72,004.00	**1.10**
2006	434,540.73	1,071,543.04	841,134	**1.79**	584.00	59,933.00	**0.97**

Source: OAE and NESDB

Table 5.11 Agricultural Capital Import and Foreign Direct Investment

Year	KM					FDI
	Ag capital import (mill baht)	Ag Net K Stock (mill baht)	**Share of Ag capital import**	Net FDI flows in Agriculture (mill baht)	Ag GDP at current prices (mill baht)	**Share of FDI in Ag GDP**
	(D)	(E)	(D)/(E)×100	(G)	(F)	(G)/(F)×100
1970	714.50	92,194	**0.77**	0.00	34,794	**0.00**
1971	664.70	98,343	**0.68**	0.00	33,254	**0.00**
1972	1,001.40	104,273	**0.96**	4.90	39,398	**0.49**
1973	1,272.90	110,461	**1.15**	5.00	56,610	**0.39**
1974	1,945.50	127,309	**1.53**	15.20	70,096	**0.78**
1975	2,564.80	132,731	**1.93**	2.10	76,288	**0.08**
1976	2,555.90	140,622	**1.82**	1.30	86,281	**0.05**
1977	3,695.60	148,941	**2.48**	-0.20	92,329	**-0.01**
1978	3,785.40	163,224	**2.32**	-18.20	110,749	**-0.48**
1979	4,100.40	173,095	**2.37**	4.50	122,953	**0.11**
1980	4,092.30	182,065	**2.25**	209.90	140,598	**5.13**
1981	5,840.60	199,337	**2.93**	7.50	149,028	**0.13**
1982	6,059.80	219,830	**2.76**	15.60	141,064	**0.26**
1983	7,605.50	220,893	**3.44**	48.10	169,386	**0.63**
1984	7,838.20	239,530	**3.27**	67.60	157,759	**0.86**
1985	8,807.00	255,487	**3.45**	77.00	150,734	**0.87**
1986	8,769.20	291,067	**3.01**	202.20	159,267	**2.31**
1987	9,751.30	288,601	**3.38**	285.90	184,459	**2.93**
1988	14,609.70	333,053	**4.39**	315.30	229,383	**2.16**
1989	18,769.46	369,814	**5.08**	603.40	251,767	**3.21**
1990	22,960.66	416,139	**5.52**	762.70	241,179	**3.32**
1991	19,649.29	463,121	**4.24**	597.80	280,555	**3.04**
1992	22,868.80	495,654	**4.61**	-150.60	306,053	**-0.66**
1993	24,713.50	539,048	**4.58**	330.10	274,063	**1.34**
1994	26,838.10	584,441	**4.59**	-157.70	329,844	**-0.59**
1995	31,645.00	629,160	**5.03**	232.30	397,929	**0.73**
1996	34,889.30	675,511	**5.16**	51.20	438,119	**0.15**
1997	33,465.80	809,497	**4.13**	37.73	447,176	**0.11**
1998	28,167.27	1,011,400	**2.78**	20.37	498,587	**0.07**
1999	29,111.59	973,303	**2.99**	70.32	435,507	**0.24**
2000	33,260.22	1,046,766	**3.18**	28.23	444,185	**0.08**
2001	39,088.15	1,138,392	**3.43**	-189.76	468,905	**-0.49**
2002	43,003.46	1,184,182	**3.63**	137.80	514,257	**0.32**
2003	50,459.46	1,260,396	**4.00**	1,160.93	615,854	**2.30**
2004	58,992.44	1,360,838	**4.34**	224.16	668,808	**0.38**
2005	59,150.67	1,513,102	**3.91**	507.32	733,276	**0.86**
2006	60,549.20	1,625,230	**3.73**	-112.46	841,134	**-0.19**

Source: OAE, NESDB and Bank of Thailand

Table 5.12 Weather-Related Factors

Year	RAIN **Rainfall (mm)**	RAIN2 **Rainy Day (day)**	Rice Harvested Area (rai)	Rice Planted Area (rai)	WEATHER **Share of rice harvested to planted area**
			(H)	(I)	(H)/(I)
1970	**1,885.45**	**145.23**	46,294,510	50,587,200	**0.92**
1971	**1,644.65**	**133.57**	47,938,230	50,806,440	**0.94**
1972	**1,562.86**	**136.75**	43,795,633	45,930,000	**0.95**
1973	**1,783.36**	**143.37**	49,117,820	51,541,582	**0.95**
1974	**1,705.83**	**141.36**	47,535,112	49,859,000	**0.95**
1975	**1,803.41**	**144.83**	51,932,998	55,311,914	**0.94**
1976	**1,677.73**	**140.38**	50,664,000	53,216,718	**0.95**
1977	**1,438.49**	**124.69**	54,509,000	56,204,453	**0.97**
1978	**1,689.71**	**141.67**	54,809,379	61,388,614	**0.89**
1979	**933.98**	**125.05**	56,037,479	61,125,380	**0.92**
1980	**1,111.82**	**204.41**	56,260,565	58,984,890	**0.95**
1981	**895.87**	**218.42**	56,585,281	59,620,231	**0.95**
1982	**1,105.30**	**214.41**	55,379,383	59,749,068	**0.93**
1983	**1,141.89**	**202.47**	57,574,725	62,077,442	**0.93**
1984	**982.22**	**217.81**	60,184,609	62,395,973	**0.96**
1985	**1,029.58**	**222.45**	60,890,953	63,845,830	**0.95**
1986	**956.14**	**204.33**	57,817,188	61,928,418	**0.93**
1987	**1,006.08**	**214.32**	56,329,348	58,211,291	**0.97**
1988	**1,213.76**	**220.00**	61,152,761	63,846,179	**0.96**
1989	**1,007.10**	**213.25**	62,440,763	64,500,509	**0.97**
1990	**926.14**	**222.25**	55,870,740	63,448,475	**0.88**
1991	**832.92**	**167.05**	55,847,665	58,882,314	**0.95**
1992	**786.74**	**126.32**	57,578,458	60,788,588	**0.95**
1993	**824.63**	**143.03**	54,051,546	60,311,220	**0.90**
1994	**1,044.10**	**164.06**	54,857,176	59,471,363	**0.92**
1995	**1,030.19**	**156.97**	55,298,959	61,710,962	**0.90**
1996	**996.90**	**157.98**	57,484,216	63,237,095	**0.91**
1997	**881.30**	**143.40**	61,217,177	63,394,628	**0.97**
1998	**934.39**	**141.79**	60,160,521	63,471,484	**0.95**
1999	**841.19**	**107.98**	61,088,084	63,040,352	**0.97**
2000	**851.75**	**112.52**	60,716,670	65,635,709	**0.93**
2001	**994.84**	**137.36**	63,624,366	66,555,482	**0.96**
2002	**1,261.15**	**168.47**	59,204,608	65,341,645	**0.91**
2003	**1,221.14**	**168.22**	63,701,098	66,504,895	**0.96**
2004	**1,213.72**	**159.51**	63,033,061	67,083,780	**0.94**
2005	**1,214.05**	**162.84**	62,762,198	66,687,416	**0.94**
2006	**1,491.43**	**179.76**	63,372,594	67,444,610	**0.94**

Source: OAE

Table 5.13 Infrastructure, Resource Reallocation and Education Factors

Year	Infrastructure		Resource reallocation		Education
	IRRIGAT	ROAD	NC	NR	EDU
	Share of irrigated area	Rural road length (km)	Share of non-crop employ.	Share of non-rice household	Share of human capital
1970	11.17	2,253	2.84	8.06	0.04
1971	10.83	2,511	2.84	8.06	0.04
1972	10.88	2,798	2.84	8.06	0.07
1973	11.16	3,119	2.84	8.06	0.05
1974	11.38	3,476	2.84	8.06	0.07
1975	11.46	3,873	2.84	8.06	0.10
1976	13.23	4,317	2.84	9.79	0.08
1977	13.77	6,258	3.31	12.18	0.09
1978	14.17	6,778	3.09	17.58	0.23
1979	15.07	7,252	3.29	13.20	0.35
1980	15.71	7,665	3.32	16.89	0.40
1981	16.34	8,398	3.76	20.70	0.50
1982	16.79	9,348	4.86	18.49	0.78
1983	17.43	9,210	3.90	20.44	0.80
1984	18.25	9,815	4.04	22.14	1.12
1985	18.58	10,342	5.05	20.18	1.19
1986	18.68	10,306	4.29	20.06	1.27
1987	19.04	10,915	5.55	19.30	1.93
1988	19.55	11,382	4.28	26.14	1.77
1989	19.71	12,045	4.27	28.17	2.12
1990	20.05	13,508	5.28	28.34	2.00
1991	20.43	16,434	6.15	33.36	1.68
1992	20.98	21,009	5.57	33.11	2.03
1993	21.60	25,278	7.14	29.53	2.02
1994	21.76	30,768	6.66	27.25	2.27
1995	21.90	34,300	6.61	34.86	2.01
1996	22.35	43,307	7.10	34.82	2.14
1997	22.64	53,351	6.38	33.34	2.33
1998	22.95	64,743	7.12	32.43	3.50
1999	22.99	68,652	8.61	33.57	3.89
2000	23.21	67,720	7.85	33.22	4.50
2001	23.48	69,528	11.33	33.11	5.11
2002	23.87	71,918	11.73	34.16	5.63
2003	24.68	74,308	13.35	34.52	6.04
2004	24.69	76,698	14.12	35.73	7.01
2005	25.12	79,088	17.44	35.73	6.99
2006	25.49	81,478	17.40	35.73	7.45

Source: OAE, Fan et al. (2004) and NSO

Chapter 6

6. Determinants of TFP Growth in Thai Agriculture: Estimation Results

6.1 Introduction

This chapter reports the findings of the econometric analysis of the determinants of TFP growth in the overall agricultural sector as well as its major subsectors of crops and livestock. The analysis combines the empirical results from the estimation of TFP growth from Chapter 4 with the strategy of estimation described in Chapter 5. The chapter aims to answer the second research question of what determines productivity growth and how agricultural research has influenced it. The general belief that the longstanding public investment in agricultural research contributed to TFP growth is empirically tested.

Based on the newly compiled data, the empirical estimations have taken into account lags and other variables often omitted in previous studies, such as foreign research spillovers, private-sector research, infrastructure and natural factors. The growth-rate model (GRM) is used as a starting point before proceeding to the error correction model (ECM). Estimated results using the two distinct methods not only sharpen an understanding of the residual TFP growth in Thai agriculture but also provide important implications for the search of TFP determinants in general.

There are three sections. Section 6.2 reports results from the growth-rate model. The results are divided into the general model covering the whole study period and the attribution model covering a shorter period with more research variables. A similar pattern applies to section 6.3 providing empirical findings from the ECM. Section 6.4 concludes with methodological and policy implications.

6.2 Results from Growth-Rate Model (GRM)

This section reports results from the econometric estimation of the growth-rate model incorporating the polynomial distributed lag structure. The results draw attention to major determinants of TFP growth based on a commonly used method and the most popular form of lag structure. They are divided into results from the general model (GM) and the attribution model (AM). Each model is estimated for the four cases of overall agriculture (Ag1), traditional agriculture (Ag2) and the crops and livestock sector. The estimation using research stock variables computed from the perpetual inventory method (PIM) is rejected by the data and therefore the results are not reported here.

Unit root test for the stationarity of the series:

Each data series is tested to determine whether the series is stationary using the Augmented Dickey-Fuller (ADF) unit root test. The tests indicate that there is no unit root in every series. The TFP growth estimates from Chapter 4 have an oscillating pattern and the series are stationary. On the right hand side, variables are expressed in rate of change (growth rate) terms and the way the growth rate is calculated is similar to taking log of a first differenced variable. Stationarity of all series is confirmed. Hence, standard inference procedures can be applied to the OLS regressions.[175]

6.2.1 General Model (1971-2006)

The estimation begins by following the general model and imposing the second-degree polynomial distributed lag (PDL) structure on both public and international research variables, as specified in the previous chapter. Unfortunately, due to the limitation that the international research data are only available from 1972, imposing the PDL costs several degrees of freedom. The model cannot explain the variations in the TFP growth (TFPG) estimates for the whole study period. Final equations for both unadjusted and adjusted TFPG are also statistically insignificant in terms of the

[175] See Appendix 6A for graphs of main variables. Note that graphs of the dependent variables are already shown in Chapter 4.

standard F test.[176] As a result, the PDL was imposed only on the public research variable where data series are available from 1961.

To search for an appropriate lag length on the public research using the Schwarz Criterion and the adjusted R^2, the estimation initially begins with a free-form lag imposing no form of lag on the research variable. The lag length of public research was chosen by searching over 9-year lags as the data are available from 1961. Insignificant variables are dropped out one at a time, arriving at the preferred model in which the adjusted R^2 stops increasing and the Schwarz criterion stops decreasing from dropping an additional variable. A second-degree polynomial or Almon lag structure is then imposed on the research variable.

Other explanatory variables are tested under various experimental runs and only the significant ones are kept in the final model. The choice of dropping or keeping variables in the final equation was statistical acceptance in terms of the joint variable deletion tests against the maintained hypothesis. The results are first summarized as general findings and then an interpretation of the results in each sector is described.

1) General Findings

In general, the growth-rate model suggests the major factors determining TFP growth in Thai agriculture are public investment in agricultural research, extension services and irrigation. Public research has a positive and significant effect on TFPG. The linkage between public research and TFPG also involves lags of four years on average. The polynomial distributed lag structure that can capture the research-productivity relationship in some cases, mostly fits well with the data in traditional agriculture and the crops sector.

The growth-rate model yields an unexpected result in terms of the negative and significant impact of agricultural extension on the TFP growth, notably in overall agriculture. However, this counterintuitive result is not a problem in other sectors. As

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[176] An attempt was also made with the agricultural extension variable, imposing the PDL on the EXT variable yields poor results and the equation does not pass the standard F test.

the interaction term between research and extension is statistically insignificant it is dropped. In any case the role of international research spillovers does not appear to be statistically significant.

As regards the impact of non-technology factors, irrigation plays an important role in influencing the TFPG in traditional agriculture and the livestock sector. The effect of resource reallocation is shown to be important for crops productivity while epidemic has quite a large impact on livestock productivity. These factors confirm that water system, agricultural diversification and natural factor are crucial for agricultural productivity. Other controlled factors, e.g., the commodity price boom, weather conditions, rural roads and trade openness, do not turn out to be significant.

2) Sectoral Findings

Overall Agriculture (Ag1)

The final equations are presented according to the dependent variables, consisting of unadjusted TFP growth (TFPGu) and TFP growth adjusted for input quality changes (TFPGa). They are referred to as model 1 and 2 corresponding to the numbers of model summarized at the end of Chapter 5 (Table 5.3). The general model and the PDL structure seem to fit these data poorly. Various experimental runs were tested but none turned out to be statistically significant in terms of the F test. Finally, the PDL was removed and only significant lags included in the final equations.

The preferred equations are reported in Table 6.1, together with the commonly used diagnostic tests. They are statistically significant at the 5% and 10% levels in terms of the F test and perform well in terms of the standard diagnostic tests for serial correlation of estimation residuals (LM), functional form specification (RESET), normality (JBN), heteroskedasticity (ARCH) and stationarity of the residuals (ADF).

In overall agriculture, which comprises crops, livestock, fisheries, forestry and agricultural services, the major factors affecting TFPG are agricultural research and extension. As expected, public investment in agricultural research has a positive and significant impact on the TFPG. However, the estimated coefficient of the agricultural extension has an unexpected (negative) sign.

In the TFPGu and TFPGa models, the public research (PUBR) variable is statistically significant at the 1% and 10% levels, respectively. The results suggest that it takes approximately two years for the research to have an impact on the TFPG. A 1 percent increase in the rate of change of PUBR can stimulate the TFPGu by 0.04 percent while the TFPGa is raised by 0.02 percent.

Agricultural extension (EXT) is statistically significant at the 5% level in both equations but has a negative sign.[177] Although this may reflect some weaknesses in the organizations involved, its significance level is somewhat unexpected. Overall, agricultural extension is regarded as 'the weakest link in the agricultural chain' and there is poor coordination between research and extension agencies in Thailand (Office of Agricultural Economics, 1998, p.34). Adding an interaction term between public research and extension does not change the result. Its coefficient is negative and insignificant thereby dropping out.

International research spillovers (SPILL) and its interaction term with the public research (PUBSPILL) are statistically insignificant. The SPILL variable is dropped whereas the interaction term is kept in the model because it is shown to improve the significance of the overall model.

Table 6.1 TFP Determinants in Overall Agriculture based on GRM and General Model

	Model	**1**	**2**
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		1.099	0.629
		(1.644)	(1.361)
$PUBR_t$	2	0.035	0.016
		(2.521)***	(1.748)*

177 Pochanukul (1992, p.192) also found a negative and significant effect of extension on rice production but the effect on other crops is not statistically significant.

EXT_t	-0.079	-0.057
	(-2.148)**	(-2.251)**
$PUBSPILL_t$	0.001	0.000
	(0.803)	(0.584)
N (no. of observations)	34	34
k (no. of parameters)	4	4
Adjusted R^2	0.16	0.10
F-statistics	3.08	2.24
S.E. of regression	3.72	2.57
Diagnostic tests:		
LM(1), F(1, N-k-1)	0.71 (p = 0.40)	0.14 (p = 0.70)
LM(2), F(2, N-k-2)	1.66 (p = 0.20)	0.22 (p = 0.80)
RESET, F(1, N-k-1)	0.34 (p = 0.56)	0.08 (p = 0.78)
JBN, $\chi^2(2)$	2.25 (p = 0.32)	1.30 (p = 0.52)
ARCH, F(1, N-2)	0.72 (p = 0.40)	0.33 (p = 0.56)
ADF	-6.56 (p = 0.00)	-5.96 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms.
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.

Traditional Agriculture (Ag2: crops and livestock only)

The preferred equations for traditional agriculture are statistically significant at the 5% level in terms of the standard F test. They also pass the commonly used diagnostic tests. The results are shown in Table 6.2. They are opposite to the overall agricultural cases such that the PDL structure fits with the data in the TFPGu and TFPGa models.

When considering only crops and livestock combined, the positive and significant linkage between agricultural research and productivity growth is still observed for both unadjusted and adjusted TFPG. For the TFPGu and TFPGa, the average time lags are 4 years and the shape of the research impact is consistent with the bell-shape lag structure. The total effect of the research or long-run elasticity, indicated by the sum of lagged coefficients, is 0.16 for both TFPGu and TFPGa. This implies a 1 percent increase in the rate of growth of public research spending results in a 0.16 percent increase in the rate of growth of TFP.

The estimated coefficient of agricultural extension still has a negative sign but is statistically insignificant. As regards the impact of other explanatory variables, irrigation appears to be a significant factor in determining the TFPGu and TFPGa. This confirms the important role of water and irrigation system in crops and livestock production, either through input quality improvement or through technological development.

Table 6.2 TFP Determinants in Traditional Agriculture based on GRM and General Model

	Model	3	4
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		-0.856	-1.118
		(-0.683)	(-0.896)
$PUBR_t$	0	0.023	0.022
		(1.922)*	(1.890)*
	1	0.036	0.036
		(1.922)*	(1.890)*
	2	0.041	0.040
		(1.922)*	(1.890)*
	3	0.036	0.036
		(1.922)*	(1.890)*
	4	0.023	0.022
		(1.922)*	(1.890)*
Sum of lags		0.161	0.158
		(1.922)*	(1.890)*
EXT_t		-0.063	-0.057
		(-1.027)	(-0.932)
$PUBSPILL_t$		0.000	0.000
		(0.142)	(0.134)
$IRRIGAT_t$		0.896	0.862
		(2.464)**	(2.384)**
N (no. of observations)		34	34
k (no. of parameters)		5	5
Adjusted R^2		0.17	0.15
F-statistics		2.63	2.48
S.E. of regression		5.27	5.25
Diagnostic tests:			
LM(1), F(1, N-k-1)		1.27 (p = 0.27)	1.50 (p = 0.23)
LM(2), F(2, N-k-2)		1.09 (p = 0.35)	1.49 (p = 0.24)
RESET, F(1, N-k-1)		1.82 (p = 0.18)	1.60 (p = 0.20)
JBN, $\chi^2(2)$		0.74 (p = 0.69)	0.80 (p = 0.66)
ARCH, F(1, N-2)		0.12 (p = 0.73)	0.19 (p = 0.66)
ADF		-6.69 (p = 0.00)	-6.80 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms. Sum of lagged coefficient indicates long-run multiplier or long-run change in the TFPG given a permanent increase in the public research spending.
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.

Crops sector

The final parsimonious growth-rate models for the crops sector are reported in Table 6.3. The TFPGu equation is statistically significant at the 1% level while that of TFPGa is significant at the 5% level. They all pass the standard diagnostic tests at the 5% level. Similar to the other sectors, the results for TFPGu and TFPGa are consistent. The application of the PDL structure fits well with the TFPGu and TFPGa models.

In the crops sector, public research (PUBR) and resource reallocation (NR) are major factors positively determining the unadjusted and adjusted TFPG. The regression estimates suggest the research variable, with 4-year lags, has a positive and significant impact on TFPGu and TFPGa. The included lags are symmetric, inverted-U shapes, with the effect of research on TFPG rising to a maximum of 0.04 and declining again to 0.02. The short-run elasticity or immediate impact is 0.02. The long term impact represented by the sum of all current and lagged coefficients is 0.16 and 0.17, that is, a 1 percent increase in the rate of growth of agricultural research spending can raise TFPGu and TFPGa by 0.16 percent and 0.17 percent, respectively.

Since all the variables are expressed in percentage growth rate, the size of the coefficients also indicates the magnitude of their relative influence. The impact of resource reallocation is the most influential factor and has the greatest impact, that is, a 1 percent increase in the non-rice employment share can raise TFPGu and TFPGa by 0.25 and 0.17 percent, respectively. This implies agricultural diversification from the traditional rice production to higher value added crops, such as fruit and vegetables, helps improve the productivity of the crops sector as a whole. The agricultural extension coefficient has a positive sign but is statistically insignificant.

Other explanatory variables do not appear to be statistically significant. It should be noted that the insignificant irrigation variable does not mean it is not important to crop productivity. Rather, irrigation raises crop production mainly through improved land quality enhancing multiple cropping that is already accounted for when adjusting the land input.

Table 6.3 TFP Determinants in Crops Sector based on GRM and General Model

	Model	**5**	**6**
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		-0.742	-0.827
		(-0.735)	(-0.795)
$PUBR_t$	0	0.022	0.023
		(1.966)**	(1.985)**
	1	0.036	0.037
		(1.966)**	(1.985)**
	2	0.040	0.042
		(1.966)**	(1.985)**
	3	0.036	0.037
		(1.966)**	(1.985)**
	4	0.022	0.023
		(1.966)**	(1.985)**
Sum of lags		0.159	0.165
		(1.966)**	(1.985)**
EXT_t		0.052	0.056
		(0.880)	(0.905)
$PUBSPILL_t$		-0.000	-0.003
		(-0.099)	(-0.663)
NR_t		0.251	0.165
		(3.653)***	(2.334)**
N (no. of observations)		34	34
k (no. of parameters)		5	5
Adjusted R^2		0.31	0.17
F-statistics		4.79	2.74
S.E. of regression		5.27	5.43
Diagnostic tests:			
LM(1), F(1, N-k-1)		1.76 (p = 0.19)	3.30 (p = 0.08)
LM(2), F(2, N-k-2)		3.13 (p = 0.06)	2.36 (p = 0.11)
RESET, F(1, N-k-1)		0.18 (p = 0.67)	0.07 (p = 0.78)
JBN, $\chi^2(2)$		0.36 (p = 0.83)	0.09 (p = 0.95)

ARCH, F(1, N-2)	0.07 (p = 0.79)	0.09 (p = 0.76)
ADF	-6.21 (p = 0.00)	-5.40 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms. Sum of lagged coefficient indicates long-run multiplier or long-run change in the TFPG given a permanent increase in the public research spending.
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.

Livestock sector

The preferred equations are statistically significant at the 5% level in terms of the F test and also pass the diagnostic tests at the 5% level. The results are shown in Table 6.4. The general models using the PDL shape fit the data better than including an individual lag.

The public research and the agricultural extension as well as the interaction term do not significantly determine both measures of the TFPG in the livestock sector. However, keeping the research variable increases the explanatory power of the joint significance of the overall models. The role of foreign research, represented by the import values of livestock breeds (BREED) and its interaction with the public research (PUBBREED), is also statistically insignificant, thereby dropping out of the preferred models.

Instead, irrigation and epidemic appear to be the most influential factors. The effect of irrigation on both series of the TFPG is 2.1 percent and significant at the 1% level. This implies that livestock productivity also depends on irrigation. Farms that locate near an irrigated area tend to have more fertile grassland and benefit from the lower transportation cost of animal feeds.[178] The Avian Influenza outbreak (BIRD) is less significant but has the largest impact on TFPG. The outbreak that occurred in 2004 reduces the TFPG on average by 17-18 percent.

[178] Most of the animal feed factories and barns are concentrated in an irrigated area, near sources of raw materials.

Table 6.4 TFP Determinants in Livestock Sector based on GRM and General Model

	Model	7	8
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		-1.494	-1.740
		(-0.519)	(-0.606)
$PUBR_t$	0	-0.038	-0.037
		(-0.916)	(-0.880)
	1	-0.058	-0.055
		(-0.916)	(-0.880)
	2	-0.058	-0.055
		(-0.916)	(-0.880)
	3	-0.038	-0.037
		(-0.916)	(-0.880)
Sum of lags		-0.194	-0.185
		(-0.916)	(-0.880)
$IRRIGAT_t$		2.102	2.099
		(2.635)***	(2.641)***
BIRD		-17.719	-17.471
		(-1.690)*	(-1.673)*
N (no. of observations)		36	36
k (no. of parameters)		5	5
Adjusted R^2		0.17	0.17
F-statistics		3.37	3.39
S.E. of regression		12.43	12.38
Diagnostic tests:			
LM(1), F(1, N-k-1)		0.21 (p = 0.64)	0.32 (p = 0.57)
LM(2), F(2, N-k-2)		3.15 (p = 0.06)	2.36 (p = 0.11)
RESET, F(1, N-k-1)		3.11 (p = 0.10)	3.33 (p = 0.08)
JBN, $\chi^2(2)$		0.86 (p = 0.64)	0.71 (p = 0.70)
ARCH, F(1, N-2)		0.80 (p = 0.37)	0.81 (p = 0.37)
ADF		-5.32 (p = 0.00)	-5.21 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms. Sum of lagged coefficient indicates long-run multiplier or long-run change in the TFPG given a permanent increase in the public research spending.
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.

6.2.2 Attribution Model (1980-2006)

To address the attribution issue, individual research performers – public, private, university and foreign research – are regressed on the TFPG to find their impacts separately. Since the private and university research data are only available from 1980s onwards, the model covers a shorter period than the general model. University research can only be tested in the overall agriculture model (Ag1) since the data cannot be disaggregated into crops and livestock research. Private research comprises only crops and livestock research. Other potential TFPG determinants are also tested and only the significant ones are kept in the final parsimonious equations. The following report is the general findings, followed by an interpretation of the results in each sector.

1) General Findings

From the attribution model, major factors affecting the TFPG in general are private research, collaboration between public and foreign research and natural factors. Among the research variables, private research is the only factor that has a positive and significant impact on TFPG in all sectors during 1980-2006. It also has a relatively large impact compared with other factors that appear statistically significant. Unlike the general model, public research and agricultural extension no longer appear to be statistically significant. There is also no evidence that university research has a significant impact. The PDL structure does not fit well with the data in the attribution model.

The foreign research spillovers do not appear to be statistically significant in all sectors. However, an interaction term between foreign and public research (PUBSPILL) is positive and statistically significant in traditional agriculture and the crops sector. This implies that international spillovers of research results alone do not affect TFP growth but require collaboration with local public research to significantly raise the TFPG in Thai agriculture. This also supports the fact that domestic research is needed because location-specific agricultural research cannot simply be borrowed.

Natural factors play an important role in the attribution model. In particular, weather condition has a positive and significant impact on the TFPG in overall agriculture with rainfall positively influencing the livestock TFPG. The significant role of resource reallocation and the Bird Flu outbreak are consistent with the results found in the general model. The release of labour from rice to other crops production can raise crops TFPG as a whole while the epidemic has a negative and sizable impact on livestock TFPG.

2) Sectoral Findings

Overall Agriculture (Ag1)

In overall agriculture, the preferred models explaining the movements of two series of TFP growth are shown in Table 6.5. They are statistically significant at the 1% level in terms of the F test. They also pass most of the diagnostic tests except that serial correlation in the second lagged residuals was found in both equations and therefore an AR(2) term was added.[179] After accounting for the serial correlation, the final equations reported in Table 6.5 perform well with all the diagnostic tests.

The polynomial distributed lag structure was initially imposed on all the research variables – public, private, university and foreign research. However, none of the estimated equations turn out to be significant in terms of the F test. As a result, some insignificant PDL-incorporated variables were dropped to improve the significance of the overall model. An individual lag was also experimented with but this did not improve the explanatory power and statistical significance of the model.

Factors explaining the variations of TFPGu and TFPGa are private investment in agricultural research (PRIR) and weather condition (WEATHER), measured as the ratio of rice harvested to rice planted area. The estimated coefficients of PRIR and WEATHER are statistically significant at the 5% level with a positive sign. The results suggest that a 1 percent increase in the rate of change of private research expenditure leads to an increase in the TFPGu and TFPGa by 0.04 percent in the

[179] See Eviews 5 User's Guide (Eviews, 2004, p.481) for details.

short run and by 0.27 percent in the long run. The research impact has an inverted U-shape with four-year lags.

The weather condition indicating the occurrence of drought and flooding also affects the TFPG positively. This implies that good weather or fewer occurrences of drought and flooding can raise the TFPGu and TFPGa by 0.38 percent and 0.37 percent, respectively. The magnitude of the coefficients also suggests natural factor has a greater impact on the TFPG than the research-induced factor. There is no evidence that other factors including university research and foreign research spillovers are statistically significant.

Table 6.5 TFP Determinants in Overall Agriculture based on GRM and Attribution Model

	Model	9	10
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		-0.134	-0.437
		(-0.217)	(-0.726)
$PUBR_t$	0	0.001	0.001
		(0.471)	(0.508)
	1	0.002	0.002
		(0.471)	(0.508)
	2	0.003	0.003
		(0.471)	(0.508)
	3	0.002	0.002
		(0.471)	(0.508)
	4	0.001	0.001
		(0.471)	(0.508)
Sum of lags		0.012	0.012
		(0.471)	(0.508)
$PRIR_t$	0	0.039	0.039
		(2.043)**	(2.098)**
	1	0.062	0.062
		(2.043)**	(2.098)**
	2	0.070	0.070
		(2.043)**	(2.098)**
	3	0.062	0.062
		(2.043)**	(2.098)**
	4	0.039	0.039
		(2.043)**	(2.098)**
Sum of lags		0.274	0.273
		(2.043)**	(2.098)**

$PUBSPILL_t$	0.004	0.004
	(1.534)	(1.542)
$WEATHER_t$	0.377	0.365
	(2.368)**	(2.372)**
N (no. of observations)	21	21
k (no. of parameters)	6†	6†
Adjusted R^2	0.51	0.53
F-statistics	5.27	5.54
S.E. of regression	3.12	3.05
Diagnostic tests:		
LM(1), F(1, N-k-1)	1.41(p = 0.25)	1.59 (p = 0.23)
LM(2), F(2, N-k-2)	0.68 (p = 0.52)	0.84 (p = 0.45)
RESET, F(1, N-k-1)	0.52 (p = 0.48)	0.19 (p = 0.67)
JBN, $\chi^2(2)$	1.14 (p = 0.56)	1.26 (p = 0.53)
ARCH, F(1, N-2)	1.03 (p = 0.32)	1.18 (p = 0.29)
ADF	-5.67 (p = 0.00)	-5.78 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms.
†include AR(2) since the original equation encountered serial correlation at the 2nd lag.
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.

Traditional Agriculture (Ag2)

The final parsimonious equations are statistically significant at the 1% level in terms of the standard F test and perform well in terms of the commonly used diagnostic tests. They are shown in Table 6.6.

From the period 1980 to 2006, private research (PRIR) and the interaction effect between public and foreign research (PUBSPILL) are factors that significantly determine both measures of TFPG. They both have a positive and significant impact on the TFPG. The PRIR variable has a relatively large impact while the PUBSPILL variable has a small effect. The PDL structure only fits well with the public research variable. However, its estimated coefficient does not appear to be statistically significant. From various experimental runs, there is no evidence that other potential factors can explain the movements of the TFPG in traditional agriculture.

