THE IMPACTS OF RESEARCH ON PHILIPPINE RICE PRODUCTION

BY

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DISSERTATION

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ABSTRACT

This is a comprehensive study of the impacts of research and development in Philippine rice production. I examined the sources of rice production growth in the Philippines from 1996 to 2007 by estimating a translog production function using a generalized instrumental variable estimator. Using a production framework, I analyzed the contributions of conventional and non-conventional inputs, and residual total factor productivity to the production growth. Higher output growth was observed during wet and dry seasons of 2001-2006 and 2002-2007 compared to that of 1996-2001 and 1997-2002. Results indicate that non-conventional inputs such as irrigation, adoption of hybrid and third generation modern inbred varieties, attendance at rice production training sessions, use of high quality seed, and machine ownership were the main sources of production growth in these periods.

Using a cost framework, I measured the contributions of public investments in R&D, extension, production subsidy, and irrigation in reducing the cost of rice production in the Philippines. I used the shadow share as a measure of marginal return to public investments in determining the need for further investments. I also decomposed the growth in total factor productivity of rice into scale economy, improvement in capacity utilization due to public investments, and rate of technical change. Results indicate that R&D has generated cost-savings and has improved productivity of rice. This implies that further investment in rice R&D is essential. I also found that investment in production subsidy is counterproductive which supports its phase-out. I also found inefficiencies in extension and irrigation investments. This suggests that reforms in the current extension system and a reorientation of the irrigation development strategies should be implemented in order to reap the potential benefits from these investments.

Finally, I used the CERES-Rice simulation model of the Decision Support System for Agrotechnology Transfer in investigating the nature of shift in individual rice supply when a hybrid rice variety was adopted. Using the DSSAT model, I determined the yield responses of hybrid and inbred rice varieties to different levels of nitrogen, potassium, and water applications. I estimated hybrid and inbred yield response functions using the DSSAT-generated yield data. Using the estimated coefficients, I recovered the profit-maximizing demands for nitrogen, potassium and water. Then, I derived the supply functions of hybrid and inbred rice by substituting these profit-maximizing demands back to the yield response functions. Results show that adopting the hybrid rice variety would lead to a pivotal and divergent shift in the individual supply. While far from being used in an aggregate scale, the method presented is a step toward a better measurement of benefits from adopting a specific technology and returns to R&D in general.

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TABLE OF CONTENTS

LIST OF ACRONYMS

ATI	-	Agricultural Training Institute
BAS	-	Bureau of Agricultural Statistics
BE	-	Between Estimation
CGIAR	-	Consultative Group for International Agricultural Research
DA	-	Department of Agriculture
DAS	-	Days After Sowing
DSSAT	-	Decision Support System for Agrotechnology Transfer
GIV	-	Generalized Instrumental Variable
HRCP	-	Hybrid Rice Commercialization Program
IRRI	-	International Rice Research Institute
LGU	-	Local Government Unit
MV	-	Modern Variety
MV1	-	First Generation Modern Variety
MV2	-	Second Generation Modern Variety
MV3	-	Third Generation Modern Variety
NSIC	-	National Seed Industry Council
NCT-MAT	-	National Coordinated Test for Multi-Adaptation Trials
NIA	-	National Irrigation Administration
OLS	-	Ordinary Least Squares
PhilRice	-	Philippine Rice Research Institute
PhP	-	Philippine Peso
POLS	-	Pooled Ordinary Least Squares
PSB	-	Philippine Seed Board
R&D	-	Research and Development
SUR	-	Seemingly Unrelated Regression
TFP	-	Total Factor Productivity
Translog	-	Transcendental Logarithmic

Chapter 1

INTRODUCTION

> *"Rice is very important to our lives. We eat rice three times a day. Even my favorite dessert is made from rice… We are lucky. We have plenty of rice to eat. My teacher said that there are too many people in Asia. Some of them do not have enough to eat… When there are lots of rice my parents are happy. Last year, when the harvest was not good, my father almost had to sell the farm to get money. Some people from the city came to our village last year. They wanted to buy the farms and make them into a golf course… Sometimes my mother looks scared. Something is happening to our rice fields that no one understands. She says that each year they have to put more fertilizer on the field to grow the same amount of rice. But the price of rice stays the same, so we get less money. My father says that he cannot tell anymore when the rains will come. Sometimes they don't. Then there is no rice crop. We are all sad because then we don't have much money and my father tries to find work so that he has money to buy rice and to send us to school. My father and mother want me to study hard so that when I grow up I can be a teacher or a doctor. They don't want me to be a rice farmer."*
>
> *Issa Sanchez*[1]

Similar to Issa and her family's circumstances, rice means life to millions of Filipinos. For them, rice is not merely a food but a grain that shapes their way of living, their hopes, and their dreams. They consider rice as a symbol of their quest for life's security and emancipation from hunger. Thus, achieving rice security is intricately related to the nation's struggle in eliminating extreme hunger and poverty – the United Nation's first Millennium Development Goal. In fact, rice security is tantamount to food security in the Philippines. As the staple food of the Filipinos, rice accounts for 46% and 35% of their caloric intake and

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[1] Issa Sanchez is a nine-year old girl from Quezon, Philippines. This is an excerpt of her essay entitled *"Why is rice important to me?"* (ARF 2006).

protein consumption (FAO 2008). As a major part of food spending, rice comprised 16% of the total expenditures of the poorest 30% of the population (World Bank 2007). Thus, a rise in rice prices could significantly raise the Filipinos' cost of living sending more people to poverty.

Rice is also the most extensively grown crop in the country, planted in about 30% of the total agricultural area harvested (Dawe 2003). For two million families, rice farming is the source of over half of the household income. In addition, millions of landless farm workers, and tens of thousands of merchants indirectly depend on rice for a living. Given the weight of rice's social and economic ramifications, rice has always been the principal focus of the government's food security policies.

Philippine rice production tripled from 5 million tons in 1970 to more than 16 million tons in 2008, with only a 44% increase in the area harvested. Instrumental to this development is the use of the Green Revolution's seed-fertilizer technology and access to irrigation facilities, which doubled the yield per hectare in the same period. Production gains fed the rapidly growing population and its increasing per-capita rice consumption. Except for a few years in the late 1970s and early 1980s, rice imports were used to fill the gap between demand and supply and to stabilize the domestic price of rice.

Although the Philippines has relied increasingly on rice imports since the 1990s, its quest for the rice self-sufficiency has persisted. In constant debate, academicians, scientists, economists, and politicians argue for and against attaining rice self-sufficiency. Some say that the Philippines' lack of comparative advantage in producing rice can be attributed to its geography (Dawe 2006). Others say that public investments required to achieve rice self-sufficiency are too costly given the competing use of scarce public resources. On the other hand, there are those who believe that self-sufficiency is justified by the thin world rice market. Since rice is mostly consumed in countries where it is produced, world supply is vulnerable to changes in the consumption and production dynamics of major producing countries. Thus, it is more practical to source rice from domestic production to avoid severe fluctuations in the world supply of rice and its price. To illustrate the political importance of self-sufficiency in rice, during the 2008 surge in the price of grains, the Philippine government enacted an open-tender policy to avoid a rice shortage while some rice exporting countries banned their rice exports.

But beyond the issue of rice self-sufficiency, expanding domestic production is essential in ensuring the availability of supply for the ever-increasing population. Improving rice productivity can contribute in reducing poverty in the rural areas because it can increase the income of small farmers and landless farm workers, specifically, who depend on rice production for a living. In addition, productivity improvement can make local producers cost-competitive with international producers, which is necessary if the country is to liberalize its rice trade.

Unfortunately, several factors threaten the future of Philippine rice production. Urbanization, industrial land-use, and competing agricultural uses have decreased the physical area devoted to rice production. From 3.4 million hectares in 1991, the actual rice area declined to 2.8 million hectares in 2001. Furthermore, the declining quality of land and water resources aggravates the diminishing quantity of physical resources as a result of years of mono-cropping practices (Cassman and Pingali 1995; Flinn and De Datta 1984).

Evidence of declining productivity abounds. On the scientific front, the yield potential of indica-inbred rice cultivars has stagnated at 9 to 10 metric tons per hectare (Peng, et al. 1999; Tiongco and Dawe 2002). The average actual farm yields are only about half of the experiment station yields (Sebastian, Bordey and Alpuerto 2006). Some studies also show a decline in rice total factor productivity (TFP) in the late 1980s (Umetsu, Lekprichakul and Chakravorty 2003) and through the 1990s (Estudillo and Otsuka 2006). Fortunately, rice research and development (R&D) holds the promise of mitigating, if not countering, the impacts of these challenges. While the Philippines is already benefiting from technological innovations, efforts are continuously made to apply science in rice production.

1.1. Developments in Rice R&D in the Philippines

The investment in rice R&D is one of the key policies used by the Philippine government to pursue its rice security objective. According to Flores-Moya, Evenson and Hayami (1978), the history of rice R&D in the Philippines can be divided into three periods. R&D during the pre-World War II period was based on a nonsystematic research conducted by scientists of the Bureau of Plant Industry and the University of the Philippines College of Agriculture (now University of the Philippines Los Baños). The second period (1955-1960) began with the establishment of the Rice and Corn Production Coordinating Council which launched the Rice and Corn Research and Production Program, guaranteeing financial support for rice research. Rice breeding research based on selecting pure lines characterized this period. The third period is marked by the establishment of the International Rice Research Institute (IRRI), the oldest and largest international agricultural research institute in

Asia (IRRI 2007). IRRI served as the model institute for research centers that make up the Consultative Group on the International Agricultural Research (CGIAR). In 1966, the major breakthrough in rice research was the release of IR8, the first inbred rice modern variety (MV) that started the Green Revolution in the tropics.[2] From 1990 to the present, IRRI has bred 47 rice varieties, which was released for commercial use by the Philippine Seed Board (PSB), later named as the National Seed Industry Council (NSIC).[3] Of these varieties, 29 are for irrigated lowlands, 4 are for rainfed lowlands, 5 are for cool elevated lands, 6 are for saline prone lowlands, and 3 for upland areas. Four of the varieties released for irrigated lowland are also hybrid cultivars. Since the 1990s, more than 90% of the rice area harvested in the Philippines has been planted with inbred MVs.

Beyond these three periods came two more significant developments in the Philippine rice R&D history. One was the creation in 1985 of the Philippine Rice Research Institute (PhilRice), a government-owned and -controlled research center. PhilRice was established to develop technologies and innovations that address specific production problems in the Philippines. PhilRice has also adapted IRRI's technologies to local conditions to promote wider adoption. Since its inception, PhilRice has helped in the development of 57 rice varieties, some through its own breeding efforts, but mostly by conducting location

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[2] Compared to the traditional varieties, inbred MVs have shorter and sturdier stems, are more responsive to fertilizer, and less photoperiod-sensitive. Thus, inbred MVs have higher yield as more fertilizers are applied, and have shorter maturity periods than the traditional varieties. As a result, modern inbred varieties can be planted twice a year in tropical countries, as long as water is not limiting. The shorter and sturdier stems prevent the rice plant from lodging. Since the introduction of IR8 in 1968, variety development has focused on improving yield stability (pest and disease tolerance), and eating quality. Nevertheless, the yield potential of all modern inbred varieties remained stagnant at around 10 tons per hectare.

[3] This listing includes rice varieties that are released only in the Philippines. In addition, IRRI also maintains a gene bank facility that serves as a repository of rice genetic materials around the world.

adaptation trials. PhilRice has also developed several crop management practices and machine designs that are suited to Philippine rice production conditions.

The advent of hybrid rice technology marked the latest development in the rice R&D history of the Philippines. Hybrid rice technology was initially introduced in 1998 but its commercialization was delayed until 2001 due to the difficulty in seed production. Given the commercial feature of hybrid rice, the private sector was enticed to invest in its R&D.[4] Since 1998, 5 out of the 9 hybrid rice varieties released were developed by private seed companies. Based on experimental evidence, hybrid rice technology offered 15% to 20% higher yields compared to inbred MVs.

1.2. Review of Rice R&D Impacts in the Philippines

IRRI's presence has necessitated a significant amount of research on impacts of R&D in the Philippines, due in part to IRRI's accountability to its donors. Pingali (2001) provided a historical overview of the impact assessment of Philippine rice research. The earliest studies focused on the extent of adoption and farm level impacts of modern varieties of inbred rice and other crops (Dalrymple 1977,1978). These provided empirical evidence of the early impacts of the Green Revolution. Herdt and Capule (1983) provided details on global, regional, and national adoption figures for inbred rice MVs. They also studied the

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[4] Originally from China, hybrid rice varieties for the tropics were introduced in the Philippines in 1998 and seeds became commercially available in 2001. Hybrid rice has similar physiological characteristics with the inbred rice except that it exploits the phenomenon of hybrid vigor and involves raising a commercial crop from the first filial (F1) generation of a cross of two rice varieties that are genetically different (e.g. a cross between japonica and indica rice). As a result of heterosis, hybrid rice has longer panicles, and more grains per panicle. Experimental evidence shows that hybrid rice could yield 15 to 20% higher than the best semi-dwarf inbred varieties. The use of fresh seed stock every season is one of the requirements for successful application of this technology. This underlies the commercial feature of hybrid rice technology and opportunity for private profits.

differential adoption of inbred rice MVs in favorable and unfavorable production environments. The latest addition to these studies in adoption and farm productivity was the midterm impact assessment of the hybrid rice commercialization program by Gonzales and associates (2007), which analyzed the profitability of hybrid rice farming compared to inbred rice production.

Flores-Moya, Evenson and Hayami (1978) conducted the assessment of the social returns to rice research in Asia and the Philippines, covering years 1966 to 1975. Results showed a 73% to 78% rate of return from national rice research, and a 74% to 102% return from international rice research. Evenson (2001) synthesized numerous studies that estimated rates of return to research in rice and other crops in different parts of the world. In addition, Alston et al. (2000) made a meta-analysis of 289 studies and concluded that a decline in the rates of return to agricultural research over time was not empirically supported.