Table 6.6 TFP Determinants in Traditional Agriculture based on GRM and Attribution Model

	Model	11	12
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		0.673	0.277
		(0.709)	(0.290)
$PUBR_t$	0	0.011	0.010
		(1.219)	(0.183)
	1	0.018	0.017
		(1.219)	(0.183)
	2	0.020	0.019
		(1.219)	(0.183)
	3	0.018	0.017
		(1.219)	(0.183)
	4	0.011	0.010
		(1.219)	(0.183)
Sum of lags		0.077	0.076
		(1.219)	(0.183)
EXT_t		-0.075	-0.069
		(-1.512)	(-1.385)
$PRIR_t$		0.169	0.164
		(2.186)**	(2.114)**
$PUBSPILL_t$		0.016	0.016
		(2.612)***	(2.561)***
$SPILL_t$		0.109	0.112
		(0.709)	(0.726)
N (no. of observations)		27	27
k (no. of parameters)		6	6
Adjusted R^2		0.36	0.35
F-statistics		3.91	3.75
S.E. of regression		3.72	3.74
Diagnostic tests:			
LM(1), F(1, N-k-1)		0.00 (p = 0.96)	0.02 (p = 0.88)
LM(2), F(2, N-k-2)		0.44 (p = 0.64)	0.60 (p = 0.56)
RESET, F(1, N-k-1)		0.54 (p = 0.47)	0.42 (p = 0.52)
JBN, $\chi^2(2)$		0.26 (p = 0.88)	0.20 (p = 0.90)
ARCH, F(1, N-2)		0.00 (p = 0.97)	0.00 (p = 0.99)
ADF		-4.87 (p = 0.00)	-4.98 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms.
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.

Crops sector

The final equations for the TFPGu and TFPGa are statistically significant at the 1% level. They are presented in Table 6.7, together with the standard diagnostic tests.

Similar to the traditional agriculture, the private research and the interaction effect between public and foreign research is positively influencing the TFPG in all cases. There is no lag involved in the private research-TFPG linkages. This probably implies that most of the private research is applied research that takes a relatively short period to yield results that effectively raise the TFPG. Public research and extension services have a positive impact but there is no evidence that they are statistically significant. This suggests the private sector has played an important role in developing agricultural technology in the crops sector and their research has quite an immediate impact on the TFPG.

For other explanatory variables, the estimated coefficient of the resources reallocation (NR) variable has a positive and significant impact on both measures of TFPG. As this variable is measured as a non-rice employment share, it implies that more workers released from rice production to other crops can increase the overall productivity of the crops sector.

Table 6.7 TFP Determinants in Crops sector based on GRM and Attribution Model

	Model	13	14
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		-1.045	-0.915
		(-1.092)	(-1.029)
$PUBR_t$	0	0.008	0.008
		(0.800)	(0.815)
	1	0.013	0.013
		(0.800)	(0.815)
	2	0.015	0.015
		(0.800)	(0.815)
	3	0.013	0.013
		(0.800)	(0.815)
	4	0.008	0.008
		(0.800)	(0.815)

Sum of lags	0.057	0.055
	(0.800)	(0.815)
EXT_t	0.043	0.039
	(0.791)	(0.773)
$PRIR_t$	0.168	0.181
	(2.062)**	(2.390)**
$PUBSPILL_t$	0.013	0.012
	(1.984)*	(2.013)**
NR_t	0.240	0.158
	(2.917)***	(2.066)**
N (no. of observations)	27	27
k (no. of parameters)	6	6
Adjusted R^2	0.42	0.41
F-statistics	4.77	4.68
S.E. of regression	4.34	4.03
Diagnostic tests:		
LM(1), F(1, N-k-1)	1.29 (p = 0.26)	0.17 (p = 0.68)
LM(2), F(2, N-k-2)	0.87 (p = 0.43)	0.83 (p = 0.44)
RESET, F(1, N-k-1)	1.28 (p = 0.27)	1.31 (p = 0.27)
JBN, $\chi^2(2)$	0.80 (p = 0.67)	1.91 (p = 0.38)
ARCH, F(1, N-2)	0.31 (p = 0.58)	0.00 (p = 0.97)
ADF	-5.97 (p = 0.00)	-4.67 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms.
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.

Livestock sector

The preferred parsimonious models are statistically significant at the 10% level. They all perform well in terms of the commonly used diagnostic tests. Like the other sectors, the TFPGu and TFPGa yield similar results as shown in Table 6.8.

In the preferred equations, private research is the only technology factor that appears to have a positive and significant impact while the other research variables (public and foreign research) turn out to be insignificant. Instead, natural factors like rainfall and epidemic have a more influencing role on TFPG. More rainfall is beneficial to the TFPG while the Bird Flu outbreak has a harmful impact. In particular, the Avian Influenza outbreak (BIRD) has the largest impact as indicated by the magnitude of its estimated coefficient. The results suggest the Bird Flu outbreak causes a reduction in the TFPGu and TFPGa by 23.2 percent and 22.9 percent, respectively.

Table 6.8 TFP Determinants in Livestock Sector based on GRM and Attribution Model

	Model	15	16
		Dependent Variables (TFPG)	
		$TFPGu_t$	$TFPGa_t$
Variables	Lag	Coefficient	Coefficient
Constant		1.910	1.504
		(0.929)	(0.748)
$PUBR_t$	0	-0.049	-0.050
		(-1.374)	(-1.410)
	1	-0.074	-0.075
		(-1.374)	(-1.410)
	2	-0.074	-0.075
		(-1.374)	(-1.410)
	3	-0.049	-0.050
		(-1.374)	(-1.410)
Sum of lags		-0.249	-0.250
		(-1.374)	(-1.410)
$BREED_t$	0	0.003	0.003
		(0.252)	(0.232)
	1	0.005	0.004
		(0.252)	(0.232)
	2	0.005	0.004
		(0.252)	(0.232)
	3	0.003	0.003
		(0.252)	(0.232)
Sum of lags		0.016	0.014
		(0.252)	(0.232)
EXT_t		-0.118	-0.102
		(-1.526)	(-1.350)
$PRIR_t$		0.224	0.214
		(2.189)**	(2.142)**
$RAIN_t$		0.290	0.293
		(1.929)*	(1.994)*
BIRD		-23.209	-22.958
		(-2.150)**	(-2.174)**
N (no. of observations)		27	27
k (no. of parameters)		7	7
Adjusted R^2		0.24	0.24
F-statistics		2.34	2.37
S.E. of regression		8.89	8.70
Diagnostic tests:			
LM(1), F(1, N-k-1)		0.16 (p = 0.69)	0.01 (p = 0.93)
LM(2), F(2, N-k-2)		0.83 (p = 0.45)	0.98 (p = 0.39)
RESET, F(1, N-k-1)		0.63 (p = 0.43)	0.96 (p = 0.34)

JBN, $\chi^2(2)$	0.24 (p = 0.88)	0.42 (p = 0.81)
ARCH, F(1, N-2)	1.47 (p = 0.23)	1.86 (p = 0.18)
ADF	-5.49 (p = 0.00)	-5.11 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%.
All variables are measured in rate of change terms.
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.

6.2.3 Implications from the GRM Findings

The results from the growth-rate model (GRM) suggest that public spending on agricultural research is a major factor in explaining the TFP growth in Thai agriculture over the study period of 1971-2006. This answers the question of this thesis of whether agricultural research has a positive and significant impact on the TFP growth. The answer is that it does but only by a small extent. This also confirms the general belief that the longstanding public investment in agricultural research is an important source of the TFP growth. There are, on average, 4 year lags between the research investment and its influence on productivity growth.

The role of international research is relatively minor. However, when it comes to the attribution model the collaboration between public and foreign research plays a more important role in explaining the TFP growth during the period 1980-2006. The private research has a positive and significant impact on the TFP in all sectors and the magnitude of the impact is relatively large. This suggests the private sector has played an important role in developing agricultural technology in the Thailand context.

It is also worth noting that the estimation results for all four sectors do not work equally well because factors affect TFPG differently in each sector. The results are also sensitive to the study period and the data. In addition, the values of F-statistics indicating the overall significance of the preferred models are generally low and only a few variables turn out to be significant. This implies the growth-rate model and the polynomial distributed lags may not be able to capture well the relationship between TFPG and its potential determinants.

The search of TFP determinants using the growth-rate model and PDL structure is meant to be the starting point of the analysis. It still suffers from omitting the level-term information and imposing a restrictive lag structure. As the estimation models include variables expressed in growth terms, the results do not capture the level effects. There may be a more meaningful long-run relationship if the TFP and its potential explanatory variables are measured in level terms. This will be investigated in the next step using the error correction modelling technique (Hendry 1995).

6.3 The Search for TFP Determinants: What the ECM tells

In the previous section, the growth-rate model and conventional lag structure was employed to explain the residual TFP growth in Thai agriculture. The variables were expressed as rates of growth, which is equivalent to taking log and first differencing on the data series. The usual practice of imposing the second-degree polynomial distributed lags (PDL) was also applied to capture the likely impact of the public research spending. However, this method is subject to two major caveats. First, important parts of the long-run relationship between the variables may have been removed with the trend element from the differencing. Second, the restrictive PDL lag structure may not be appropriate. To overcome these limitations, this section explores other estimation procedures.

To capture the level information, this section considers the variables measured in level terms in search of factors explaining the TFP. However, most of the variables expressed in levels are non-stationary, which increases the possibility of spurious or nonsense regressions. Error Correction Modelling (ECM) offers a reasonable option as it helps capture both short-run and long-run relationships while guarding against the possibility of estimating spurious relationships. The dynamic lag structure is also allowed without imposing any restrictive form of lag (Athukorala and Sen, 2002).

This section reports estimation results of the final parsimonious equations for the general and attribution models. General findings are reported first, followed by an interpretation of the results in each sector.[180]

6.3.1 General Model (1971-2006)

1) General Findings

In general, public agricultural research appears to be the major factor positively influencing TFP in major agricultural sectors, particularly for crops and livestock. However, it does not turn out to be significant for overall agriculture (Ag1). This is likely due to the definition of public research that mainly includes crops and livestock research and therefore does not explain the variation of overall TFP as effectively as it explains TFP in traditional agriculture (Ag2, combining crops and livestock together) or in crops or in livestock.[181]

The positive and significant impact of public research is consistent with the theory and findings from previous studies.[182] This supports the general belief that research-induced technical change is a main driving force behind the impressive growth of TFP in Thai agriculture.[183] It is also consistent with the findings from international studies that agricultural research is a prime source of technical change that improves productivity in many countries (Evenson, 1993, Fuglie, 1999, Ruttan, 2002 and Thirtle et al., 2003).

Other major determinants of TFP are international research spillovers, agricultural extension, rainfall, rural roads, trade openness, the world agricultural commodity boom and the Avian Influenza outbreak. These variables are statistically significant

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[180] Detail of ECM results (the general model) is shown in Appendix 6B.
[181] See Chapter 5 for the definition of variables and data sources.
[182] The previous Thai studies (Setboonsarng and Evenson, 1991 and Pochanukul, 1992) employing the profit function method found a positive and significant public research impact on productivity in the crops sector.
[183] Tinakorn and Sussangkarn (1996, 1998) and Poapongsakorn and Anuchitworawong (2006) believed that the relatively high TFP growth in the agricultural sector was due to public investment in agricultural research. However, this belief was not empirically tested.

with expected signs. The findings are generally consistent between the unadjusted and adjusted TFP equations.

International research spillovers play a particularly important role in the crops sector. This finding conforms to prior expectation that modern rice or other crops varieties developed by CGIAR supporting centres (IRRI, CYMMYT and CIAT) positively influence crops productivity in Thailand. Failure to account for this spillover effect will result in a biased (higher) estimate of public research impact. The results also suggest foreign research contributed more to productivity gains than local public research during the studied period.

Compared with the estimated results from the growth-rate model, the ECM uncovers a more meaningful long-run relationship between the variables. More variables are shown to influence TFP such as rainfall (in Ag1 and Ag2) and foreign research, rural roads and commodity boom (in Ag2 and crops). Most of the determinants only have a significant impact on TFP in the long run. The ECM yields better results in terms of the coefficients of agricultural extension (EXT) in overall agriculture.[184] The extension variable, which has unexpected negative sign in the case of overall agriculture using the GRM, turns out to be statistically insignificant.

As TFP is well recognized as a measure of our ignorance (Abramoviz, 1956), it is hard by itself to find a well fitting model that explains the variations of TFP empirically. In particular, the residual TFP measure depends on many factors, both economic and non-economic, some of which are difficult to measure properly. This is why in most cases several potential variables were found to be statistically insignificant and about half of TFP variations are still left unexplained as indicated by the adjusted R-square.

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[184] In the growth-rate model, agricultural extension has a negative and significant impact on the TFPG in overall agriculture.

2) Sectoral Findings

Overall Agriculture (Ag1)

In overall agriculture, all the TFP determinant equations are statistically significant at the 1% level in terms of the standard F test and perform well in terms of standard diagnostic tests for serial correlation (LM), functional form specification (RESET), normality (JBN), heteroskedasticity (ARCH) and stationarity of the residuals (ADF). The final parsimonious equations are shown in Table 6.9. The choice of dropping or keeping variables in the final models was statistical acceptance in terms of 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.

The results indicate that most of the variables have a long-run impact on TFP, as shown by the significance of the estimated coefficients in the level rather than the change terms. Searching for the determinants of TFP using only the first differenced or growth rate as in the previous section can miss out these level relationships. Major factors significantly influencing TFP turn out somewhat differently between the two sets of TFP measures.

Major factors influencing unadjusted TFP are education (EDU), rainfall (RAIN) and the world commodity boom (BOOM). The estimated coefficients of EDU and RAIN are statistically significant at the 1% level while that of BOOM is significant at the 10% level. All these variables have the expected positive signs. The long-run elasticities calculated from the steady-state solutions for EDU, RAIN and BOOM are 0.04, 0.11 and 0.04, respectively. The significant positive impact of education implies that it improves farmers' ability to process information and select, manage, and operate new technologies. More rainfall increases agricultural production and hence productivity. The world commodity boom encouraged farmers to grow more crops and use existing inputs more intensively thereby raising agricultural productivity.

For the adjusted TFP equation, major factors affecting overall agricultural productivity are trade openness and rainfall. The education variable does not influence the adjusted TFP because it has already been accounted for when adjusting labour quality. The dummy variable capturing the world commodity boom does not appear to be significant in this TFPa model. The significant role of trade openness (TO), measured as the ratio of agricultural import and export to agricultural output, is consistent with the fact that Thailand is a major agricultural exporter and adopts a relatively liberal agricultural trade policy. Trade openness helps in achieving economies of scale by expanding market size through export as well as enhancing competition and new technological development, thereby increasing TFP.

The coefficients of the lagged dependent variable (TFP_{t-1}) are statistically significant with the expected negative signs in every equation. They indicate the speed of adjustment of TFP to exogenous shocks. The coefficients corresponding to $TFPu_{t-1}$ and $TFPa_{t-1}$ are quite large, implying a very high speed of adjustment to dissipate the shock in the absence of policy action. It takes approximately 4 years for the TFPu model and 9 years for the TFPa model to clear the shock and reach the long run equilibrium.

The coefficients of public research (PUBR) and extension (EXT) variables have expected positive signs but there is no evidence that they are statistically significant in either the short run or the long run. The foreign research spillovers (SPILL) variable and its interaction term with public research have unexpected negative signs but they are statistically insignificant and were therefore dropped. Other explanatory variables including infrastructure, resource reallocation, capital imports and weather condition do not appear to be statistically significant.

It is important to note that the results could reflect data problems. In particular, the foreign research spillovers variable covers only agricultural research spending on some major crops (rice, cassava, maize and wheat). The public agricultural research and extension variables cover mainly crops and livestock expenditure. Given the partial measures of these variables, it is not safe to infer they are unimportant in explaining the variation of TFP in the overall sector that includes crops, livestock, fisheries, forestry and agricultural services.

Table 6.9 TFP Determinants in Overall Agriculture based on ECM and General Model

ECM Model	17		18	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-0.665		-0.025	
	(-1.448)		(-0.119)	
$\Delta PUBR_t$	0.012		0.004	
	(1.079)		(0.349)	
ΔEXT_t	0.005		0.024	
	(0.139)		(0.716)	
$PUBR_{t-2}$	0.007	0.007	0.008	0.010
	(0.733)	(0.729)	(0.780)	(0.764)
EXT_{t-1}	0.002	0.002	0.022	0.028
	(0.107)	(0.107)	(1.171)	(1.187)
TO_{t-2}	0.077	0.078	0.123	0.154
	(1.445)	(1.492)	(2.964)***	(3.770)***
EDU_{t-2}	0.037	0.038		
	(2.555)**	(2.779)***		
$RAIN_{t-1}$	0.113	0.115	0.051	0.063
	(2.354)**	(2.636)***	(1.757)*	(1.683)*
$BOOM_t$	0.043	0.044	0.037	0.046
	(1.864)*	(1.836)*	(1.457)	(1.391)
TFP_{t-1}	-0.983		-0.798	
	(-6.208)***		(-4.971)***	
N (no. of observation)	34		34	
k (no. of parameters)	10		10	
Adjusted R^2	0.54		0.44	
F-statistics	5.38		4.38	
S.E. of regression	0.03		0.03	
Diagnostic tests:				
LM(1), F(1, N-k-1)	0.04 (p = 0.83)		0.07 (p = 0.79)	
LM(2), F(2, N-k-2)	1.82 (p = 0.18)		1.21 (p = 0.31)	
RESET, F(1, N-k-1)	0.58 (p = 0.45)		2.55 (p = 0.12)	
JBN, $\chi^2(2)$	0.76 (p = 0.68)		0.76 (p = 0.68)	
ARCH, F(1, N-2)	0.88 (p = 0.35)		0.55 (p = 0.46)	
ADF	-5.78 (p = 0.00)		-5.47 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

Traditional Agriculture (Ag2: Crops and Livestock only)

For traditional agriculture, the final parsimonious equations are statistically significant at the 1% level in terms of the F test. They all pass the standard diagnostic tests. The error correction coefficients (TFP_{t-1}) are statistically significant with expected negative signs implying the equilibrium relationship will hold in the long run. In general, the final equations yield promising results with the expected signs, as shown in Table 6.10.

Major factors explaining the residual TFP in traditional agriculture, combining crops and livestock together, are public research, foreign research spillovers, rainfall, rural roads and the world commodity boom. These factors have a positive and significant impact on both adjusted and unadjusted TFP.

Public research has a positive and significant impact on TFPu and TFPa only in the long run. The associated long-run elasticities, computed at the steady state solutions, are 0.04 and 0.05, respectively. This suggests a 1 percent increase in public research spending increases unadjusted and adjusted TFP by 0.04 and 0.05 percent, respectively, in the long run. The short-term research impact on productivity is also positive but not statistically significant as shown by the estimated coefficient in the change term. Note that agricultural extension and its interaction term with public research do not appear to be statistically significant in various experimental runs and were therefore dropped from the final equations.[185]

Similar to public research, foreign research spillovers (SPILL) are statistically significant and positively influence the TFPu and TFPa in the long run, whereas the positive short-term impact does not appear to be significant. The magnitude of the foreign research impact is larger than that of public research. A 1 percent increase in the international agricultural research spending encourages unadjusted and adjusted TFP by 0.14 and 0.12 percent, respectively, in the long run. Although the foreign research variable is partially measured as international spending on major crops, its

[185] The choice of dropping variables was statistical acceptance in term of the joint variable deletion test against the maintained hypothesis.

significance is consistent with the fact that crops dominates agricultural output and its positive sign conforms to prior expectation that the spillovers of foreign technology and varieties should benefit output and productivity in Thai agriculture. However, this finding is subject to data constraints regarding the crude measure of the foreign research variable. This point is highlighted in the last chapter discussing the limitations of this study.

Other controlled factors that appear statistically significant are rainfall (RAIN), rural roads (ROAD) and the world commodity boom during 1972-1974 (BOOM). These variables have expected positive signs and affect TFP only in the long-run. The long-run elasticities of RAIN, ROAD and BOOM are estimated at 0.10, 0.07 and 0.16, respectively, using the estimated coefficients from the TFPa model. This implies infrastructure, weather-related and case-specific factors are important drivers of the relatively high rate of growth of TFP in traditional agriculture.[186] Other explanatory variables, e.g., resource reallocation, irrigation and trade openness, were tested from various experimental runs but do not appear to be statistically significant.

The coefficients of the lagged dependent variable (TFP_{t-1}) in both equations are statistically significant with the expected negative signs and their magnitudes are quite large. This implies a very high speed of adjustment to clear exogenous shock in the absence of policy action, which takes approximately 5 years to reach the long run steady-state.

Table 6.10 TFP Determinants in Traditional Agriculture based on ECM and General Model

ECM Model	**19**		**20**	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-2.552 (-4.569)***		-2.260 (-4.408)***	
$\Delta PUBR_{t-1}$	0.043 (0.958)		0.046 (1.055)	

[186] In Chapter 4, the traditional agriculture (Ag2) was shown to have the highest measured TFP growth.

$\Delta SPILL_{t-1}$	0.146		0.030	
	(0.911)		(0.201)	
$PUBR_{t-2}$	0.042	0.046	0.049	0.050
	(1.824)*	(1.788)*	(2.175)**	(2.153)**
$SPILL_{t-1}$	0.131	0.144	0.120	0.122
	(2.934)***	(2.939)***	(2.795)***	(2.767)***
$RAIN_{t-1}$	0.121	0.132	0.102	0.104
	(2.205)**	(2.266)**	(1.949)*	(1.972)*
$ROAD_{t-1}$	0.091	0.099	0.069	0.071
	(3.541)***	(5.034)***	(3.102)***	(3.970)***
$BOOM_{t}$	0.169	0.185	0.159	0.161
	(3.191)***	(3.448)***	(3.131)***	(3.339)***
TFP_{t-1}	-0.913		-0.983	
	(-5.499)***		(-5.731)***	
N (no. of observation)	33		33	
k (no. of parameters)	9		9	
Adjusted R^2	0.58		0.59	
F-statistics	6.45		6.75	
S.E. of regression	0.04		0.04	
Diagnostic tests:				
LM(1), F(1, N-k-1)	0.29 (p = 0.59)		0.54 (p = 0.47)	
LM(2), F(2, N-k-2)	0.14 (p = 0.86)		0.49 (p = 0.61)	
RESET, F(1, N-k-1)	0.62 (p = 0.44)		0.34 (p = 0.56)	
JBN, $\chi^2(2)$	0.20 (p = 0.90)		0.27 (p = 0.87)	
ARCH, F(1, N-2)	0.35 (p = 0.55)		0.16 (p = 0.69)	
ADF	-5.02 (p = 0.00)		-4.90 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

Crops Sector

As shown in Table 6.11, the TFP determinant models in the crops sector are statistically significant at the 1% level in terms of the F test. All equations pass the standard diagnostic tests. The error correction coefficients (TFP_{t-1}) also have expected negative signs and are statistically significant at the 1% level. Major factors affecting TFP are agricultural research, both public and foreign research, agricultural extension, infrastructure and the commodity boom. The results yield expected signs and are consistent between unadjusted and adjusted TFP equations.

Public agricultural research (PUBR) 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 by 1 percent leads to an increase in the rate of growth of TFPu and TFPa by 0.15 percent and 0.16 percent, respectively. The short-run effects also operate with three-year lags. In the long-run, a 1 percent increase in the public research spending seems to raise the TFPu and the TFPa by 0.06 percent and 0.07 percent, respectively.

Agricultural extension (EXT) affects the TFPu and the TFPa only in the short run. The estimated coefficients of the change term of EXT (ΔEXT_{t-1}) 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.[187]

Foreign research spillovers (SPILL), measured as the CGIAR spending on IRRI, CIMMYT and CIAT, have a positive and significant impact on TFP in the long run. A 1 percent increase in foreign research spending seems to result in a steady-state (long-run) increase in TFPu and TFPa by 0.12 percent and 0.11 percent, respectively. This is consistent with prior expectation that the spillovers of crops varieties, particularly rice varieties from IRRI, benefit crops productivity locally. The failure to account for this factor tends to bias upward the estimated coefficient of local research.[188]

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

[187] The choice of dropping lagged level of EXT variable is statistical acceptance.
[188] When dropping the foreign research variable, public research turns out to be more significant and have a larger impact on TFP.

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.

Table 6.11 TFP Determinants in Crops Sector based on ECM and General Model

ECM Model	21		22	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-1.205		-1.056	
	(-6.563)***		(-6.460)***	
$\Delta PUBR_{t-3}$	0.146		0.155	
	(4.129)***		(4.423)***	
ΔEXT_{t-1}	0.132		0.137	
	(3.530)***		(3.665)***	
$PUBR_{t-3}$	0.052	0.060	0.059	0.067
	(1.958)*	(2.230)**	(1.876)*	(2.117)**
$SPILL_{t-1}$	0.101	0.117	0.092	0.105
	(3.203)***	(3.331)***	(2.955)***	(3.045)***
$ROAD_{t-1}$	0.046	0.053	0.033	0.038
	(2.659)**	(2.684)***	(1.977)**	(1.962)**
$BOOM_t$	0.136	0.158	0.127	0.145
	(3.291)***	(3.409)***	(3.104)***	(3.189)***
TFP_{t-1}	-0.864		-0.872	
	(-6.667)***		(-6.664)***	
N (no. of observation)	34		34	
k (no. of parameters)	8		8	
Adjusted R^2	0.69		0.69	
F-statistics	11.51		11.31	
S.E. of regression	0.03		0.03	
Diagnostic tests:				
LM(1), F(1, N-k-1)	0.00 (p = 0.95)		0.06 (p = 0.79)	
LM(2), F(2, N-k-2)	0.49 (p = 0.61)		1.42 (p = 0.26)	
RESET, F(1, N-k-1)	0.66 (p = 0.42)		0.89 (p = 0.35)	
JBN, $\chi^2(2)$	0.85 (p = 0.65)		0.77 (p = 0.68)	
ARCH, F(1, N-2)	0.03 (p = 0.85)		0.00 (p = 0.98)	
ADF	-5.64 (p = 0.00)		-5.79 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

Livestock Sector

The parsimonious equations in the livestock sector also pass the standard F test and diagnostic tests at the 1% level, as shown in Table 6.12. Unlike the preferred models in other sectors, insignificant variables are kept despite the unexpected signs, such as the coefficients of foreign research (BREED) and extension (EXT). The reason is that by dropping these insignificant variables the model does not pass the RESET functional form test. The final equations generally yield results that conform to the theoretical framework.

The major factors explaining the livestock TFP are public agricultural research and the Avian Influenza outbreak. The determinants are consistent between the two TFP measures. Public research (PUBR) has a positive and significant impact only in the long run. The estimated long-run elasticity, statistically significant at the 5% level, suggests a 1 percent increase in the government research spending leads to a 0.17 percent increase in both TFPu and TFPa.

The coefficient of extension expressed in change term is statistically significant at the 10% level only in the TFPa equation. This suggests livestock extension has a positive and significant impact on the adjusted TFP only in the short run and its impact operates with a one-year lag. The long-run impact of agricultural extension has unexpected negative sign but does not appear to be statistically significant.

There is no evidence that the foreign research variable (BREED), measured as the import of livestock breeds as a share of livestock output, is statistically significant in determining the productivity in both the short and long run.

For other explanatory variables, the dummy variable representing the Bird Flu outbreak (BIRD) has a negative impact on the TFP as expected. Its coefficient is statistically significant at the 5% level in the TFPu model and at the 1% level in the TFPa model. The commodity boom dummy variable does not turn out to be significant as it is not directly relevant to livestock as in the case of crops. Other variables were tested from various experimental runs but do not appear to be statistically significant and were therefore dropped from the final equation.

Table 6.12 TFP Determinants in Livestock Sector based on ECM and General Model

ECM Model	23		24	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	0.283		0.386	
	(1.639)		(2.246)**	
ΔEXT_{t-1}	0.105		0.119	
	(1.488)		(1.728)*	
$\Delta BREED_t$	0.007		0.012	
	(0.318)		(0.517)	
$PUBR_{t-3}$	0.125	0.168	0.128	0.173
	(1.976)*	(2.021)**	(2.074)**	(2.111)**
EXT_{t-1}	-0.069	-0.094	-0.089	-0.121
	(-1.219)	(-1.211)	(-1.590)	(-1.578)
$BREED_{t-1}$	-0.014	-0.019	-0.003	-0.004
	(-0.769)	(-0.760)	(-0.168)	(-0.167)
$BIRD$	-0.135	-0.182	-0.165	-0.224
	(-2.194)**	(-2.063)**	(-2.720)***	(-2.593)***
TFP_{t-1}	-0.743		-0.739	
	(-5.379)***		(-5.510)***	
N (no. of observation)	35		35	
k (no. of parameters)	8		8	
Adjusted R^2	0.49		0.50	
F-statistics	5.60		5.93	
S.E. of regression	0.09		0.09	
Diagnostic tests:				
LM(1), F(1, N-k-1)	0.00 (p = 0.95)		0.00 (p = 0.99)	
LM(2), F(2, N-k-2)	0.99 (p = 0.38)		1.47 (p = 0.25)	
RESET, F(1, N-k-1)	2.15 (p = 0.15)		1.80 (p = 0.19)	
JBN, $\chi^2(2)$	1.09 (p = 0.57)		0.86 (p = 0.65)	
ARCH, F(1, N-2)	1.25 (p = 0.27)		1.31 (p = 0.26)	
ADF	-4.86 (p = 0.00)		-4.89 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

6.3.2 Attribution Model (1980-2006)

1) General Findings

In addressing the attribution issue (addressing which types of research expenditure contribute most to TFP), the attribution model includes more research variables – public, private, university and foreign– but covers a shorter period (due to data limitations). The ECM still yields results that are generally consistent with the theory and prior expectation. The attribution models do not work equally as well as the general model due to the inclusion of different variables and a shorter period. Nonetheless, the attribution model using ECM fits the data better than the growth-rate model in the previous section (6.2.2) in terms of the standard F test and more variables turn out to be statistically significant.

Focusing on agricultural research, the general finding is that all major types of research spending have played an important role in influencing TFP. Public, university, and private research have all had a positive and significant impact on overall TFP (either in short or long run). Foreign research does not appear to be significant in the case of adjusted TFP in overall agriculture or in all cases of crops and traditional agriculture. Private-sector research contributes the most to TFP in all agricultural sectors. The public-sector research is still attributable to TFP but to a smaller extent. This may be because the public-sector provides more basic and health maintenance research that does not increase the measured productivity directly while private research is more profit-oriented and directed to raise output and productivity.

Moreover, the ECM uncovers more meaningful level relationships between TFP and other factors, namely, rainfall, rural roads and trade openness. These relationships were missed when considering only the rate of change variables. It is therefore obvious that the ECM gives better results than the growth-rate model under the attribution model specification. The meaning of the findings is discussed further in the conclusion.

It is also worth noting that the attribution model was initially estimated using the composite domestic research which sums all types of domestic research in order to compare local with foreign research. In general, both domestic and foreign research does not appear to have a significant long-term impact on TFP and only a few variables were shown to be statistically significant. This is mainly because each type of domestic research affects TFP differently and summing them together does not give a clear impact on the TFP. It is preferable not to use the composite domestic research variable mainly because public research produces knowledge as a public good while private research produces knowledge which is largely excludable from farmers who do not pay for it as a private good. Not surprisingly, in view of this theoretical point using disaggregated research variables also performs better statistically. The following discussion focuses on the results using disaggregated research variables.

2) Sectoral Findings

Overall Agriculture (Ag1)

The attribution models incorporating private and university research from 1980-2006 are statistically significant at the 1% level in terms of the standard F test. The final parsimonious equations explaining the unadjusted and adjusted TFP also pass the diagnostic tests, as shown in Table 6.13. The TFPu model encountered an autocorrelation problem in the three lagged residuals. It is corrected by adding three autoregressive (AR) terms in the equation.

Focusing on agricultural research, all types of research spending – public, private, university, and foreign variables have the expected positive signs. Other determinants are agricultural extension and rainfall. Significant variables turn out to be slightly different between the two TFP measures.

In the TFPu equation, the public and university research are statistically significant at the 1% level with a positive sign only in the short run. International research spillovers (SPILL) has a positive and significant impact in both the short and long run. The estimated results suggest a 1 percent increase in CGIAR funding to IRRI, CIAT and CIMMYT leads to an increase in the unadjusted TFP growth by 0.18 percent in the short run and 0.09 percent in the long-run. Private research and public extension spending affect TFP only in the long run with elasticities of 0.16 and 0.02, respectively. They are statistically significant at the 1% level. In terms of relative importance, private research has the largest impact as indicated by the magnitude of its long-run elasticity.