Herdt (1979) followed by Herdt and Mandac (1981) examined the rice yield gap as affected by biophysical and socioeconomic factors. These studies identified the constraints to achieving high yields and profits from inbred MV adoption. Pingali (2001) concluded that these two studies provided a significant impetus to further investigate the technical and economic efficiency of rice farming. Umetsu et al. (2003) documented the Philippine rice TFP, efficiency, and technical change in the post-Green Revolution period. They concluded that the period of positive productivity growth coincided with the introduction of new inbred rice MVs. Similarly, Estudillo and Otsuka (2006) assessed the yield and TFP growth in major rice areas in the Philippines. They found the diffusion of inbred rice MVs, which are resistant to pests and diseases, is a major contributor to the increase in yield and productivity in irrigated areas.

Several studies analyzed the impacts of rice research on crop management practices. Herdt (1983, 1987) examined the chronology of the mechanization of Philippine rice farms. He found that power-intensive operations such as tillage and transport were mechanized the most. Farm activities requiring knowledge and judgment such as weeding and harvesting were mechanized the least. David (1976) and David and Barker (1978) examined the determinants of fertilizer use in the rice production and found that the adoption of rice MVs contributed significantly to increases in fertilizer demand at the farm level. IRRI also conducted research on the impacts of insecticide use and integrated pest management. Results indicated that rice farmers who did not apply insecticides had higher expected returns compared to farmers who applied insecticides on a preventive basis (Herdt, Castillo and Jayasuriya 1984). Similarly, utilizing a zero pesticide strategy was more profitable considering the costs of health damages that insecticide inhalation can bring to farmers (Rola and Pingali 1993).

Several studies have assessed the distributional impacts of rice technologies. David and Otsuka (1994) found that farmers in favorable and irrigated areas enjoyed the largest gains from the Green Revolution’s seed-fertilizer technology. They further argued that farmers from less favorable environments also benefited through technology spillovers, and labor opportunities in more productive areas. The increase in farm wages benefited landless workers, suggesting that technology impacts were not just concentrated on a few wealthy farmers.

1.3. Statement of the Problem

Despite the abundance of literature on the positive impacts of the Green Revolution, criticisms about the negative effects of rice R&D exist. According to a policy brief of the International Food Policy Research Institute, the criticisms about the Green Revolution include environmental degradation, increased income inequality, inequitable asset distribution, and worsened absolute poverty.

In the Philippines, politicians, news media, and even ordinary people often ask why the country still imports rice despite the presence of IRRI and PhilRice. The tendency to overstate the negative implications of research and the Philippines' failure to achieve rice self-sufficiency breeds cynicism on the part of policy makers and cast shadows on policy support for rice R&D. To counter this growing doubt, it is important to provide policy makers with some fresh insights into the impacts of rice R&D based on precise analyses of recent data.

Most of the studies mentioned in this review showed the impacts of rice R&D during the Green Revolution period. Fifty years later, only a handful of studies have evaluated the current impacts of new generations of inbred MVs, and even fewer studies have investigated recent technological developments such as hybrid rice. The shortage of studies on the impacts of rice R&D in recent years may be contributing to the skepticism of policy makers. Up-to-date research on the current impacts of rice R&D is essential if policy makers are to have a more optimistic outlook about the Philippines' rice production.

In addition, the 2008 world food crisis and the volatility of the international rice market renewed the interest in finding alternative means of increasing domestic production. Given this, ascertaining the viability of rice R&D as a public investment and a means of expanding domestic production will help secure financial support for rice R&D. All these point to the need for current knowledge about accurate impacts of rice R&D.

1.4. Scope and Coverage

The remainder of this dissertation is composed of four chapters. In Chapter 2, I examined the contribution of various technologies and other non-conventional inputs to increases in rice production at the farm level. Using the generalized instrumental variable (GIV) estimator to estimate a transcendental logarithmic (translog) production function, I analyzed the effects on rice production at the farm level of hybrid varieties, different generations of inbred MVs, high quality seed, access to irrigation, attendance to training, and asset ownership. I separated the production effects of these factors from the impacts of conventional inputs and residual TFP. As opposed to previous studies which utilized data from only a few provinces, the farm level and panel data I used was from a survey of 30 major rice producing provinces in the Philippines.

In Chapter 3, I used panel data to measure the impacts of public investments in rice R&D, extension, production subsidy and irrigation on the cost of rice production at the regional level. I estimated a system of five equations that includes a translog cost function and four cost share equations using the seemingly unrelated regression (SUR). I used the shadow share as a measure of marginal return to public investments in determining the need for further investments. I also decomposed the growth in TFP of rice into scale economy, improvement in capacity utilization due to public investments, and the rate of technical change.

In Chapter 4, I investigated the nature of the shift in supply when a hybrid rice variety is adopted in the Philippines. I used the CERES-Rice simulation model of the Decision Support System for Agrotechnology Transfer (DSSAT) in examining the nature of the shift in individual supply when a hybrid rice variety was adopted. Initially, I investigated the yield responses of hybrid and inbred rice varieties to different levels of nitrogen, potassium, and water applications. I estimated the hybrid and inbred yield response functions using the yield data generated by DSSAT. Using the estimated coefficients, I recovered the profit-maximizing demands for nitrogen, potassium and water. I derived supplies of hybrid and inbred rice by substituting these profit-maximizing demands back to the yield response functions.

Chapter 5 summarizes the overall policy implications of the dissertation. I integrated the results from previous chapters and looked for consistent and contradictory patterns. Using this information, I recommended some policies that can increase rice production in the Philippines.

Chapter2

PRODUCTIVITY OF RICE FARMING IN THE PHILIPPINES: PATTERNS AND SOURCES

Fifty years after the onset of the Green Revolution, the Philippines continues to struggle with producing sufficient rice to feed its population. Except for a few years in the late 1970s to the early 1980s, rice imports have been needed to fill the gap between the domestic production and consumption. Figure 2.1 shows an increasing importance of rice imports in the domestic consumption from 1990 to 2006. With a 2% annual population growth rate and a steady increase in per capita rice consumption, imports will likely continue to play an important role in meeting the domestic demand.

However, relying on the thinly traded international rice market to meet a basic need can be problematic for policy makers. Since only about 7% of world rice production is traded, the world price of rice can be very sensitive to changes in production in primary exporting countries and consumption in major importing countries. Krugman (2008) and Von Braun (2008) stated that recent global hikes in cereal prices, which were driven by the increased food demand in some parts of Asia and the diversion of resources from food to biofuel production in western countries, have greatly concerned the net importing countries. Since the Philippines is one of the world's major rice importers, the surge in the world price of rice has increased the domestic price of regular milled rice by 35% from the end of 2007 to mid-2008. This hike in rice prices compromised the nutrition of the population, especially the poor who spend the majority of their income on food.

Given the upward trend in the world price of rice and in the share of Philippine rice imports to local consumption, increasing rice production has come to the forefront of the government's agricultural program. While intensifying the use of conventional inputs such as land, labor, capital and materials can increase rice production, the increased use of non-conventional inputs and improvements in the residual TFP can sustain the growth in output (Estudillo and Otsuka 2006; Teruel and Kuroda 2005; Umetsu, Lekprichakul, and Chakravorty 2003).

Knowing the patterns and sources of rice production growth in recent years can provide insights to alternative ways of increasing rice production in the immediate future. However, knowing the direction of the production change at the national level does not provide enough information for policy makers to design a more effective rice production program. Given the high variability in yield of rice producing areas in the Philippines, it is critical to examine the variation in production growth and its sources in major rice producing provinces.

In this paper, I identified the sources of rice production growth in the Philippines from 1996 to 2007. Using GIV estimation of a translog production function, I separated the contributions to production growth of conventional and non-conventional inputs, and the growth in residual total factor productivity. Wet season rice production grew by 22% from 2001 to 2006 while dry season rice production rose by 14% from 2002 to 2007. Results indicated that non-conventional inputs such as irrigation, adoption of hybrid varieties and third generation inbred modern varieties (MV3), participation of farmers in rice production training, use of high quality seed, and machine ownership were the main sources of production growth in these periods.

Although several past papers have examined Philippine rice production, this study offers the following contributions. First, the analysis of recent rice production can explain the sources and sustainability of the growth spurts of 2001-2007. Second, because the data used covers 30 provinces (Figure 2.2), which produce about three-quarters of the total production, I was able to provide a provincial-specific analysis. This can help in accurately targeting and effectively designing the government's rice program. Third, the use of extensive and previously unavailable farm-level and panel data on production and input use made it possible for me to identify the input-output relationships more precisely. Finally, the availability of panel data allowed the use of the GIV approach to estimate the production function, increasing the accuracy of the estimated productivity measures.

2.1. Overview of Rice Production in the Philippines

Table 2.1 summarizes the exponential growth rates of rice production, area harvested, and yield from 1970 to 2007. Yield growth was the major factor pushing rice production from 1970 to 1990. Barker (1984) and Panganiban (2000) attributed the gains in yield to the introduction of inbred MVs, development of large-scale irrigation systems, information campaigns, and subsidized credit. However, during 1990-2000 the growth in yield decelerated as a result of the decline in the world price of rice, stagnant investments in public irrigation, exhaustion of productivity potential from MVs, and soil degradation brought about by intensified cropping systems (Hayami and Kikuchi 1999; Mundlak, Larson, and Butzer 2002).

The contribution of land expansion through cultivation of new areas was exhausted in the 1990s. An increase in area harvested was brought about by crop intensification in irrigated areas and the development of public and private small-scale irrigation systems (Llanto 2003). Given the competing uses of land for industrial and residential purposes, the Philippines may need to produce more rice from less land in the future.

From 2000 to 2007, rice production grew at rates similar to those during the height of the Green Revolution in the 1970s. Improvement in yield contributed to almost 80% of the output growth. Irrigated and rainfed yields increased annually by 3% and 4%, offsetting the decelerating growth in area harvested. Although yield trends provided an indication of productivity change, it did not adequately explain the real cause of productivity growth. Yield can grow due to the increased use of seed, fertilizers, labor, and machinery, making it complicated to identify the sources of potential productivity growth. The production function provided a framework in isolating the contribution of TFP growth from the role of growth in inputs.

Umetsu, Lekprichakul, and Chakravorty (2003) investigated rice TFP in the Philippines from 1971 to 1990. They constructed the Malmquist TFP indices using linear programming and regional aggregate data. Results showed that productivity declined by 2% from 1971 to 1975 followed by a 2.4% growth from 1976 to 1980. A positive TFP growth of 3.6% was observed from 1981 to 1985, but a 1.8% drop was seen from 1986 to 1990. The authors attributed the positive TFP growth to the introduction and rapid adoption of second generation modern varieties (MV2). In addition, from 1986 to 1990, they ascribed the TFP decline to the intensified rice production in lowland irrigated farms.

Estudillo and Otsuka (2006) also analyzed rice TFP in the Philippines from 1966 to 1999. They used panel data on irrigated farms in Central Luzon to determine factor shares, which were then used in computing the Tornqvist-Theil productivity indices. In addition, they related rice productivity performance to the introduction of successive generations of inbred MVs. The authors noted that the TFP decline from 1966 to 1974, which coincided with the introduction of first generation modern varieties (MV1), suggested a relatively small contribution of technological change to productivity growth during this period. Similar to the Umetsu, Lekprichakul, and Chakravorty study, Estudillo and Otsuka attributed the 1979-1987 TFP growth to the introduction of MV2. They also identified that the productivity impacts of MV2 and MV3 were roughly the same size.

Growth spurts in aggregate rice production and in per hectare yield have occurred since 2000. However, it is not clear whether this growth was due to the increased use of conventional inputs or to TFP growth. This study can provide significant insights into the sources of rice production growth during this period. Policy makers can use this information to create policies that can sustain the increase in production.

2.2. Methodology and Data

2.2.1. The Model

The profit-maximization problem of a farmer is expressed as

$$\text{(2-1)} \quad \underset{x_j \in X}{Max} \quad pf\left(X\left(c_i,t,Z\right);c_i,t,Z\right)-wX\left(c_i,t,Z\right),$$

where p is the output price, $f\left(X\left(c_i,t,Z\right);c_i,t,Z\right)$ is the production function, X is a vector of inputs, c_i is the unobserved management ability of the farmer, t is time representing technical change, Z is a vector of time-invariant variables, and w is a vector of input prices. The solution to the profit-maximization problem is the vector of inputs $X^*\left(c_i,t,Z,w,p\right)$.

The first order conditions are given by

(2-2) $$\frac{\partial f\left(X^*\left(c_i,t,Z,w,p\right),c_i,t,Z\right)}{\partial x_j} \le \frac{w_j}{p},\ \forall j,$$ with equality if $X^*\left(c_i,t,Z,w,p\right) > 0$.

Since farms are small in general, it can be assumed that farmers are price takers and face similar relative prices (i.e. w_{ji}/p_i is similar for each input j, and for all individuals i). Although relative prices can vary over space and time, the potential similarity in relative prices leads to limited variability in these explanatory variables. In this case, the primal estimates of production technology, which utilizes information from input use, are more statistically efficient than estimates based on duality (Mundlak 1996, p.431). Hence, I used the primal approach for the estimation of a production function to reconstruct production technology. Using the linearized Cobb-Douglas form for simplicity, the production function is expressed as

(2-3) $$\ln y_{it} = \alpha + \sum_j \beta_j \ln x_{jit} + \sum_n \gamma_n Z_{ni} + \sum_t \delta_t T_t + u_{it},$$

where T_t are year dummies, $\alpha,\beta,\gamma,\delta$ are parameters to be estimated, and u_{it} is the composite error term that can be expressed as

(2-4) $$u_{it} = c_i + \varepsilon_{it}.$$

I used the translog function as an alternative form of production function, which is written as

(2-5) $$\ln y_{it} = \alpha + \sum_j \beta_j \ln x_{jit} + \frac{1}{2} \sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \sum_n \gamma_n Z_{ni} + \sum_t \delta_t T_t + u_{it} .$$

This form is flexible and allows the elasticity of substitution between inputs to vary from unity (Christensen, Jorgenson and Lau 1973). I imposed parameter restrictions in the estimation (i.e. $\beta_{jk} = \beta_{kj}$) to ensure the concavity of the estimated translog production function.

Noting that *y*, and *X* were functions of time, TFP growth was computed by totally differentiating equation (2-3) and (2-5) with respect to time, yielding

(2-6) $$\frac{d \ln y}{dt} = \frac{\partial \ln y}{\partial t} + \sum_j \varepsilon_{yj} \frac{d \ln x_j}{dt} ,$$

Where ε_{yj} is the elasticity of output with respect to input *j*. Assuming profit maximization and equilibrium, these elasticities can be interpreted as cost shares (i.e. $\varepsilon_{yj} = w_j x_j / C$). For the Cobb-Douglas and translog functional forms, the elasticities of output with respect to input *j* are calculated as

(2-7) $\varepsilon_{yj} = \beta_j$, and

(2-8) $$\varepsilon_{yj} = \beta_j + \sum_k \beta_{jk} \ln x_k .$$

I computed the TFP growth as the difference between the growth rate of output and the weighted sum of growth rates of conventional inputs, and expressed it as

(2-9) $$\overset{\bullet}{TFP} = \frac{\partial \ln y}{\partial t} = \frac{d \ln y}{dt} - \sum_j \varepsilon_{yj} \frac{d \ln x_j}{dt} .$$

I used the exponential growth rates in approximating the continuous rates of growth of output and inputs. Diewert (1976) showed that the TFP growth estimated from the translog production function was equivalent to the superlative and exact Tornqvist-Theil productivity growth index. For this reason, I reported the TFP growth measure derived from the translog function.

2.2.2. Estimation Procedure

Although estimating a production function is one of the foundations for TFP analysis, it is confounded with problems of endogeneity. In particular, input quantities are choice variables from farmers' point of view and are correlated with their unobserved management abilities (Griliches and Mairesse 1998). In addition, there are also time-invariant state variables like irrigation, land ownership, and education that are correlated to the farmers' management abilities. However, due to the lack of an appropriate measure, farmers' management abilities are often omitted from the analysis and captured in the error term. This leads to the dependence of explanatory variables on the error term and a bias in the estimated coefficients.

To obtain consistent and efficient estimates, I adopted an estimator defined by Im, et al. (1999) which Wooldridge (2002, p.327) refers to as GIV. Essentially, this is a three-stage least squares estimator using the demeaned time-dependent variables as the instruments for endogenous time-dependent variables, and using the exogenous time-dependent variables as the instruments for endogenous time-independent ones. Im, et al. (1999) showed that this is the efficient generalized method of moments (GMM) estimator if the errors have a random effect structure (Theorem 4.4).

Without loss of generality, the production function can be rewritten as:

(2-10) $Y = X\beta + u$

where *Y* is a vector of logarithm of *y*, *X* is a matrix of time–dependent explanatory variables $\left(X_1, X_2\right)$ and time-independent $\left(Z_1, Z_2\right)$ explanatory variables, and *u* is the vector of composite error terms (i.e. $u_{it} = c_i + \varepsilon_{it}$). Then, the *X* matrix was partitioned into exogenous $\left(X_1, Z_1\right)$ and endogenous $\left(X_2, Z_2\right)$ variables. Using the time-demeaning matrix, $Q_T = \mathrm{I}_T - j_T\left(j_T^{'} j_T\right) j_T^{'}$, the demeaned time-dependent variables were constructed as $Q_T X_2$.

The estimation was implemented as a feasible three-stage least squares approach. First, the production function was estimated using a pooled two-stage least squares with instruments $\left(Q_T X_2, Z_1, X_1\right)$. Using the residuals from this stage, the random effects variance components, $\hat{\sigma}_u^2$ and $\hat{\sigma}_c^2$, were estimated as

(2-9) $$\hat{\sigma}_u^2 = \frac{\sum_i \sum_t \hat{u}_{it}^2}{nT - k}, \text{ and}$$

(2-10) $$\hat{\sigma}_c^2 = \frac{\sum_{i=1}^{n} \sum_{t=1}^{T-1} \sum_{s=t+1}^{T} \hat{u}_{it} \hat{u}_{is}}{\left(nT\left(T-1\right)/2\right) - k},$$

where *n* is the number of individuals, *T* is the number of periods, and *k* is the number of estimated parameters. Then, these two estimates were used to construct the weight

(2-11) $$\hat{\lambda} = 1 - \left(\frac{1}{1 + \left(T\hat{\sigma}_c^2 / \hat{\sigma}_u^2\right)}\right)^{\frac{1}{2}}.$$

This estimate was used to quasi-time demean the dependent variables, the explanatory variables, and the instrumental variables, in the generalized least squares step of three-stage least squares. Finally, the transformed variables were used in a pooled two-stage least squares estimation. All statistics from the final stage of the estimation are asymptotically valid.

The use of GIV regression assumes that all explanatory variables are strictly exogenous. This indicates that the error term at period t, u_{it}, is uncorrelated with the explanatory variables for all units within cluster i (Wooldridge 2002, p. 330). For example, a production shock in the period t should not change the behavior and management decisions of farmers in period $t+1$. While the occurrence of a year-specific shock like a drought or excessive rain might affect the input decisions in the same season in succeeding crop year, it is highly unlikely that it would affect the input decisions after five crop years. Since the data that I used for the study have an interval of five years, then the strict exogeneity of input variables is a sound assumption.

2.2.3. Data and Description

I obtained data on rice production and input use from 30 provinces from the PhilRice *Rice-Based Farm Household Survey*. These data were based on wet season surveys for 1996, 2001 and 2006, and dry season surveys for 1997, 2002 and 2007.[5] After removing observations with missing data and outliers, there were 11,686 observations available for the analysis. However, to make a robust time-demeaning procedure, observations that appeared once were also removed, leaving 10,644 observations for the analysis.

Table 2.2 shows the variables used in the analysis. The dependent variable is the rice output per farm expressed in kilograms of paddy rice. The conventional inputs taken into

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[5] Dry and wet cropping seasons run from January-June and July-December each year.

consideration are land, seed, fertilizer, labor, and machinery.[6] Some non-conventional inputs were included to account for their impacts on production. These were grouped into rural infrastructure, human capital, technology, and resource ownership.

Rural infrastructure has been established to improve agricultural production (Fan, Hazell and Haque 2000) and will likely affect the rice production in the Philippines. Better roads and ease in transport can encourage the use of fertilizers and higher production. Furthermore, human capital variables were included to control for the effect of potential improvement in management skills of farmers over time (Schultz 1964). Adoption of different generations of inbred MVs, uses of certified seed[7] and machinery were also included to measure impacts of technology on production. Asset ownership was included to control for the ability to make effective and timely farm operation decisions (Schultz 1964). Finally, year dummies were added to control for time effects and eliminate a possible source of serial correlation.

Table 2.3 displays the groupings of rice varieties based on the updated classification of inbred MVs by Estudillo and Otsuka (2006). The updates included the NSIC series of hybrid and inbred MVs. Traditional and farmer-named varieties, which were not found in the NSIC list, were used as the control group. However, it is possible that some of the farmer-named varieties are actually inbred MVs, and if so would lead to a downward bias on

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[6] Chemical inputs were included at first, but the estimated elasticities were economically insignificant. The benefits of chemical application arise only when the crop is subjected to stress from weeds or pests. With data on crop stress lacking, it would be difficult to measure the true impact of chemicals on production, hence chemical variables were removed from the final model. In addition, Dawe (2006, p. 85-87) showed that Filipino farmers applied the least amount of insecticides compared to other Southeast Asian farmers. He indicated that the low level of insecticide use in the Philippines was a culmination of a declining trend, which began slowly in the mid-1980s and accelerated in the 1990s. He further noted that by the mid-1990s, the levels of insecticide use were slightly lower than what they were before the Green Revolution began.

[7] Certified seed is a term used for the high quality seed certified by the National Seed Quality Control Services

the coefficients of different generations of inbred MVs. Except for hybrids, MV1, MV2 and MV3 were available in all survey periods.

With the exception of machine rent, all other conventional input variables were considered endogenous. Machine rent was considered exogenous because it was predetermined by the institutional arrangement between farmers and contract workers.[8] The distance variable was also considered as predetermined. Variables on irrigation, human capital, technology, and resource ownership were assumed to be endogenous. Output prices for each year were used as additional instruments to identify the model.

Table 2.4 summarizes the rice output and input use per hectare. In all ecosystems, yield generally increased over time, though faster growth was observed during the 2001-2006 wet seasons and the 2002-2007 dry seasons. Irrigated yields exceeded rainfed yields by approximately 25% to 30% during the wet season, and by as much as 62% during the dry season. Yield variances in both areas were similar. This implied that rainfed yields had higher coefficients of variation, suggesting larger risks.

On average, the amount of seed use declined and was closer to the recommended seeding rate of 40 kilogram per hectare. This reflected an improvement in the efficiency of seed use. Similarly, labor use decreased across periods. Labor uses in irrigated and rainfed areas were comparable. On the other hand, fertilizer use increased in irrigated farms. The real value of machine rent was fairly stable although the rental cost was around 11% to 17%

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[8] Farmers enter into a contract with farm-workers who can provide tractors and services for land preparation activities. Often, the provisions of the contract indicate that the same workers who prepared the land will also perform threshing activities. Payment for threshing is based on a sharing arrangement (a certain %age of output) agreed upon by the farmers and the contractors. For the contractor, this ensures a certain job during the harvest season. On the farmer's view point, this avoids the difficulty of finding workers who will do threshing activities in the event of bad harvest.

higher in irrigated areas than in rainfed areas.[9] Farm size declined over time, but irrigated farms were generally bigger than rainfed farms.

Table 2.5 shows the distribution of respondents in terms of infrastructure, technology use, human capital, and asset ownership. The percentage of farmers with irrigated farms rose from 64% in 1996 to 76% in 2007. On average, farms were about 5 kilometers away from the nearest market. The share of trained farmers also increased from 19% in 1996 to 53% in 2007. By 2007, 43% of the farmers finished elementary schooling while about a quarter graduated from high school. Farmers in irrigated areas were more educated than farmers with rainfed farms.

The MV3 were the most commonly used rice varieties though their adoption rates were higher in irrigated than in rainfed areas. About 9% and 6% of farmers in irrigated and rainfed areas were using hybrids by 2007. The use of high quality seed increased from 10% in 1996 to 29% in 2007. A greater fraction of farmers in irrigated areas used high quality seed compared to rainfed areas. Probably due to the importance of having a well-leveled field, which can only be achieved with the complementary use of tractor and animal[10], a purely mechanized land preparation became less popular.

Farmers in irrigated areas tended to use higher levels of technology than those in rainfed areas, as shown by their greater use of high-quality seed and machines. This is not surprising as returns to rice production are higher and less risky in irrigated areas, making it wise to invest more in technology. This is consistent with previous results showing the

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[9] I used a deflator constructed from the price of paddy rice to compute the real value of machine rent.

[10] In addition to tractor use, animal-drawn planks were used in leveling a field with bunds. A properly leveled field saves on water use, reduces incidence of weeds, and allows for better management of snails, which saves on cost and can lead to a higher production.

availability of irrigation as the most important physical factor affecting the adoption of MVs (David and Otsuka 1994; Estudillo and Otsuka 2006). Less than half of the respondents cultivated their own land. From 21% in 1996, the percentage of farmers who owns machines rose to 30% in 2007. Although the number of resource owners increased, having less than half of the respondents being non-owners of land or machinery suggested that the process of decision-making for timely farm operations was less effective.

2.3. Results and Discussion

2.3.1. Production Function

Table 2.6 summarizes the estimated parameters of the production functions and their heteroskedasticity-robust standard errors. Columns 2 and 3 show the pooled ordinary least squares (POLS), and the between-farm (BE) estimates. Although results of the POLS and the BE regressions have higher R^2 values, indicating a good fit of the model, the estimated coefficients may be biased because of endogeneity. An example of the magnitude of the bias is the coefficient of irrigation, which is 0.216 and 0.19 under POLS and BE but is 0.715 and 0.563 under the GIV estimates of Cobb-Douglas and translog functions. The underestimation of the irrigation coefficient under the POLS and BE regression arises because it attributes the yield-decreasing effects of the unobserved variables such as pest incidence and soil quality to irrigation. Because of intensive cultivation practices, there is greater build-up of pests and lower soil quality in irrigated farms resulting in lower yield in these areas. However, these omitted variables are subsumed in the error term resulting in endogeneity and a downward bias in the coefficient of irrigation.

The GIV regression provides parameter estimates that are consistent and robust to the presence of arbitrary heteroskedasticity and intra-group correlation. The instrumental variable heteroskedasticity test reports a Pagan-Hall general test statistics of 165.75 and 176.49 under the Cobb-Douglas and translog specifications, rejecting the null hypothesis of homoskedasticity at 99% level of confidence. Given this, the Kleibergen-Paap rk LM and the Hansen J statistics are appropriate for tests of under-identification of the model and over-identifying restrictions (Hayashi 2000, p. 227-228, 407 and 417). The Kleibergen-Paap rk LM statistic shows that the GIV estimates for Cobb-Douglas and translog models are identified and the Hansen J test statistics for over-identifying restrictions indicate validity of the chosen instrument.

Using the Cobb-Douglas functional form, the output elasticities of seed, fertilizer, labor, machinery, and land were individually and jointly significant at 99% confidence level (Table 2.6, Column 4). Among the inputs, land made the highest contribution to production with an elasticity of 0.407 followed by the output elasticities of machinery (0.301), labor (0.204), seed (0.082) and fertilizer (0.007).

The estimated parameters and median input data were used to compute the translog elasticities of output with respect to inputs. The standard errors of these elasticities were approximated using the Delta method. All elasticity estimates were found statistically significant at 99% confidence level. The estimated translog elasticities of output were 0.065 for seed, 0.082 for fertilizer, 0.159 for labor, 0.351 for machinery, and 0.381 for land. While the translog elasticities of output with respect to seed, labor, machinery, and land were relatively closer to the estimated Cobb- Douglas elasticities, the translog elasticity of output with respect to fertilizer was more economically significant than the Cobb-Douglas estimate. The difference between the Cobb-Douglas and the translog output elasticities of fertilizer may result from allowing for variable elasticities of input substitution. Under the translog specification, the elasticity of scale was significantly greater than one, indicating an increasing return to scale at the farm level. This is not surprising as rice farms in the Philippines are already small and consolidation towards a moderately bigger size can result in gains from increasing scale.