For the adjusted TFP, the determinants of TFPa are similar to that of TFPu, except that the international research spillovers and agricultural extension do not appear to be significant. Public and university research have a positive and significant impact in the short run. Factors affecting TFP in the long run are private research and rainfall. The computed long-run TFP elasticities with respect to private research and rainfall are 0.12 and 0.11, respectively.

Table 6.13 TFP Determinants in Overall Agriculture based on ECM and Attribution Model

ECM Model	25		26	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-2.053 (-7.550)***		-1.482 (-4.082)***	
$\Delta PUBR_{t-2}$	0.017 (2.843)***		0.020 (2.109)**	
$\Delta UNIR_t$	0.078 (3.450)***		0.094 (3.001)***	
$\Delta SPILL_t$	0.181 (1.847)*		0.139 (1.192)	
$PRIR_{t-1}$	0.191 (8.551)***	0.157 (10.489)***	0.137 (3.136)***	0.123 (3.434)***
$SPILL_{t-1}$	0.111 (3.944)**	0.092 (4.871)***	0.014 (0.256)	0.013 (0.258)
EXT_{t-1}	0.027 (3.259)***	0.022 (3.393)***	0.030 (1.428)	0.027 (1.421)
$RAIN_{t-1}$	0.138 (5.269)***	0.113 (7.310)***	0.130 (2.946)***	0.116 (3.027)***
TFP_{t-1}	-1.219 (-9.233)***		-1.113 (-6.377)***	
N (no. of observation)	25		25	
k (no. of parameters)	12†		9	
Adjusted R^2	0.85		0.65	

F-statistics	12.06	6.50
S.E. of regression	0.02	0.02
Diagnostic tests:		
LM(1), F(1, N-k-1)	3.03 (p = 0.11)	0.74 (p = 0.40)
LM(2), F(2, N-k-2)	2.07 (p = 0.18)	1.70 (p = 0.22)
RESET, F(1, N-k-1)	0.05 (p = 0.81)	0.03 (p = 0.86)
JBN, $\chi^2(2)$	0.45 (p = 0.79)	1.02 (p = 0.60)
ARCH, F(1, N-2)	0.00 (p = 0.97)	0.24 (p = 0.62)
ADF	-5.22 (p = 0.00)	-5.17 (p = 0.00)

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
† includes 3 AR terms since the original equation encountered autocorrelation problem at 3 lags.
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.

Traditional Agriculture (Ag2)

In traditional agriculture, the attribution model considers only public, private and foreign research because data on university research are not available. The final parsimonious estimate of the attribution model, together with a set of commonly used diagnostic statistics, are reported in Table 6.14. All the equations are statistically significant at the 1% level in terms of the F test and pass the standard diagnostic tests.

The results suggest major factors contributing to traditional agricultural TFP are public research, private research and rural roads. This finding is similar for both sets of TFP measure. Like the general model, public research spending (PUBR) contributes to the long-term growth of TFP. The long-run elasticities, computed at the steady state solutions, suggest that a 1 percent increase in public R&D spending can raise the growth rate of TFPu and TFPa by 0.05 percent and 0.06 percent, respectively.

Besides the public research, private research is also attributable to productivity. The coefficients on both change and level variables of private research (PRIR) are significant with positive sign. This suggests an increase in private research expenditure can raise TFP in the short and long run. The computed long-run private

R&D elasiticities for TFPu and TFPa are 0.23 and 0.19, respectively. The magnitude of the PRIR elasticities are also the largest indicating it has the most influential impact on TFP. In this, the finding is consistent with the general expectation and that of the growth-rate model in the previous section. The private sector particularly the CP Group has played an important role in developing agricultural technology effectively raising agricultural productivity, notably in crops and livestock.

Foreign research spillovers (SPILL) do not appear to be statistically significant but it was kept in the final equations because it increases the significance of the overall model.[189] There is also no evidence that agricultural extension is statistically significant in influencing the TFP during 1980-2006.

As regards the impact of other potential determinants of TFP, only the coefficient on the rural roads (ROAD) variable is statistically significant with the expected (positive) sign. This suggests that not only technology but also infrastructure factor is important to TFP. The coefficient of ROAD in lagged level is statistically significant at the 1% level in both TFP models. The computed long-run TFP elasticity with respect to roads is 0.09 and 0.07 in TFPu and TFPa equations, respectively.

Table 6.14 TFP Determinants in Traditional Agriculture based on ECM and Attribution Model

ECM Model	**27**		**28**	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-1.762 (-3.688)***		-1.478 (-3.646)***	
$\Delta PUBR_{t-1}$	-0.004 (-0.113)		0.007 (0.197)	
$\Delta PRIR_t$	0.220 (3.054)***		0.202 (2.838)***	
$\Delta SPILL_t$	0.036 (0.218)		0.021 (0.130)	
$PUBR_{t-2}$	0.046 (2.265)**	0.050 (2.119)**	0.055 (2.623)***	0.057 (2.545)***

[189] Insignificant variables are kept in the final equation because dropping them does not pass the joint variable deletion tests against the maintained hypothesis.

$PRIR_{t-1}$	0.212	0.227	0.180	0.188
	(2.564)**	(3.553)***	(2.358)**	(3.025)***
$SPILL_{t-1}$	-0.030	-0.033	-0.049	-0.052
	(-0.349)	(-0.346)	(-0.562)	(-0.559)
$ROAD_{t-1}$	0.089	0.096	0.069	0.073
	(3.091)***	(4.709)***	(2.719)***	(3.669)***
TFP_{t-1}	-0.930		-0.955	
	(-4.029)***		(-4.116)***	
N (no. of observation)	27		27	
k (no. of parameters)	9		9	
Adjusted R^2	0.48		0.48	
F-statistics	4.04		4.05	
S.E. of regression	0.03		0.03	
Diagnostic tests:				
LM(1), F(1, N-k-1)	0.79 (p = 0.38)		0.65 (p = 0.43)	
LM(2), F(2, N-k-2)	0.92 (p = 0.41)		0.97 (p = 0.40)	
RESET, F(1, N-k-1)	1.16 (p = 0.29)		0.80 (p = 0.38)	
JBN, $\chi^2(2)$	0.18 (p = 0.91)		0.00 (p = 0.09)	
ARCH, F(1, N-2)	2.70 (p = 0.11)		2.67 (p = 0.11)	
ADF	-4.26 (p = 0.00)		-5.14 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

Crops Sector

As shown in Table 6.15, the preferred models are statistically significant at the 1% level in terms of the standard F test and also pass the commonly used diagnostic tests at the 5% level. The results are quite similar for both measures of the dependent variables.

Major factors affecting crops TFP during the shorter period of 1980-2006 are technology-related and infrastructure, including public research (PUBR), private research (PRIR), extension services (EXT) and rural roads (ROAD). However, the technological factors only have a positive and significant impact in the short run and the magnitude of the impact is the estimated coefficients in the change terms of the PUBR, PRIR and EXT variables. The coefficients of public, private and foreign research variables expressed in level terms have the expected positive signs but their associated long-run elasticities do not turn out to be statistically significant.[190] Only the rural roads variable has a positive and significant impact on the unadjusted TFP in the long run. There is no evidence that other explanatory variables are statistically significant in either the short or long run.

Table 6.15 TFP Determinants in Crops Sector based on ECM and Attribution Model

ECM Model	29		30	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	-1.371		-1.161	
	(-4.341)***		(-4.064)***	
$\Delta PUBR_{t-3}$	0.159		0.161	
	(3.112)***		(3.071)***	
$\Delta PRIR_t$	0.124		0.125	
	(1.863)*		(1.848)*	
ΔEXT_{t-1}	0.144		0.150	
	(3.099)***		(3.113)***	
$PUBR_{t-3}$	0.043	0.047	0.045	0.049
	(1.219)	(1.301)	(1.231)	(1.320)
$PRIR_{t-1}$	0.077	0.084	0.066	0.073
	(1.288)	(1.415)	(1.106)	(1.194)
$SPILL_{t-1}$	0.106	0.115	0.085	0.094
	(1.041)	(1.021)	(0.821)	(0.808)
$ROAD_{t-1}$	0.042	0.046	0.029	0.031
	(1.907)*	(2.134)**	(1.345)	(1.434)
TFP_{t-1}	-0.924		-0.910	
	(-4.689)***		(-4.552)***	
N (no. of observation)	27		27	
k (no. of parameters)	9		9	
Adjusted R^2	0.57		0.56	
F-statistics	5.41		5.13	
S.E. of regression	0.03		0.03	
Diagnostic tests:				
LM(1), F(1, N-k-1)	1.87 (p = 0.19)		1.69 (p = 0.21)	
LM(2), F(2, N-k-2)	2.98 (p = 0.08)		2.58 (p = 0.11)	
RESET, F(1, N-k-1)	0.85 (p = 0.36)		0.95 (p = 0.34)	
JBN, $\chi^2(2)$	4.04 (p = 0.13)		4.38 (p = 0.11)	
ARCH, F(1, N-2)	0.79 (p = 0.38)		0.73 (p = 0.39)	
ADF	-4.83 (p = 0.00)		-5.98 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.

[190] Note that when ignoring the private research, there is no change on the public research impact.

The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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.

Livestock Sector

The results from the preferred equations are reported in Table 6.16. They are all statistically significant at the 1% level in terms of the standard F test and pass the commonly used diagnostic tests. Like other sectors, determinants of the livestock TFP are shown to be similar between the two dependent variables.

The attribution model including all major types of research expenditure during the period 1980-2006 reveals that major factors determining livestock productivity are public research, private research, foreign research, extension, trade openness and the Bird Flu outbreak.

All research variables have a positive and significant impact on TFP as expected. Public research (PUBR) and private research (PRIR) only affect TFPu and TFPa in the long run. Foreign research (BREED), measured as imports of livestock breeds, has both a short- and long-term impact on the TFPa whereas it only has a short-term impact on the TFPu. For the TFPa which is a preferred measure of TFP, the computed long-run elasticities of public, private and foreign research are 0.14, 0.32, and 0.03, respectively. The magnitude of the private research impact is the largest, followed by public and foreign research.[191] This conforms to previous studies that large private companies, particularly the CP Group, have played an important role in the livestock sector including transferring technology to farmers.[192] Both public and private research has also relied on imported technology and animal breeds.

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[191] Note that when excluding the private research variable, both public and foreign research variables turn out to be insignificant.
[192] Kohpaiboon (2006) maintained that technology transfer to agriculture in Thailand occurs mostly through non-FDI channels and the Charoen Pokphand (CP) Group has played an important role in

Agricultural extension has an unexpected negative impact on TFP. This could be due to competing resources and funding between research and extension. Livestock extension spending has always been larger than research and the expenditure on research has declined since the mid-1990s.[193] It could be possible that resources were drawn from research to extension thereby reducing research-induced productivity.[194]

For other explanatory variables, trade openness and epidemic appear to be statistically significant factors. The coefficient of trade openness is statistically significant at the 1% level and positively signed. A 1 percent increase in the degree of trade openness can increase the TFPu and TFPa by 0.36 percent and 0.32 percent, respectively. The Bird Flu outbreak has a negative and significant impact on both measures of TFP. The occurrence of Avian Influenza results in a decline in the TFPu and TFPa by 0.40 percent and 0.45 percent, respectively. Compared with other significant determinants, the dummy variable capturing epidemic has the largest impact on TFP.

Table 6.16 TFP Determinants in Livestock Sector based on ECM and Attribution Model

ECM Model	31		32	
	Dependent Variables (ΔTFP)			
	$\Delta TFPu_t$	Long-run elasticity	$\Delta TFPa_t$	Long-run elasticity
Constant	0.554 (1.870)*		0.545 (1.858)*	
$\Delta BREED_t$	0.046 (2.805)***		0.051 (3.067)***	
$PUBR_{t-3}$	0.119 (2.407)**	0.138 (2.507)**	0.119 (2.431)**	0.139 (2.533)**
$PRIR_{t-1}$	0.256 (1.811)*	0.296 (1.895)*	0.277 (1.950)*	0.324 (2.073)**
EXT_{t-1}	-0.201 (-3.777)***	-0.233 (-3.878)***	-0.207 (-3.909)***	-0.243 (-4.039)***
$BREED_{t-1}$	0.017 (1.219)	0.020 (1.210)	0.027 (1.849)*	0.031 (1.859)*

transferring technology to farmers. Siamwalla et al. (1993) claimed that the success of the Thai poultry industry was partly driven by the adoption of modern breeds and advanced farming methods.

[193] See Figure 3.11 in Chapter 3 for the figure of livestock R&E over time and Appendix 5 in Chapter 5 for the data series.

[194] Some extension activities may contribute to non-productivity enhancing activities such as animal disease prevention which does not count as measured productivity gain

TO_{t-1}	0.308	0.357	0.270	0.316
	(3.879)***	(3.619)***	(3.454)***	(3.211)***
BIRD	-0.345	-0.400	-0.148	-0.451
	(-4.095)***	(4.070)***	(-2.935)***	(4.612)***
TFP_{t-1}	-0.863		-0.855	
	(-6.974)***		(-6.860)***	
N (no. of observation)	27		27	
k (no. of parameters)	9		9	
Adjusted R^2	0.73		0.73	
F-statistics	10.02		9.77	
S.E. of regression	0.05		0.05	
Diagnostic tests:				
LM(1), F(1, N-k-1)	1.44 (p = 0.24)		0.86 (p = 0.36)	
LM(2), F(2, N-k-2)	1.74 (p = 0.20)		1.51 (p = 0.25)	
RESET, F(1, N-k-1)	0.03 (p = 0.85)		0.00 (p = 0.97)	
JBN, $\chi^2(2)$	1.60 (p = 0.45)		1.65 (p = 0.43)	
ARCH, F(1, N-2)	0.03 (p = 0.85)		0.29 (p = 0.59)	
ADF	-6.04 (p = 0.00)		-6.60 (p = 0.00)	

Notes: Numbers in parentheses underneath each coefficient are the t-ratio of the coefficient.
The level of statistical significance is denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. Long-run elasticity can be computed by dividing the estimated coefficient of the level term with the positive value of the coefficient of the lagged dependent variable.
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;
White White's heteroskedasticity test;
ADF Augmented Dickey-Fuller test for residual stationarity.

6.4 Conclusion

6.4.1 Methodological Conclusion

Regarding the two estimation methods, the dynamics of the relationship between productivity and its main determinants are captured better by the error correction model (ECM) than the growth-rate model (GRM). The growth-rate model does not capture the long run relationship because it omits level information.

The results from the two models covering long and short periods are presented because they serve different purposes. The general model (GM) provides answers to the main research question of what factors drive the measured TFP growth in Thai agriculture for the whole study period, accounting for the role of international research spillovers and as many potential factors as the data allow. The attribution model (AM), capturing more research variables, answers the sub-question of what type of research spending –public, private, university, foreign– contributes most to TFP growth. Although it achieves this purpose, the attribution model does not perform particularly well mainly because of the shorter period.

The findings from the general model (GM) are different from those of the attribution model (AM). This suggests the determinants of TFP growth are sensitive to the period of study and the inclusion of explanatory variables. Since each type of research influences TFP differently separating them yields different results. The results of all 32 cases are summarized in Table 6.17.

Table 6.17 An Overview of TFP Estimation Results: F-Statistics and Significance

	Methods	**GRM-PDL**		**ECM**	
	Models	**GM**	**AM**	**GM**	**AM**
Sectors	Dependent Var.				
Ag1	TFPGu	1 (3.08)**	9 (5.27)***	17 (5.38)***	25 (12.06)***
	TFPGa	2 (2.24)*	10 (5.54)***	18 (4.38)***	26 (6.50)***
Ag2	TFPGu	3 (2.63)**	11 (3.91)***	19 (6.45)***	27 (4.04)***
	TFPGa	4 (2.48)*	12 (3.75)***	20 (6.75)***	28 (4.05)***
Crops	TFPGu	5 (4.79)***	13 (4.77)***	21 (11.51)***	29 (5.41)***
	TFPGa	6 (2.74)**	14 (4.68)***	22 (11.31)***	30 (5.13)***
Livestock	TFPGu	7 (3.37)**	15 (2.34)*	23 (5.60)***	31 (10.02)***
	TFPGa	8 (3.39)**	16 (2.37)*	24 (5.93)***	32 (9.77)***

Notes: GRM-PDL = Growth-rate model incorporating polynomial distributed lags
ECM = Error correction model
GM = General model (1971-2006 and includes public and foreign research)
AM = Attribution model (1980-2006 and includes public, private, university and foreign research)
Ag1 = Overall agriculture (crops, livestock, fisheries, forestry and agricultural services)
Ag2 = Traditional agriculture (crops and livestock only)
TFPGu = Unadjusted total factor productivity growth
TFPGa = Total factor productivity growth adjusted for input quality changes
Numbers in the table indicate the sequence of estimation equations presented in this chapter (corresponding to Table 5.3 in the previous chapter). Numbers in the parentheses are the F-statistics of the relevant models. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. See Appendix 6B Table 6.30 for a summary of significant variables in all cases.

The results for the four sectors do not work equally well because factors affect TFP in each sector differently. In terms of the research-productivity nexus, the results from both the GRM and ECM explain the TFP better for traditional agriculture (Ag2) than for overall agriculture (Ag1). This is presumably because the link between research variables and TFP is different for crops, livestock, fisheries, forestry and agricultural services.

As far as TFP is concerned, measurement is always a problem, from its own measurement to the factors that explain it. To a certain extent, the measurement problems weaken the empirical results. Despite these unavoidable issues, the present thesis is the first study that attempts to use the ECM to investigate the link between TFP and agricultural research in Thai agriculture. The analysis covers the longest series of TFP in Thai agriculture (based on the growth accounting method)[195] as well as disaggregating it into crops and livestock. This is apparently the first Thai study that attempts to incorporate the role of foreign research spillovers, private and university research in the TFP determinants model. In general, the results are satisfactory and sharpen understanding of the impressive growth of TFP in Thai agriculture over the past four decades. These ECM results form the basis of the policy conclusions discussed below.

6.4.2 Implication of the Results

In the context of Thai agriculture focusing on crops and livestock, the general belief that public investment in agricultural research drives TFP growth has been confirmed. The results of this study indicate that public, private and foreign research have been major driving forces behind the productivity growth. The general findings conform to Griliches (1997, p.1) that 'technical change is a major source of TFP growth and that such technical change was not purely exogenous, they were the result of economic activity, especially where its main purpose was to generate such changes as in organized public and private research'. 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.

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[195] See Table 2.1 in Chapter 2 for a summary of the previous Thai studies.

Regarding the attribution among major research performers, the ECM results indicate international research spillovers contributed more to productivity gains in crops and traditional agriculture than local public research for the whole of the studied period. However, for the shorter period of 1980-2006 the spillovers of foreign research do not appear to have played a statistically significant role. Instead, private-sector research plays a more contributing role, especially in the livestock sector. Public research remains significant for both the long and short period.

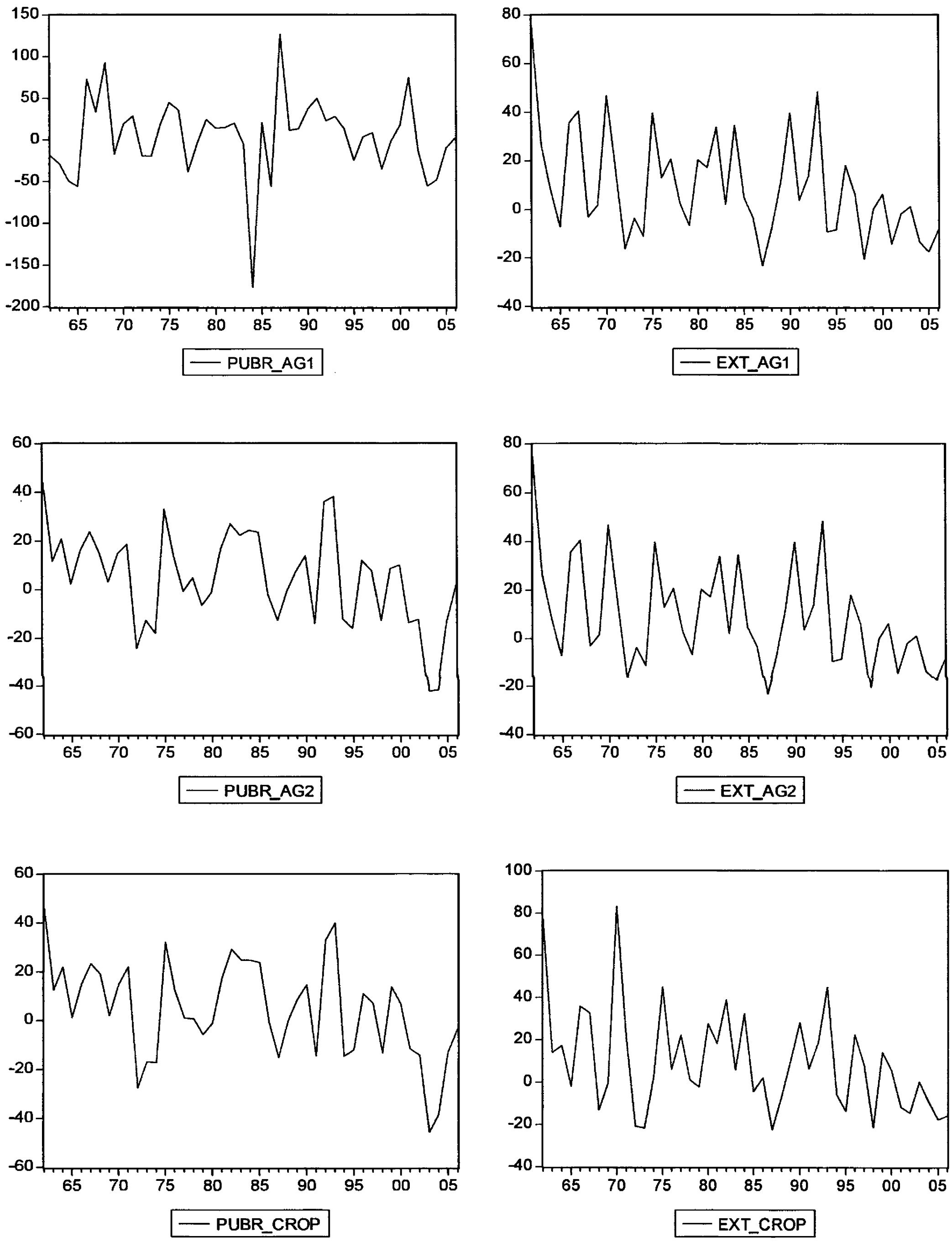
The determinants of TFP growth are not confined only to agricultural research, but also extension services, infrastructure, weather and case-specific factors, such as the commodity boom and the Bird Flu outbreak. Other factors left unexplained are likely to be due to measurement errors and unmeasured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

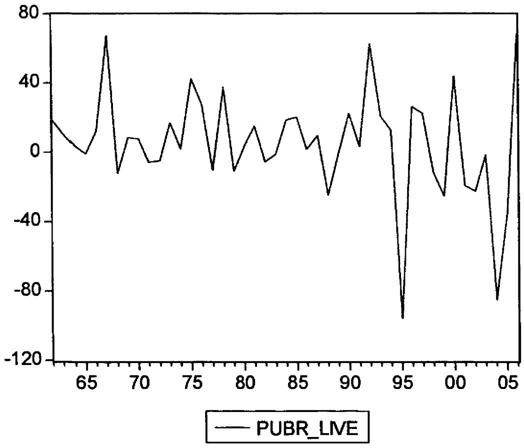
Although this chapter provides answers to the question of whether and to what extent public investment in agricultural research enhances productivity growth, it has no implication as to whether more or less investment should be made on research activities. In other words, it is still not clear whether there has been an under- or over-investment in the national research system. To determine the effectiveness of public agricultural research investment in the past decades, social rates of return on research are needed and will be undertaken in the next chapter.

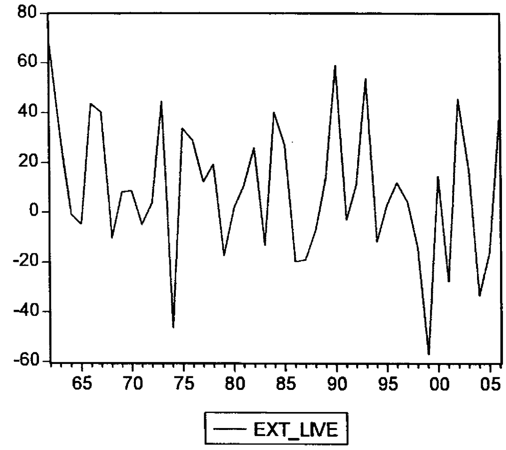
Appendix 6 Main Variables and ECM Results

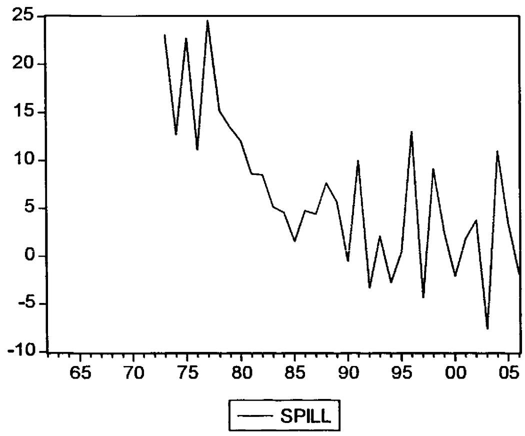
Appendix 6A: Main Variables and Summary Statistics

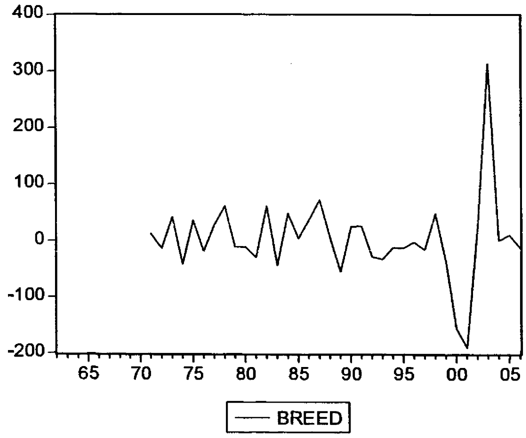
Figure 6.1 Graphs of Main Variables used in the Growth-Rate Model
(All variables expressed in rate of change terms):

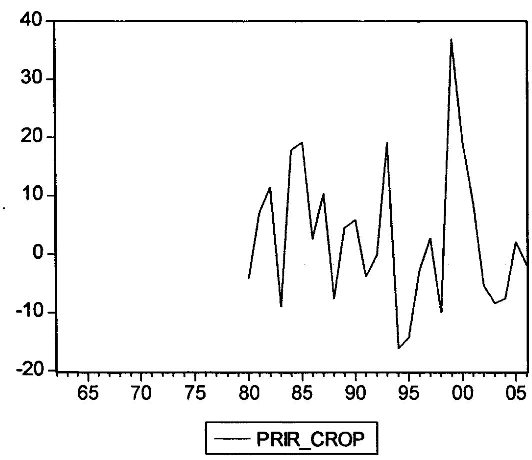



80
40
0
-40
-80
-120
65 70 75 80 85 90 95 00 05
PUBR_LIVE


80
60
40
20
0
-20
-40
-60
65 70 75 80 85 90 95 00 05
EXT_LIVE


25
20
15
10
5
0
-5
-10
65 70 75 80 85 90 95 00 05
SPILL


400
300
200
100
0
-100
-200
65 70 75 80 85 90 95 00 05
BREED


40
30
20
10
0
-10
-20
65 70 75 80 85 90 95 00 05
PRIR_CROP

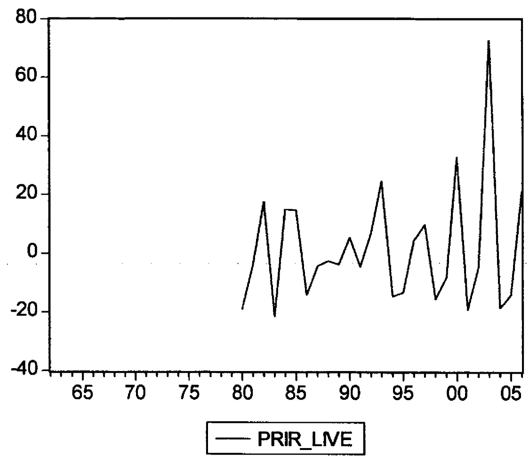
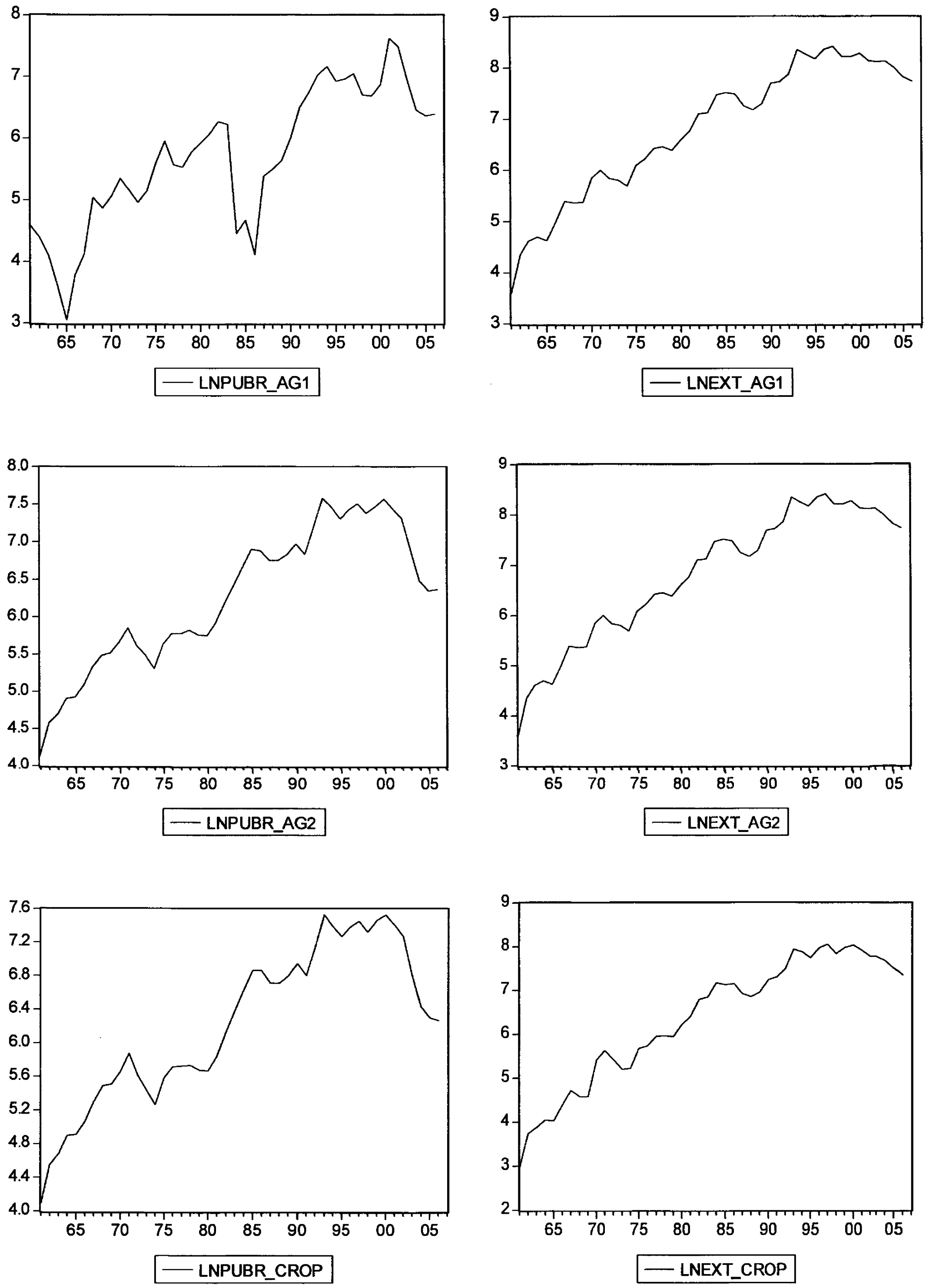
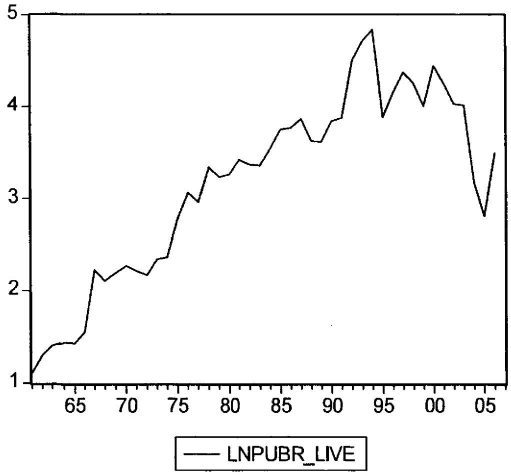
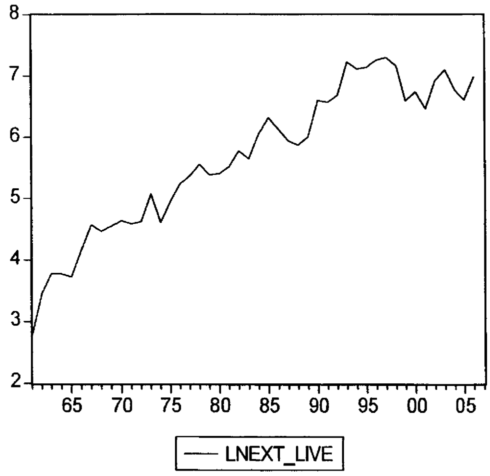
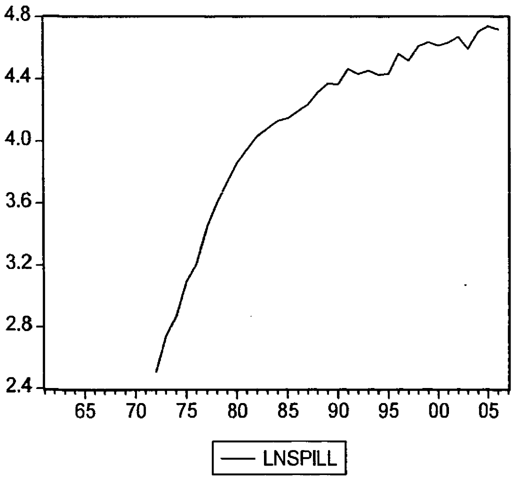