The output elasticities estimated by Mundlak, Larson and Butzer (2002) for Philippine agriculture were 0.31 for land, 0.07 for fertilizer, 0.05 for capital-machinery, 0.09 for capital-agricultural origin (trees and forestry), and 0.16 for labor. Though not directly comparable, the proximity of the estimated elasticities of output with respect to land, fertilizer and labor for the rice production to the elasticities for Philippine agriculture estimated by Mundlak, Larson, and Butzer provided a degree of confidence in the estimation process. However, the big difference in the estimated production elasticities of capital may stem from their use of a capital stock variable, as opposed to my use of a flow variable in the form of machine rent.

As expected, irrigation was one of the non-conventional inputs that significantly increased production. On average, irrigated farms had 76% higher production than rainfed farms.[11] Technology and access to information were also found to have positive impacts on rice production. Farmers who participated in rice production training had a 4% higher production level than those who did not. Farmers who used different generations of MVs

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[11] Note that the estimated coefficient of the dummy variable for irrigation represents the difference between the natural logarithm of production of an irrigated and a rainfed farm. Thus the percentage difference in production is given by $\left(Y_{\text{Irrigated}} - Y_{\text{Rainfed}}\right)/Y_{\text{Rainfed}} = \left(e^{\beta_{\text{Irrigated}}} - 1\right)$. I used similar formula in calculating the average effects of other dummy variables.

also had significantly higher production than those using traditional and farmer-named varieties. The test for equality of the coefficients of MV1, MV2, and MV3 failed to reject the null (p-value = 0.3688), suggesting that different generations of inbred varieties have similar production advantages of around 5%. This is not surprising since all these inbred varieties are progenies of IR8, and therefore share the same yield potential.

On the other hand, farmers who used hybrid varieties had 18% higher production than those who used traditional and farmer-named varieties. A simple linear test showed that the coefficient of hybrid varieties was significantly higher than the coefficients of different generations of MVs (p-value = 0.0545). In addition, farmers who used high quality seed had a 6% higher production, suggesting the importance of using fresh seed stock every season. These results underscored the importance of continuous development and diffusion of new technologies in increasing production.

Machine ownership was also found to positively affect rice production. On average, farmers who owned tractors and threshers had 5% higher production compared to those who rented, attributing to the timeliness of land preparation and threshing activities. It was often observed that late planting, caused by delayed land preparation or labor bottlenecks during the planting season, results in higher pest incidence and lower production. Timeliness of threshing activities can also reduce postharvest losses. Farmers who owned a machine may also have lower supervision costs than those who rented, enabling them to achieve more thorough land preparation and threshing.

2.3.2. Production Growth Accounting

The exponential growth rates of the mean output and inputs, along with elasticities estimated from the translog production function, were used in decomposing production growth. Table 2.7 summarizes rice production growth and the aggregate contributions of growths in the residual TFP, and in the uses of conventional and non-conventional inputs on output growth. Results showed that wet season rice production declined by 9% from 1996 to 2001 while dry season rice production increased marginally by 1% from 1997 to 2002. This dismal performance was reversed as production during wet and dry seasons grew by 22% from 2001 to 2006 and by 14% from 2002 to 2007.

The substantial decrease in the use of conventional inputs caused the decline in output from 1996 to 2001 and the marginal output growth from 1997 to 2002. Only the improvement in the residual TFP, which grew by 5% in 1996 to 2001 and by 6% from 1997 to 2002, countered the effects of the decline in conventional input use. This implies an annual TFP growth rate of around 1%, which is slightly higher than the 1% annual TFP decline from 1990 to 1999 as estimated by Estudillo and Otsuka (2006) and the 1.8 % TFP decrease from 1986 to 1990 found by Umetsu, Lekprichakul, and Chakravorty (2003).

The residual TFP's contribution to output growth diminished over the last five years. TFP grew by 1% from 2001 to 2006 and by 4% from 2002 to 2007. In contrast, the use of non-conventional inputs contributed significantly to output growth in these periods. The use of non-conventional inputs increased by 6% in the 2001-2006 wet seasons and 10% in the 2002-2007 dry seasons. Specifically, output growth during these years was mainly due to irrigation, adoption of hybrid varieties, and the training of rice farmers. The use of high-quality seed and machine ownership contributed to production growth as well.

Compared to the TFP measurement alone, the approach employed in decomposing the output growth provided useful information in policy-making. In particular, it identified policy variables that can increase production. Moreover, this approach was more precise than the two-step procedure commonly employed in the literature, as the direct production impacts of non-conventional inputs were measured with less bias. In the two-step procedure, the TFP is measured residually from an estimation of a production function. Then, the measured TFP is regressed with factors affecting productivity. However, these factors are also correlated with the output and omitting them in the first-stage regression results in bias.

2.3.3. Geographical Variation in Productivity

Figures 2.3 and 2.4 demonstrate the provincial variation in growths in output, and conventional input uses during dry seasons of 2002-2007. Using the output elasticities of conventional and non-conventional inputs as weights, I created measures of overall growth in conventional and non-conventional inputs. Out of 30, only 18 provinces that are located in Luzon and Mindanao islands had positive growth in rice production. The growth in output, especially in the provinces of Ilocos Norte, Cagayan, Agusan del Sur, Bukidnon, and the Zamboanga peninsula, were achieved with declining use of conventional inputs. In contrast, provinces in the Visayas islands, particularly Iloilo, have had declining rice output during dry season of 2002-2007 despite the increased use of conventional inputs.

The large variation in output across geographical areas can be explained by differences in growths in uses of non-conventional inputs and TFP during dry seasons of 2002-2007. Figures 2.5 and 2.6 illustrates that 27 out of 30 provinces had an increased in the use of non-conventional inputs while only 18 provinces experienced growth in the residual TFP. Though it is hard to discern the causes of provincial variation in TFP, the geographical variation in the growth in uses of non-conventional inputs can be attributed to the intensity of implementing the rice program in each province, and the level of farmers' participation in such programs. The presence of key information sources like PhilRice in Nueva Ecija and IRRI in Laguna can also affect the level of non-conventional input use in these provinces.

2.4. Policy Implications

Rice production in the Philippines has increased significantly since 2001. The growth in output in this period was supported by the greater use of non-conventional inputs such as irrigation, hybrid rice varieties, and farmers' training. This implies that increasing farmers' access to these factors can further increase the total rice production in the country. As an example, transferring management of large irrigation systems to local water-user associations can improve the schedule of water releases. This, in turn, can increase the service area of an irrigation facility and the number of farmers who can access irrigation water. Some schemes of irrigation-management transfer may have failed before. However, this should not hinder the development managers from emulating and implementing successful models of transferring irrigation management (Inocencio and Barker 2006).

The positive effects of technology and knowledge products in rice production exemplify the importance of continuous research and development. Nevertheless, the high degree of variability in the use of technology and knowledge products across major rice producing provinces should be a cause of concern. Given this, the search for location-specific technologies should be enhanced. For example, not all hybrid varieties are adaptable to a wide range of production environments. Thus, identifying the suitable areas for planting should be done before promoting a particular hybrid rice variety. A one-technology-fits-all policy may not be optimal. This entails the need for a thorough understanding of the rice production environment in each province when designing location-specific research projects.

To improve the adoption of technology, a strong extension system should complement the rice research program (Gapasin 2006). Having an increased awareness of the existing technology is the first step towards the improvement of farmers' access to technology. To do this, the current extension system should be strengthened. For one, measures to upgrade the skills of extension workers must be institutionalized. Investments on computer equipment with Internet connections could also be another way of increasing the extension worker's access to information. This could enhance the flow of technology and knowledge from research organizations to the end-users.

Public provision of the identified productivity-enhancing variables such as hybrid rice, high quality seed, irrigation and training should be guided by the principles of efficiency. The benefits from providing these variables must be compared with the costs of provision. In this case, cost-benefit analyses are useful for prioritizing the investment decisions of the government.

It is not clear whether the Philippines will be able to domestically produce the nations' rice requirements. Opportunely, this study sends a clear message: productivity enhancements contributed to the increase in rice production in the Philippines. While the Philippines is on the right track towards a productivity-based increase in production, greater progress in this direction can be achieved by improving rural infrastructure, intensifying technology creation, increasing farmers' access to technology, and localizing the technology application to each geographic region.

2.5. Figures and Tables

Figure 2.1. Imports as share of domestic rice consumption, 1990-2006

Source: Bureau of Agricultural Statistics

Figure 2.2. Major rice-producing provinces in the Philippines and sample coverage