80
60
40
20
0
-20
-40
65 70 75 80 85 90 95 00 05
PRIR_LIVE

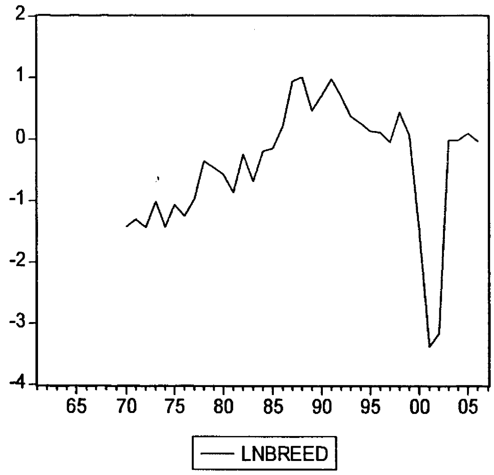
Figure 6.2 Graphs of Main Variables used in the Error Correction Model
(All variables expressed as log of original data)

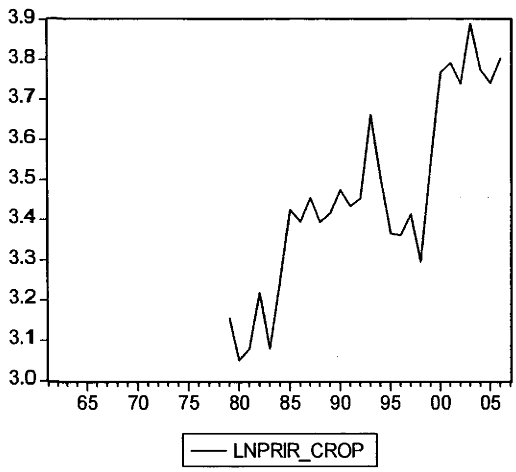



5
4
3
2
1
65 70 75 80 85 90 95 00 05
LNPUBR_LIVE


8
7
6
5
4
3
2
65 70 75 80 85 90 95 00 05
LNEXT_LIVE


4.8
4.4
4.0
3.6
3.2
2.8
2.4
65 70 75 80 85 90 95 00 05
LNSPILL


2
1
0
-1
-2
-3
-4
65 70 75 80 85 90 95 00 05
LNBREED


3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
65 70 75 80 85 90 95 00 05
LNPRIR_CROP

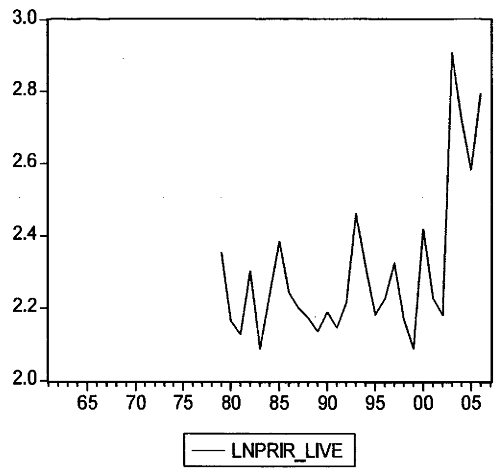

3.0
2.8
2.6
2.4
2.2
2.0
65 70 75 80 85 90 95 00 05
LNPRIR_LIVE

Table 6.18 Summary Statistics of Data used in the Growth-Rate Model
(All variables are expressed in rate of change terms)

Ag1	TFPGu	TFPGa	PUBR	EXT	SPILL	PUBSPILL	UNIR	PRIR	EDU
Mean	0.848	0.614	4.038	9.189	6.510	20.013	8.719	2.394	14.890
Median	1.349	0.942	11.644	3.692	4.986	-4.798	9.775	2.139	10.194
Maximum	10.555	9.896	127.009	74.891	24.635	1021.258	50.264	24.466	99.140
Minimum	-6.353	-6.618	-176.548	-23.199	-7.569	-942.204	-36.123	-15.641	-32.596
Std. Dev.	4.056	4.023	47.605	21.492	7.805	366.443	18.975	11.877	24.857
Observations	36	36	45	45	34	34	25	27	36

	KM	FDI	TO	RAIN	RAIN2	WEATHER	IRRIGAT	ROAD
Mean	4.361	310.195	3.957	-0.651	0.592	0.073	2.293	9.967
Median	5.824	-30.802	4.074	-0.976	1.352	0.054	1.828	8.559
Maximum	35.127	7486.417	22.836	23.720	49.143	7.427	14.375	37.133
Minimum	-39.504	-736.842	-23.192	-59.286	-28.547	-9.473	-3.043	-1.487
Std. Dev.	16.421	1456.643	9.600	16.107	14.144	3.726	2.625	8.299
Observations	36	36	36	36	36	36	36	36

Ag2	TFPGu	TFPGa	PUBR	PRIR	PUBSPILL	EXT	NC
Mean	1.347	1.062	4.962	2.394	16.906	9.189	5.034
Median	1.971	1.709	7.793	2.139	-7.317	3.692	2.312
Maximum	19.776	20.303	44.156	24.466	753.378	74.891	36.744
Minimum	-18.209	-18.254	-41.993	-15.641	-456.624	-23.199	-25.895
Std. Dev.	7.216	7.205	19.394	11.877	193.450	21.492	14.133
Observations	36	36	45	27	34	45	36

Crops	TFPGu	TFPGa	PUBR	PRIR	PUBSPILL	EXT	NR
Mean	0.877	0.680	4.830	2.919	16.507	9.729	4.137
Median	0.020	-0.142	6.719	2.180	-1.225	5.819	0.000
Maximum	16.408	17.020	45.965	37.005	730.862	83.080	36.690
Minimum	-14.754	-14.345	-45.592	-16.069	-421.260	-22.359	-28.649
Std. Dev.	6.859	6.845	19.939	12.271	194.963	24.136	13.016
Observations	36	36	45	27	34	45	36

Livestock	TFPGu	TFPGa	PUBR	PRIR	PUBBREED	BREED	EXT
Mean	0.876	0.670	5.301	-1.377	-37.947	3.880	9.339
Median	0.991	1.207	3.575	-5.429	-48.264	-0.610	8.694
Maximum	33.230	33.228	68.389	66.246	3664.328	314.220	67.753
Minimum	-30.467	-29.558	-95.625	-27.985	-6834.501	-190.006	-56.659
Std. Dev.	13.639	13.596	31.138	20.014	1496.598	74.736	27.488
Observations	36	36	45	27	36	36	45

Table 6.19 Summary Statistics of Data used in the Error Correlation Model

Ag1	dlnTFPu	dlnTFPa	lnPUBR	lnSPILL	lnPUBSPILL	lnPRIR	lnUNIR	lnEXT	lnEDU
Mean	0.009	0.006	5.694	4.119	25.481	3.462	4.839	6.807	-0.093
Median	0.014	0.009	5.709	4.367	25.439	3.430	4.992	7.152	0.572
Maximum	0.100	0.094	7.622	4.741	35.324	3.890	5.908	8.420	2.008
Minimum	-0.066	-0.068	3.056	2.510	12.951	3.052	3.560	3.604	-3.352
Std. Dev.	0.040	0.040	1.115	0.609	6.393	0.238	0.713	1.306	1.661
Observations	35	35	46	35	35	28	26	46	37

	lnTO	lnKM	FDI	lnRAIN	lnRAIN2	lnWEATHER	lnIRRIGAT	lnROAD
Mean	0.091	1.067	146.879	7.045	5.088	-0.063	2.893	9.651
Median	0.171	1.217	37.733	6.951	5.062	-0.054	2.973	9.340
Maximum	0.765	1.707	1160.933	7.542	5.405	-0.031	3.238	11.308
Minimum	-0.842	-0.392	-189.761	6.668	4.682	-0.127	2.382	7.720
Std. Dev.	0.482	0.526	275.849	0.259	0.211	0.026	0.275	1.156
Observations	37	37	37	37	37	37	37	37

Ag2	dlnTFPu	dlnTFPa	lnPUBR	lnPRIR	lnPUBSPILL	lnEXT	lnNC
Mean	0.006	0.003	6.263	3.462	27.634	6.807	1.680
Median	0.019	0.017	6.360	3.430	29.884	7.152	1.619
Maximum	0.130	0.130	7.584	3.890	34.962	8.420	2.858
Minimum	-0.201	-0.202	4.137	3.052	14.089	3.604	1.044
Std. Dev.	0.068	0.067	0.932	0.238	6.335	1.306	0.547
Observations	35	35	46	28	35	46	37

Crops	dlnTFPu	dlnTFPa	lnPUBR	lnPRIR	lnPUBSPILL	lnEXT	lnNR
Mean	0.002	0.000	6.221	3.462	27.421	6.373	3.045
Median	-0.003	-0.004	6.286	3.430	29.607	6.858	3.263
Maximum	0.123	0.122	7.533	3.890	34.755	8.054	3.576
Minimum	-0.160	-0.155	4.095	3.052	14.070	2.971	2.087
Std. Dev.	0.065	0.064	0.926	0.238	6.320	1.421	0.538
Observations	35	35	46	28	35	46	37

Livestock	dlnTFPu	dlnTFPa	lnPUBR	lnPRIR	lnPUBBREED	lnEXT	lnBREED
Mean	0.007	0.006	3.172	2.307	5.043	5.681	-0.404
Median	0.012	0.017	3.367	2.227	5.180	5.824	-0.148
Maximum	0.286	0.287	4.844	2.909	6.660	7.301	1.010
Minimum	-0.363	-0.350	1.112	2.089	2.518	2.786	-3.377
Std. Dev.	0.133	0.133	1.009	0.213	1.206	1.192	1.007
Observations	35	35	46	28	37	46	37

Notes: dln = first-differenced and log of a variable

Table 6.20 Correlation Matrix (common sample) from the Growth-Rate Model

(All variables are expressed in rate of change terms, 1971-2006)

Ag1	TFPGu	TFPGa	PUBR	PUBR(-1)	PUBR(-2)	PUBR(-3)	PUBR(-4)	EXT	PUBSPILL
TFPGu	1.00								
TFPGa	1.00	1.00							
PUBR	-0.11	-0.12	1.00						
PUBR(-1)	-0.07	-0.06	0.00	1.00					
PUBR(-2)	0.35	0.34	0.02	-0.01	1.00				
PUBR(-3)	-0.05	-0.04	-0.32	0.02	-0.01	1.00			
PUBR(-4)	-0.06	-0.06	0.01	-0.32	0.00	-0.06	1.00		
EXT	-0.42	-0.42	-0.04	0.12	0.16	0.36	-0.03	1.00	
PUBSPILL	0.10	0.09	0.66	0.04	-0.01	-0.31	0.16	0.00	1.00

Ag2	TFPGu	TFPGa	PUBR	PUBR(-1)	PUBR(-2)	PUBR(-3)	PUBR(-4)	EXT	PUBSPILL	IRRIGAT
TFPGu	1.00									
TFPGa	1.00	1.00								
PUBR	0.00	0.01	1.00							
PUBR(-1)	0.30	0.29	0.43	1.00						
PUBR(-2)	0.11	0.11	0.00	0.38	1.00					
PUBR(-3)	0.49	0.50	0.01	-0.02	0.37	1.00				
PUBR(-4)	-0.23	-0.24	0.02	0.02	-0.09	0.24	1.00			
EXT	-0.05	-0.04	0.73	0.33	-0.05	-0.07	0.02	1.00		
PUBSPILL	-0.04	-0.03	0.49	0.22	-0.10	-0.09	0.06	0.54	1.00	
IRRIGAT	0.40	0.39	0.13	0.35	-0.07	0.03	-0.27	0.13	0.00	1.00

Crops	TFPGu	TFPGa	PUBR	PUBR(-1)	PUBR(-2)	PUBR(-3)	PUBR(-4)	EXT	PUBSPILL	NR
TFPGu	1.00									
TFPGa	0.93	1.00								
PUBR	0.26	0.20	1.00							
PUBR(-1)	0.30	0.36	0.45	1.00						
PUBR(-2)	0.09	0.09	0.02	0.39	1.00					
PUBR(-3)	0.33	0.41	0.01	-0.02	0.38	1.00				
PUBR(-4)	-0.18	-0.20	0.02	0.00	-0.08	0.27	1.00			
EXT	0.23	0.19	0.72	0.31	-0.10	-0.07	0.12	1.00		
PUBSPILL	0.12	0.02	0.47	0.26	-0.13	-0.17	0.11	0.57	1.00	
NR	0.52	0.36	-0.06	-0.11	0.15	0.12	-0.43	0.01	0.02	1.00

Livestock	TFPGu	TFPGa	PUBR	PUBR(-1)	PUBR(-2)	PUBR(-3)	PUBR(-4)	EXT	PUBBREED	IRRIGAT	BIRI
TFPGu	1.00										
TFPGa	1.00	1.00									
PUBR	0.11	0.12	1.00								
PUBR(-1)	-0.04	-0.04	-0.06	1.00							
PUBR(-2)	0.02	0.03	-0.20	0.02	1.00						
PUBR(-3)	0.31	0.32	0.05	-0.04	-0.11	1.00					
PUBR(-4)	-0.12	-0.10	-0.09	0.08	-0.03	-0.17	1.00				
EXT	0.05	0.07	0.48	-0.03	-0.13	0.15	0.06	1.00			
PUBBREED	-0.01	-0.02	-0.27	0.18	0.08	0.04	-0.08	-0.13	1.00		
IRRIGAT	0.41	0.41	0.16	0.19	-0.03	0.21	-0.10	0.23	-0.06	1.00	
BIRD	-0.27	-0.27	-0.19	-0.42	-0.39	-0.22	-0.07	-0.12	-0.08	-0.11	1.

Table 6.21 Correlation Matrix (common sample) from the Error Correction Model

(All variables are expressed in natural log, d = first-difference, 1971-2006)

Ag1	dTFPu	dTFPa	dPUBR	dEXT	PUBR(-2)	EXT(-1)	SPILL(-1)	TO(-2)	EDU(-2)	RAIN(-1)	BOOM
dTFPu	1.00										
dTFPa	1.00	1.00									
dPUBR	-0.05	-0.05	1.00								
dEXT	-0.24	-0.23	-0.10	1.00							
PUBR(-2)	0.04	0.02	-0.30	-0.14	1.00						
EXT(-1)	-0.01	-0.03	-0.07	-0.33	0.69	1.00					
SPILL(-1)	-0.05	-0.07	-0.05	-0.21	0.60	0.94	1.00				
TO(-2)	-0.01	-0.03	-0.07	-0.30	0.70	0.94	0.93	1.00			
EDU(-2)	-0.02	-0.04	-0.07	-0.26	0.59	0.93	0.97	0.96	1.00		
RAIN(-1)	0.06	0.08	-0.15	-0.01	-0.32	-0.73	-0.75	-0.59	-0.69	1.00	
BOOM	0.22	0.24	-0.02	-0.18	-0.24	-0.46	-0.61	-0.43	-0.47	0.43	1.00

Ag2	dTFPu	dTFPa	dPUBR(-1)	dSPILL(-1)	PUBR(-2)	EXT(-1)	SPILL(-1)	RAIN(-1)	ROAD(-1)	BOOM
dTFPu	1.00									
dTFPa	1.00	1.00								
dPUBR(-1)	0.31	0.31	1.00							
dSPILL(-1)	0.12	0.14	0.02	1.00						
PUBR(-2)	0.08	0.06	-0.24	-0.73	1.00					
EXT(-1)	0.12	0.10	-0.10	-0.75	0.95	1.00				
SPILL(-1)	0.11	0.08	-0.15	-0.73	0.87	0.94	1.00			
RAIN(-1)	-0.12	-0.10	-0.20	0.64	-0.64	-0.71	-0.74	1.00		
ROAD(-1)	0.04	0.01	-0.35	-0.63	0.86	0.90	0.88	-0.50	1.00	
BOOM	0.03	0.04	-0.13	0.38	-0.25	-0.35	-0.46	0.36	-0.30	1.00

Crops	dTFPu	dTFPa	dPUBR(-3)	dEXT(-1)	PUBR(-3)	EXT(-1)	SPILL(-1)	ROAD(-1)	BOOM
dTFPu	1.00								
dTFPa	1.00	1.00							
dPUBR(-3)	0.41	0.41	1.00						
dEXT(-1)	0.26	0.25	-0.20	1.00					
PUBR(-3)	-0.06	-0.07	0.03	-0.31	1.00				
EXT(-1)	0.03	0.02	0.00	-0.02	0.90	1.00			
SPILL(-1)	0.05	0.04	-0.06	-0.03	0.84	0.94	1.00		
ROAD(-1)	-0.06	-0.07	-0.17	-0.20	0.90	0.91	0.88	1.00	
BOOM	-0.04	-0.04	0.19	-0.35	-0.26	-0.47	-0.61	-0.41	1.00

Livestock	dTFPu	dTFPa	dPUBR	dEXT(-1)	dBREED	PUBR(-3)	EXT(-1)	BREED(-1)	BIRD
dTFPu	1.00								
dTFPa	1.00	1.00							
dPUBR	0.12	0.12	1.00						
dEXT(-1)	0.20	0.20	-0.05	1.00					
dBREED	0.09	0.09	-0.02	0.24	1.00				
PUBR(-3)	-0.13	-0.15	-0.23	-0.13	-0.06	1.00			
EXT(-1)	-0.16	-0.18	-0.26	0.04	-0.03	0.92	1.00		
BREED(-1)	-0.18	-0.19	0.05	-0.05	-0.39	0.30	0.34	1.00	
BIRD	-0.33	-0.33	-0.20	-0.18	-0.02	0.23	0.26	0.13	1.00

Appendix 6B: ECM Results

Table 6.22 Details of TFP Determinants in Overall Agriculture: General Model (Dependent variable = $\Delta TFPu_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPu_{t-1}$)
	Full model	Preferred model **Model 17**†	
Constant	-0.344 (-0.367	-0.665 (-1.448)	
$\Delta PUBR_t$	0.020 (0.311)	0.012 (1.079)	
ΔEXT_t	0.016 (0.334)	0.005 (0.139)	
$\Delta PUBSPILL_t$	-0.003 (-0.225)		
ΔTO_t	-0.034 (-0.473)		
ΔEDU_t	0.006 (0.215)		
$\Delta RAIN_t$	0.001 (0.014)		
$PUBR_{t-2}$	0.016 (1.022)	0.007 (0.733)	0.007 (0.729)
EXT_{t-1}	0.004 (0.145)	0.002 (0.107)	0.002 (0.107)
$SPILL_{t-1}$	-0.024 (-0.265)		
$PUBSPILL_{t-1}$	-0.004 (-1.053)		
TO_{t-2}	0.153 (1.594)	0.077 (1.445)	0.078 (1.492)
EDU_{t-2}	0.039 (1.303)	0.037 (2.555)**	0.038 (2.779)***
$RAIN_{t-1}$	0.091 (1.151)	0.113 (2.354)**	0.115 (2.636)***
$BOOM_t$	0.037 (0.723)	0.043 (1.864)*	0.044 (1.836)*
$TFPu_{t-1}$	-1.089 (-5.631)***	-0.983 (-6.208)***	
N	34	34	
Adj. R^2	0.437	0.536	
F-statistics	2.707	5.376	
SE	0.030	0.027	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. †Model 17 refers to the sequence of estimation shown in Table 6.9.

Table 6.23 Details of TFP Determinants in Overall Agriculture: General Model (Dependent variable = $\Delta TFPa_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPa_{t-1}$)
	Full model	Preferred model **Model 18**†	
Constant	-0.661	-0.025	
	(-0.731)	(-0.119)	
$\Delta PUBR_t$	0.013	0.004	
	(0.198)	(0.349)	
ΔEXT_t	0.044	0.024	
	(0.873)	(0.716)	
$\Delta PUBSPILL_t$	-0.003		
	(-0.191)		
ΔTO_t	-0.048		
	(-0.659)		
$\Delta RAIN_t$	0.003		
	(0.072)		
$PUBR_{t-2}$	0.005	0.008	0.010
	(0.320)	(0.780)	(0.764)
EXT_{t-1}	0.013	0.022	0.028
	(0.404)	(1.171)	(1.187)
$SPILL_{t-1}$	0.049		
	(0.880)		
$PUBSPILL_{t-1}$	-0.005		
	(-1.220)		
TO_{t-2}	0.135	0.123	0.154
	(1.474)	(2.964)***	(3.770)***
$RAIN_{t-1}$	0.088	0.051	0.063
	(1.087)	(1.757)*	(1.683)*
$BOOM_t$	0.067	0.037	0.046
	(1.422)	(1.457)	(1.391)
$TFPa_{t-1}$	-1.027	-0.798	
	(-5.144)***	(-4.971)***	
N	34	34	
Adj. R^2	0.376	0.443	
F-statistics	2.531	4.383	
SE	0.020	0.030	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. The dependent variable (TFPa) is TFP adjusted for labour and land quality.
†Model 18 refers to the sequence of estimation shown in Table 6.9.

Table 6.24 Details of TFP Determinants in Traditional Agriculture: General Model (Dependent variable = $\Delta TFPu_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPu_{t-1}$)
	Full model	Preferred model **Model 19**†	
Constant	-4.719 (-2.281)**	-2.552 (-4.569)***	
$\Delta PUBR_{t-1}$	0.524 (1.313)	0.043 (0.958)	
ΔEXT_t	0.004 (0.097)		
$\Delta SPILL_{t-1}$	0.065 (0.337)	0.146 (0.911)	
$\Delta RAIN_t$	0.004 (0.055)		
ΔNC_t	0.020 (0.287)		
$PUBR_{t-2}$	0.114 (2.266)**	0.042 (1.824)*	0.046 (1.788)*
EXT_{t-1}	-0.077 (-1.212)		
$PUBRE_{t-1}$	-0.092 (-1.220)		
$SPILL_{t-1}$	0.133 (1.894)*	0.131 (2.934)***	0.144 (2.939)***
$PUBSPILL_{t-1}$	0.056 (0.402)		
$RAIN_{t-1}$	0.021 (0.192)	0.121 (2.205)**	0.132 (2.266)**
$ROAD_{t-1}$	0.136 (2.763)**	0.091 (3.541)***	0.099 (5.034)***
NC_t	0.027 (0.222)		
$BOOM_t$	0.125 (1.936)*	0.169 (3.191)***	0.185 (3.448)***
$TFPu_{t-1}$	-0.992 (-4.736)***	-0.913 (-5.499)***	
N	33	33	
Adj. R^2	0.552	0.576	
F-statistics	3.469	6.449	
SE	0.039	0.038	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. †Model 19 refers to the sequence of estimation shown in Table 6.10.

Table 6.25 Details of TFP Determinants in Traditional Agriculture: General Model (Dependent variable = $\Delta TFPa_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPa_{t-1}$)
	Full model	Preferred model **Model 20**†	
Constant	-4.574 (-2.154)**	-2.260 (-4.408)***	
$\Delta PUBR_{t-1}$	0.555 (1.365)	0.046 (1.055)	
ΔEXT_t	0.009 (0.192)		
$\Delta SPILL_{t-1}$	0.094 (0.485)	0.030 (0.201)	
$\Delta RAIN_t$	0.003 (0.033)		
ΔNC_t	0.004 (0.056)		
$PUBR_{t-2}$	0.101 (2.020)**	0.049 (2.175)**	0.050 (2.153)**
EXT_{t-1}	-0.059 (-0.926)		
$PUBRE_{t-1}$	-0.076 (-0.989)		
$SPILL_{t-1}$	0.124 (1.732)*	0.120 (2.795)***	0.122 (2.767)***
$PUBSPILL_{t-1}$	0.021 (0.151)		
$RAIN_{t-1}$	0.088 (0.894)	0.102 (1.949)*	0.104 (1.972)*
$ROAD_{t-1}$	0.063 (1.843)*	0.069 (3.102)***	0.071 (3.970)***
NC_t	0.063 (0.681)		
$BOOM_t$	0.121 (1.846)*	0.159 (3.131)***	0.161 (3.339)***
$TFPa_{t-1}$	-0.991 (-4.568)***	-0.983 (-5.731)***	
N	33	33	
Adj. R^2	0.533	0.589	
F-statistics	3.808	6.751	
SE	0.040	0.037	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. The dependent variable (TFPa) is TFP adjusted for labour and land quality.
†Model 20 refers to the sequence of estimation shown in Table 6.10.

Table 6.26 Details of TFP Determinants in Crops Sector: General Model (Dependent variable = $\Delta TFPu_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPu_{t-1}$)
	Full model	Preferred model **Model 21**†	
Constant	-0.870 (-3.401)***	-1.205 (-6.563)***	
$\Delta PUBR_{t-3}$	0.139 (3.241)***	0.146 (4.129)***	
ΔEXT_{t-1}	0.115 (2.086)**	0.132 (3.530)***	
$\Delta SPILL_t$	-0.115 (-0.787)		
$\Delta ROAD_t$	-0.063 (-0.716)		
$PUBR_{t-3}$	0.056 (1.905)*	0.052 (1.958)*	0.060 (2.230)**
EXT_{t-1}	0.026 (0.633)		
$PUBRE_{t-1}$	-0.020 (-1.265)		
$SPILL_{t-1}$	0.061 (1.243)	0.101 (3.203)***	0.117 (3.331)***
$PUBSPILL_{t-1}$	0.039 (0.615)		
$ROAD_{t-1}$	0.045 (2.254)**	0.046 (2.659)**	0.053 (2.684)***
$BOOM_t$	0.119 (2.508)**	0.136 (3.291)***	0.158 (3.409)***
$TFPu_{t-1}$	-0.941 (-5.665)***	-0.864 (-6.667)***	
N	34	34	
Adj. R^2	0.681	0.690	
F-statistics	7.671	11.509	
SE	0.035	0.033	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. †Model 21 refers to the sequence of estimation shown in Table 6.11.

Table 6.27 Details of TFP Determinants in Crops Sector: General Model (Dependent variable = $\Delta TFPa_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPa_{t-1}$)
	Full model	Preferred model **Model 22**†	
Constant	-0.677	-1.056	
	(-2.857)***	(-6.460)***	
$\Delta PUBR_{t-3}$	0.148	0.155	
	(3.491)***	(4.423)***	
ΔEXT_{t-1}	0.117	0.137	
	(2.143)**	(3.665)***	
$\Delta SPILL_t$	-0.115		
	(-0.789)		
$\Delta ROAD_t$	-0.046		
	(-0.534)		
$PUBR_{t-3}$	0.060	0.059	0.067
	(1.759)*	(1.876)*	(2.117)**
EXT_{t-1}	0.025		
	(0.604)		
$PUBRE_{t-1}$	-0.058		
	(-1.611)		
$SPILL_{t-1}$	0.053	0.092	0.105
	(1.079)	(2.955)***	(3.045)***
$PUBSPILL_{t-1}$	0.003		
	(0.225)		
$ROAD_{t-1}$	0.031	0.033	0.038
	(1.546)	(1.977)**	(1.962)**
$BOOM_t$	0.109	0.127	0.145
	(2.308)**	(3.104)***	(3.189)***
$TFPu_{t-1}$	-0.939	-0.872	
	(-5.604)***	(-6.664)***	
N	34	34	
Adj. R^2	0.665	0.686	
F-statistics	7.453	11.310	
SE	0.035	0.033	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. The dependent variable (TFPa) is TFP adjusted for labour and land quality.

†Model 22 refers to the sequence of estimation shown in Table 6.11.

Table 6.28 Details of TFP Determinants in Livestock Sector: General Model (Dependent variable = $\Delta TFPu_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPu_{t-1}$)
	Full Model	Preferred model **Model 23†**	
Constant	0.552	0.283	
	(1.300)	(1.639)	
$\Delta PUBR_t$	-0.011		
	(-0.210)		
ΔEXT_{t-1}	0.124	0.105	
	(1.596)	(1.488)	
$\Delta BREED_t$	0.009	0.007	
	(0.346)	(0.318)	
ΔTO_t	-0.054		
	(-0.263)		
$PUBR_{t-3}$	0.113	0.125	0.168
	(1.589)	(1.976)*	(2.021)**
EXT_{t-1}	-0.106	-0.069	-0.094
	(-1.372)	(-1.219)	(1.211)
$BREED_{t-1}$	-0.006	-0.014	-0.019
	(-0.310)	(-0.769)	(-0.760)
TO_t	0.085		
	(0.636)		
$BIRD_t$	-0.156	-0.135	-0.182
	(-2.215)**	(-2.195)**	(-2.063)**
$TFPu_{t-1}$	-0.759	-0.743	
	(-5.131)***	(-5.379)***	
N	35	35	
Adj. R^2	0.438	0.486	
F-statistics	3.651	5.606	
SE	0.099	0.095	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. As described in text, dropping insignificant variables in Model 23 does not pass the diagnostic tests. †Model 23 refers to the sequence of estimation shown in Table 6.12.

Table 6.29 Details of TFP Determinants in Livestock Sector: General Model (Dependent variable = $\Delta TFPa_t$)

Variable	Estimated coefficients (t-ratio)		Long-run elasticity =coefficient of X/ (-coefficient of $TFPa_{t-1}$)
	Full model	Preferred model **Model 24**†	
Constant	0.585	0.386	
	(1.404)	(2.246)**	
$\Delta PUBR_t$	-0.012		
	(-0.232)		
ΔEXT_{t-1}	0.124	0.119	
	(1.596)	(1.728)*	
$\Delta BREED_t$	0.012	0.012	
	(0.478)	(0.517)	
ΔTO_t	-0.079		
	(-0.395)		
$PUBR_{t-3}$	0.122	0.128	0.173
	(1.742)	(2.074)**	(2.111)**
EXT_{t-1}	-0.117	-0.089	-0.121
	(-1.346)	(-1.590)	(1.578)
$BREED_{t-1}$	-0.003	-0.003	-0.004
	(-0.148)	(-0.168)	(-0.167)
TO_t	0.058		
	(0.448)		
$BIRD_t$	-0.182	-0.165	-0.224
	(-2.612)**	(-2.720)***	(-2.593)***
$TFPa_{t-1}$	-0.749	-0.739	
	(-5.227)***	(-5.510)***	
N	35	35	
Adj. R^2	0.454	0.503	
F-statistics	3.828	5.930	
SE	0.097	0.093	

Notes: Numbers in parentheses underneath each coefficient is the t-ratio of the coefficient. The level of statistical significance denoted as: * = 10%, ** = 5% and *** = 1%. All variables are measured in natural logarithms. The dependent variable (TFPa) is TFP adjusted for labour quality only.

†Model 24 refers to the sequence of estimation shown in Table 6.12.