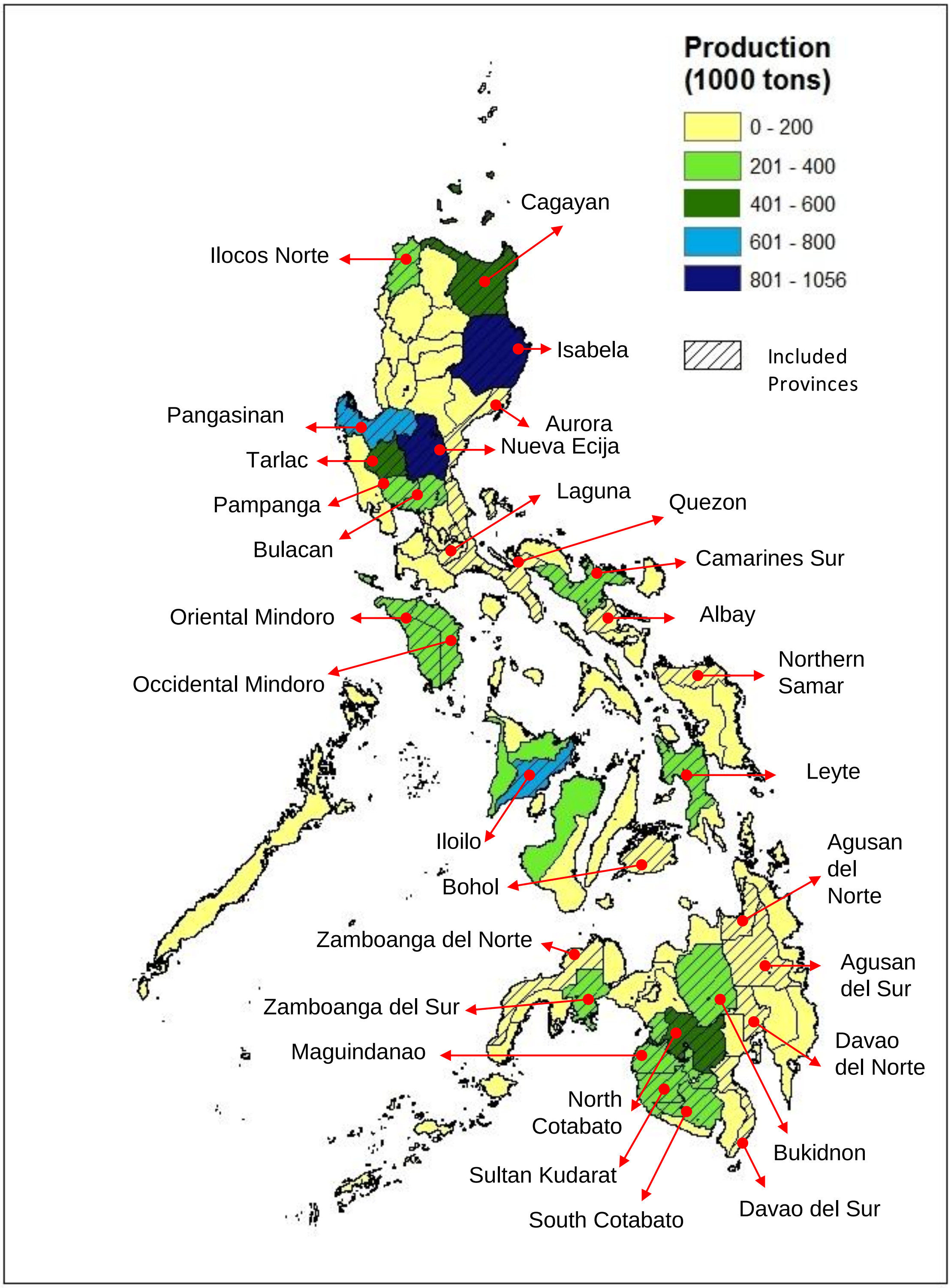

Figure 2.3. Provincial variation in output growth , dry season 2002-2007

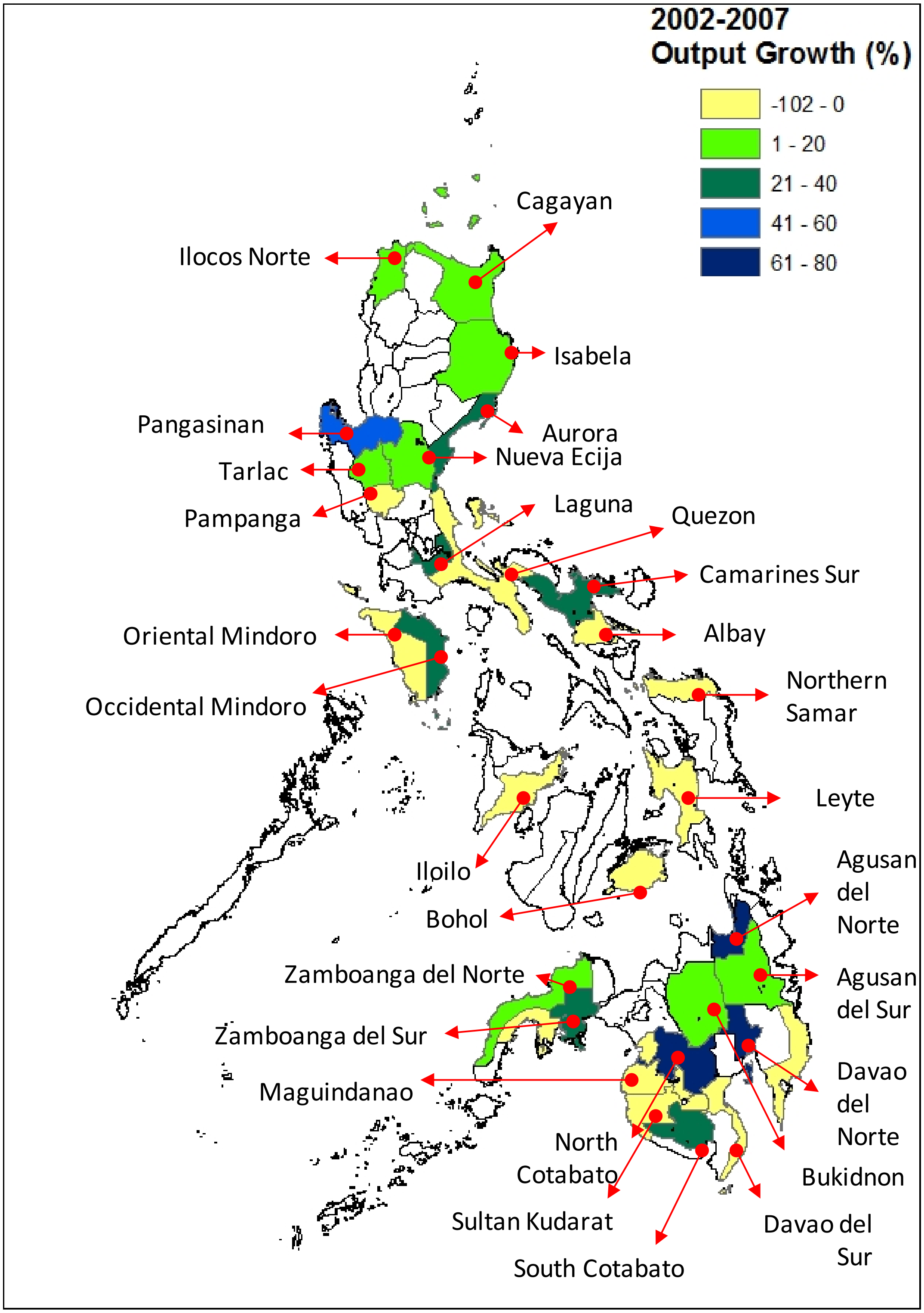

Figure 2.4. Provincial variation in growth in conventional inputs, dry season 2002-2007

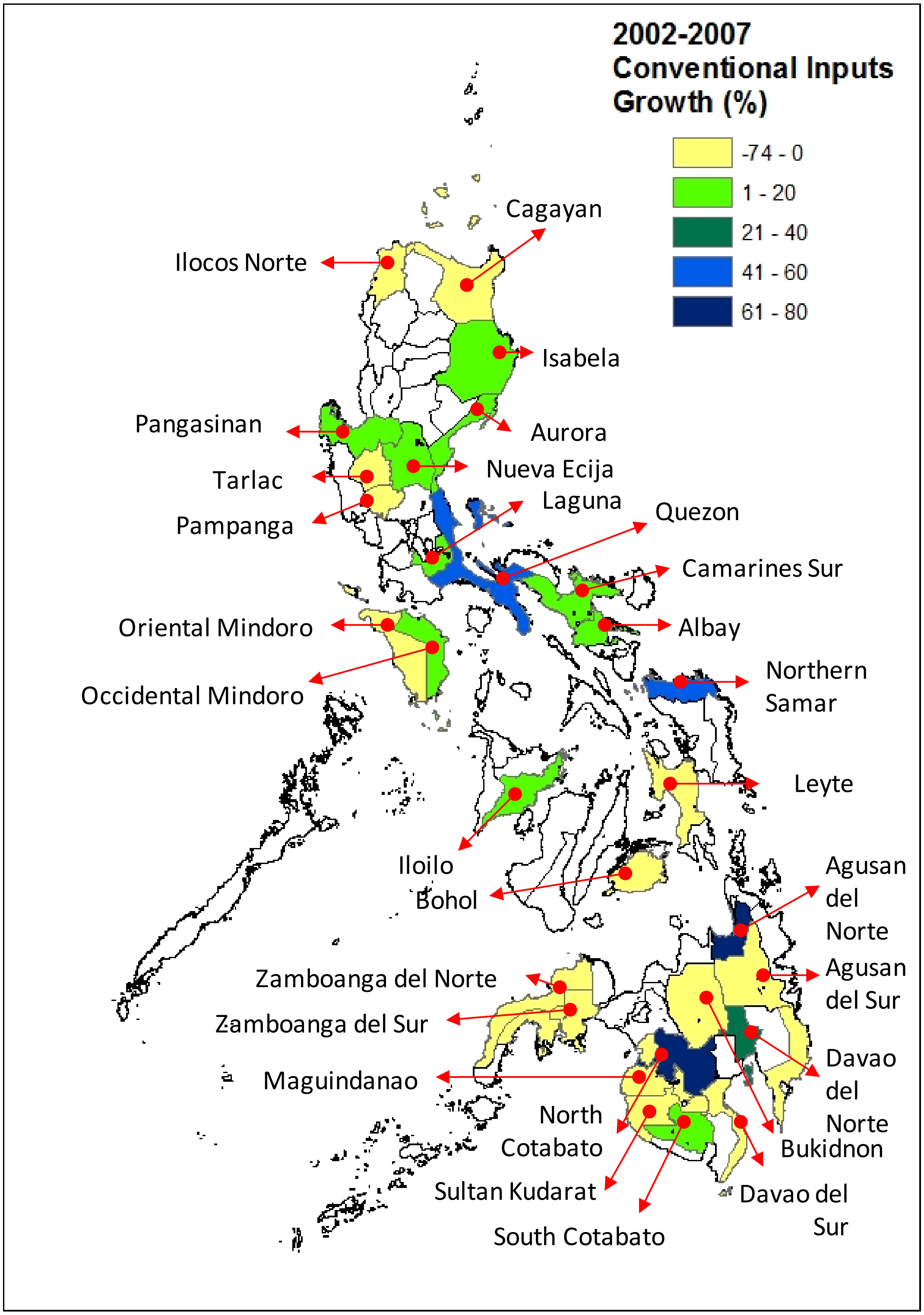

Figure 2.5. Provincial variation in growth in unconventional inputs, dry season 2002-2007

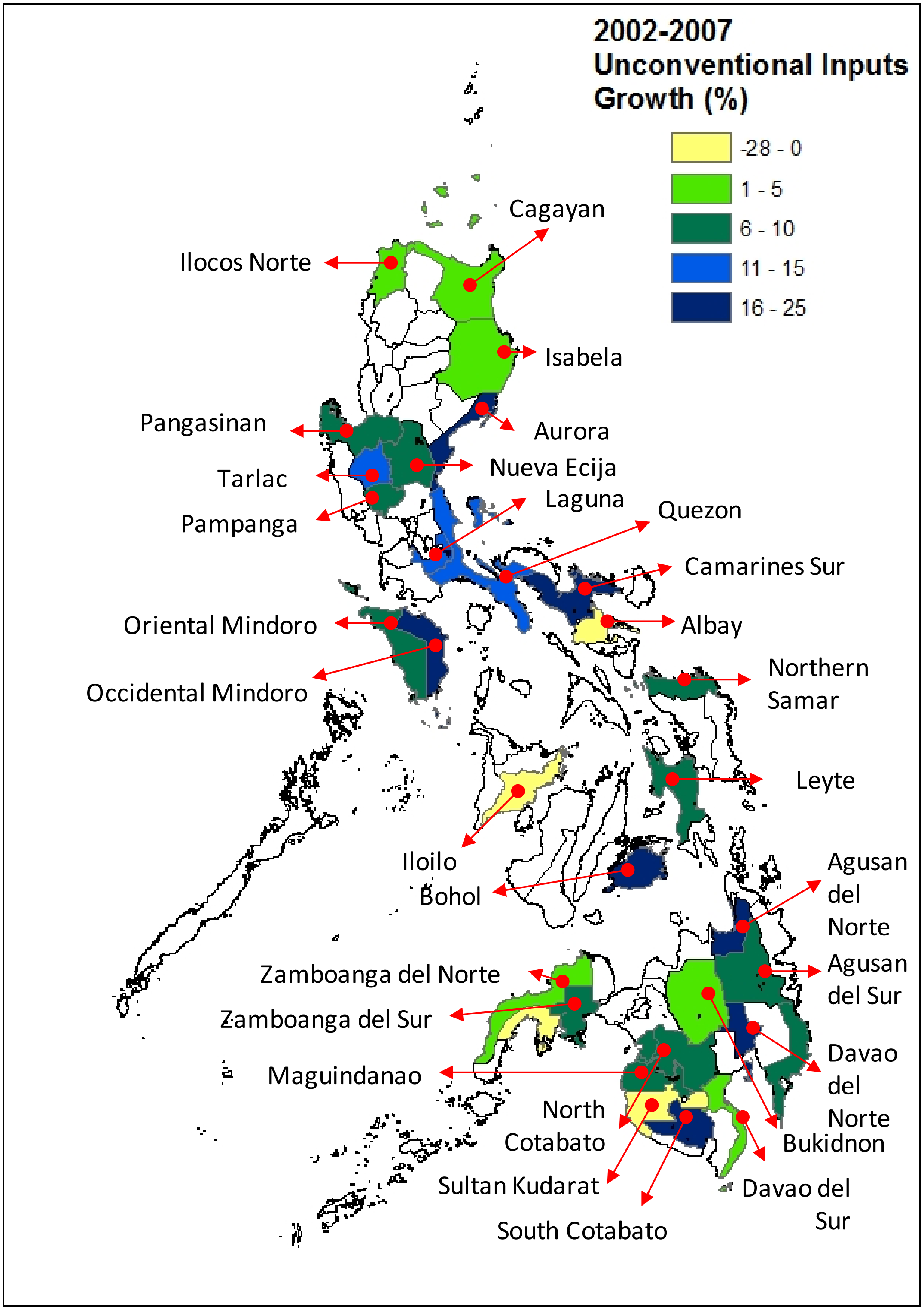

Figure 2.6. Provincial variation in TFP growth, dry season 2002-2007

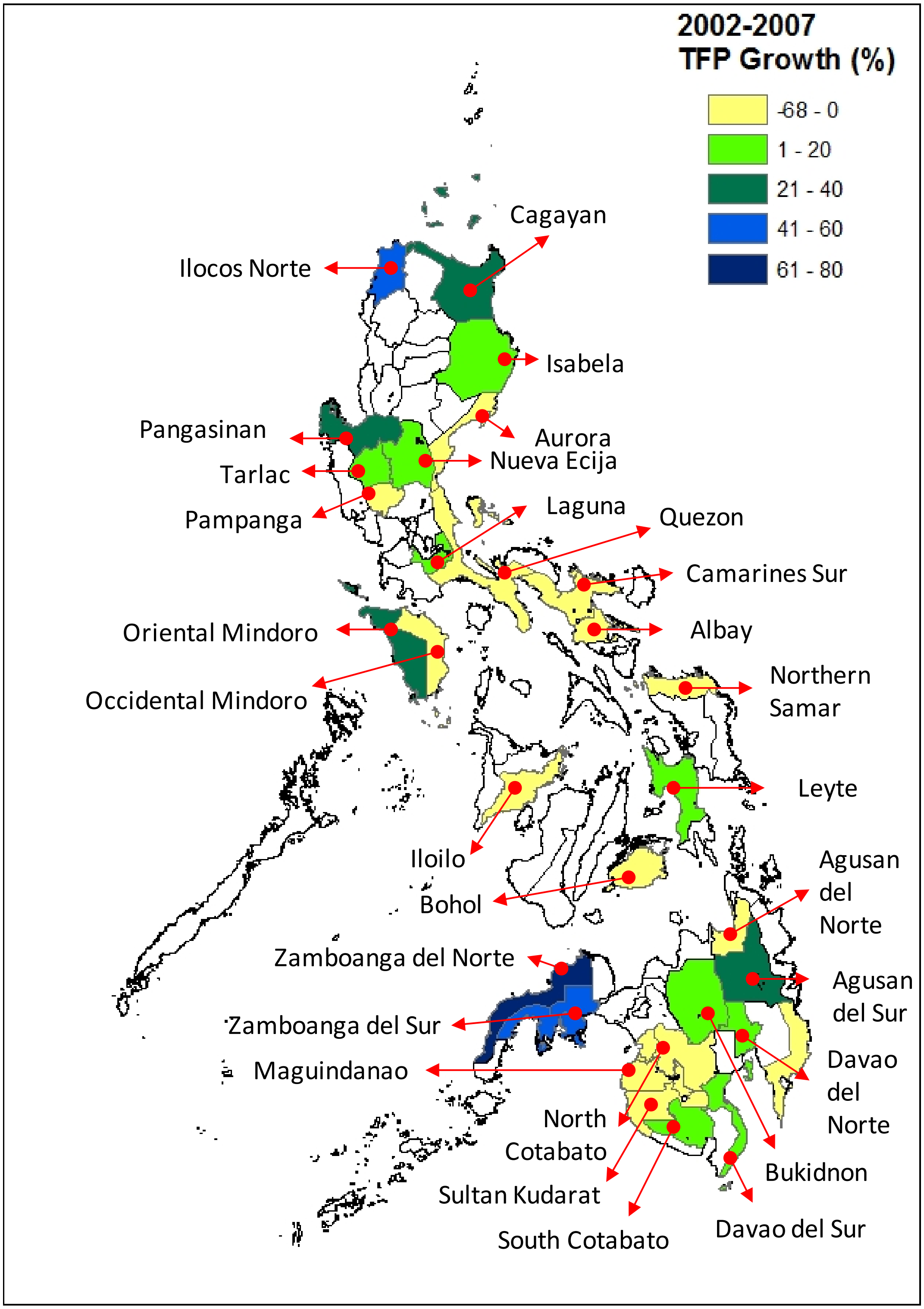

Table 2.1. Annual growth rates(%) in rice production, area harvested, and yield, 1970-2007

Year	All Area			Irrigated			Rainfed		
	Production	Area Harvested	Yield	Production	Area Harvested	Yield	Production	Area Harvested	Yield
1970-1980	3.62	1.11	2.51	4.23	1.17	3.07	2.81	1.07	1.75
1980-1990	1.98	-0.45	2.43	3.82	2.23	1.60	-1.46	-3.52	2.07
1990-2000	2.85	1.96	0.89	3.54	2.96	0.58	0.92	0.20	0.73
2000-2007	3.87	0.81	3.06	3.79	1.09	2.70	4.12	0.22	3.89

Source: BAS-PhilRice Philippine Rice Statistics Handbook and http://www.bas.gov.ph

Table 2.2. Description of variables in the regression

Variables	Description
Rice Output	Kilograms of paddy rice per farm.
Conventional Inputs	
Seed	Kilograms of seed used per farm.
Fertilizer	Kilograms of nitrogen, phosphate, and potash applied per farm.
Labor	Total person-days used in farm activities such as land preparation, planting,
Machinery	Total machine rent used in land-preparation and threshing activities.
Land	Area planted in hectares.
Rural Infrastructure	
Irrigation	1 if farm is irrigated either through public system of privately owned pumps and 0 if
Distance	Distance of farm to nearest market in kilometers
Human Capital	
Training	1 if farmer attended rice production training in the last 5 years and 0 otherwise
Elementary	1 if farmer has finished elementary schooling and 0 otherwise.
Secondary	1 if farmer has finished secondary schooling and 0 otherwise.
College	1 if farmer has finished college education and 0 otherwise.
Technology	
MV1	1 if farmer used first generation modern inbred varieties and 0 otherwise.
MV2	1 if farmer used second generation modern inbred varieties and 0 otherwise.
MV3	1 if farmer used third generation modern inbred varieties and 0 otherwise.
Hybrid	1 if farmer used hybrid rice varities and 0 otherwise.
High Quality Seed	1 if farmer used certified, registered, or foundation seeds and 0 otherwise.
Power	1 if farmer used tractor as source of power in land preparation and thresher in
Resource Ownership	
Land Owner	1 if farmer is cultivating own land and 0 otherwise.
Machine Owner	1 if farmer owned tractor and thresher and 0 if renting.