Table 6.30 Results Summary: Significant Variables and Overall F-Statistics

	Methods	GRM-PDL		ECM	
	Models	**GM**	**AM**	**GM**	**AM**
Ag1	TFPu	+PUBR(-2) –EXT	+PRIR(PDL4) +WEATHER	+EDU (LR) +RAIN (LR) +BOOM (LR)	+PUBR (SR) +UNIR (SR) +PRIR (LR) +SPILL (LR) +EXT (LR) +RAIN (LR)
	F =	3.08	5.27	5.38	12.06
	TFPa	+PUBR(-2) –EXT	+PRIR(PDL4) +WEATHER	+TO (LR) +RAIN (LR)	+PUBR (SR) +UNIR (SR) +PRIR (LR) +RAIN (LR)
	F =	2.24	5.54	4.38	6.50
Ag2	TFPu	+PUBR(PDL4) +IRRIGAT	+PRIR +PUBSPILL	+PUBR (LR) +SPILL (LR) +RAIN (LR) +ROAD (LR) +BOOM (LR)	+PUBR (LR) +PRIR (SR&LR) +ROAD (LR)
	F =	2.63	3.91	6.45	4.04
	TFPa	+PUBR(PDL4) +IRRIGAT	+PRIR +PUBSPILL	+PUBR (LR) +SPILL (LR) +RAIN (LR) +ROAD (LR) +BOOM (LR)	+PUBR (LR) +PRIR (SR&LR) +ROAD (LR)
	F =	2.48	3.75	6.75	4.05
Crops	TFPu	+PUBR(PDL4) +NR	+PRIR +PUBSPILL +NR	+PUBR (SR&LR), +EXT(SR) +SPILL (LR) +ROAD (LR) +BOOM (LR)	+PUBR (SR) +PRIR (SR) +EXT (SR) +ROAD (LR)
	F =	4.79	4.77	11.51	5.41
	TFPa	+PUBR(PDL4) +NR	+PRIR +PUBSPILL +NR	+PUBR (SR&LR) +EXT (SR) +SPILL (LR) +ROAD (LR) +BOOM (LR)	+PUBR (SR) +PRIR (SR) +EXT (SR) +ROAD (LR)
	F =	2.74	4.68	11.31	5.13
Livestock	TFPu	+IRRIGAT +BIRD	+PRIR +RAIN –BIRD	+PUBR (LR) –BIRD (LR)	+PUBR (LR) +PRIR (LR) –EXT (LR) +TO (LR) +BREED (SR) –BIRD (LR)
	F =	3.37	2.34	5.60	10.02
	TFPa	+IRRIGAT +BIRD	+PRIR +RAIN –BIRD	+PUBR (LR) +EXT (SR) –BIRD (LR)	+PUBR (LR) +PRIR (LR) –EXT (LR) +TO (LR) +BREED (SR&LR) –BIRD (LR)
	F =	3.39	2.37	5.93	9.77

Note: +/– indicate signs of estimated coefficients. LR = long run and SR = short run.

Chapter 7

7. Measuring Returns on Agricultural Research

7.1 Introduction

It is widely held that the returns to agricultural research are high for society as a whole and that investment in agricultural research is underfunded in many countries. In this context, empirical findings on the research payoffs have gained considerable attention in the literature. This is of particular importance to developing countries where agriculture plays a crucial role and a limited government budget has to be allocated to various competing alternatives. However, few studies are available which measure the returns to research in Thai agriculture at an aggregate level. This chapter aims to fill this gap.

This chapter assesses public investment in agricultural research, focusing on crops and livestock, by estimating its social rate of return. The significant positive relationship between research expenditure and productivity found in the previous chapter implies positive payoffs to agricultural research, but to what extent will be empirically determined. Specifically, this chapter translates the estimated coefficients of public research from TFP determinants regression into a stream of research benefits. Following the usual practice, the effectiveness of research is measured as the marginal internal rate of return (MIRR) to public research spending.

Although a number of previous studies have estimated MIRR to agricultural research investment there are only two studies in Thailand. The previous two studies have focused solely on crops using partial productivity measures. This is apparently the first study for Thai agriculture using TFP decomposition and the error correction modelling (ECM) method developed by Hendry (1995).[196] It is also the first to quantify the rate of return on crops and livestock research at the aggregate level after carefully accounting for the important issues of lags, spillovers and attribution[197] in the Thai agricultural context. In particular, the rates of return are estimated for crops and livestock separately, based on the TFP function. TFP growth is also adjusted for input quality changes so that it reflects the pure technical change component more closely. Factors that have often been ignored in previous studies, that is, international research spillovers, infrastructure and irregular factors (for example, weather, epidemic and commodity boom) are also accounted for in the TFP determinants model. The estimation method also allows for both short- and long-run relationship among variables and does not impose any restrictive form of lags.

The findings are intended to address the question of whether the rate of return on research has been high and whether there has been underinvestment in agricultural research. The empirical results are also expected to shed light on policy implications regarding research funding.

The chapter proceeds as follows. Section 7.2 describes the methodology used to estimate the rate of return on agricultural research. Section 7.3 reports and discusses the results. Section 7.4 compares the results with other studies and draws some implications on evaluating the rates of return. Finally, Section 7.5 draws conclusions.

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[196] Among previous international studies investigating the relationship between agricultural research and productivity, the number of studies that used ECM is relatively small, for example, Makki et al. (1999), Schimmelpfennig and Thirtle (1994) and Thirtle et al. (2002).
[197] Here, attribution means that major factors affecting TFP have been accounted for in the regression.

7.2 Methodology for Estimating Returns to Research[198]

First, it is important to clarify the meaning of the social rate of return on research. The social rate of return on research spending is defined in this study as a percentage return on each baht spent on research.[199] The return is "social" because it captures all of the economywide benefits from higher productivity. These returns benefit not only farmers but also food processing, agro-industry and consumers, who gain from increased availability and lower cost commodities (Fuglie and Heisey, 2007).

Since technologies produced by research have no obvious prices, it is not easy to compare whether there has been over or under investment. Therefore, the effectiveness of research expenditure is determined by calculating rates of return (ROR) (Schimmelpfennig et al., 2000). It is also convenient to compare the ROR on research investment with other returns on investment as they are measured in percentage. Typically, internal rates of return (IRR) have been used in ex post evaluation studies.[200]

Two basic methodologies dominate the calculation of returns to agricultural research. The IRR calculation methods are broadly classified as an aggregate level (regression-based approach) and project level evaluation (project evaluation approach).

The first method typically uses regression to find a statistical relationship between past research expenditure and changes in productivity. The regression-based method takes into account expenditure on research at an aggregate level that may or may not lead to success. The computed rate of return is based on the estimated coefficient of the research variable, usually derived from production or productivity function, and therefore it is referred to as the 'marginal' internal rate of return (MIRR).

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[198] This section is mainly drawn from Fuglie and Heisey (2007), Thirtle and Bottomley (1989), Davis (1981a) and Lu et al. (1979).

[199] Baht is the Thai currency. In early 2009, 1 US dollar = 35 baht.

[200] Net present value (NPV) has been used in ex ante evaluation and priority-setting studies. It does not provide a convenient ranking of alternatives (Alston et al., 1998b). Ex post studies are done more often to justify past investment while ex ante studies are done more often with a view to allocating resources (Alston et al., 2000).

The second method is usually referred to as cost-benefit analysis of specific research programs or economic surplus studies. Instead of using an econometric technique, this approach measures research benefits based on the economic surplus derived from the shift in a supply function. The project evaluation or case study method is limited to selected successful cases and therefore it is impossible to draw general conclusions from their findings. Studies using this method often report 'average' internal rates of return.[201]

This chapter employs the first method as the evaluation is based on past investment and regression analysis. It measures the rate of return on overall agricultural research, no matter whether it leads to success or not. The first method encompasses all research, thereby providing a more balanced measure of average returns to a research system that fits well with the objective of this thesis.

The MIRR has also been widely used in most economic impact studies (for example, Thirtle and Bottomley 1989, Evenson and Pray, 1991, Mullen and Cox, 1995, Huffman and Evenson, 2005). It refers to real (i.e. inflation adjusted), marginal (i.e. for incremental research expenditure) and ex post (i.e. for past investment).

The criterion for evaluating research programs is that an investment is worthwhile if it yields positive returns and has an IRR greater than the social interest rate or the opportunity cost of funds.[202] A high rate of return implies there had been underinvestment, implying that additional investment in agricultural research is desirable (Ruttan, 1982b, Fuglie et al., 1996).

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[201] See Evenson (2001, p.596-606) for details and a summary of previous studies using both methods. Davis (1981a) showed that benefits to an increase in research expenditure as measured by the value marginal product are approximately equal to the change in economic surplus associated with the increase, hence, both the production function and economic surplus approaches conceptually measure the same research benefits.

[202] The criterion of comparing the IRR with social discount rate is common in any IRR study (Belli et al., 2001).

Computational Procedure of MIRR

The effectiveness of research is usually measured as a marginal internal rate of return (MIRR) because it is useful for making decisions on additional investment (Peterson and Hayami, 1977, p.522). It is referred to as marginal since the research benefit is estimated based on the marginal impact of research on productivity and the net return is calculated per unit of additional investment. Conceptually, calculating the MIRR is similar to finding an internal rate of return to an investment by a firm or household. The internal rate of return is defined as the rate of interest which equates the flow of costs and the flow of benefits over time.

The MIRR of research investment is the value of r which solves the equation:

$$\sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t} = 0 \qquad (7.1)$$

where B_t is the benefit from research in year t

C_t is cost or expenditure on research in year t

r is the IRR

T is life of streams of research benefit and cost (full duration of research effect)

In practice, previous studies have used various techniques in computing the MIRR of agricultural research.[203] The critical part is the procedure adopted to distribute the benefits of research through time (Davis, 1981a). This depends mostly on the methodology used to derive the coefficient of the research variable and associated lag structure. Most studies have concentrated on estimating the research coefficient but none has provided detailed calculation of how the MIRR is estimated (examples include Hall and Scobie, 2006, Setboonsarng and Evenson, 1991, Makki et al., 1999). This is likely due to the fact that the IRR calculation is conceptually the same, that is,

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203 See, for example, Griliches (1964b), Davis (1981a), Alston et al. (1998a), Schimmelpfennig et al. (2000), Evenson (2001), Plastina and Fulginiti (2007).

finding the discount rate that equates the net present value of an investment to zero; thereby detailed procedure is deemed unnecessary.

In this thesis, the TFP function is used and expressed in double log form. From the TFP determinant function, the estimated coefficient of the public research variable or the elasticity of TFP with respect to research indicates that a 1 percent increase in a public agricultural research budget results in some particular percentage increase in TFP. This increase in TFP must be converted into a rise in the value of output before the internal rate of return to agricultural research can be calculated (Thirtle and Bottomley, 1989).

Following the common practice based on a productivity function, a two-step procedure is used to find the returns to research (for example, Bredahl and Peterson, 1976, Lu et al., 1979, Davis, 1981a, Nagy, 1991). First is to find a net return represented by the value marginal product (VMP) of research. This is done by finding a marginal product (MP), multiplying the estimated research elasticity with the average product of research, and then turning the MP into a change in value of output.[204] Second is to determine the discount rate which equates the flow of costs and the flow of benefits over time, in other words, the rate of interest that results in a benefit/cost ratio of one (Peterson and Hayami 1977, p.521). A general procedure for finding the marginal internal rate of return is that which satisfies discounted VMP – 1 = 0, meaning that a discount rate that equates a stream of net return from one currency unit (or baht in this case) investment in public research to zero. This two-step procedure is expressed as follows.[205]

Step 1: Finding the value marginal product of agricultural research (VMP):
From the TFP determinant function, the elasticity of TFP at year t with respect to agricultural research (R) at year $t-i$ (α_i) is defined as

[204] Since the TFP function was estimated in a double log form, the partial coefficients are elasticities.
[205] The expressions mainly follow Thirtle and Bottomley (1989) and Lu et al. (1979).

$$\alpha_i = \frac{\partial \ln TFP_t}{\partial \ln R_{t-i}} = \frac{\partial TFP_t}{\partial R_{t-i}} \times \frac{R_{t-i}}{TFP_t} \tag{7.2}$$

where α_i is elasticity of TFP at year t with respect to agricultural research at year $t-i$

R_{t-i} is the value of real agricultural research expenditure at time $t-i$

TFP_t is the total factor productivity index at time t

The marginal product of research can be expressed as the elasticity multiplied by the average product,

$$\frac{\partial TFP_t}{\partial R_{t-i}} = \alpha_i \left(\frac{TFP_t}{R_{t-i}} \right) \tag{7.3}$$

Replacing $\left(\frac{TFP_t}{R_{t-i}} \right)$ by the geometric means of TFP indices and research expenditure over the period under consideration and changing to discrete approximations gives[206]

$$\frac{\Delta TFP_t}{\Delta R_{t-i}} = \alpha_i \left(\frac{\overline{TFP_t}}{\overline{R_{t-i}}} \right) \tag{7.4}$$

The change in productivity can be converted into the change in the value of output by multiplying both sides of equation (7.4) by the average net increases in the value of output caused by a one-index-point increase in productivity.[207] That is, the required VMP can be derived by multiplying each annual marginal product with the value or price of one unit of TFP index (Nagy, 1991, p.109). Note that, in actual calculation,

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[206] It is a common practice to use sample average values of productivity (or output) and research expenditure because most studies aim to find an overall rate of return for the whole period. This general practice has also been followed to overcome the problem of projecting productivity and price forward for the lag length years (Mullen and Cox, 1995). However, a calculation using the values at each time period can also be done (Alston et al., 1998b, p.197). Note that all variables should be in real terms.

[207] There are variations in the literature regarding the VMP measure. Some studies argue that it is not necessary to convert the research benefits into monetary values because TFP growth can be directly interpreted as the growth rate of output or the rate of cost reduction (Alston et al., 1998a and Esposti and Pieranti, 2003). Some studies derived the VMP by multiplying the marginal product of research with an index of output prices (Mullen and Cox, 1995 and Makki et al., 1999).

all variables in the following equations are usually expressed as geometric means, except the elasticity.

$$\frac{\Delta TFP_t}{\Delta R_{t-i}}\frac{\Delta Q_t}{\Delta TFP_t}dTFP = \alpha_i\left(\frac{\overline{TFP_t}}{\overline{R}_{t-i}}\right)\frac{\Delta Q_t}{\Delta TFP_t}dTFP \qquad (7.5)$$

where Q_t is value of real output at time t

Then, the value marginal product (VMP) of research in period $t-i$ can be expressed as

$$VMP_{t-i} = \frac{\Delta Q_t}{\Delta R_{t-i}} = \alpha_i \frac{\overline{TFP_t}}{\overline{R}_{t-i}}\frac{\Delta Q_t}{\Delta TFP_t} \qquad (7.6)$$

The above equations are usually applied to the polynomial distributed lag (PDL) structure, where the research effect rises to a peak and eventually dies off.[208] The PDL is a commonly used form of lag in the literature but it tends to give an overestimated rate of return caused by its short truncated lag. The error correction model (ECM) allows for dynamic and infinite lags using time-series technique and data transformation. This helps overcome the arbitrary truncation of the lag distribution for the stream of net benefits which could lead to serious upward biases in the rate of return (Alston et al., 2000).

In the case of ECM, the agricultural research impact on TFP operates through the adjustment process towards the steady-state or long-run equilibrium. The estimated long-run elasticities are used to determine their trajectories until reaching the steady-state, where all external shocks are dissipated. In the long run, the elasticities are stable and remain constant over time. The VMP is calculated at time t starting from year 1 to infinity. This stream of research benefits is used to find the MIRR which equates it with a research cost of a 1 baht investment in public research.

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[208] See, for example, Lu et al. (1979), Thirtle and Bottomley (1989) and Nagy (1991).

The VMP formula used to solve the MIRR in this chapter is expressed as

$$VMP_t = \alpha_t \frac{\overline{TFP_t}}{\overline{R_t}} \frac{\overline{\Delta Q_t}}{\overline{\Delta TFP_t}} \tag{7.7}$$

where α_t is elasticity of TFP with respect to agricultural research at year t

$\overline{R_t}$ is sample average value of real agricultural research expenditure

$\overline{TFP_t}$ is sample average value of total factor productivity index

$\overline{\Delta Q_t}$ is sample average value of net increase in real output

$\overline{\Delta TFP_t}$ is sample average value of annual change in TFP index

Step 2: The marginal internal rate of return (MIRR) can be calculated from the following equation in which the MIRR is equal to r:

$$\sum_{t=1}^{\infty} \left[VMP_t / (1+r)^t \right] - 1 = 0 \tag{7.8}$$

The MIRR equates a stream of discounted benefits to an initial investment of 1 baht, thereby the net present value of a 1 baht investment is equal to zero. The research cost of 1 baht occurs in year 0 while the research benefit begins from year 1 to infinity. Under the ECM, the annual research benefit or 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.[209] Equation (7.8) is used to find the social rate of return on public agricultural research in this chapter.

Although the majority of previous studies assume the benefits last for a finite period, discounted returns from distant periods have a very small and perhaps trivial

[209] This reflects the fact that today's research is built on past research. In other words, every baht spent on today research more or less contribute to future research. Therefore, an investment in research may yield benefits that continue into perpetuity.

impact.[210] Hence, there shall not be much difference between finite and infinite cases. This is confirmed by the sensitivity analysis undertaken afterwards.

7.3 Results and Discussion

This section explains in detail how the estimates of social marginal internal rate of return are derived by applying the procedure described in the previous section. The estimation of MIRR is done for crops and livestock separately. A sensitivity analysis is also undertaken.

In order to measure the social rate of return on agricultural research, a stream of research benefits has to be estimated based on the elasticity of TFP with respect to public research. The long-run elasticity derived from the general model of TFP determinants using the ECM is employed.[211] The reason is that the ECM yields statistically more significant results (as shown in Chapter 6) compared with the Growth-Rate Model (GRM), and the general model covers the whole study period.[212] The long-run research elasticity derived from the ECM is used to find the spread of research impact on productivity over time, which is required for the estimation of value marginal product (VMP) of research and hence the MIRR.

To serve the objective of the thesis that focuses on crops and livestock, the two major subsectors of agricultural output with longstanding public investment in their research, an emphasis is individually given to crops and livestock. Table 7.1 summarizes the long-run TFP elasticities with respect to public research computed

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[210] Some studies computed the internal rate of return for an infinite period, for example, Peterson (1967), Alston et al. (1998a), Esposti and Pieranti, (2003).

[211] 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.

[212] One of the objectives of the thesis is to explain the TFP growth during the whole period of 1970-2006. Hence, the general model is used to estimate the social rate of return on agricultural research. Note that in Thailand context, several studies showed TFP growth contributed most in the agricultural sector (Chandrachai et al., 2004, Warr, 2006). The TFP growth estimates were found positive and higher than non-agricultural sectors, therefore it is important to investigate factors driving the remarkable agricultural TFP growth (see literature review in Chapter 2 for more details).

from the steady-state solutions for the sectors of interest. They are all positive and statistically significant at the 5% level.

Table 7.1 Long-term TFP Elasticities with respect to Public Research Variable Estimated from the ECM-General Model Regression

	TFPu		TFPa	
	$\hat{\alpha}_u$	(t-ratio)	$\hat{\alpha}_a$	(t-ratio)
Crops	0.060	(2.23)**	0.067	(2.12)**
Livestock	0.168	(2.02)**	0.173	(2.11)**

Notes: $\hat{\alpha}$ is estimated long-run elasticity of TFP with respect to public agricultural research (PUBR). ** indicates statistical significance at the 5% level. TFPu is unadjusted TFP and TFPa is TFP adjusted for input quality changes, see Chapter 4 for details.

The estimated elasticities are obtained from the results described in the previous chapter. There are two sets of the dependent variable, the unadjusted TFP (TFPu) and TFP adjusted for labour and land quality changes (TFPa). It was argued in Chapter 4 that once the productivity arising from input quality changes was removed, the adjusted TFP growth would reflect the pure technical change more closely than the unadjusted one. Hence, the adjusted TFP should be a more valid measure. However, both sets of TFP are presented for comparative purposes. The long-run elasticities are slightly higher under the adjusted TFP model. This implies the agricultural research impact is captured more accurately when the TFP is adjusted for non-technology factors that are not direct results of research.

Finding the spread of R&D impact over time: how long is the long run?

To find the MIRR, the number of years over which past public research spending has had an impact on TFP and associated output is required. Under the ECM, this can be estimated from the number of years required to clear X percent of an exogenous shock through automatic adjustment using the formula (Baffes et al., 1999, Jongwanich and Kohpaiboon, 2008):[213]

$$(1-X)=(1-|\hat{A}|)^T \qquad (7.9)$$

[213] Jongwanich and Kohpaiboon (2008) employ the same ECM method as in this thesis and also adopt this formula.

where $|\hat{A}|$ is the absolute value of estimated coefficient of TFP_{t-1} and T is the required number of years. The equation is solved to find T. The solution for T can be interpreted as the number of years required to reach the long-term equilibrium.

A statistically significant negative error correction coefficient ($\hat{A}$) implies that the equilibrium relationship will hold in the long run, even if there were shocks to the relationship. Its value indicates the speed of adjustment of TFP to exogenous shocks. The lower the value of the adjustment coefficient, the larger the extent to which actual data deviate from the long-run relationship and therefore the longer it takes to dissipate the shocks.

From the previous chapter, all the adjustment coefficients ($\hat{A}$) are statistically significant at the 1 percent level. As $\hat{A}$ is known, the length of long-run can be determined by the number of years required to dissipate the shock (T). By assuming 100 percent of exogenous shock (X), T can be solved from equation (7.9). The adjustment coefficients and the number of years (T) required for the long-run relationship to hold are reported in the following table.

Table 7.2 Adjustment Coefficients and Associated Long-Run Period

Sector	Coefficient of $TFPu_{t-1}$ ($\hat{A}$)	T (years)	Coefficient of $TFPa_{t-1}$ ($\hat{A}$)	T (years)
Crops	-0.864	8	-0.872	7
Livestock	-0.743	11	-0.739	12

Notes: T is calculated based on formula in equation (7.9).

From Table 7.2, it takes approximately 8 years for crops research (or R&D) to have a full and stable impact on the unadjusted TFP and the magnitude of the full impact equals to the estimated long-run elasticity reported in Table 7.1. For the adjusted TFP, it requires 7 years to clear all the exogenous shocks. For the livestock sector, the R&D impact on the unadjusted and adjusted TFP takes 11 and 12 years, respectively, to reach the long-run equilibrium and remains constant into perpetuity.

The adjustment periods to reach the long-run equilibrium are different among studied sectors and dependent variables (TFP) because significant variables in the TFP determinant functions are not the same as shown in the previous chapter. Therefore, the dynamic adjustments are different among cases.

Intuitively, the longer adjustment periods in the livestock sector imply that it takes a longer time for livestock research to have a permanent impact on TFP. This suggests livestock farmers adopt new technology more slowly than crops farmers. One probable cause is that the nature of livestock breeding and farming is generally more complicated and time consuming than crops. Public livestock research focuses on large animals (e.g., cattle, dairy cows and buffalos) with long life spans, thereby taking time for research to be successful.[214] The crops production and research system is well-established and has a longer history than livestock. In addition, the adoption and diffusion of livestock research takes time as livestock extension services are not as widespread as crops.[215] This is due to the fact that crops are the dominant sector and there is a separate agency that is responsible only for crops extension (the DOAE). The availability of crops extension workers at the district level helps hasten the adoption of new crop varieties. Moreover, some efforts of livestock extension officers have to be allocated to non-productivity enhancing activities such as educating farmers to prevent animal diseases. While these activities may prevent disasters such as disease outbreaks that might otherwise have happened, they do not raise measured productivity. With limited resources (money, staff and equipment), this may slow the dissemination period that translates livestock research into TFP growth.

Once the length of adjustment is known, the spread of R&D impact prior to the long-run is determined. The R&D impact before reaching the long-run equilibrium can be determined by finding the trajectory of the long-run elasticity over time until it reaches the steady state. This trajectory can also be calculated based on the formula

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[214] See Chapter 3, section 3.3 for the background of agricultural research system in Thailand.

[215] Crops extension services are available at the district level whereas those of livestock are not available.

specified in equation (7.9).[216] The estimated R&D impacts on TFP representing a series of elasticities that will be used to calculate the net return on agricultural research are shown in Figures 7.1 and 7.2.[217] The dashed line indicates the trajectory of R&D impact on the unadjusted TFP (TFPu) while the solid line represents that of the TFP adjusted for labour and land quality changes (TFPa). The two-step procedure described in the previous section is implemented subsequently.

Figure 7.1 Trajectory of R&D Impact on TFP in Crops Sector

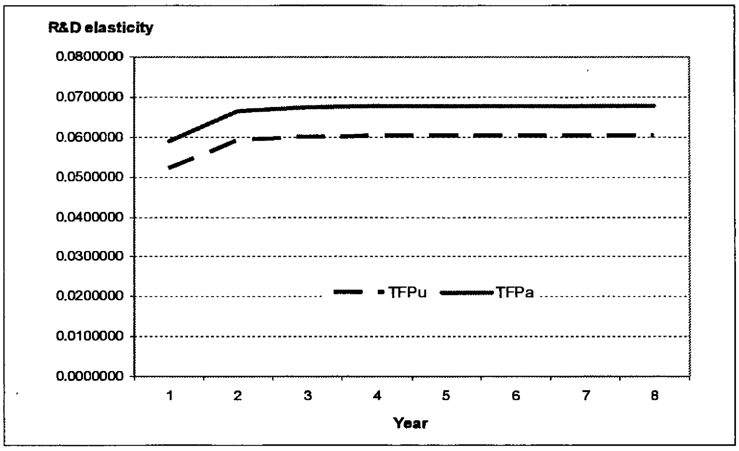
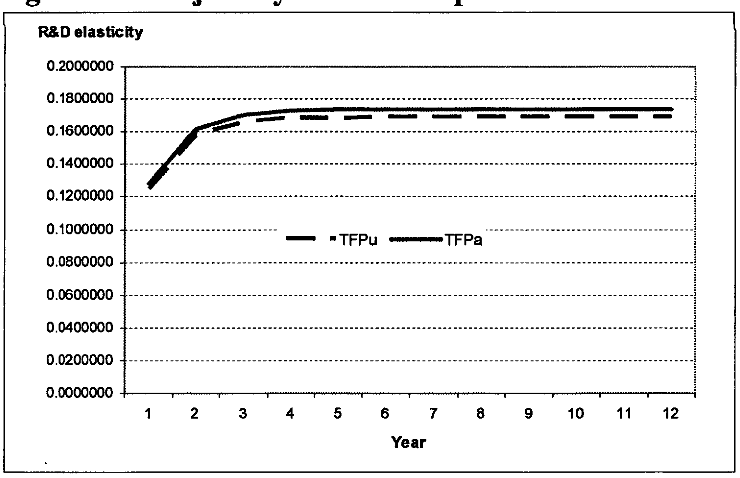


Figure 7.2 Trajectory of R&D Impact on TFP in Livestock Sector



[216] As T and long-run elasticity are known, X% of exogenous shock can be spread for each period and then the spread of R&D elasticities over time can be obtained.
[217] See details in Appendix 7 Table 7.7.

Step 1: Value Marginal Product of Research

The value marginal product (VMP) of agricultural research is calculated based on the marginal impact of research on productivity or the elasticities presented in Figures 7.1 and 7.2, using the formula in equation (7.7). It indicates a return (in terms of the change in value of output) from a 1 baht investment in public research. As all variables in equation (7.7) are sample averages, shown in Table 7.3, VMPs are varied with the value of elasticities and remain constant in the long run. Figures 7.3 and 7.4 illustrate the values of VMP from the first year until reaching their stationary values (VMP_∞).

Table 7.3 Value Marginal Product of Agricultural Research

Sector	Average value of TFP index ($\overline{TFP}$)	Average value of real research expenditure ($\overline{R}$)	Average net increase in real output (ΔQ)	Average change in TFP index (ΔTFP)	VMP in the long run (VMP_∞)
Crops		880.817			
TFPu	102.781		0.060	0.002	0.181
TFPa	99.167		0.067	0.001	0.304
Livestock		44.272			
TFPu	148.611		0.167	0.077	1.225
TFPa	146.619		0.172	0.056	1.742

Note: Calculation is based on equation (7.7). See details in Appendix7 Table 7.8.

Figure 7.3 Value Marginal Product of Research in Crops Sector

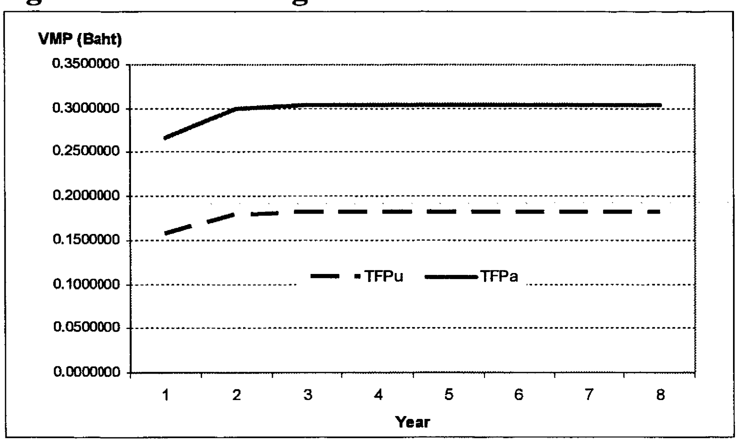
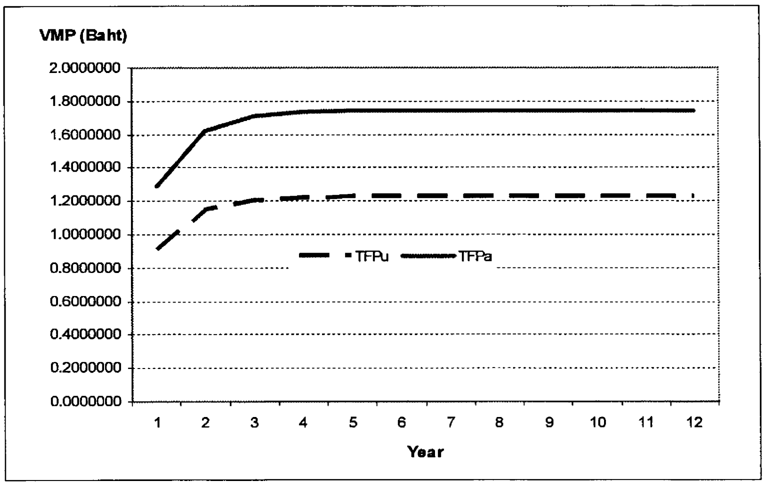


Figure 7.4 Value Marginal Product of Research in Livestock Sector



Step 2: Marginal Internal Rates of Return on Agricultural Research

Since the rate of return is based on a marginal concept, the calculation compares an initial investment of 1 baht versus the stream of research benefits estimated based on the ECM. At the period of investment (t = 0), there is no contribution from research and the net return is $VMP_0 = 0 - 1 = -1$. The benefits are attained from year 1 until perpetuity. Applying the formula in equation (7.8), the MIRRs on agricultural research are reported in Table 7.4. The results are classified according to the two sets of estimated coefficients derived from TFP determinant functions, unadjusted TFP (TFPu) and quality-adjusted TFP (TFPa).

Table 7.4 Marginal Internal Rates of Return (MIRR)

Sector	MIRR (%)	
	TFPu	TFPa
Crops	17.73	29.48
Livestock	104.28	144.21
Crops and livestock	22.06	35.21

Note: Calculation is based on equation (7.8). See calculation details in Appendix 7.
MIRR for crops and livestock combined is calculated as a weighted average using crops and livestock shares in total agricultural research expenditure (average value of crops share is 0.95 and livestock share is 0.05).

The social rates of return on agricultural research (MIRRs) for the country as a whole are estimated to be in the range of 22.06 to 35.21 percent, using both sets of TFP measures. These estimates are average rates of return calculated by combining the rates of return on crops and livestock research using their shares in total agricultural research expenditure (summing crops and livestock research spending together).

The MIRRs are higher when using the estimated coefficients from the adjusted TFP function in all cases. This occurs because the input quality adjustment removes non-technology effects out of the residual TFP measure and the agricultural research impact is captured more appropriately. When the TFP measure is clouded by non-technology factors, it is less clear what the impact of research is, thereby lowering the measured rate of return relative to its true value. As the factor input adjustment helps reflect the actual contribution of inputs as well as TFP, the MIRR based on the TFPa is therefore a preferred and correct one.[218]

The computed MIRRs are the rates of interest that equate the discounted future benefit with the initial investment. Since the estimation is based on constant prices, these estimates are national real rates of return to agricultural research. The MIRR estimate of 29.48 percent in crops sector reveals that for every baht spent on crops research conducted by the Department of Agriculture (DOA) the nation was reaping an annual increase of 0.29 baht in the value of output. A similar interpretation applies for livestock. The MIRR estimate of 144.21 percent means that for every baht spent on livestock research conducted by the Department of Livestock Development (DLD), Thailand was reaping an annual benefit of 1.44 baht increase in the value of output.