Table 2.3. Classification of modern rice varieties, by breeder and year of release

Generation of modern variety	Rice variety	Developer	Year released
MV1	IR5-IR34 UPL and C series BPI Ri series	International Rice Research Institute (IRRI) University of the Philippines- Los Banos (UPLB) Bureau of Plant Industry (BPI)	mid-1960s to mid-1970s
MV2	IR36-IR62	IRRI	mid-1970s to mid-1980s
MV3[1]	IR64-IR72 PSB Rc series NSIC Rc series	IRRI IRRI, Philippine Rice Research Institute (PhilRice) IRRI, PhilRice, UPLB	mid-1980s to present
Hybrid	Mestiso series	IRRI, PhilRice, Bayer Philippines, SL Agritech, Hyrice Inc., Bioseed Inc.	1998 to present

[1] Include only inbred varieties.

Source: Estudillo and Otsuka 2002, and Philippine Seed Board/National Seed Industry Council List of Rice Varieties (1991-2007).

Table 2.4. Mean and standard deviation of rice output and input use per hectare, 1996-2007

Variable	Wet Season			Dry Season		
	1996	2001	2006	1997	2002	2007
All Area	(n=2088)	(n=2155)	(n=1557)	(n=1713)	(n=1840)	(n=1291)
Yield (kg/ha)	3,161	3,208	3,602	3,286	3,475	3,893
	[1349]	[1252]	[1455]	[1518]	[1480]	[1557]
Seed (kg/ha)	123	115	98	122	114	97
	[55]	[52]	[50]	[59]	[56]	[51]
Fertilizer (kg NPK/ha)	78	90	113	75	91	101
	[55]	[56]	[91]	[57]	[59]	[66]
Labor (person-day/ha)	69	57	50	66	57	55
	[31]	[22]	[20]	[30]	[24]	[19]
Machine Cost (Peso/ha)	2,669	2,406	2,612	2,589	2,358	2,379
	[1190]	[924]	[1022]	[1213]	[968]	[1248]
Area (ha)	1.32	1.10	1.16	1.27	1.10	1.09
	[1.41]	[1.09]	[0.93]	[1.35]	[1.02]	[0.94]
Irrigated Area	(n=1337)	(n=1368)	(n=1060)	(n=1230)	(n=1275)	(n=1037)
Yield (kg/ha)	3,464	3,449	3,899	3,686	3,827	4,201
	[1286]	[1213]	[1380]	[1435]	[1403]	[1444]
Seed (kg/ha)	124	115	98	127	116	98
	[55]	[53]	[50]	[58]	[56]	[50]
Fertilizer (kg NPK/ha)	87	100	119	87	104	112
	[55]	[55]	[89]	[57]	[59]	[64]
Labor (person-day/ha)	70	59	52	66	56	56
	[31]	[22]	[21]	[28]	[24]	[19]
Machine Cost (Peso/ha)	2,767	2,497	2,720	2,748	2,464	2,487
	[1177]	[880]	[1016]	[1216]	[958]	[1274]
Area (ha)	1.47	1.21	1.25	1.43	1.18	1.12
	[1.60]	[1.13]	[0.98]	[1.48]	[1.01]	[0.96]

Table 2.4. (cont.)

Variable	Wet Season			Dry Season		
	1996	2001	2006	1997	2002	2007
Rainfed Area	(n=751)	(n=787)	(n=497)	(n=483)	(n=565)	(n=254)
Yield (kg/ha)	2,622	2,788	2,966	2,268	2,681	2,637
	[1290]	[1208]	[1408]	[1222]	[1335]	[1360]
Seed (kg/ha)	122	114	100	109	109	93
	[56]	[52]	[49]	[58]	[57]	[53]
Fertilizer (kg NPK/ha)	62	74	102	45	61	54
	[52]	[55]	[94]	[44]	[49]	[54]
Labor (person-day/ha)	67	54	46	64	59	50
	[32]	[21]	[19]	[33]	[25]	[19]
Machine Cost (Peso/ha)	2,495	2,246	2,382	2,186	2,120	1,941
	[1193]	[977]	[997]	[1107]	[949]	[1027]
Area (ha)	1.04	0.92	0.96	0.85	0.94	0.93
	[0.93]	[0.99]	[0.78]	[0.80]	[1.03]	[0.81]

Standard deviations in brackets

Source: Rice-based Farm Household Survey

Table 2.5. Percentage distribution of technology use, asset ownership, and training, 1996-2007

Variables	1996	1997	2001	2002	2006	2007
All Area	(n=2088)	(n=1713)	(n=2155)	(n=1840)	(n=1557)	(n=1291)
Infrastructure						
Irrigated Farms (%)	64	72	62	69	65	76
Distance from Farm to Market (km)	4.73	4.55	4.28	5.41	4.78	5.05
Human capital						
Rice Production Training (%)	19	20	21	20	41	53
Elementary Graduate (%)	45	45	45	44	43	43
Secondary Graduate (%)	25	24	24	23	26	26
College Graduate (%)	5	5	6	5	6	7
Technology						
MV1 (%)	6	6	9	15	4	3
MV2 (%)	21	21	17	11	2	2
MV3 (%)	61	65	65	63	76	77
Hybrid Variety Users (%)	-	-	-	-	7	8
High Quality Seed Users (%)	10	10	19	20	30	29
Machine as Power Source (%)	26	24	25	18	11	18
Resource Ownership						
Machine Owner (%)	21	21	20	18	31	30
Land Owner (%)	47	46	46	47	48	47

Table 2.5. (cont.)

Variables	1996	1997	2001	2002	2006	2007
Irrigated Area	(n=1337)	(n=1230)	(n=1368)	(n=1275)	(n=1060)	(n=1037)
Infrastructure						
Distance from Farm to Market (km)	4.31	4.29	3.78	4.84	4.55	4.91
Human capital						
Rice Production Training (%)	22	23	20	21	43	54
Elementary Graduate (%)	46	45	45	44	42	43
Secondary Graduate (%)	26	26	26	26	27	28
College Graduate (%)	6	6	7	6	8	7
Technology						
MV1 (%)	6	6	9	14	3	3
MV2 (%)	20	22	15	12	2	2
MV3 (%)	62	65	69	65	78	78
Hybrid Variety Users (%)	-	-	-	-	8	9
High Quality Seed Users (%)	12	12	20	23	34	31
Machine as Power Source (%)	26	27	25	20	11	19
Resource Ownership						
Machine Owner (%)	24	25	23	19	34	32
Land Owner (%)	46	46	45	48	48	47
Rainfed Area	(n=751)	(n=483)	(n=787)	(n=565)	(n=497)	(n=254)
Infrastructure						
Distance from Farm to Market (km)	5.60	5.28	5.30	6.95	5.33	5.64
Human capital						
Rice Production Training (%)	14	13	23	18	34	48
Elementary Graduate (%)	44	47	45	43	45	44
Secondary Graduate (%)	22	19	21	18	23	17
College Graduate (%)	4	3	4	4	3	5
Technology						
MV1 (%)	7	7	8	16	4	6
MV2 (%)	23	19	20	9	4	1
MV3 (%)	59	66	59	58	72	73
Hybrid Variety Users (%)	-	-	-	-	5	6
High Quality Seed Users (%)	6	7	16	12	23	19
Machine as Power Source (%)	25	17	24	12	11	10
Resource Ownership						
Machine Owner (%)	16	11	16	14	22	22
Land Owner (%)	49	45	48	46	48	46

Source: Rice-based Farm Household Survey

Table 2.6. Regression results of the production function

	Cobb-Douglas			Translog
Coefficient	POLS	BE	GIVE	GIVE
(1)	(2)	(3)	(4)	(5)
ε (Seed)	0.130***	0.149***	0.082***	0.065***
	[0.011]	[0.014]	[0.017]	[0.019]
ε (Fertilizer)	0.011***	0.012***	0.007***	0.082***
	[0.001]	[0.001]	[0.001]	[0.011]
ε (Labor)	0.241***	0.278***	0.204***	0.159***
	[0.017]	[0.025]	[0.024]	[0.026]
ε (Machine cost)	0.339***	0.358***	0.301***	0.351***
	[0.016]	[0.022]	[0.022]	[0.023]
ε (Land)	0.346***	0.294***	0.407***	0.381***
	[0.018]	[0.024]	[0.025]	[0.027]
Irrigation	0.216***	0.190***	0.715**	0.563**
	[0.012]	[0.013]	[0.280]	[0.280]
Distance	-0.005	-0.003	-0.031	-0.028
	[0.005]	[0.006]	[0.025]	[0.025]
Training	0.044***	0.043**	0.044***	0.037**
	[0.010]	[0.018]	[0.015]	[0.015]
Elementary	0.054***	0.043***	-1.165	-1.060
	[0.014]	[0.013]	[1.320]	[1.350]
Secondary	0.079***	0.071***	-0.024	0.278
	[0.015]	[0.015]	[1.170]	[1.190]
College	0.106***	0.090***	-3.080*	-3.276**
	[0.024]	[0.025]	[1.61]	[1.640]
MV1	0.027	-0.041	0.068**	0.059*
	[0.024]	[0.039]	[0.030]	[0.030]
MV2	0.040*	0.016	0.032	0.022
	[0.021]	[0.033]	[0.028]	[0.028]
MV3	0.045***	0.007	0.057**	0.045**
	[0.017]	[0.027]	[0.022]	[0.023]
Hybrid	0.212***	0.168**	0.212***	0.164***
	[0.033]	[0.071]	[0.050]	[0.054]
High Quality Seed	0.132***	0.178***	0.068***	0.059***
	[0.011]	[0.021]	[0.018]	[0.018]
Power	0.067***	0.067***	0.171	0.258
	[0.012]	[0.014]	[0.520]	[0.530]
Machine Owner	0.066***	0.059***	0.054**	0.050**
	[0.012]	[0.017]	[0.024]	[0.024]

Table 2.6. (cont.)

Coefficient (1)	POLS (2)	Cobb-Douglas BE (3)	GIVE (4)	Translog GIVE (5)
Machine Owner	0.066***	0.059***	0.054**	0.050**
	[0.012]	[0.017]	[0.024]	[0.024]
Land Owner	0.026**	0.027**	0.659*	0.636
	[0.010]	[0.011]	[0.390]	[0.400]
Constant	3.390***	2.913***	1.535***	2.220***
	[0.11]	[0.14]	[0.35]	[0.61]
Elasticity of Scale	1.067	1.091	1.001	1.038
R-squared	0.803	0.876	0.344	0.317
Observations	10644	10644	10644	10644
Underidentification test (Kleibergen-Paap rk LM statistic)			5.221*	5.198*
Chi-sq(2) P-value			0.074	0.074
Hansen J statistic (overidentification test of all instruments)			0.396	0.400
Chi-sq(1) P-value			0.529	0.527

Robust standard errors in brackets

*, **, *** imply significance at 90%, 95%, and 99% confidence levels

Table 2.7. Rice production growth accounting

Variable	Wet Season		Dry Season	
	1996-2001	2001-2006	1997-2002	2002-2007
Output (y)	**-8.79**	**22.27**	**0.85**	**14.10**
Conventional Inputs	**-14.02**	**14.95**	**-4.45**	**0.18**
Seed	-1.28	-0.43	-0.85	-1.15
Fertilizer	3.19	4.29	6.86	2.14
Labor	-4.31	-0.28	-3.22	0.19
Machinery	-7.02	6.85	-4.78	-1.70
Land	-4.60	4.53	-2.46	0.70
Unconventional Inputs	**0.61**	**5.91**	**-0.65**	**9.89**
Irrigated	-0.31	2.59	-1.41	6.21
Distance	0.00	0.00	0.00	0.00
MV1	0.12	-0.28	0.49	-0.65
MV3	0.20	0.48	-0.09	0.62
Hybrid	0.00	1.21	0.00	1.36
High Quality Seed	0.55	0.69	0.56	0.54
Training	0.08	0.71	-0.01	1.19
Machine Owner	-0.03	0.51	-0.19	0.61
TFP	**4.62**	**1.42**	**5.94**	**4.04**

Chapter 3

PRODUCTIVITY IMPACTS OF PUBLIC INVESTMENTS IN PHILIPPINE RICE INDUSTRY

Rice is one of the most valuable crops in Philippine agriculture. Rice contributes about 17% of the total agricultural gross value added and 2.6% of the gross domestic product, which is the largest for any single agriculture commodity (NSCB 2009). As the staple food of the Filipinos, rice accounts for 46% and 35% of dietary energy and protein consumption for the period 2003-2005 (FAO 2008). In addition, the poorest 30% of the population spends more than 16% of their total expenditures in rice (World Bank 2007). Thus, poor people will be deeply affected by an increase in the price of rice.