The results reveal a much higher rate of return for livestock research than for crops research. This reflects the relatively low level of investment in livestock research and the relatively high level of livestock production.[219] In addition, the very high rate of return to public livestock research may also capture the return to private research that was omitted from the general model of the TFP determinant function. The attribution

[218] Table 7.4 presents the results of TFPu in order to compare the impact of the adjustment of input quality changes. This does not mean that the results for TFPu and TFPa are equally reasonable.
[219] See Figure 7.5 for the real agricultural R&D spending in crops and livestock sector. For more details of output and research characteristics, see Chapter 3.

model covering a shorter period reveals that both public and private research have a significant positive impact on livestock productivity. If the attribution model results are assumed to hold for the whole study period then it is likely that the measured rate of return reflects the percentage return to both public and private research. The social rate of return to public research investment, computed from the attribution model of livestock TFPa function, is 87.93 percent, confirming that even accounting for the significant role of private research the MIRR estimate is still well above the opportunity cost of public funds.[220]

Sensitivity Analysis

To perform a sensitivity analysis, the length of period is arbitrarily varied into 20, 36 and 50 years. The computed MIRRs are shown in Table 7.5. The sensitivity tests suggest that the results are not sensitive to the varying numbers of years and the computed MIRR is hardly changed no matter if it continues for a finite or infinite period. Hence, summing the research benefits over an infinite period yields estimates of the social rates of return on research that are quite stable for a wide range of end period.

Table 7.5 Sensitivity Analysis of MIRR (%)

No. of years	20	36	50	∞
Sector	$MIRR_{20}$	$MIRR_{36}$	$MIRR_{50}$	$MIRR_{\infty}$
Crops				
TFPu	16.95	17.68	17.72	17.73
TFPa	29.31	29.48	29.48	29.48
Livestock				
TFPu	104.24	104.24	104.24	104.28
TFPa	144.21	144.21	144.21	144.21

[220] Note that in the case of crops the results indicate that the private research impact is not statistically significant in the long run (Chapter 6).

7.4 Comparison with Other Studies and Appraisal

Although the estimated MIRRs are not directly comparable among studies, due mainly to different methodology and coverage, it is worth looking at what previous studies have done as some useful implications may be drawn. This section evaluates the estimates of MIRR by comparing them with previous studies. It aims to provide an explanation for why the estimates are lower or higher than the existing rates, which brings out some implications regarding the methodology and research lags. In addition, issues that capture interest in the rate of return literature are discussed. Particularly, the issue of over- and under-investment is addressed, followed by some discussion on the possibility of bias and limitations of the computed MIRR that are important for policy considerations.

A large number of previous studies have estimated the internal rates of return to public agricultural research in various countries. These studies employed different estimation procedures, controlled for different factors in the estimation equations and cover different commodities and study periods. Despite the wide range of IRR estimates, the common findings are that returns to agricultural research have been high and worthwhile for additional investment. A recent summary of this work from Evenson (2001) shows a median IRR of 40 percent from 260 studies (Townsend and Thirtle, 2001). Evenson and Pray (1991) found the rates of return to public research investment in Asia ranged from 19 to 218 percent.

Some recent estimates for Thailand and other countries that adopted similar estimation procedures to this study are summarized in Table 7.6.[221] For example, Makki et al. (1999) using cointegration technique and ECM found a MIRR of 27 percent to U.S. public agricultural research. This MIRR was lower than their previous study (Makki and Tweeten, 1993) applying polynomial distributed lags to the same data set (MIRR = 93 percent), but comparable to Chavas and Cox (1992) that used a

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[221] See the literature review in Chapter 2 for more evidence of rates of return on agricultural research from various studies. In Thailand context, there is no study measuring the rate of return used similar method as this thesis. There is only empirical evidence from other countries that used similar method, i.e., using TFP function.

nonparametric method (MIRR = 28 percent). Mullen and Cox (1995) computed their own TFP index and used a new data series on R&D expenditure. They found the MIRR from research in Australian broadacre agriculture were in the range of 15 to 40 percent.[222] Hall and Scobie (2006) employed OLS and various techniques in incorporating research lags including the Almon polynomial distributed lags, Perpetual Inventory Method (PIM) and Koyck transformation. They also accounted for the spillover effects from foreign research. They found a wide range of MIRR estimates for agricultural research in New Zealand, which are sensitive to the type of model used and the specification of the variables. Their preferred model yielded the rate of return of 17 percent to domestic research, including both public and private research.

Table 7.6 Internal Rates of Return to Public Agricultural Research in Some Countries

Study	Country	Period	Method	Commodity	IRR
Makki et al. (1999)	U.S.	1930-1990	TFP function and ECM	All agriculture	27
Thirtle and Bottomley (1989)	U.K.	1965-1980	TFP function and PDL	All agriculture	100
Mullen and Cox (1995)	Australia	1953-1988	TFP function and PDL	Broadacre agriculture	15-40
Hall and Scobie (2006)	New Zealand	1926-2000	TFP function and OLS	All agriculture	17
Setboonsarng and Evenson (1991)	Thailand	1967-1980	Profit function and SUR	Crops	42
Pochanukul (1992)	Thailand	1961-1987	Profit function and SUR	Crops	44.95
Thirtle et al. (2003)	Africa, Asia, Latin America	2000	Causal chain models and 3SLS	All agriculture	23 (Thailand)

Note: SUR = Zellner's seemingly unrelated regression, 3SLS = three-stage least square method, PDL = polynomial distributed lag.

222 Broadacre agriculture refers to sheep, beef and cropping industries.

In the Thailand context, existing studies specifically measuring the MIRR have focused only on crops research. Setboonsarng and Evenson (1991) found the rate of return to national crops research was 42 percent. Extending from this first study, Pochanukul (1992) incorporated intra-national research spillovers found a slightly higher rate of 44.95 percent. Another study by Thirtle et al. (2003) estimated the rate of return to national research at 23 percent, which is derived from the elasticities of value-added per unit of land with respect to agricultural research. This study focuses mainly on measuring the impact of research-led agricultural productivity growth on poverty reduction in various countries and the IRR is not measured as MIRR. None of these studies derived the research impact from total factor productivity.

Compared with previous studies, the computed rates of return in this chapter (Table 7.4) are lower than the estimates of the previous Thai studies that focused on crops and adjusted neither for input quality changes nor accounted for international research spillovers. Nevertheless, the estimated MIRRs are reasonable when compared with Makki et al. (1999). They used the error correction model and found a 27 percent rate of return on public agricultural research in the U.S. As mentioned above, this rate of return is lower than their previous estimate using the conventional Almon lag structure. The lower estimates can then be explained by two probable causes related to the inclusion of explanatory variables and the estimation model.

First, the lower rates of return estimated in this chapter are attributable to the inclusion of international research spillovers and other non-market factors such as weather, education and rural roads as well as controlling for price surge from the world commodity boom. A failure to account for the benefits that spill over from the international research agencies could overestimate the rates of return to research in Thai agriculture. The present study confirmed (Chapter 6) that this result did occur, particularly in the crops sector where the CGIAR has played a contributing role. Similarly, past studies that did not control for non-market inputs might have resulted in misleadingly high payoffs to agricultural research investments. Hence, the high rates of return in previous studies may have been inflated by not controlling for these important factors.

Second, the results suggest that ignoring data nonstationarity and long-run relationships in earlier studies may have overestimated the actual payoffs to agricultural research investments (Makki et al., 1999). Thus, the ECM incorporating the long-run relationships likely yields lower IRR.[223] Moreover, this technique helps guard against spurious regressions while addressing the issue of constrained lag structure. The potentially serious source of bias in measured rates of return on agricultural research, found in most studies, is associated with restrictive form and a finite lag of research investments (Fuglie et al., 1996). As production or productivity is modelled as a function of research expenditure, the finite lag implies that if research were to cease there would be zero production as a result (Alston et al., 1998a). Under the ECM, finite lags of research investments can be used to model an effect of research on productivity that last infinitely even though the data set used for the analysis is necessarily of finite length. More importantly, the ECM has been shown to fit well with the Thai data. Hence, this estimation method is likely to yield a more realistic research impact as well as rates of return.

It is important to note that due to different methodologies, data, study periods, and uncertainty associated with the lag length and shape of research, the estimated MIRRs are not directly comparable with previous studies. In particular, it is not possible to make direct comparisons across countries or over time. Therefore, it is difficult to assert that Thailand's agricultural research system performed better or worse than the research industries of other countries. Nevertheless, the general finding that agricultural research yields relatively high returns seems very robust.

The Social Rate of Return as a Guide to Funding Decisions

With regard to the typical IRR evaluation, social returns to public investment are often compared with the benchmark return to government bonds as a measure of the opportunity cost of public funds (Fuglie and Heisey, 2007). Without finding the interest rates of public funds, the measured MIRRs of 29 percent to over 100 percent are high enough to suggest that economic returns to agricultural research have been

[223] Alston et al. (1998a) asserted that when appropriate estimation techniques are used, rates of return to research are actually quite low.

favourable relative to alternative capital investment. The results of this chapter are also consistent with other studies that the return to public agricultural research has been higher than the benchmark return from government securities. Therefore, the rates of return are high enough to justify continued public investment in agricultural research in Thailand.

The estimated rates of return can yield insights on how much resources should be allocated to research. The findings suggest crops and livestock research investment is a valuable investment. A lower rate of return on crops research does not mean it is less effective but rather that past investment in livestock research has been too low.

Since the estimated social rates of return represent the net returns to society as a whole, a high ROR implies that the gains (for example, lower production costs for farmers and lower product prices for consumers) to winners from the new technology exceed the losses to those who may lose from the new technology (Fuglie et al., 1996). However, it is important to keep in mind, especially for policy consideration, that the measured ROR only reflects returns to the past investment in agricultural research (Fuglie et al., 1996). If the research system performance will be the same in the future, then the funding implications from the estimated MIRRs will hold.

Has Thailand been over or under invested in public research?

The high rates of return to crops and livestock research imply that the past investment has been too small. The findings support the general belief that there is an underinvestment in public agricultural research. The question arises would be why there is an underinvestment in research activity that offers such a high return?[224] One probable cause is related to the public-good issue. Agricultural research has certain characteristics of public goods: non-excludability and non-rivalry (Dalrymple 2003, 2008). That is, once research knowledge or new technology is invented it is available to all and its adoption by one person does not diminish its availability to others,

[224] There are a number of studies thoroughly investigating the pervasive underinvestment in public agricultural research, see, for example, Oehmke (1986), Ruttan (1987), Roseboom (2002) and Pardey et al., (2006c).

although these aspects are usually confined to a sector or commodity. The public-good characteristics reduce private incentives to invest in agricultural research.

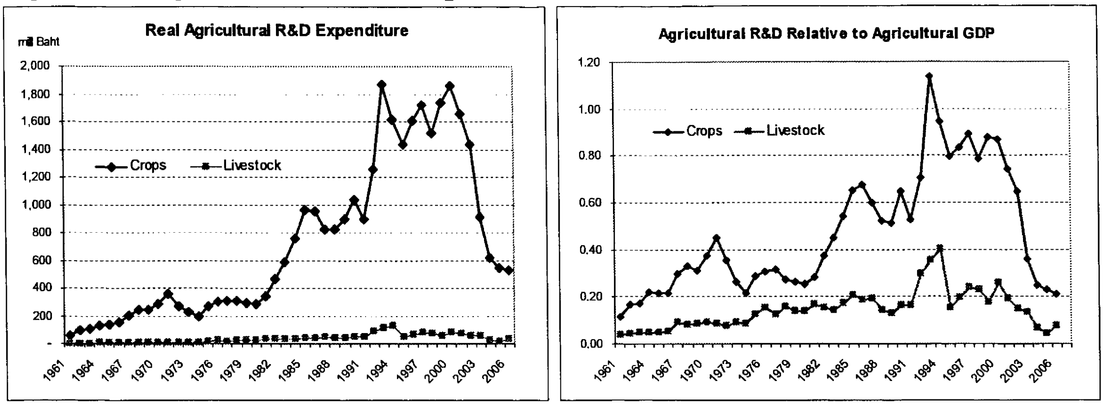
To a large extent, agricultural research in Thailand is still considered a service provided by the public sector. However, the government itself has many policy objectives. Agricultural research is time consuming and it takes an uncertain number of years to be successful. As a result, it cannot respond quickly to policy makers who tend to prefer short-term returns (Pochanukul, 1992). It is therefore typical for agricultural research to be underfunded.

The majority of previous studies have found an underinvestment in agricultural research (Ruttan, 1980, 1982b, Evenson and Pray, 1991, Roseboom, 2002). Underinvestment in agricultural research implies the economy has failed to reap substantial new income streams that could have been realized at a relatively low cost and this failure reflects the problem of 'market failure' (Ruttan, 1982b, p.323). Market failure and government failure are generally considered as factors that prevent the economy to obtain socially optimal level of agricultural technology, thereby causing pervasive underinvestment in research in many countries (Ruttan, 1987, Harris and Lloyd, 1991, Pardey et al., 1991, Pardey et al., 2006c).[225] The findings from this chapter also conform to the previous studies.

In Thailand, despite the high payoffs to agricultural research and its importance for long-term growth, there is a slowdown in the public research investment measured in both real terms and its intensity (agricultural research spending as share in agricultural GDP), shown in Figure 7.5. As agricultural research impact on TFP is proven significant, the recent slowdown in the public agricultural research expenditure is a reason for serious concern.

[225] See literature review in Chapter 2, section 2.5.1 for detail.

Figure 7.5 Agricultural R&D Expenditure in Thailand, 1961-2006



Source: Agricultural R&D expenditure data are from the Bureau of the Budget and agricultural GDP are from the NESDB.

Has ROR been over or under estimated?

It is important to keep in mind the limitations of the estimated MIRRs in drawing a conclusion or policy implication. Like the productivity measure, the rates of return are also subject to data and measurement problems, which lead to the issue of over or under estimation. These are discussed as follows.

With regards to the measurement of rates of return (ROR) on research, there are two possibilities of bias raised in the literature. On the one hand, the existing ROR may have been overestimated due to omitted variable bias. Studies often ignore the role of foreign research spillovers and private research, potentially causing the social RORs on the public investment to be overestimated. Imposing a short and restrictive form of lag also tends to cause upward biases in the estimated rate of return (Alston et al., 1998a, Alston et al., 2000, Alston and Pardey, 2001).[226] In addition, research costs tend to be underestimated. Ignoring opportunity costs and deadweight losses of public research investment financed by taxes on private sector activity is another cause of overestimated ROR (Fuglie et al., 1996, Schimmelpfennig et al., 2000).

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[226] Alston et al., 1998a showed that the arbitrary truncation of the lag distribution for the stream of net research benefits could lead to serious upward biases in the rate of return.

On the other hand, some economists argue that the existing RORs may have been underestimated due to the implicit assumption underlying the estimation of internal rate of return. Studies have usually been based on the implicit assumption that if there were no research there would be neither growth nor decline in output or productivity (Townsend and Thirtle, 2001). These studies do not account for the losses that would occur in the absence of research, particularly health maintenance research that helps prevent animal and plant diseases. Benefits from disease prevention, food safety R&D, and the spillover benefits from agricultural R&D into non-agricultural applications may not show up clearly in commodity markets and some are not captured in conventional productivity measures (Alston and Pardey, 2001).[227] Ignoring these issues leads to an underestimation of the rate of return.

In addition, a failure to account for undesirable outputs caused by research, such as environmental degradation, can overestimate the ROR whereas omitting new technology that reduces undesirable outputs results in an underestimation of the ROR (Fuglie and Heisey, 2007).

Nevertheless, the previous chapter has attempted to tackle the omitted variable bias by including foreign research spillovers, infrastructure, agricultural commodity boom, weather and other major factors influencing TFP. Therefore, to a certain extent, the rate of return estimates have guarded against most of the overestimation bias. The relatively low MIRR estimates of crops research found in this chapter also conforms to this argument. What remains arguable is therefore related to the deadweight loss, the omission of private research and the possibility of underestimation.

The estimated MIRR has to be compared with the opportunity cost of public funds, which includes the opportunity costs and deadweight losses associated with the tax collection used to finance the public research. The MIRR may also be adjusted

[227] Some research activities, particularly post-harvest research, are related to the agribusiness sector whose production value is counted as manufacturing not agriculture thereby excluded from agricultural GDP (and hence TFP measure).

downward if accounting for the role of private research, particularly in the livestock sector. However, as mentioned in the previous section, even accounting for the role of private research the MIRR is still well above the cost of public funds.

In contrast, the measured MIRR may increase if the losses that would occur in the absence of research are account for. Nonetheless, the potential output losses that would occur in the absence of agricultural research, such as animal and plant diseases that were prevented by research-induced agricultural technology are difficult to measure in practice. The health and environmental effects of new technology are also limited by data constraints.

On balance, the estimated MIRRs are still high and in a range that is substantially above the opportunity cost of public funding.[228] The measured MIRR on agricultural R&D is well above a reference bond yield or any other interest rates in the financial market.

Regarding the comparison of marginal returns among different types of public investment in Thailand, Fan et al. (2004) show that agricultural research has by far the largest productivity impact and the highest return compared with investment in irrigation, roads, education and electricity. Their study suggests the marginal returns to public investment in agricultural research is about 20 percent higher than the returns on irrigation and rural roads and 3-6 percent higher than those on electricity and education investment, respectively.[229]

[228] This cost of public fund is commonly represented by government bond yield. For example, Fuglie and Heisey (2007, p.3) used the long-run yield of U.S. government securities to represent the cost of social capital. This discount rate (i) can be used to convert IRR into benefit-cost ratio (B/C); IRR = B/C × i. In Thailand, the government bond yield is commonly used as a reference rate for public borrowing.

[229] Fan et al., (2004) calculated the marginal returns for 1999 in terms of benefit-cost ratios. Agricultural labour productivity is employed as a measure of productivity. The B/C for agricultural R&D, irrigation, roads, education and electricity are 12.62, 0.71, 0.86, 2.12 and 4.89, respectively. If allowing 5 percent (the average government bond yield in 1999) to represent the cost of social capital, then the corresponding rates of return are 63.10, 3.55, 4.30, 10.60 and 24.45 percent, respectively.

The MIRRs are derived based on the TFP function that accounts for all the potential determinants as well as allowing for dynamic research lags and long-run effect using the ECM method. The results have passed the test of ignoring issues that are major sources of bias. The exact estimates may be adjusted upward or downward depending on the two opposite forces of bias left unmeasured. It is precautionary to note unmeasured costs and benefits when using the computed rates of return.

7.5 Conclusion

The social rates of return on public agricultural research, focusing on crops and livestock, were estimated to be 29.48 percent for crops and 144.21 percent for livestock. These national real rates of return are derived from the productivity function that accounts for the spillover effects and other important attributable factors to TFP growth that was adjusted for input quality changes. Together with the estimation method (ECM) that accounts for long-term research impact this yields relatively lower estimates of the MIRRs, compared with some previous studies. Nevertheless, the estimates are high enough to justify continued and increased public investment in agricultural research.

The results indicate the return to livestock research is about seven fold higher than crops, suggesting past public investment in livestock research was too low. Overall, the estimated marginal internal rates of return are high, implying an underinvestment in agricultural research for the past four decades. Despite some weaknesses in the measurement and constraints in capturing all research benefits and costs, these rates of return suggest high payoffs to society as a whole from additional investment in agricultural research.

Appendix 7 Calculation of Internal Rate of Return

Table 7.7 Estimated Elasticities Over Time

Year	Crop_TFPu	Crop_TFPa	Live_TFPu	Live_TFPa
1	**0.0520080**	**0.0590360**	**0.1254240**	**0.1284800**
2	**0.0590845**	**0.0665358**	**0.1575846**	**0.1620053**
3	**0.0600473**	**0.0674886**	**0.1658311**	**0.1707533**
4	**0.0601783**	**0.0676096**	**0.1679456**	**0.1730360**
5	**0.0601962**	**0.0676250**	**0.1684878**	**0.1736317**
6	**0.0601986**	**0.0676269**	**0.1686268**	**0.1737871**
7	**0.0601989**	**0.0676272**	**0.1686624**	**0.1738277**
8	**0.0601990**	0.0676272	**0.1686716**	**0.1738382**
9	0.0601990	0.0676272	**0.1686739**	**0.1738410**
10	0.0601990	0.0676272	**0.1686745**	**0.1738417**
11	0.0601990	0.0676272	**0.1686747**	**0.1738419**
12	0.0601990	0.0676272	0.1686747	**0.1738420**
13	0.0601990	0.0676272	0.1686747	0.1738420
14	0.0601990	0.0676272	0.1686747	0.1738420
15	0.0601990	0.0676272	0.1686747	0.1738420
16	0.0601990	0.0676272	0.1686747	0.1738420
17	0.0601990	0.0676272	0.1686747	0.1738420
18	0.0601990	0.0676272	0.1686747	0.1738420
19	0.0601990	0.0676272	0.1686747	0.1738420
20	0.0601990	0.0676272	0.1686747	0.1738420
21	0.0601990	0.0676272	0.1686747	0.1738420
22	0.0601990	0.0676272	0.1686747	0.1738420
23	0.0601990	0.0676272	0.1686747	0.1738420
24	0.0601990	0.0676272	0.1686747	0.1738420
25	0.0601990	0.0676272	0.1686747	0.1738420
26	0.0601990	0.0676272	0.1686747	0.1738420
27	0.0601990	0.0676272	0.1686747	0.1738420
28	0.0601990	0.0676272	0.1686747	0.1738420
29	0.0601990	0.0676272	0.1686747	0.1738420
30	0.0601990	0.0676272	0.1686747	0.1738420
31	0.0601990	0.0676272	0.1686747	0.1738420
32	0.0601990	0.0676272	0.1686747	0.1738420
33	0.0601990	0.0676272	0.1686747	0.1738420
34	0.0601990	0.0676272	0.1686747	0.1738420
35	0.0601990	0.0676272	0.1686747	0.1738420
∞	0.0601990	0.0676272	0.1686747	0.1738420

Table 7.8 Value Marginal Product Over Time

Year	Crop_TFPu	Crop_TFPa	Live_TFPu	Live_TFPa
1	**0.1568054**	**0.2658680**	**0.9114949**	**1.2880526**
2	**0.1781411**	**0.2996433**	**1.1452159**	**1.6241545**
3	**0.1810441**	**0.3039341**	**1.2051454**	**1.7118563**
4	**0.1814391**	**0.3044792**	**1.2205123**	**1.7347410**
5	**0.1814929**	**0.3045484**	**1.2244525**	**1.7407125**
6	**0.1815002**	**0.3045572**	**1.2254629**	**1.7422707**
7	**0.1815012**	**0.3045583**	**1.2257220**	**1.7426772**
8	**0.1815013**	0.3045583	**1.2257884**	**1.7427833**
9	0.1815013	0.3045583	**1.2258054**	**1.7428110**
10	0.1815013	0.3045583	**1.2258098**	**1.7428182**
11	0.1815013	0.3045583	**1.2258109**	**1.7428201**
12	0.1815013	0.3045583	1.2258109	**1.7428206**
13	0.1815013	0.3045583	1.2258109	1.7428206
14	0.1815013	0.3045583	1.2258109	1.7428206
15	0.1815013	0.3045583	1.2258109	1.7428206
16	0.1815013	0.3045583	1.2258109	1.7428206
17	0.1815013	0.3045583	1.2258109	1.7428206
18	0.1815013	0.3045583	1.2258109	1.7428206
19	0.1815013	0.3045583	1.2258109	1.7428206
20	0.1815013	0.3045583	1.2258109	1.7428206
21	0.1815013	0.3045583	1.2258109	1.7428206
22	0.1815013	0.3045583	1.2258109	1.7428206
23	0.1815013	0.3045583	1.2258109	1.7428206
24	0.1815013	0.3045583	1.2258109	1.7428206
25	0.1815013	0.3045583	1.2258109	1.7428206
26	0.1815013	0.3045583	1.2258109	1.7428206
27	0.1815013	0.3045583	1.2258109	1.7428206
28	0.1815013	0.3045583	1.2258109	1.7428206
29	0.1815013	0.3045583	1.2258109	1.7428206
30	0.1815013	0.3045583	1.2258109	1.7428206
31	0.1815013	0.3045583	1.2258109	1.7428206
32	0.1815013	0.3045583	1.2258109	1.7428206
33	0.1815013	0.3045583	1.2258109	1.7428206
34	0.1815013	0.3045583	1.2258109	1.7428206
35	0.1815013	0.3045583	1.2258109	1.7428206
∞	0.1815013	0.3045583	1.2258109	1.7428206

Appendix 7A Calculation Formula of MIRR

$$1=\sum_{t=1}^{\infty}\frac{VMP_t}{(1+r)^t}$$

VMP is varying from period 1 to period T (long-run) and remains constant from period T until perpetuity.

$$1=\frac{VMP_1}{1+r}+\frac{VMP_2}{(1+r)^2}+...+\frac{VMP_T}{(1+r)^T}+\left(\frac{VMP_T}{(1+r)^{T+1}}+\frac{VMP_T}{(1+r)^{T+2}}+...+\frac{VMP_T}{(1+r)^{T+\infty}}\right)$$

$$1=\frac{VMP_1}{1+r}+\frac{VMP_2}{(1+r)^2}+...+\frac{VMP_T}{(1+r)^T}+\frac{VMP_T}{(1+r)^{T+1}}\left(1+\frac{1}{(1+r)}+\frac{1}{(1+r)^2}+...+\frac{1}{(1+r)^{\infty}}\right)$$

$$1=\frac{VMP_1}{1+r}+\frac{VMP_2}{(1+r)^2}+...+\frac{VMP_T}{(1+r)^T}+\left(\frac{VMP_T}{(1+r)^{T+1}}\times\frac{1}{1-\frac{1}{1+r}}\right)\quad \text{(By geometric series)}$$

Chapter 8

8. Conclusion and Policy Implications

8.1 Introduction

This thesis empirically investigates the impact of agricultural research on productivity in Thailand. It is widely believed that public agricultural research has a positive and significant impact on productivity and that its marginal payoffs have been high, implying an underinvestment in agricultural research. This belief has not previously been carefully tested in the context of Thai agriculture. The important issues of lags, spillovers and attribution usually ignored in previous studies are addressed in the present study. The empirical analysis covers the Thai agricultural sector with a particular focus on crops and livestock for the period 1970-2006.

Three empirical estimations are undertaken to answer each of the following three research questions.

1. *What are sources of output growth in Thai agriculture?*

   The total factor productivity (TFP) growth is estimated using the conventional growth accounting method to decompose agricultural growth into growth from each input and growth from TFP (Chapter 4).
2. *What determines TFP growth and how has agricultural research influenced it?*

   The determinants of TFP growth are investigated with an emphasis on the role of agricultural research. A wide range of potential factors is examined using time-series econometric models along with the major sources of agricultural research spending –public, private, university and foreign (Chapter 5-6).
3. *What is the social rate of return on public agricultural research investment?*

The social rates of return on public agricultural research investment are estimated to determine whether the research payoffs are as high as widely believed and whether more or less should be invested in future agricultural research (Chapter 7).

This chapter is organized as follows. Section 8.2 provides a summary of the empirical findings in response to the three main research questions as set out in Chapter 1. Section 8.3 draws on some of the implications of these results. Section 8.4 spells out some limitations of the current research and suggests a number of extensions and possible future research directions that could address some of the limitations of this thesis.

8.2 Findings on the Three Research Questions

The empirical analysis is undertaken to answer the above three questions. The main findings are as follows.

8.2.1 Question 1: TFPG Measurement

Using the national income-based growth accounting framework, outputs and inputs are measured in real terms. The sources of overall agricultural growth during 1970-2006 are attributable to capital accumulation, followed by TFP, labour and land. This is consistent with the expectation and with previous studies. The relative importance of factor inputs and TFP remains the same for both the crops sector and traditional agriculture (combining crops and livestock together), but not for the livestock sector where labour is the largest source of growth, followed by TFP. The contribution of TFP to output growth fluctuated over time.

A factor input adjustment is undertaken on labour and land to remove the productivity growth arising from input quality changes out of the residual TFP measure. On this basis, TFP growth should more closely reflect the pure technical change which is an outcome of agricultural research. The results indicate a slight improvement in labour quality, measured in terms of age, sex and education, and land quality due to improved irrigation. The improvement in labour and land quality increases the contribution of input growth and lowers TFP growth slightly. Thus, the differences between unadjusted and adjusted TFP growth are minor. Although the adjusted TFP is a preferred measure of productivity, both sets of TFP measures are used as the dependent variables in the study of TFP determinants, below, for comparison purposes.

8.2.2 Question 2: TFPG Determinants

The second empirical part of the thesis investigates the determinants of measured TFP growth. Since TFP growth is measured as a residual and commonly referred to as 'a measure of our ignorance' (Abramovitz, 1956), there are many candidates to explain the residual. In the Thai agriculture context, these factors are categorized into four major groups (technical change, efficiency gains, economies of scale and natural/case-specific factors) comprising eight key factors; agricultural research, extension services, technology transfer, education, infrastructure, trade openness, resource reallocation and natural and case-specific factors.

The results are divided into two parts according to the estimation methods; the growth-rate model (GRM) incorporating the polynomial distributed lags (PDL) and the error correction model (ECM) allowing for both short- and long-term relationships and dynamic lag structure. Each method consists of two models: the general model (GM) covering the whole studied period; and the attribution model (AM) covering a shorter period but including more research variables to address the attribution issue. The results suggest the ECM better explains the variations in the unadjusted and adjusted TFP growth than the GRM. The results are consistent between the unadjusted and adjusted TFP models. The relationship between productivity and its main determinants are captured better by accounting for both short- and long-run information. The ECM does not impose any of the restrictive and finite research lags applied in the majority of studies thereby overcoming the potential bias caused by imposing too short and mis-specified forms of lags (Fuglie et al., 1996, Alston et al., 1998a, Alston and Pardey, 2001).

The thesis attempts to capture the research lags using different methods: the 2nd degree polynomial distributed lags or Almon lags, the Perpetual Inventory Method (PIM) and dynamic lags under the ECM. The likely gestation, blossoming and eventual obsolescence of research results commonly assumed under the Almon lag structure does not fit well with the Thai data. The geometric depreciation of research effects and the stock of research knowledge assumed under the PIM also fail to capture the distribution of the research impact on productivity. Only the flow of real agricultural research spending captured by the dynamic and infinite lags under the ECM fits well with the data.

The general findings using the ECM provide empirical evidence for the general belief that agricultural research is one of the main driving forces behind TFP growth in Thai agriculture. In particular, the longstanding public investment in agricultural research has a positive and significant impact on TFP growth in both the crops and livestock sectors. This important role of public research holds for the whole (GM) and the shorter periods (AM). There is evidence that international research spillovers, measured as the CGIAR funding to IRRI, CIAT and CIMMYT, also contribute to TFP growth in the traditional agriculture and crops sector. This conforms to the prior expectation that the modern rice or crops varieties developed by the CGIAR centres that have a close collaboration with Thailand have benefited local productivity. The magnitude of the foreign research impact is also larger than that of public research. Failure to account for these spillover effects is likely to result in an upward bias in both the estimates of local research impact and the associated rate of return. The reason is that the omission of foreign research tends to overattribute observed gains in productivity to local research. However, the role of foreign research spillovers (CGIAR) does not appear to be statistically significant during the shorter period.

Under the attribution model (AM) covering the shorter period of 1980-2006, all major types of local agricultural research expenditure (public, private and university) contributed positively to the productivity gains in overall agriculture, either in the short or the long run. The results suggest that private-sector research has contributed most to productivity growth, particularly in the traditional agriculture and livestock sector. In fact, both public and private research investment have played a significant role in the traditional agriculture and livestock sector but the magnitude of the private research impact is larger. This is consistent with the general belief that large private companies, notably the CP Group, have played an important role in developing technology particularly in animal feeds. In the case of livestock, foreign research is measured in this analysis as expenditure on imported livestock breeds. It is found that foreign research also has a significant role in influencing livestock productivity. This conforms to the fact that Thai livestock production as well as public and private research still rely on imported technology.

The determinants of TFP growth are not confined only to agricultural research but also include other factors, both economic and non-economic. Infrastructure, as represented in this thesis by rural roads, appears to have a positive and significant impact on agricultural productivity. Agricultural extension is also important in disseminating research results to farmers for adoption. The natural environment, measured as the amount of rainfall, also influences TFP growth. In addition, the 1972-74 world commodity boom positively influences crops productivity while the Avian Influenza outbreak negatively affects livestock TFP.

8.2.3 Question 3: Returns on Agricultural Research

The measured agricultural research impact on TFP growth from the previous analysis is employed in the final part to estimate the social rate of return. The findings are expected to provide evidence on the payoffs to the longstanding public investment in agricultural research after carefully accounting for the major sources of biases commonly found in the literature. Focusing on crops and livestock, the social rates of return are shown to be high as has normally been found in the literature despite the attempts to account for major sources of overestimation. This implies an underinvestment in public agricultural research and thereby justifies additional investment.

The rate of return on crops research is estimated at 29.5 percent. This measured payoff is lower than, but comparable to, the previous Thai studies (Setboonsarng and Evenson, 1991, Pochanukul, 1992). Despite different methods, periods and coverage, the lower return is most likely explained by the TFP determinant models controlling for the international research spillovers and other potential factors as well as the ECM that accounts for the long-run relationships among variables. The rate of return on livestock research is estimated at 144.2 percent, which is substantially above the opportunity cost of public funds. This indicates that past investment in public livestock research has been too low. These are apparently the first estimates for Thai agriculture that carefully account for the issues of lags, spillovers and attribution, all of which are potential sources of bias. Although the accuracy of the estimates of rates of return must be qualified, due to the possibility of measurement errors, the findings strongly suggest that agricultural research investment yields high returns and that past research activities have been underfunded. This finding also raises a concern over the recent slowdown in public agricultural research expenditure.

Almost all the previous studies found a positive and significant impact of agricultural research investment on productivity and the associated social rates of return were high. Several studies have suspected the estimated returns were too high and have attempted to push the estimates down by accounting for the omitted variable bias using a wide range of techniques. Nevertheless, the high measured rates of return on agricultural research passed the tests and stayed well above the benchmark returns on other public funds. The findings from this thesis provide new empirical evidence on Thai agriculture, and also support the broad findings of the majority of previous studies.

8.3 Policy Implications of the Findings

Despite the high rate of return, a pervasive underinvestment in the agricultural research system is commonly found in the rate-of-return literature and still persists in a number of countries (Ruttan, 1982b, Evenson and Pray, 1991, Evenson, 2001, Roseboom, 2002). This is also the case for Thailand and the situation seems worrisome as declining trends in public crops and livestock research budget have been observed from the mid-1990s. The probable cause is related to the public-good issue, market failure and government failure mentioned in Chapter 7. The public-good characteristics, together with time-consuming research with no certainty of successful results that requires large funding reduces the incentive for the private-sector to increase participation or the government to conduct the handsomely productive research themselves. This does not necessarily imply that the amount of government spending should increase but the government can change the incentives for others to increase their investment in agricultural research (Pardey et al., 2006c). However, this study does not investigate the distribution of gains from research and private research may not be perfectly substitutable for public research. Further study on the role of public and private research is needed to qualify the following discussion.

There are a variety of policy tools to induce more investment, for instance, improving intellectual property protection and providing subsidies. Pray and Fuglie (2001) provide a summary of the conceptual determinants of private research and relevant public policies (Table 8.1). These policies have largely been implemented in Thailand but tend to lack the strong commitment, consistency and proper sequencing of policies. If the significance of agricultural research is well recognized and is used as a policy tool to maintain agricultural output using fewer resources then a serious and consistent policy commitment is necessary.

Regarding the research policy, R&D tax incentives have increasingly become a common policy tool to address the public-good issue and induce private and foreign R&D investment, mostly in the context of industry (see Hall and Reenen, 2000, Thomson, 2008). For agriculture, private and foreign R&D have also been recognized as important sources of funding that could compensate for the declining public agricultural research investment and free public resources for other priorities. On this basis, Pray and Fuglie (2001) provide evidence, using data from the mid-1980s to the mid-1990s, that private research will not fill the gap needed to support rapid growth in demand for agricultural products. Instead, foreign research has made an important contribution to private research in Asian countries including Thailand. Their findings suggest the liberalization of industrial policy that allowed private and foreign firms to operate and expand in agricultural input industries was the most important policy with the second most important policy being investment in public research.

Table 8.1 Public Policies and Incentives for Private Agricultural Research

Private research determinants	Policies affecting determinants
General state of the economy	Macroeconomic stability Public infrastructure General education and training Development of capital and insurance markets
Size of input markets	Market share of state-own enterprises Restrictions of foreign participation in input markets Trade restrictions on inputs Price interventions in input or product markets
Appropriability	Intellectual property laws (patents, plant breeders' rights, trademarks, trade secret protection) and enforcement Technology-licensing requirements and regulations affecting technology imports Competitiveness and antitrust policies
Technological opportunity and cost of research inputs	Public investment in agricultural research and education Trade restrictions on inputs and restrictions on foreign direct investment Registration and testing requirements on new seed and agricultural chemicals Biosafety requirements for biotechnology field trials Public subsidies for private research, including tax holidays, tax credits, research grants and technology parks

Source: Pray and Fuglie (2001, p.11). Notes: Private research refers to research conducted by domestic and foreign companies. Appropriability refers to ability to capture some benefits from research and turn them into profits. See Pray and Fuglie (2001) for more details.

Patents and tax incentives seem to have little effect but could be important in the future. On the contrary, there is evidence from EU countries[230] that economic incentives and institutions have strong impacts on private agricultural R&D investment, which accounts for about 10-50 percent of total agricultural R&D (Alfranca and Huffman, 2001). In the case of Thailand, where the majority of agricultural R&D activities are dominated by the public sector, continued public support on agricultural research is deemed necessary, especially in providing basic

[230] The study included Austria, Germany, Italy, The Netherlands, Portugal, Spain and Sweden.

research or research activities that complement private research.[231] Strengthening the national research system is strongly encouraged.

Strengthening the national agricultural research system has long gained considerable attention from both the government and international agencies like The World Bank (Setboonsarng et al., 1991, Byerlee and Alex, 1998). Policy issues mainly involve *ex ante* research resource allocation and research priority settings. These issues are beyond the scope of this thesis and require thorough analysis, but the *ex post* rates of return estimated by this thesis have implications for research resource allocation. The high measured rate of return implies underinvestment in agricultural research, making additional investment worthwhile. Although it is not certain that high ex post rates of return implies high ex ante rates of return, historical information on costs and returns do form a basis for making future investment decisions (Ruttan, 1982b). However, implications cannot be drawn as to how the money should be distributed and money is not the only important resource, research personnel and facilities are also worth considering. These issues are often addressed in research priority setting studies (see, for example, Alston et al., 1998b, Norton et al., 1992, McCalla and Ryan, 1992).

The findings also have implications for public research policy regarding research collaboration and local research capacity. The positive and significant impact of major types of research spending – government, private sector, international research agencies and university – suggest additional investment and increased research collaboration should produce agricultural productivity growth. The government should play a more active role in encouraging increased collaboration among major research performers. The significant role of international 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 able to make efficient use of foreign technology. Given the slowdown in productivity-enhancing research investment in developed countries which has been

[231] As mentioned in Chapter 3, agricultural research policy and public research in Thailand has been a complement, rather than compete with the private sector (Fuglie, 2001).

the major source of worldwide agricultural technology (Pardey et al., 2006d), the results of this study suggest that the country should continue to develop its own agricultural science capacity and demand for more effective research planning and management.

Furthermore, the empirical finding from this thesis seems to signal weak cooperation between research and extension as indicated by the insignificance of its interaction term. This finding is consistent with the previous study by the Office of Agricultural Economics (1998). Strengthening the linkage between research and extension is another important policy as it will increase the efficacy of agricultural research and hence long-term productivity. In the case of foreign technology that can be applied directly in local conditions, agricultural extension should be strengthened to transfer technology from abroad to farmers more effectively.

The evidence presented in this thesis suggests agricultural research deserves greater policy consideration as it is shown to play a significant role in raising agricultural productivity and hence output growth in Thai agriculture. This implication is also consistent with previous studies providing evidence for developing countries that agricultural research investment is significant for agricultural growth (e.g., Evenson and Pray, 1991, Fan and Rao, 2003, Pingali and Heisey, 2003, Ananth et al., 2006). In Asian countries, including Thailand, agricultural research expenditure has had a much larger impact on productivity than non-research spending such as irrigation, education and roads, and the rates of return to agricultural research are far higher than other types of public sector projects (Fan and Rao, 2003, Pray, 1991).

Nonetheless, agricultural research investment cannot stand alone in sustaining long-term productivity growth. Other factors especially infrastructure, agricultural extension, education and trade openness are also important. The significant roles of natural factors also point out the merits of policy warning about natural events that may be relevant for agricultural production and timely response to help farmers adapt their production pattern when faced with aberrant weather and animal disease outbreaks. The surveillance and relief package in response to weather aberration and epidemics, channelled mainly through agricultural extension services, should be strengthened to prevent output losses.

The significance of agricultural research is widely recognized (CGIAR, 2009). Many studies advocate agricultural research as a significant part of official development assistance, especially in fostering agricultural productivity and growth (Schultz, 1953, Ruttan, 1987, Pardey et al., 1991, Evenson, 2001, Pardey et al., 2006c). Thai agricultural production has become less reliant on land and labour and more on capital and technology, highlighting the importance of research in sustaining long-term growth. Agricultural research also plays an important role in maintaining agricultural competitiveness in the world market (Office of Agricultural Economics, 1998). On this recognition, despite various policy options agricultural research policy deserves ongoing commitments from all parties to revitalize agriculture.

8.4 Limitations and Future Research

The findings of this thesis must be qualified by the existence of data limitations. Although careful efforts have been made in compiling consistent data series, some variables, such as output, inputs and research variables, are still subject to measurement errors. Under the national income based growth accounting, output is measured as agricultural value added which excludes intermediate inputs, such as fertilizers and pesticides. These intermediate inputs, especially fertilizers, are potential factors affecting agricultural productivity as they may capture foreign or local technology. However, due to the lack of data, value added or GDP growth provides the longest and most consistent data series at an aggregate level.

Regarding input measures, the number of employed persons is used to represent labour input. This may not reflect the actual contribution as closely as working hours.[232] Future research may also consider the role of migrant workers, which has

[232] However, as noted in Chapter 4, it was found that hours reported in agriculture were a mixture of both on- and off-farm work, which includes non-agricultural activities (Tinakorn and Sassangkarn,

been an increasingly important source of labour since 1996. Ignoring it likely underestimates the contribution of labour growth to output growth.[233] Lack of disaggregated data prevents this study from estimating TFP, allowing for foreign migration. Lack of disaggregated data impedes this study to carefully estimate the TFP incorporated foreign migration. Capital inputs for crops and livestock are estimated by disaggregating the NESDB's net capital stock in overall agriculture. This technique may be subject to measurement errors although the results are comparable with the previous study using different methods.

Agricultural research variables are measured using budget data. The budget data are commonly used in Thailand to approximate research expenditure, due to their availability. Although the budget is allocated and research is mainly conducted at the national level they may overestimate actual expenditure. Future studies could trace the differences between budget and spending data so that a discount factor to map from budget to spending can be applied. In the longer-run, when the survey data on R&D expenditure conducted by the NRCT since 1995 are available for a long enough period, future research can apply these actual spending data. Alternatively, if data permitted, research variables could be measured from other sources, for instance using numbers of scientists, education attainment levels of scientists and research publications.

The crude measure of the foreign research variable should also be emphasized. Due to the lack of data, foreign research is measured as total research funding for the three major CGIAR centres. The findings based on this measure should also be qualified. In addition, private extension designed in the forms of contract farming is omitted due to lack of data. This should cause an upward bias in the estimated impact of private research, because this omitted explanatory variable (private extension) is

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1996, p.55). Poapongsakorn (2006) using both measures of labour inputs showed that the contribution of labour using working hours were lower than that using employment (see Table 2.1 in Chapter 2).

[233] The discussion on the role of migrant workers and the likely bias resulting from omitting it (due to lack of data) is shown in Chapter 3 and Chapter 4.

likely to be correlated with the private research variable. Future study can improve on these data constraint.

The lack of data also limits the current research to the use of time-series data. Extending the period under consideration and adding a geographical dimension to the analysis could strengthen the findings and may yield more useful implications. Panel data, including regional or district data, would allow for more options in measuring TFP, for example by using the frontier approach. Data on the location dimension of R&D would also allow an investigation of spatial spillovers within a country, for instance the impact of agricultural R&D spillovers among regions. Possible extension can be undertaken by extending data series on foreign, private and university research to cover longer periods. University research data should also be disaggregated into crops and livestock. This should give a clearer picture on the research attribution issue and longer data series are beneficial to investigate the lag issue.

Beyond overcoming data limitations, there is additional room for future research to contribute on this subject. First, the majority of rate of return studies, including the current research, are overwhelmed with efforts to account for the sources of overestimation. Future research can balance the literature by providing empirical evidence accounting for the losses that would occur in the absence of research. Townsend and Thirtle (2001) provided evidence for African livestock accounting for the losses that would occur without health maintenance research. Application and extension in the context of Thai agriculture could be interesting and important. The rate of return measurement can also be extended by incorporating the environmental effects of agricultural R&D.

Second, factors explaining the pervasive underinvestment in public agricultural research can be further investigated in future research. In particular, the public-good dimension of agricultural research can be examined with empirical applications in order to draw implications for agricultural research policy (for instance, future research may try to find the best policy tool to address the public-good issue and underinvestment in agricultural research in Thailand). There is a large body of literature on agricultural research policy, research priority setting and policy tools for strengthening public-private collaboration in agricultural research (e.g., Ruttan, 1982a, 1987, Pardey et al., 1991, Alston et al., 1998b, Fuglie and Schimmelpfennig, 2000). This established framework has largely been applied to developed countries. It can guide future research with applications to Thailand or other developing countries.

Third, the welfare implication of the agricultural research impact is another area this thesis does not cover. Future research can explore the distributional implications of how farmers, landowners and consumers should share in the new income streams generated by agricultural research. In addition, the implications for poverty reduction can be of importance as the majority of poor people in Thailand are directly involved in agricultural production. International studies have shown that research-led agricultural productivity growth has a significant impact on poverty reduction in many developing countries (e.g., Thirtle et al., 2003, Fan and Rao, 2003, Ryan, 2002), but little research has been undertaken on this subject for Thailand.

Bibliography

Abramovitz, M. (1956) Resource and Output Trends in the United States Since 1870. *The American Economic Review,* 46, 5-23.

Acemoglu, D. & Zilbotti, F. (1999) Productivity Differences. *NBER Working Papers No.6879,* 1-44.

Adams, J. D. (1990) Fundamental Stocks of Knowledge and Productivity Growth. *The Journal of Political Economy,* 98, 673.

Adulvidhaya, K., Isarangkura, R., Apibunyopas, P. & Dulyasatit, N. (1987) Evaluation of Agricultural Research in Thailand. In Douglas Daniels (Ed.) *Proceedings of A Workshop.* Ottawa.

Aghion, P. & Howitt, P. (1998) *Endogenous Growth Theory,* Cambridge, MIT Press.

Alauddin, M., Headey, D. & Rao, D. S. P. (2005) Explaining Agricultural Productivity Levels and Growth: An International Perspective. *CEPA Working Paper Series No. 02/2005.* Centre for Efficiency and Productivity Analysis, School of Economics, University of Queensland.

Alfranca, O. & Huffman, W. E. (2001) Impact of Institutions and Public Research on Private Agricultural Research. *Agricultural Economics,* 25, 191-198.

Alston, J. M. (2002) Spillovers. *The Australian Journal of Agricultural and Resource Economics,* 46, 315-346.

Alston, J. M., Craig, B. & Pardey, P. G. (1998a) Dynamics in the Creation and Depreciation of Knowledge, and the Returns to Research. *EPTD Discussion Paper No. 35.* Washington, D.C., Environment and Production Technology Division, International Food Policy Research Institute.

Alston, J. M., Marra, M. C., Pardey, P. G. & Wyatt, T. J. (2000) Research Return Redux: A Meta-Analysis of the Returns to Agricultural R&D. *Australian Journal of Agricultural and Resource Economics,* 44, 185-215.

Alston, J. M., Norton, G. W. & Pardey, P. G. (1998b) *Science Under Scarcity: Principles and Practices for Agricultural Research Evaluation and Priority Setting,* Wallington, CABI Publishing.

Alston, J. M. & Pardey, P. G. (2001) Attribution and Other Problems in Assessing the Returns to Agricultural R&D. *Agricultural Economics,* 25, 141-152.

Alston, J. M., Pardey, P. G. & Carter, H. O. (1994) *Valuing UC Agricultural Research and Extension,* Davis, University of California, Department of Agriculture and Natural Resources.

Ananth, G. S., Chengappa, P. G. & Janaiah, A. (2006) Impact of Research Investment on Technology Development and Total Factor Productivity in Major Field Crops of Peninsular India. *International Association of Agricultural Economics Conference.* Goldcoast, Australia, August 12-18, 2006.

Anselin, L. (1988) *Spatial Econometrics: Methods and Models,* Boston, Kluwer Academic Publishers.

APO (2001) *Measuring Total Factor Productivity: Survey Report,* Tokyo, Asian Productivity Organization.

Araji, A. A., White, F. C. & Guenthner, J. F. (1995) Spillovers and the Returns to Agricultural Research for Potatoes in the U.S. *Journal of Agricultural Resource Economics,* 20, 263-276.

Archawanichkul, K. (2004) *Migrant Workers in Thailand: Who are they? How many? Which database is the answer? (in Thai),* Nakorn Patom. , Institute for Population and Social Research, Mahidol University.

ARDA (2007) About ARDA: Visions and Goals. *Agricultural Research Development Agency.* Available at http://www.arda.or.th.

Areekul, S. (2000) Assessment Project on National Research in Thailand, 1992-1996: A Full Report (in Thai). *Prepared for the Office of the National Research Council of Thailand.* Bangkok.

Aswicahyono, H. H. (1998) Total Factor Productivity in Indonesian Manufacturing, 1975-1993. Ph.D. dissertation. *Division of Economics, Research School of Pacific and Asian Studies.* Canberra, The Australian National University.

Athukorala, P. & Sen, K. (2002) Appendix 2: The Econometric Methodology. *Saving, Investment and Growth in India.* Oxford University Press.

Athukorala, P. & Tsai, P.-L. (2003) Determinants of Household Saving in Taiwan: Growth, Demography and Public Policy. *The Journal of Development Studies,* 39, 65-88.

Baffes, J., Elbadawi, I. A. & O'Connell, S. A. (1999) Single-Equation Estimation of the Equilibrium Real Exchange Rate. In Hinkle, L. E. & Montiel, P. J. (Eds.) *Exchange Rate Misalignment: Concept and Measurement for Developing Countries.* Oxford, Oxford University Press.

Balcombe, K., Bailey, A. & Fraser, I. (2005) Measuring the impact of R&D on Productivity from a Econometric Time Series Perspective. *Journal of Productivity Analysis,* 24, 49-72.

Beintema, N. & Stads, G.-J. (2008) Measuring Agricultural Research Investments: A Revised Global Picture. *ASTI Background Paper.* Washington, D.C., International Food Policy Research Institute.

Belli, P., Anderson, J. R., Barnum, H. N., Dixon, J. A. & Tan, J.-P. (2001) *Economic Analysis of Investment Operations: Analytical Tools and Practical Applications,* Washington D.C., The World Bank.

Blakeley, N., Lewis, G. & Mills, D. (2005) The Economics of Knowledge: What Makes Ideas Special for Economic Growth? *Policy Perspectives Paper 05/05.* Wellington, New Zealand Treasury.

Bredahl, M. & Peterson, W. (1976) The Productivity and Allocation of Research: U.S. Agricultural Experimental Stations. *American Journal of Agricultural Economics,* 54, 684-692.

Budhaka, B. (1987) Thailand. In Asian Productivity Organization (Ed.) *Productivity Measurement and Analysis: Asian Agriculture.* Tokyo, APO.

Bureau of Agricultural Development Policy and Planning (1996) Analysis of Budget Allocation under the Ministry of Agriculture and Cooperatives during the 5th-7th National Economic and Social Development Plans (in Thai). Office of Agricultural Economics.

Byerlee, D. & Alex, G. E. (1998) *Strengthening National Agricultural Research Systems: Policy Issues and Good Practice,* Washington D.C., The World Bank.

Caselli, F. (2003) The Missing Input: Accounting for Cross-Country Income Differences. *Handbook of Economic Growth.* Available at http://personal.lse.ac.uk/CASELLIF/papers/handbook.pdf.

Caves, D. W., Christensen, L. R. & Diewert, W. E. (1982) The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometrica,* 50, 1393-1414.

CGIAR (2009) Why Agricultural Research Matters?, Consultative Group on International Agricultural Research. Available at http://cgiar.org/who/index.html.

Chalamwong, Y. (1996) An Estimated of Undocumented Migrant Workers in Thailand (in Thai). Bangkok, Thailand Development Research Institute.

Chalamwong, Y., Jirarachawaro, C. & Kittisarawutthiwej, K. (2003) Foreign Workers and Human Security (in Thai). *2003 TDRI-Year End Conference on Human Security.*

Ambassador City Jomtien Hotel, Chonburi, Thailand Development Research Institute.

Chalamwong, Y. & Prugsamatz, R. (2009) The Economic Role of Migration. Labor Migration in Thailand: Recent Trends and Implications for Development. *TDRI Quarterly Review,* 24, 3-9.

Chalamwong, Y., Prugsamatz, R. & Achariyahiranchai, P. (2009) Research on the Management of Seasonal Migrant Workers in Mae Sot and Trat, Thailand. Bangkok, Thailand Development Research Institute.

Chalamwong, Y. & Sussangkarn, C. (1996) The Management of Foreign Migrant Workers in The Long Run. Bangkok, Thailand Development Research Institute.

Chandrachai, A., Bangorn, T. & Chockpisansin, K. (2004) National Report: Thailand. *Total Factor Productivity Growth: Survey Report.* Tokyo, Asian Productivity Organization.

Chang, H.-S. & Zepeda, L. (2001) Agricultural Productivity for Sustainable Food Security in Asia and the Pacific: the Role of Investment. In Zepeda, L. (Ed.) *Agricultural Investment and Productivity in Developing Countries. FAO Economic and Social Development Papers 148.* Rome, Food and Agriculture Organization of the United Nations.

Chavas, J.-P. & Cox, T. L. (1992) A Nonparametric Analysis of the Influence of Research on Agricultural Productivity. *American Journal of Agricultural Economics,* 74, 583-591.

Chen, E. K. Y. (1997) The Total Factor Productivity Debate: Determinants of Economic Growth in East Asia. *Asian-Pacific Economic Literature,* 11, 18-38.

Chockpisansin, K. (2002) Analysis of Total Factor Productivity Growth in Thailand: 1977-1999. M.A. Thesis (in Thai). *Faculty of Economics.* Bangkok, Chulalongkorn University.

Christensen, L., Jorgenson, D. & Lau, L. (1973) Transcendental Logarithmic Production Frontiers. *Review of Economics and Statistics,* 55, 28-45.

Coe, D., T. & Helpman, E. (1995) International R&D Spillovers. *European Economic Review,* 39, 859-887.

Coelli, T. J. (1996) Measurement of Total Factor Productivity Growth and Biases in Technological Change in Western Australian Agriculture. *Applied Econometrics,* 11, 77-91.

Coelli, T. J. & Rao, D. S. P. (2003) Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 Countries, 1980-2000. *CEPA Working Paper Series No. 02/2003.* Centre for Efficiency and Productivity Analysis, School of Economics, University of Queensland.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. & Battese, G. E. (2005) *An Introduction to Efficiency and Productivity Analysis,* New York, Springer.

Cowing, T. & Stevenson, R. (1981) Introduction: Productivity Measurement and Regulated Industries. In Cowing, T. & Stevenson, R. (Eds.) *Productivity Measurement in Regulated Industries.* New York, Academic Press.

Coxhead, I. (1992) Book Reviews: Research and Productivity in Asian Agriculture by Robert Evenson and Carl Pray. *Asian-Pacific Economic Literature,* 6, 106-107.

Coxhead, I. & Plangpraphan, J. (1998) Thailand's Economic Boom and Agricultural Bust: Some Economic Questions and Policy Puzzles. *University of Wiscousin-Madison, Department of Agricultural and Applied Economics, Staff Paper Series No.419,* September, 1-41.

Coxhead, I. & Plangpraphan, J. (1999) Economic Boom, Financial Bust, and the Decline of Thai Agriculture: Was Growth in the 1990s too fast? *Chulalongkorn Journal of Economics,* 11, 1-17.

Cuthbertson, K., Hall, S. G. & Taylor, M. P. (1992) Dynamic Modelling - The General to Specific Methodology. *Applied Econometric Techniques.* Ann Arbor, University of Michigan Press.

Dalrymple, D., G. (2003) Scientific Knowledge as a Global Public Good: Contributions to Innovation and the Economy. In Esanu, J. M. & Uhlir, P. F. (Eds.) *The Role of Scientific and Technical Data and Information in the Public Domain: Proceedings of a Symposium.* Washington, D.C., The National Academies Press.

Dalrymple, D., G. (2008) International Agricultural Research as a Global Public Good: Concepts, the CGIAR Experience, and Policy Issues. *Journal of International Development,* 20, 347-379.

Davidson, J. E. H., Hendry, D. F., Srba, F. & Yeo, S. (1978) Econometric Modelling of the Aggregate Time Series Relationship Between Consumers' Expenditure and Income in the United Kingdom. *Economic Journal,* 88, 661-692.

Davis, J. S. (1981a) A Comparison of Procedures for Estimating Returns to Research Using Production Functions. *Australian Journal of Agricultural Economics,* 25, 60-72.

Davis, J. S. (1981b) The Relationship Between the Economic Surplus and Production Function Approaches for Estimating Ex-Post Returns to Agricultural Research. *Review of Marketing and Agricultural Economics,* 49, 95-105.

Denison, E. F. (1961) Measurement of Labor Input: Some Questions of Definition and the Adequacy of Data. *Output, Input and Productivity Measurement.* Princeton, The National Bureau of Economic Research, Princeton University.

Denison, E. F. (1967) *Why Growth Rates Differ: Postwar Experience in Nine Western Countries,* Washington D.C., Brookings Institution.

Denison, E. F. (1969) Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches. *Survey of Current Business,* 49, 1-27.

Denny, M., Fuss, M. & Waverman, L. (1981) The Measurement and Interpretation of Total Factor Productivity in Regulated Industries, with an Application to Canadian Telecommunications. In Cowing, T. & Stevenson, R. (Eds.) *Productivity Measurement in Regulated Industries.* New York, Academic Press.

Department of Livestock Development (2006) *Livestock Statistics (in Thai),* Bangkok, Bureau of Livestock Development and Technology Transfer.

Diewert, W. E. (1976) Exact and Superlative Index Numbers. *Journal of Econometrics,* 4, 115-145.

Edwards, S. (1998) Openness, Productivity and Growth: What Do We Really Know? *The Economic Journal,* 108, 383-398.

Engle, R. F. & Granger, C. W. J. (1987) Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica,* 55, 251-276.

Esposti, R. & Pierani, P. (2003) Building the Knowledge Stock: Lags, Depreciation, and Uncertainty in R&D Investment and Link with Productivity Growth. *Journal of Productivity Analysis,* 19, 33-58.

Evenson, R. E. (1982) Agriculture, Chapter 5. In Nelson, R., R. (Ed.) *Government and Technical Progress.* New York, Pergamon Press.

Evenson, R. E. (1989) Spillover Benefits of Agricultural Research: Evidence from U.S. Experience. *American Journal of Agricultural Economics,* 71, 447-452.

Evenson, R. E. (1993) Research and Extension Impacts on Food Crop Production in Indonesia. *Upland Agriculture in Asia: Proceeding of a Workshop* Bogor, Indonesia.

Evenson, R. E. (2001) Economic Impacts of Agricultural Research and Extension. In Gardner, B. L. & Rausser, G. C. (Eds.) *Handbook of Agricultural Economics, edition 1, volume 1, chapter 11, pages 573-628.* Elsevier.

Evenson, R. E. & McKinsey, J. W. (1991) Research, Extension, Infrastructure and Productivity Change in Indian Agriculture. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.

Evenson, R. E. & Pray, C. E. (1991) *Research and Productivity in Asian Agriculture,* Ithaca, Cornell University Press.

Evenson, R. E., Pray, C. E. & Rosegrant, M. W. (1999) Agricultural Research and Productivity Growth in India. *IFPRI Research Report No.109.* Washington, D.C., International Food Policy Research Institute.

Evenson, R. E. & Quizon, J. (1991) Technology, Infrastructure, Output Supply, and Factor Demand in Philippine Agriculture. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.

Eviews (2004) Eviews 5 User's Guide. Quantitative Micro Software.

Fan, S., Jitsuchon, S. & Methakunnavut, N. (2004) The Importance of Public Investment for Reducing Rural Poverty in Middle-Income Countries: The Case of Thailand. *DSGD Discussion Paper No.7.* Washington, D.C., International Food Policy Research Institute.

Fan, S. & Pardey, P. G. (1997) Research, Productivity, and Output Growth in Chinese Agriculture. *Journal of Development Economics,* 53, 115-137.

Fan, S. & Rao, N. (2003) Public Spending in Developing Countries: Trends, Determinants and Impact. *EPTD Discussion Paper No.99.* Washington, D.C., International Food Policy Research Institute.

Feder, G., Just, R. E. & Zilberman, D. (1985) Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change,* 33, 255.

Felipe, J. (1997) Total Factor Productivity Growth in East Asia: A Critical Survey. *EDRC Report Series No. 65.* Manila, Economics and Development Resource Center, Asian Development Bank.

Fuglie, K., Ballenger, N., Day, K., Klotz, C., Ollinger, M., Reilly, J., Vasavada, U. & Yee, J. (1996) Agricultural Research and Development: Public and Private Investments under Alternative Markets and Institutions. *Agricultural Economics Report No. (AER735).* Economic Research Service, USDA. Available at http://www.ers.usda.gov/publications/aer735/.

Fuglie, K., O., (1999) Investing in Agricultural Productivity in Indonesia. *Forum Penelitian Agro Ekonom,* 17, 1-16.

Fuglie, K., O., & Heisey, P. W. (2007) Economic Returns to Public Agricultural Research. *USDA Economic Brief No.10.* United States Department of Agriculture, Economic Research Service. Available at http://www.ers.usda.gov/publications/eb10/eb10.pdf.

Fuglie, K. & Schimmelpfennig, D. (2000) *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications,* Iowa, Iowa State University Press.

Fuglie, K. O. (2001) Private Investment in Agricultural Research: Thailand. *Agricultural Economic Report No. (AER 805).* Washington, D.C., Economic Research Service of the U.S. Department of Agriculture (ERS/USDA). Available at http://www.ers.usda.gov/Publications/AER805/.

Fuglie, K. O. (2004) Productivity Growth in Indonesian Agriculture, 1961-2000. *Bulletin of Indonesian Economic Studies,* 40, 209-225.

Furtan, W. H. & Holzman, J. J. (2004) The Effect of FDI on Agriculture and Food Trade: An Empirical Analysis. *Agriculture and Rural Working Paper Series No.68.* Ontario, Statistics Canada, Agriculture Division.

Granger, C. W. J. & Newbold, P. (1974) Spurious Regressions in Econometrics. *Journal of Econometrics,* 2, 111-120.

Griliches, Z. (1957) Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica,* 25, 501-522.

Griliches, Z. (1958) Research Costs and Social Returns: Hybrid Corn and Related Innovations. *The Journal of Political Economy,* 66, 419-431.