On the production side, rice is the most extensively grown crop in the Philippines, planted in 30% of the total agricultural area in the country (Dawe 2003). Rice farming also provides more than half of the household income for two million families. Due to its importance in the economy, rice has historically been the focus of the government's food security policy (David and Balisacan 1995).

Self-sufficiency in rice is the primary goal of agricultural policy in the Philippines. In fact, the government equates rice self-sufficiency to food security as indicated in the Agriculture and Fisheries Modernization Act (AFMA) of 1997. As such, the rice industry captures the largest share of the agricultural public expenditures. The World Bank (2007) reported that the increase in the agricultural public spending during 1998-2005 largely went to production subsidies and large-scale irrigation systems for rice. A substantial portion was also spent on the National Food Authority (NFA)'s operations on rice importation, stockkeeping, and distribution. The World Bank emphasized that the pursuit of rice self-sufficiency has been costly for the Philippine society, with an estimated welfare cost of PhP 68 billion per year during 2000-2005.[12]

The World Bank report claimed that the bias in allocation of public resources toward rice has been detrimental to the overall growth of the agriculture sector. Indeed, the Philippine agriculture sector has been exhibiting a declining TFP growth over the years. The TFP of the agriculture sector grew by 2% yearly in 1970-1980 and barely 1% annually in 1990-2000 (Teruel and Kuroda 2005). Mundlak, Larzon, and Butzer (2002) stated that this growth was below international standards. They reported that the TFP of Philippine agriculture grew only by 0.13% in 1980-1998[13] while the agricultural TFP in Thailand and Indonesia rose by 1.02 in 1981-1995 and 1.49 % in 1981-1998.

The rice-centric agricultural public spending has been viewed to have negative effects on TFP growth of the agriculture sector but little is known about its direct effects on rice productivity in the country. Improving rice productivity is important because it can increase the income specifically of small farmers and landless farm workers who depend on rice production for a living. This can also have impacts in poverty reduction in rural areas. In addition, productivity improvement can make local producers cost-competitive with international producers, which is necessary if the country has to liberalize its rice trade. Thus, it is essential to determine if the outpouring of resources toward rice has improved its productivity.

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[12] As of February 2010, the peso-dollar exchange rate is PhP46.53 per US$1.00. The large welfare cost is mainly due to the social costs of quantitative restrictions in rice trade.

[13] It is unfortunate that Mundlak and associates selected 1998 as the ending year of their analysis. In 1998, the Philippines was severely hit by a drought due to the *El Niño Phenomenon*. During this year, agricultural output contracted tremendously because of smaller area planted and the deleterious effects of drought in yields.

In this study, I examined the impacts of public spending on R&D, extension, production support, and irrigation on rice TFP. Using a cost framework and shadow prices, I measured the contribution of these public investments in reducing the cost of rice production at the regional level. Results show that R&D investment has driven up rice productivity in the Philippines, which has grown by 5% annually in 1992-2007. This signifies the importance of continuing the public support to R&D. Results also indicate that investments in production subsidies, extension, and irrigation did not improve rice productivity. Because of this, I recommend the phasing-out of government subsidies on inputs. Though extension and irrigation investments need not be reduced, there is a need to reform the current extension system and reorient the irrigation development strategy so that benefits can be reaped from these public investments.

3.1. Trends in Rice Public Investments in the Philippines

3.1.1. Research and Development

Among different crops in Philippine agriculture, R&D in rice is probably the most organized. PhilRice plans and coordinates the national R&D program for rice and rice-based farming systems. A network of 57 agencies composed of PhilRice experiment stations, regional agricultural research centers, and state universities implements rice R&D activities nationwide. Every year, researchers from these agencies send proposals to PhilRice central experiment station for approval and allocation of funds.

Sebastian, Bordey and Alpuerto (2006) discussed the major rice R&D activities in the Philippines. The local R&D activities consist of varietal development and testing, improvement of crop management practices, development of farm machinery, and integration of rice farming with other agricultural activities. The development of rice varieties involves the use of biotechnology and conventional breeding techniques to create cultivars that are suited to various production ecosystems in the Philippines such as irrigated and favorable rainfed lowlands, rainfed uplands, cool and elevated areas, and saline-prone areas. A nation-wide testing of these varieties is also conducted to assess the yield stability and suitability to the target environment. Recent breeding activities also include biofortification wherein genetically engineered traits such as richness in Vitamin A and iron are transferred to locally adaptable varieties.

The research on improving crop management practices includes the development of decision support tools that help farmers in managing the standing crop. Some examples are the uses of *Leaf Color Chart* that can indicate the proper timing of nitrogen application, and *Minus One Element Kit* that can identify the missing micro-nutrients in the soil, which if absent, can limit the plant's absorption of major nutrients. Profiling of pest and disease cycles in various hot spots is also one of the studies undertaken to improve crop management.

Drum seeders, mechanical transplanters, riding tractors, mini-combine harvester and thresher, and flatbed dryers are some of the small farm machinery that were developed by the local R&D. In addition, research on rice-based cropping systems resulted in the integration of rice farming with other agricultural activities such as vegetable farming during the fallow period, mushroom production, freshwater fish culture, and small-scale production of animals (hogs, poultry, and small ruminants). The main idea is using the by-products in one activity as inputs in another. Through these techniques, farmers' risks are diversified, household food security is improved, and household income is increased. Finally, rice research also develops new extension modalities. In particular, rice R&D makes e-learning modules for modern rice production, develops low-cost WiFi connectivity, and creates an Internet portal for farmers. These research activities have direct effects on rice farming productivity.

PhilRice has a strong research collaboration with IRRI, which was established in the country in 1960. Donations from governments, development agencies, and foundations finance IRRI's R&D operations. However, with a global mandate, IRRI's R&D efforts cannot respond to the specific technology needs of the Philippines alone. Thus, PhilRice was created in 1985 to adapt IRRI's technologies to local conditions and promote a wider adoption in the country. Many of IRRI's innovations are tested first in the Philippines in partnership with PhilRice. In addition, IRRI plays an important role in the development of the human capital of local R&D workers and consequently on their research productivity through technical trainings, access to its facilities including the library, laboratories, and the International Rice Genebank.

The appropriated budget to PhilRice is the primary source of government funds for rice R&D in the Philippines (Figure 3.1). Since its full operation in 1987, PhilRice's budget in real terms rose from PhP 14 to 207 million in 1994. A series of declines in the PhilRice real budget were observed in the mid- and late 1990s until it finally stabilized to around PhP 200 million per year in the early to mid-2000s. Since 1994, the Rice Program of the Department of Agriculture (DA) is the second major source of funds for R&D. This fund, which is released by DA to PhilRice for management, augmented the total rice R&D funds in the late-1990s. The DA-Rice Program's allocation for R&D has significantly declined since 2001, which might be due to its reoriented focus from R&D to production subsidy. At that time, PhilRice managed the hybrid rice commercialization component of the DA-Rice Program, including the allocated funds for hybrid seed subsidy.

Although IRRI's R&D activities are not tailored specifically for Philippine conditions, its R&D expenditures in the country can have huge spillover effects on the productivity of local R&D workers. IRRI real expenditures in the Philippines grew from PhP 146 million in 1970 to PhP 1.3 billion in 1990 (Figure 3.2). Then, it declined in the early to mid-1990s and stabilized around PhP 850 million by 2000. This can be partly attributed to the declining agricultural rice prices since 1980, indicating that the donors attach less importance to rice production.

3.1.2. Extension

In contrast to rice R&D, the extension system in the Philippines is highly fragmented (Gapasin 2006). The enactment of the Local Government Code in 1991 abolished the DA's Bureau of Agricultural Extension and transferred its manpower to the local government at the provincial and municipal levels. This transfer reduced the extension function of DA to training support for the devolved extension workers. To carry out this function, the Agricultural Training Institute (ATI) was established. In 2000, more than 25,000 extension workers are employed in extension offices of the local government units (LGUs) in 79 provinces, 115 cities, and 1,495 municipalities around the country. These extension offices are autonomous and have no vertical or horizontal links with each other. In addition, the devolved extension offices have weak linkages with the ATI and technology developers (i.e. PhilRice, IRRI, DA Regional Agricultural Research Centers, state colleges and universities) at the national and regional levels. This resulted in a highly dispersed and uncoordinated extension system in the Philippines. To complicate matters further, the LGU management provided low priority and under-financed extension activities. The insufficient support of LGU management to extension programs also led to deterioration of capacity among the majority of extension workers (Contado 2004).

The AFMA recognized the importance of extension in agricultural development. It mandated the ATI to act as the primary extension and training arm of DA. Aside from capacity-building, the ATI is reorganized to integrate and coordinate extension activities at the local level and link these activities with technology developers and private providers of extension services. The AFMA also allocated about 10% of its budget to extension programs and activities. However, this integration has not been realized and the expected budget did not materialize (Gapasin 2006). Though the LGUs provide the salaries of extension workers, the DA-Rice Program controls the budget for rice extension programs. The extension budget for rice has been variable and negligible at times due perhaps to disarray in the system and the lack of means to monitor the output of local extension offices (Figure 3.3).

3.1.3. Production Support

The DA started to implement a rice program following the disastrous crop year of 1972 (Barker 1984). Since 1973, the rice programs implemented by the government are

Masagana 99 (Bountiful 99, 1973-1985), *Rice Production Enhancement Program* (1986-1990), *Rice Action Program* (1990-1992), *Grains Production Enhancement Program* (1993-1997), *Gintong Ani* (Golden Harvest, 1998), and *Agrikulturang Makamasa* (Agriculture for the Masses, 1999-2000). However it was only during implementation of the current rice program, *Ginintuang Masaganang Ani* (Golden and Bountiful Harvest) that a full-time director was appointed to oversee the program operations. With each change in the political administration, the name of the rice program changes but the objective of self-sufficiency in rice remains and so with the strategy to achieve this. The DA-Rice Program uses input subsidy as one of the key strategies to increase rice production.

Figure 3.4 shows an increasing trend in the real spending by the government on input subsidies. The government subsidized fertilizer following a common perception that rice farmers are under-using fertilizer. Dawe and associates (2006, p.73) found that farmers were using insufficient amounts of nitrogen fertilizer based on the comparison of farmers' practice and fertilizer use in experiment station. The government also subsidized certified seed of inbred rice MVs. This aims to encourage farmers to use fresh seed stock every season, which is proven to minimize recurrence of disease infestation and promote seedling vigor leading to a higher yield (PhilRice 2007). Public expenditures on input subsidies declined substantially in the late 1990s, due perhaps to the tight fiscal policies during the Asian Financial Crisis in 1997.

In addition to the subsidies given to fertilizer and inbred certified seed, the government started to subsidize hybrid rice seed in 2001. From PhP 0.5 billion in 2001, real public expenditures on input subsidies for rice rose to PhP 1.2 billion in 2007. This resulted in increased area harvested to hybrid rice from 5,000 hectares in 2001 to almost 400,000 hectares in 2005. Hybrid rice production has also increased from nearly 30,000 metric tons to more than 2 million metric tons in the same period. Initially, the government, through PhilRice, took charge of hybrid seed procurement and distribution. Though the government maintained the subsidy, it eventually stopped its marketing functions owing to the quick deterioration of hybrid seed, and the geographic/time mismatch between supply and demand. Given this, the government encouraged the private sector to market hybrid seed.

Gonzales and associates (2007) reported that farm level experience in the Philippines showed an 8% to 13% yield superiority of hybrid over inbred rice yield during the wet cropping season. The yield advantage was slightly higher at 11% to 14% during the dry cropping season probably due to the higher solar radiation and less damage from heavy rains, pests, and diseases. While the yield per hectare for hybrid rice was higher, the cost per kilogram was not significantly different from that of inbred rice production, even when the price of seed was not subsidized. This led to a higher net income from hybrid compared to inbred rice production.

Gonzales and associates also indicated that hybrid rice is not a “fool-proof” technology. It takes time for farmers to master the skills necessary for successful hybrid rice production. Experiences of early adopters showed that while getting higher yield was more plausible when using hybrid rice, many farmers did not profit from their initial trials. This can be attributed to improper crop management practices. Over time, hybrid rice yield tend to improve while production costs tend to decrease as farmers learn more and become accustomed to the technology. Because of this, adoption of hybrid rice in the Philippines has been variable and many early adopters of hybrid rice have discontinued its use.

A PhilRice survey of five major rice-producing provinces for crop years 2004 to 2006 revealed that hybrid rice adoption ranged from 16% to 42%. Only 20% of the hybrid rice adopters have continuously planted it for the survey period. The bulk of them have planted hybrid seed only once or twice in the same period. These partial adopters argued that hybrid seed is expensive and susceptible to pests and diseases. On the other hand, full adopters cite high yield as the key factor that convinced them to use hybrid seed continuously.

There is an ongoing debate on whether to continue or withdraw government subsidy on hybrid seed. After years of R&D in new varieties, development of farmers' human capital, and keen interest of the private sector in hybrid seed production, proponents argue that the Philippines is set to benefit from hybrid rice. On the other hand, critics believe that hybrid rice only benefits the wealthy farmers and seed companies. These critics argue further that the subsidy in hybrid seed drains the already scarce resources of the government and should therefore be phased-out.