Griliches, Z. (1963) The Sources of Measured Productivity Growth: United States Agriculture, 1940-60. *The Journal of Political Economy,* 71, 331-346.
Griliches, Z. (1964a) Notes on the Measurement of Price and Quality Changes. *Models of Income Determination.* The National Bureau of Economic Research. Available at http://www.nber.org/chapters/c1823.
Griliches, Z. (1964b) Research Expenditures, Education, and the Aggregate Agricultural Production Function. *The American Economic Review,* 54, 961-974.
Griliches, Z. (1967) Distributed Lags: A Survey. *Econometrica,* 35, 16-49.
Griliches, Z. (1970) Notes on the Role of Education in Production Functions and Growth Accounting. In Hansen, W. L. (Ed.) *Education, Income, and Human Capital.* National Bureau of Economic Research.
Griliches, Z. (1979) Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics,* 10, 92-116.
Griliches, Z. (1992) The Search for R&D Spillovers. *Scandinavian Journal of Economics,* 94 (Supplement), 29-47.
Griliches, Z. (1994) Productivity, R&D, and the Data Constraint. *The American Economic Review,* 84, 1.
Griliches, Z. (1996) The Discovery of the Residual: A Historical Note. *Journal of Economic Literature,* 34, 1324-1330.
Griliches, Z. (1997) Introduction. *R&D and Productivity: The Econometric Evidence.* Chicago, The University of Chicago Press. Available at http://post.economics.harvard.edu/faculty/zgrilich/R&D_INTRO.pdf.
Griliches, Z. (1998a) *R&D and Productivity: The Econometric Evidence,* Chicago, The University of Chicago Press.
Griliches, Z. (1998b) R&D and Productivity: The Unfinished Business. *Estudios de Economia. University of Chile, Department of Economics,* 25, 145-160.
Guindo, O. (1989) The Role of Adaptive Research in Increasing Agricultural Productivity: The Experience from Haiti. *Canadian Journal of Agricultural Economics,* 37, 887.
Hall, B. & Reenen, J. V. (2000) How Effective are Fiscal Incentives for R&D? A Review of the Evidence. *Research Policy,* 29, 449-469.
Hall, J. & Scobie, G. (2006) The Role of R&D in Productivity Growth: The Case of Agriculture in New Zealand: 1927 to 2001. *New Zealand Treasury Working Paper 06/01.* Wellington, New Zealand Treasury.
Harberger, A. C. (1996) Reflections on Economic Growth in Asia and the Pacific. *Journal of Asian Economics,* 7, 365-392.
Harris, M. & Lloyd, A. (1991) The Returns to Agricultural Research and the Underinvestment Hypothesis - A Survey. *Australian Economic Review,* 24, 16-27.
Harris, R. (1995) *Using Cointegration Analysis in Econometric Modelling,* Prentice Hall.
Harvey, A., C. (1993) *Time Series Models. Second Edition,* London, Harvester Wheatsheaf.
Helpman, E. (1997) R&D and Productivity: The International Connection. *National Bureau of Economic Research Working Paper Series,* No. 6101.
Hendry, D. F. (1995) *Dynamic Econometrics,* Oxford, Oxford University Press.
Hendry, D. F., Pagan, A. & Sargan, J. D. (1984) Dynamic Specification. In Griliches, Z. & Intriligator, M. D. (Eds.) *The Handbook of Econometrics Vol. II.* Amsterdam, North-Holland.
Hossain, M., Gollin, D., Cabanilla, V., Cabrera, E., Johnson, N., Khush, G. S. & McLaren, G. (2003) International Research and Genetic Improvement in Rice: Evidence from Asia and Latin America. In Evenson, R. E. & Gollin, D. (Eds.) *Crop variety improvement and its effect on productivity: The impact of international agricultural research.* Wallingford, CABI Publishing.
Hoy, M., Livernois, J., McKenna, C., Rees, R. & Stengos, T. (1996) *Mathematics for Economics,* Addison-Wesley Publishers Limited.

Huffman, W. E. & Evenson, R. E. (1992) Contributions of Public and Private Science and Technology to U.S. Agricultural Productivity. *American Journal of Agricultural Economics,* 74, 752-756.

Huffman, W. E. & Evenson, R. E. (2005) New Econometric Evidence on Agricultural Total Factor Productivity Determinants: Impact of Funding Composition. *Working Papers Series No.03029.* Iowa, Department of Economics, Iowa State University.

Huffman, W. E. & Evenson, R. E. (2006) Do Formula or Competitive Grant Funds Have Greater Impacts on State Agricultural Productivity? *American Journal of Agricultural Economics,* 88, 783-798.

Hulten, C. R. (1973) Divisia Index Numbers. *Econometrica,* 41, 1017-1025.

Hulten, C. R. (2000) Total Factor Productivity: A Short Biography. University of Maryland and National Bureau of Economic Research. Available at http://www.bsos.umd.edu/econ/hulten/biopdf.pdf.

Hulten, C. R. (2002) Review: R&D, Education, and Productivity: A Retrospective by Griliches, Zvi. *Journal of Economic Literature,* 40, 961-963.

IFPRI (2007) Agricultural Science and Technology Indicators. International Food Research Policy Institute. Available at http://www.asti.cgiar.org/technical.aspx.

IMF (1986) A Manual on Government Finance Statistics. International Monetary Fund. Available at http://www.imf.org/external/pubs/ft/gfs/manual/1986/eng/index.htm.

Inder, B. (1993) Estimating Long-Run Relationships in Economics : A Comparison of Different Approaches. *Journal of Econometrics,* 57, 53-68.

International Rice Research Institute (IRRI) (1997) Fact about Cooperation: Thailand and IRRI. Available at http://www.irri.org/media/facts/pdfs/THAILAND.pdf.

Isarangkura, R. (1981) Inventory of Agricultural Research Expenditures and Manpower in Thailand. In Douglas Daniels and Barry Nestel (Ed.) *Proceedings of a workshop.* Singapore, 8-10 June 1981.

Isarangkura, R. (1986) Thailand and the CGIAR Centers: A Study of Their Collaboration in Agricultural Research. *CGIAR Study Paper No.16.* Washington, D.C., The World Bank.

Isvilanonda, S. (2000) Assessing Impacts of the Program of Quality Development and Cost Reduction in Jasmine Rice Production (in Thai). *Assessing Impacts of Agricultural and Agro-industrial Research.* Bangkok, Center for Applied Economic Research, Faculty of Economics, Kasetsart University.

Isvilanonda, S. & Hossain, M. (2000) Recent Changes in Thailand's Rural Economy: A Case Study of Six Villages in the Central and Northeast Regions. Reprint Paper November, 2000. . Bangkok, Faculty of Kasetsart University.

Isvilanonda, S. & Praneetvatakul, S. (2003) Evaulation of National Research System in Thailand (in Thai). Bangkok, Applied Research Center, Faculty of Economics, Kasetsart University.

Jamison, D. T. & Lau, L. (1982) *Farmer Education and Farm Efficiency,* Baltimore, Johns Hopkins University Press.

Jaroensathapornkul, J. (2007) Impacts of Government Spending on Thailand's Agricultural Sector. Ph.D. dissertation. *Department of Agricultural and Resource Economics.* Bangkok, Kasetsart University.

Jinnawaso, K. (1996) Foreign Migrant Workers: Facts, Issues and Remedies (in Thai). Bangkok, Thailand Development Research Institute.

Johansen, S. (1988) Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control,* 12, 231-254.

Johnson, D. & Evenson, R. E. (1999) R&D Spillovers to Agriculture: Measurement and Application. *Contemporary Economic Policy,* 17, 432.

Johnson, R. W. M., Razzak, W. A. & Stillman, S. (2005) Has New Zealand Benefited From Its Investment in Research and Development? *Working Paper.* Wellington, Department of Labour.
Johnston, B. F. & Mellor, J. W. (1961) The Role of Agriculture in Economic Development. *The American Economic Review,* 51, 566-593.
Jongwanich, J. & Kohpaiboon, A. (2008) Private Investment: Trends and Determinants in Thailand. *World Development,* 36, 1709-1724.
Jorgenson, D. W. (1966) The Embodiment Hypothesis. The University of Chicago Press.
Jorgenson, D. W. (1988) Productivity and Postwar U.S. Economic Growth. *The Journal of Economic Perspectives,* 2, 23-41.
Jorgenson, D. W. (1995) *Productivity Volume 2: International Comparisons of Economic Growth,* London, The MIT Press.
Jorgenson, D. W., Gollop, F. M. & Fraumeni, B. M. (1987) *Productivity and U.S. Economic Growth,* Cambridge, Harvard University Press.
Jorgenson, D. W. & Griliches, Z. (1967) The Explanation of Productivity Change. *The Review of Economic Studies,* 34, 249-283.
Jorgenson, D. W. & Griliches, Z. (1972) Issues in Growth Accounting: A Reply to Edward F. Denison. *Survey of Current Business,* 52, 65-94. Available at http://fraser.stlouisfed.org/publications/SCB/page/8658.
Jorgenson, D. W. & Nishimizu, M. (1978) U.S. and Japanese Economic Growth, 1952-1974: An International Comparison. Blackwell Publishing for the Royal Economic Society.
Judd, M. A., Boyce, J. K. & Evenson, R. E. (1991) Investment in Agricultural Research and Extension Programs: A Quantitative Assessment. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.
Kaipornsak, P. (1995) Sources of Economic Growth in Thailand: 1970-1989. Ph.D. dissertation. *National Centre for Development Studies.* Canberra, The Australian National University.
Kaipornsak, P. (1998) Total Factor Productivity Growth in Thailand: An Econometric Approach (in Thai). Bangkok, Faculty of Economics, Chulalongkorn University.
Kaipornsak, P. (1999) Role of Total Factor Productivity Growth in Thai Economy (in Thai). *Thammasat Economic Journal,* 16, 5-54.
Kasetsart University (2006) Kasetsart University Budget Document (in Thai). Bangkok, Kasetsart University.
Kelvin, B., Alastair, B. & Iain, F. (2005) Measuring the Impact of R&D on Productivity from a Econometric Time Series Perspective. *Journal of Productivity Analysis,* 24, 49.
Kendrick, J., W. (1955) Productivity. In Fabricant, S. (Ed.) *Government in Economic Life. 35th Annual Report.* New York, NBER, p.44-47.
Klein, L. R., Long, V., Greenspan, A., Greenwald, D., Edmonson, N. & Perry, G. (1973) Capacity Utilization: Concept, Measurement, and Recent Estimates. *Brookings Papers on Economic Activity,* 1973, 743-763.
Kohpaiboon, A. (2006) *Multinational Enterprises and Industrial Transformation: Evidence from Thailand,* Edward Elgar.
Kompas, T. & Che, T. (2004) Productivity in the Australian Dairy Industry. *Agribusiness Review,* 12, 1-24.
Krasachat, W. (1997) The Dynamic Adjustment of Structure and Demand for Labour in Thai Agriculture. Ph.D. dissertation. *Department of Agricultural and Resource Economics.* Armidale, NSW, The University of New England.
Krasachat, W. (2002) Deforestation and Productivity Growth in Thai Agriculture. *International Symposium: Sustaining Food Security and Managing Natural Resources in Southeast Asia-challenges for the 21st Century.* Chiang Mai, Thailand. January 8-11, 2002.

Krasachat, W. & Kuroda, Y. (1999) Production Structure and Technical Change in Thai Agriculture, 1972-1994. *Institute of Policy and Planning Sciences discussion paper series no.844.* Tsukuba, University of Tsukuba.

Kumbhakar, S. C. & Lovell, C. A. K. (2000) *Stochastic Frontier Analysis,* Cambridge, Cambridge University Press.

Kwon, J. K. (1986) Capital Utilization, Economies of Scale and Technical Change in the Growth of Total Factor Productivity: An Explanation of South Korean Manufacturing Growth. *Journal of Development Economics,* 24, 75-89.

Lau, L. J., Jamison, D. T. & Louat, F. F. (1991) Education and Productivity in Developing Countries : An Aggregate Production Function Approach. *Policy Research Working Paper Series no.612. The World Bank,* 1-35.

Lau, L. J. & Yotopoulos, P. A. (1989) The Meta-Production Function Approach to Technological Change in World Agriculture. *Journal of Development Economics,* 31, 241-269.

Lawrence, D. & McKay, L. (1980) Inputs, Outputs and Productivity Change in the Australian Sheep Industry. *Australian Journal of Agricultural Economics,* 24, 46-59.

Lovell, C. A. K. (1993) Production Frontiers and Productive Efficiency. In Fried, H. O., Lovell, C. A. K. & Schmidt, S. S. (Eds.) *The Measurement of Productive Efficiency: Techniques and Applications.* New York, Oxford University Press.

Lu, Y., Cline, P. & Quance, L. (1979) Prospects for Productivity Growth in U.S. Agriculture. *Agriculture Economic Report No. 435.* Washington, DC., ESCS, USDA.

Mahadevan, R. (2002) *New Currents in Productivity Analysis: Where to Now?,* Tokyo, Asian Productivity Organization.

Mahadevan, R. (2003) To Measure or Not To Measure Total Factor Productivity Growth? *Oxford Development Studies,* 31, 365 - 378.

Makki, S. S., Thraen, C. S. & Tweeten, L. G. (1999) Returns to American Agricultural Research: Results from a Cointegration Model. *Journal of Policy Modeling,* 21, 185-211.

Makki, S. S. & Tweeten, L. G. (1993) Impact of Research, Extension, Commodity Programs, and Prices on Agricultural Productivity. *Paper presented at the 1993 Meetings of the American Agricultural Economic Association.* Orlando, Florida.

Manarangsan, S. (2002) *Development of Agricultural Sector and Impact on Farmers in Thailand, Post WWII - 1993 (in Thai),* Bangkok, Chulalongkorn University Press.

Martin, P. (2007) The Economic Contribution of Migrant Workers to Thailand: Towards Policy Development. Bangkok, International Labour Organization.

Martin, W. J. & Warr, P. G. (1994) Determinants of Agriculture's Relative Decline: Thailand. *Agricultural Economics,* 11, 219-235.

McCalla, A. F. & Ryan, J. G. (1992) Setting Agricultural Research Priorities: Lessons from the CGIAR Study. *American Journal of Agricultural Economics,* 74, 1095-1099.

McMillen, W. (1929) *Too Many Farmers: The Story of What is Here and Ahead in Agriculture,* New York, William Morrow and Company.

Morrison Paul, C. J. (1999) *Cost Structure and the Measurement of Economic Performance: Productivity, Utilization, Cost Economics, and Related Performance Indicators*, Kluwer Academic Publishers.

Mullen, J. (2007) Productivity Growth and the Returns from Public Investment in R&D in Australian Broadacre Agriculture. *51st Annual Conference of Australian Agricultural and Resource Economics Society (AARES).* Queenstown, New Zealand.

Mullen, J. & Cox, T. L. (1995) The Returns From Research in Australian Broadacre Agriculture. *Australian Journal of Agricultural Economics,* 39, 105-128.

Mullen, J., D., Scobie, G. M. & J., C. (2006) Trends in Research, Productivity Growth and Competitiveness in Agriculture in New Zealand and Australia.

Mundlak, Y. (2000) *Agriculture and Economic Growth: Theory and Measurement,* London, Harvard University Press.
Mundlak, Y., Larson, D. & Butzer, R. (1997) The Determinants of Agricultural Production: A Cross-Country Analysis. *Policy Research Working Paper 1827,* The World Bank, Washington, DC.
Mundlak, Y., Larson, D. & Butzer, R. (2004) Agricultural Dynamics in Thailand, Indonesia and the Philippines. *The Australian Journal of Agricultural and Resource Economics,* 48, 95-126.
Mundluk, Y. (1992) Agricultural Productivity and Economic Policies: Concepts and Measurements. *OECD Development Centre Working Paper No. 75,* OECD Development Centre.
Mundluk, Y., Larson, D. F. & Butzer, R. (2002) Determinants of Agricultural Growth in Indonesia, the Philippines, and Thailand. *Policy Research Working Paper 2803,* The World Bank, Washington, DC.
Nagy, J. G. (1991) Returns from Agricultural Research and Extension in Wheat and Maize in Pakistan. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.
National Economic and Social Development Board (NESDB) (1998) *National Income of Thailand: 1951-1996 Edition,* Bangkok, Office of the National Economic and Social Development Board.
National Economic and Social Development Board (NESDB) (2006) *Capital Stock of Thailand 2006 edition,* Bangkok, Office of the National Economic and Social Development Board.
National Research Council of Thailand (NRCT) (2003) Agricultural Research Status in Thailand, Fiscal Year 2003 (in Thai). Available at http://www.nrct.net.
National Research Council of Thailand (NRCT) (2007) National Survey on R&D Expenditure and Personnel of Thailand. Bangkok, Office of Research Policy and Strategy. Available at http://www.nrct.net.
Norton, G. W. & Davis, J. S. (1981) Evaluating Returns to Agricultural Research: A Review. *American Journal of Agricultural Economics,* 63, 685-699.
Norton, G. W., Pardey, P. G. & Alston, J. M. (1992) Economic Issues in Agricultural Research Priority Setting. *American Journal of Agricultural Economics,* 74, 1089-1094.
OECD (2007) Main Science and Technology Indicators Manual. Organization for Economic Cooperation and Development. Available at http://www.esds.ac.uk/international/support/user_guides/oecd/sti_manual.pdf.
Oehmke, J. F. (1986) Persistent Underinvestment in Public Agricultural Research. *Agricultural Economics,* 1, 53-65.
Office of Agricultural Economics (OAE) (1998) Thailand Agriculture Sector Needs Assessment Study. *A Draft Final Report of TA 3002-THA Prepared under Technical Assistance Provided by the Asian Development Bank.* Bangkok, Ministry of Agriculture and Cooperatives.
Office of Agricultural Economics (OAE) (2004) *Agriculture in Thailand,* Bangkok.
Office of Agricultural Economics (OAE) (2006a) Agricultural Economic Indicators of Thailand 2005 (in Thai). Bangkok.
Office of Agricultural Economics (OAE) (2006b) Agricultural Statistics of Thailand 2006. Bangkok, Sahamitra Printing and Publishing Ltd.
Office of Agricultural Economics (OAE) (2006c) Thailand Foreign Agricultural Trade Statistics. Bangkok.
Oguchi, N. (2001) Integrated Summary. *Measuring Total Factor Productivity: Survey Report.* Tokyo, Asian Productivity Organization.

Oguchi, N. (2004) Integrated Report. *Total Factor Productivity Growth: Survey Report.* Tokyo, Asian Productivity Organization.

Pardey, P. G., Alston, J., James, J., Glewwe, P., Binenbaum, E., Hurley, T. & Wood, S. (2007) *Science, Technology and Skills,* St. Paul, International Science & Technology Practice & Policy, University of Minnesota.

Pardey, P. G., Alston, J. M. & Beintema, N. (2006a) Agricultural R&D Spending at a Critical Crossroads. *Farm Policy Journal,* 3, 1-9.

Pardey, P. G., Alston, J. M., Chan-Kang, C., Magalhaes, E. C. & Vosti, S. A. (2006b) International and Institutional R&D Spillovers: Attribution of Benefits among Sources for Brazil's New Crop Varieties. *American Journal of Agricultural Economics,* **88,** 104-123.

Pardey, P. G., Alston, J. M. & Piggot, R. R. (2006c) *Agricultural R&D in the Developing World: Too Little, Too Late?,* Washington, DC.

Pardey, P. G., Alston, J. M. & Piggot, R. R. (2006d) Shifting Ground: Agricultural R&D Worldwide. *IFPRI Publication No.46.* International Food Policy Research Institute.

Pardey, P. G., Beintema, N., Dehmer, S. & Wood, S. (2006e) Agricultural Research: A Global Growing Divide? *Agricultural Science and Technology Indicators Initiative.* Washington, D.C., International Food Policy Research Institute.

Pardey, P. G. & Craig, B. (1989) Casual Relationships between Public Sector Agricultural Research Expenditures and Output. *American Journal of Agricultural Economics,* 71, 9-19.

Pardey, P. G., Craig, B. & Holloway, M. L. (1987) US Agricultural Research Deflators: 1890-1985. *Staff Paper Series P87-25, August.* Minnesota, Department of Agricultural and Applied Economics, University of Minnesota.

Pardey, P. G., Roseboom, J. & Anderson, J. R. (1991) *Agricultural Research Policy : International Quantitative Perspectives,* Cambridge, Cambridge University Press.

Patamasiriwat, D. & Suewattana, S. (1990) Sources of Agricultural Growth 1961-1985: Analysis based on Thailand Development Research Institute Model (in Thai). *Thammasat Economic Journal,* 8, 43-69.

Pesaran, M. H., Shin, Y. & Smith, R. J. (2001) Bounds Testing Approaches to the Analysis of Level Relationships. *Journal of Applied Econometrics,* 16, 289-326.

Peterson, W. (1967) Returns to Poultry Research in the U.S. *Journal of Farm Economics,* 49, 656-669.

Peterson, W. & Hayami, Y. (1977) Technical Change in Agriculture. In Martin, L. R. (Ed.) *A Survey of Agricultural Economics Literature: Volume 1.* Minneapolis, University of Minnesota Press.

Phillips, P. C. B. & Hansen, B. E. (1990) Statistical Inference in Instrumental Variables Regression with I(1) Processes. *Review of Economic Studies,* 57, 99-125.

Pindyck, R. S. & Rubinfeld, D. L. (1998) *Econometric Models and Economic Forecasts. Fourth Edition*, McGraw-Hill.

Pingali, P. L. & Heisey, P. W. (2003) Cereal Crop Productivity in Developing Countries: Past Trends and Future Prospects. *CIMMYT Economics Paper 99-03.* Mexico D.F., CIMMYT.

Plastina, A. S. & Fulginiti, L. E. (2007) Rates of Return to Public Agricultural Research in 48 U.S. States. *American Agricultural Economics Association Annual Meeting.* Portland, Oregon, July 29-August 1, 2007.

Poapongsakorn, N. (1985) The Commercial Broiler and Swine Industries in Thailand. In Panayotou, T. (Ed.) *Food Policy Analysis in Thailand.* Bangkok, Agricultural Development Council.

Poapongsakorn, N. (2006) The Decline and Recovery of Thai Agriculture: Causes, Responses, Prospects and Challenges. *Rapid Growth of Selected Asian Economies:*

Lessons and Implications for Agriculture and Food Security. Bangkok, FAO Regional Office for Asia and the Pacific.

Poapongsakorn, N. & Anuchitworawong, C. (2006) Total Factor Productivity in Thai Agriculture during 1980-2003. *2nd National Conference of Economists.* Chulalongkorn University, International Information Center.

Poapongsakorn, N., Ruhs, M. & Tangjitwisuth, S. (1998) Problems and Outlook of Agriculture in Thailand. *TDRI Quarterly Review,* 13, 3-14.

Poapongsakorn, N., Siamwalla, A., Titapiwatanakun, B., Netayalak, P., Suzuki, P., Pookpakdi, A. & Preedasak, P. (1995) *Agricultural Diversification / Restructuring of Agricultural Production Systems in Thailand,* A Paper prepared for The Food and Agricultural Organization of the United Nations. Bangkok, Thailand Development Research Institute.

Pochanukul, P. (1986) The Role of Research and Extension in Thai Rice Production. Master Thesis. *Faculty of Economics.* Bangkok, Thammasat University.

Pochanukul, P. (1992) An Economic Study of Public Research Contributions in Thai Crop Production: A Time and Spatial Analysis. Ph.D. dissertation. *Graduate School.* Kyoto University, Japan.

Pray, C. E. (1991) The Development of Asian Research Institutions: Underinvestment, Allocation of Resources, and Productivity. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.

Pray, C. E. & Fuglie, K. (2001) Private Investment in Agricultural Research and International Technology Transfer in Asia. *Agricultural Economic Report No. (AER 805).* Washington, D.C., Economic Research Service of the U.S. Department of Agriculture (ERS/USDA). Available at http://www.ers.usda.gov/Publications/AER805/.

Romer, P. M. (1989) Human Capital and Growth: Theory and Evidence. *NBER Working Papers No.3173,* 1-41.

Romer, P. M. (1990) Endogenous Technological Change. *The Journal of Political Economy,* 98, S71-S102.

Roseboom, J. (2002) Underinvestment in Agricultural R&D Revisited. *International Conference on Impacts of Agricultural Research and Development, 4-7 February 2002.* Costa Rica.

Rosegrant, M. W. & Evenson, R. E. (1992) Agricultural Productivity and Sources of Growth in South Asia. *American Journal of Agricultural Economics,* 74, 757-761.

Rozelle, S., Jin, S., Huang, J. & Hu, R. (2003) The Impact of Investments in Agricultural Research on Total Factor Productivity in China. In Evenson, R. E. & Gollin, D. (Eds.) *Crop variety improvement and its effect on productivity: The impact of international agricultural research.* Wallingford, CABI Publishing.

Ruttan, V. W. (1980) Bureaucratic Productivity: The Case of Agricultural Research. *Public Choice,* 35, 529-547.

Ruttan, V. W. (1982a) *Agricultural Research Policy,* Minneapolis, University of Minnesota Press.

Ruttan, V. W. (1982b) Bureaucratic Productivity: The Case of Agricultural Research Revisited - A Rejoinder. *Public Choice,* 39, 319-329.

Ruttan, V. W. (1987) *Agricultural Research Policy and Development,* Rome, Food and Agriculture Organization of the United Nations.

Ruttan, V. W. (2002) Productivity Growth in World Agriculture: Sources and Constraints. *Journal of Economic Perspectives,* 16, 161-184.

Ryan, J. (2002) Agricultural Research and Poverty Alleviation. Invited paper for the John L. Dillon AO Commemorative Day on 'Agricultural Research: Challenges and Economics in the New Millennium' The University of New England Armidale NSW Australia. *ACIAR Working Paper No.56.* Canberra, Australian Centre for International Agricultural Research.

Salmon, D., C (1991) Rice Productivity and the Returns to Rice Research in Indonesia. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.

Sattaphon, W. (2006) Do Japanese Foreign Direct Investment and Trade Stimulate Agricultural Growth in East Asia? Panel Cointegration Analysis. *International Association of Agricultural Economists Conference.* Gold Coast, Australia.

Schimmelpfennig, D. & Thirtle, C. (1994) Cointegration, and Causality: Exploring the Relationship Between Agricultural R&D and Productivity. *Journal of Agricultural Economics,* 45, 220-231.

Schimmelpfennig, D. & Thirtle, C. (1999) The Interntionalization of Agricultural Technology: Patents, R&D Spillovers, and Their Effects on Productivity in the European Union and United States.

Schimmelpfennig, D., Thirtle, C., van Zyl, J., Arnade, C. & Khatri, Y. (2000) Short and Long-Run Returns to Agricultural R&D in South Africa, or Will the Real Rate of Return Please Stand Up? *Agricultural Economics,* 23, 1-15.

Schultz, T., W. (1953) *The Economic Organization of Agriculture,* New York, McGraw-Hill.

Setboonsarng, S. & Evenson, R. E. (1991) Technology, Infrastructure, Output Supply, and Factor Demand in Thai Agriculture. In Evenson, R. E. & Pray, C. E. (Eds.) *Research and Productivity in Asian Agriculture.* Ithaca, Cornell University Press.

Setboonsarng, S., Pochanukul, P., Areepakorn, K., Kaoparisud, J. & Namaheng, J. (1991) Crops Research Priority Setting in Thailand (in Thai). Bangkok, Department of Agriculture, Thailand Development Research Institute and Australian Centre for International Agricultural Research.

Shintani, M. (2003) *Process of Agricultural Growth in Thailand: Analysis of Long-term Economic Statistics for the period 1950-1997,* Kyushu University Press.

Siamwalla, A. (1996) Thai Agriculture: From Engine of Growth to Sunset Status. *TDRI Quarterly Review,* 11, 3-10.

Siamwalla, A., Patmasiriwat, D. & Setboonsarng, S. (1987) Productivity and Competitiveness in Thai Agriculture: Some Lessons from the Past. *TDRI Year-End Conference on Efficiency and Competitiveness of the Thai Economy.* Bangkok, Thailand Development Research Institute.

Siamwalla, A., Patmasiriwat, D. & Setboonsarng, S. (1991) *Thai Agriculture: Resources, Institutions and Policies,* Bangkok, Thailand Development Research Institute.

Siamwalla, A. & Setboonsarng, S. (1991) Thailand. In Krueger, A. O., Schiff, M. & Valdes, A. (Eds.) *The Political Economy of Agricultural Pricing Policy (Volume 2).* Baltimore, The Johns Hopkins University Press.

Siamwalla, A., Setboonsarng, S. & Patmasiriwat, D. (1993) Agriculture. In Warr, P. G. (Ed.) *The Thai Economy in Transition.* Cambridge, Cambridge University Press.

Solow, R. M. (1957) Technical Change and Aggregate Production Function. *Review of Economics and Statistics,* 39, 312-320.

Songsiengchai, P. (2007) The Growth and Total Factor Productivity of Thai Agricultural Sector. M.Sc.Thesis (in Thai). *Department of Agricultural and Resource Economics.* Bangkok, Kasetsart University.

Sussangkarn, C. (1996) Macroeconomic Impacts of Migrant Workers: Analyses with a CGE Model. *TDRI Quarterly Review,* 11, 3-11.

Thailand Development Research Institute (TDRI) (1988) Dynamics of Thai Agriculture, 1961-1985. Bangkok.

Thapinta, A. & Hudak, P. F. (2000) Pesticide Use and Residual Occurrence in Thailand. *Environmental Monitoring and Assessment,* 60, 103-114.

The World Bank (2007) *World Development Report 2008: Agriculture for Development,* Washington, DC.

The World Bank (2009) The Commodity Boom: Longer-Term Prospects. *Global Economic Prospects 2009.* Available at http://siteresources.worldbank.org/INTGEP2009/Resources/10363_WebPDF-02Chapter2.pdf.

Thirtle, C. & Bottomley, P. (1989) The Rate of Return to Public Sector Agricultural R&D in the UK, 1965-1980. *Applied Economics,* 21, 1063 - 1086.

Thirtle, C., Lin, L. & Piesse, J. (2003) The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. *World Development,* 31, 1959-1975.

Thirtle, C. G., Schimmelpfennig, D. E. & Townsend, R. E. (2002) Induced Innovation in United States Agriculture, 1880-1990: Time Series Tests and an Error Correction Model. *American Journal of Agricultural Economics, American Agricultural Economics Association,* 84, 598-614.

Thomson, R. (2008) Investment in Research and Development: Does Tax Policy Matter? Ph.D. dissertation. *The Arndt-Corden Division of Economics, Research School of Pacific and Asian Studies.* Canberra, The Australian National University.

Tinakorn, P. (2001) National Report: Thailand. *Measuring Total Factor Productivity: Survey Report.* Tokyo, Asian Productivity Organization.

Tinakorn, P. & Sussangkarn, C. (1994) *Research and Information Development for Macroeconomic Policy Formulation: Productivity Growth in Thailand,* Bangkok, National Economic and Social Development Board and Thailand Development Research Institute.

Tinakorn, P. & Sussangkarn, C. (1996) *Productivity Growth in Thailand,* Bangkok, Thailand Development Research Institute.

Tinakorn, P. & Sussangkarn, C. (1998) *Total Factor Productivity Growth in Thailand: 1980-1995,* Bangkok, Thailand Development Research Institute.

Tongpan, S. (1993) *Thai Agricultural Policy (in Thai),* Bangkok, Department of Agricultural and Resource Economics, Faculty of Economics, Kasetsart University.

Tornqvist, L. (1936) The Bank of Finland's Consumption Price Index. *Bank of Finland Monthly Bulletin,* 10, 1-8.

Townsend, R. & Thirtle, C. (2001) Is Livestock Research Unproductive?: Separating Health Maintenance from Improvement Research. *Agricultural Economics,* 25, 177-189.

Urata, S. & Yokota, K. (1994) Trade Liberalization and Productivity Growth in Thailand. *The Development Economies,* 32, 444-458.

Van der Eng, P. (2004) Productivity and Comparative Advantage in Rice Agriculture in South-East Asia Since 1870*. *Asian Economic Journal,* 18, 345-370.

Van der Eng, P. (2009) Total Factor Productivity and Economic Growth in Indonesia. *Working Papers in Trade and Development,* Working Paper No. 2009/01. The Arndt-Corden Division of Economics, Research School of Pacific and Asian Studies, ANU College of Asia and the Pacific.

Warr, P. (2004) Globalization, Growth, and Poverty Reduction in Thailand. *ASEAN Economic Bulletin,* 21, 1.

Warr, P. G. (2005) Boom, Bust and Beyond. In Warr, P. G. (Ed.) *Thailand Beyond the Crisis.* New York, Routledge Curzon.

Warr, P. G. (2006) Productivity Growth in Thailand and Indonesia: How Agriculture Contributes to Economic Growth. *Working Paper in Economics and Development Studies No. 200606,* Center for Economics and Development Studies, Department of Economics, Padjadjaran University, Bandung, Indonesia.

Warr, P. G. (2008) Trade Policy and the Structure of Incentives in Thai Agriculture. *ASEAN Economic Bulletin,* 25, 249-70.

White, F. C., He, S. & Fletcher, S. (2003) Research Spillovers and Returns to Wheat Research Investment. *Southern Agricultural Economics Association Annual Meeting.* Mobile, Alabama, February 1-5, 2003.

Wilson, N. (2006) Linkages amongst Foreign Direct Investment, Trade and Trade Policy: An Economic Analysis with Applications to the Food Sector. *American Agricultural Economics Association Annual Meeting.* Long Beach, California.

Wise, W. S. (1986) The Calculation of Rates of Returns on Agricultural Research from Production Functions. *Journal of Agricultural Economics,* 37, 151-161.

Yee, J., Huffman, W., Ahearn, M. & Newton, D. (2002) Sources of Agricultural Productivity Growth at the State Level, 1960-1993. In Ball, V. E. & Norton, G. W. (Eds.) *Agricultural Productivity: Measurement and Sources of Growth.* Kluwer Academic Publishers.

Yule, G. U. (1926) Why Do We Sometimes Get Nonsense Correlations Between Time Series?: A Study in Sampling and the Nature of Time Series. *Journal of the Royal Statistical Society,* 89, 1-64.

Zepeda, L. (2001) Agricultural Investment, Production Capacity and Productivity. In Zepeda, L. (Ed.) *Agricultural Investment and Productivity in Developing Countries. FAO Economic and Social Development Papers 148.* Rome, Food and Agriculture Organization of the United Nations.