3.1.4. Irrigation

The National Irrigation Administration (NIA) is a government-owned and -controlled corporation that is primarily responsible for developing and sustaining public irrigation facilities in the Philippines. Based on actual expenditures of NIA in real terms, public irrigation investments decreased from PhP 21 billion in 1980 to PhP 6 billion in 2007 (Figure

3.5). The shrinking government investment in irrigation can be attributed to the decline in its benefit-cost ratio (Inocencio and Barker 2006). One cause of the falling benefit-cost ratio was the remarkable drop in the real price of rice since 1970. This drop was due to the growth in rice production in the Philippines and in different parts of Asia. The rising cost of construction and the poor performance of high profile irrigation projects also make irrigation investments less attractive. Finally, the Philippine financial crisis during the mid-1980s has crowded-out public irrigation investments.

Despite the declining trend, irrigation investments remain to be a large portion of the total agricultural public spending. From 2001 to 2007, irrigation spending accounts for 46% of the aggregate agricultural expenditures (World Bank 2007). Since 2000, real expenditure in irrigation per year ranged from PhP 3 to 7 billion, with a total of nearly PhP 44 billion by the end of 2007. These investments have built large-scale facilities that irrigate 1.26 million hectares or about 40% of the country's total irrigable area (NIA 2007).

Using the force of gravity, the large-scale irrigation systems are designed to deliver huge volumes of water at scheduled times, favoring rice production. Irrigation has improved rice land productivity and has minimized risks of lower yield due to adverse weather conditions. As an enabling mechanism, access to irrigation also leads to the greater adoption of improved seeds (World Bank 2007). On average, rice yield in irrigated farms are 39% higher than in rainfed areas (BAS 2008).

Large-scale irrigation systems have performed poorly in terms of cost recovery and delivery of services (David 2003). David reports that the collection rate of irrigation service fees is only at 58% of the total amount collectible. The dissatisfaction with the water release schedule is one reason for the low rate of collection. With large-scale irrigation systems, farmers have a lesser degree of control over irrigation water as NIA manages the schedule of water release. In addition, penalties against nonpayment of irrigation fees are insubstantial. Because of the low cost recovery, irrigation investments become unsustainable and unattractive to donors.

3.2. Methods and Data

3.2.1. A Cost-Based Model of Production Structure

The analysis starts with the behavioral assumption that a representative producer minimizes the costs of production. The producer's cost-minimization problem is expressed as

(3-1) Min $C = W'X$ s.t. $f\left(X(t) \mid Z(t), t\right) = Y$

where *X* is a vector of variable inputs, *W* is a vector of variable input prices, *Y* is output, *Z* is a vector of quasi-fixed factors, and *t* is a time counter. The cost-minimization problem yields a restricted total cost function of the form

(3-2) $C^*(Y, W, Z, t) = G\left(Y(t), W(t) \middle| Z(t), t\right) + P_z Z(t)$

where P_Z is a vector of prices paid by firms for the use of the quasi-fixed factors. The first and second terms in (2) represent variable and fixed costs. For a cost function to be a dual of a certain production function, the sufficient conditions are monotonicity in output and input prices, concavity in input prices, and homogeneity of degree one in input prices (Diewert 1974). The cost function is monotonic in output if the derivative of equation (3-2) with respect to output is non-negative. That is, (3-3) $$\frac{\partial C^*(Y,W,Z,t)}{\partial Y} \geq 0,\ \forall (Y,W,Z,t).$$

The cost function is monotonic in input if applying the Shephard's lemma to equation (3-2) yields non-negative conditional factor demands,

(3-4) $$\frac{\partial C^*(Y,W,Z,t)}{\partial W_i} = X_i^*(Y,W,Z,t) \geq 0 \qquad (i=1,\dots,N).$$

To satisfy concavity in input prices, the matrix of second partial derivatives (the Hessian) of the cost function with respect to prices of variable inputs should be negative semi-definite. The concavity of the cost function implies that the own-price elasticity of a factor demand must be non-positive. In addition, the symmetry of the Hessian matrix indicates that cross price effects must be equal (i.e. $\partial X_i^* / \partial W_j = \partial X_j^* / \partial W_i$). Positive (negative) cross price elasticity implies that inputs are substitutes (complements). Inputs are substitutes (complements) if the demand for one increases (decreases) as the price of the other input rises.

By Euler's theorem, the cost function is homogenous of degree one in prices if

(3-5) $$C^*(Y,W,Z,t) = \sum_{i=1}^{N} W_i \frac{\partial C^*(Y,W,Z,t)}{\partial W_i}.$$

This can be accounted for in the cost estimation by imposing a unitary sum of cost share equations (S_i),

(3-6) $$\sum_{i=1}^{N} \frac{W_i X_i^*}{C^*(Y,W,Z,t)} = \sum_{i=1}^{N} S_i = 1.$$

These properties (monotonicity, concavity, and homogeneity) must be imposed in estimating the cost function to ensure a complete reconstruction of the original technology (Varian 1992, p.83).

3.2.2. A Model of Cost Impacts of Public Investments

Public investments in R&D, extension, and irrigation generate stocks of quasi-fixed inputs that affect knowledge, specialization, and human capital. These, in turn, affect the productive capacity of farms. These factors are quasi-fixed because public investments are external to the farms' decisions and cannot be adjusted instantaneously. Although the level of public investments and consequently the amount of quasi-fixed inputs are outside the realm of the producer's decisions, changes in these factors can affect private costs and productivity levels. The capacity utilization accounts for the changes in marginal costs due to changes in quasi-fixed inputs (Morrison and Schwartz 1994).

Let w_{Zk} be the shadow value or the negative of the marginal cost reduction due to the additional stock of Z_k, $\left(w_{Zk} \equiv -\partial G / \partial Z_k\right)$. The amount of a quasi-fixed factor Z_k is in its long run equilibrium level if the marginal benefit of additional stock $\left(w_{Zk}\right)$ is equal to the marginal cost of using that additional stock $\left(P_{Zk}\right)$. If the marginal benefit of Z_k is less than its marginal cost $\left(w_{Zk} < P_{Zk}\right)$, then producers have an excess capacity of the quasi-fixed input. This implies that producers underutilize the existing stock of quasi-fixed input. Therefore, a decrease in investment is desirable to reduce the current stock of quasi-fixed input. If the quasi-fixed input has a larger marginal benefit compared to its marginal cost $\left(w_{Zk} > P_{Zk}\right)$, then producers have an inadequate capacity of quasi-fixed input. This indicates an overutilization of the current stocks of quasi-fixed input and the desirability of increasing investments (Morrison and Schwartz 1994).

The benefits of Z_k can be expressed in terms of cost elasticity,

$$(3\text{-}7)\qquad \varepsilon_{CZk} \equiv \frac{\partial \ln C}{\partial \ln Z_k} = \left(\frac{\partial G}{\partial Z_k} + P_{Zk} \right) \frac{Z_k}{C} = \left(-w_{Zk} + P_{Zk} \right) \frac{Z_k}{C}.$$

Assuming a zero private price (P_{Zk}=0) [14], equation (3-7) simplifies into

$$(3\text{-}8)\qquad \varepsilon_{CZk} = \frac{-w_{Zk} Z_k}{C} = -S_{Zk},$$

where S_{Zk} is the shadow share of Z_k. A negative cost elasticity (positive S_{Zk}) implies that the quasi-fixed input has decreased the costs and the benefits accrue to producers. This indicates that further investment is desirable in order to increase the existing stock of quasi-fixed input. On the other hand, a positive cost elasticity (negative S_{Zk}) suggests that the quasi-fixed input has increased the costs of production. This implies the need to decrease the investment to reduce the existing stock of quasi-fixed input. If the quasi-fixed input has a zero cost elasticity $\left(\text{i.e. } -\partial G / \partial Z_k = 0\right)$, then the current stock of quasi-fixed input is “just right” from the producers’ point of view and should be maintained at that level (Morrison and Schwartz 1994). However, since the provision of the quasi-fixed input has costs, a zero marginal benefit can be interpreted as an inefficiency of the investment. This suggests that

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[14] Rice producers do not directly pay the government for providing R&D and extension services. Rice producers are supposed to pay for seed, fertilizer and irrigation at subsidized rates but the rate of collection is very low. I did not count the taxes paid by producers as payment for these services because the government can spend those in other forms of public investments.

the public investment fails to improve the cost productivity of producers. In the succeeding analyses, I used these concepts in determining the optimality of future public investments.

3.2.3. Total Factor Productivity and Public Investments

Decomposing TFP growth is an alternative way of looking at the benefits from public investments. The growth in TFP measures the increase in output that is not accounted for by growth in input uses. Equivalently, TFP growth is a measure of cost savings that cannot be attributed to changes in output and factor prices. Thus, improvement in TFP is an important factor in agricultural development.

By totally differentiating equation (3-2) with respect to *t* and rearranging it, I obtain

$$\text{(3-9)}\quad -\varepsilon_{Ct} = -\frac{d\ln C}{dt} + \varepsilon_{CY}\frac{d\ln Y}{dt} + \sum_i S_i \frac{d\ln W_i}{dt} - \sum_k S_{Zk}\frac{d\ln Z_k}{dt}$$

where ε_{Ct} is $\partial \ln C / \partial t$, and ε_{CY} is $\partial \ln C / \partial \ln Y$, and S_i are the cost shares of each variable input *i*. Since $C(t)$ is also equal to $\sum_i W_i(t) X_i(t)$, we can write

$$\text{(3-10)}\quad \frac{d\ln C}{dt} = \sum_{i=1} S_i \frac{d\ln X_i}{dt} + \sum_{i=1} S_i \frac{d\ln W_i}{dt}.$$

Substituting equation (3-10) into equation (3-9) yields

$$\text{(3-11)}\quad -\varepsilon_{Ct} = \varepsilon_{CY}\frac{d\ln Y}{dt} - \sum_{i=1} S_i \frac{d\ln X_i}{dt} - \sum_k S_k \frac{d\ln Z_k}{dt}.$$

The primal measure of TFP growth is

$$\text{(3-12)}\quad \dot{TFP} = \frac{d\ln Y}{dt} - \sum_i S_i \frac{d\ln X_i}{dt}.$$

Combining equations (3-11) and (3-12) yields the TFP decomposition as

(3-13) $\dot{TFP} = (1-\varepsilon_{CY})\frac{d\ln Y}{dt} + \sum_k S_k \frac{d\ln Z_k}{dt} - \varepsilon_{Ct}$.

The term $(1-\varepsilon_{CY})(d\ln Y/dt)$ represents the contribution of the economy of scale in TFP growth (Christensen and Greene 1976). A positive economy of scale $(1-\varepsilon_{CY} > 0)$ implies that producers can take advantage of the declining per unit cost as they expand their scale of operations. Purchasing materials by bulk, increasing specialization of managers, and obtaining a lower cost of credit are some potential sources of positive economy of scale. On the other hand, a negative economy of scale $(1-\varepsilon_{CY} < 0)$ indicates that producers should operate at a smaller size. A zero value for this term indicates constant returns to scale, implying no need to change the scale of operations.

The term $\sum_k S_{Zk}(d\ln Z_k/dt)$ corresponds to productivity impacts of public investments and can be interpreted as improvement in capacity utilization. In particular, the cost-savings effects of public investments in R&D and extension captures the productivity contributions of the improvement in technology. The term $-\varepsilon_{Ct}$ reflects the rate of technical change, which is the residual rate of cost diminution over time (Teruel and Kuroda 2005). The rate of technical change should not be confused with the improvement in technology. Technical change can be attributed to better management skills, organizational changes, the quality of inputs, and weather aberrations. The estimation of technical change depends upon the estimation of other components. Since the rate of technical change is calculated as a residual, its measured impact on productivity will be smaller as more variables are considered in the model.

3.2.4. *Empirical Approach*

To model the restricted cost function, I used the translog form which is a second order (Taylor series) approximation to an arbitrary twice-differentiable surface. It is flexible and allows for quadratic and interaction terms. It also does not impose *a priori* restriction on the elasticities of substitution between inputs. The translog form also permits non-constant returns to scale, non-neutrality and non-homotheticity of the production technology (Christensen, Jorgenson and Lau, Transcendental logarithmic production frontiers 1973).

I estimated the cost function model as

$$\text{(3-14)}\quad \ln C = \alpha_0 + \alpha_Y \ln Y + \frac{1}{2}\alpha_{YY}\left(\ln Y\right)^2 + \sum_i \alpha_{Yi} \ln Y \ln W_i + \sum_k \alpha_{Yk} \ln Y \ln Z_k$$

$$+ \sum_i \beta_i \ln W_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln W_i \ln W_j + \sum_i \sum_k \delta_{ik} \ln W_i \ln Z_k$$

$$+ \sum_k \gamma_k \ln Z_k + \frac{1}{2}\sum_k \sum_l \gamma_{kl} \ln Z_k \ln Z_l + \lambda_t t + v$$

where C is the variable cost of rice production per region, Y is the total production of rice per region, W_i are prices of seed, fertilizer, labor, water, and machines, Z_k are stocks of public investments in research, extension, production support, and irrigation, t is the time trend, and v is the error term. I included the time trend variable to account for technical change over time.[15] To estimate a well-behaved cost function, I imposed restrictions on linear homogeneity in input prices and symmetry of the input-price Hessian matrix in the estimation. The parameter restrictions for linear homogeneity and symmetry are

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[15] I attempted to include a dummy variable for each year but this resulted in non-convergence of the iterated regression model. I also excluded the interactions of *t* with output, input prices, and public investments variables to facilitate convergence, and to avoid multicollinearity.

(3-15) $\sum_i \beta_i = 1; \sum_i \alpha_{Yi} = \sum_i \sum_j \beta_{ij} = \sum_k \delta_{ik} = 0$;

(3-16) $\beta_{ij} = \beta_{ji}$,   for $i \neq j$.

I imposed a total of 52 constraints in the estimation. To derive the cost share equations for each variable input *i*, I applied the Shephard's lemma to equation (3-14) and obtained

(3-17) $S_i = \beta_i + \sum_j \beta_{ij} \ln W_j + \sum_k \beta_{ik} \ln Z_k + \alpha_{Yi} \ln Y$.

To satisfy the linear homogeneity condition, the cost share equations must add up to unity $\left(\text{i.e. } \sum_i S_i = 1\right)$. The adding-up criterion leads to a singular error covariance matrix. Thus, I dropped the equation for water share in the estimation and recovered it from the estimated parameters. Using the iterated Zellner procedure for seemingly unrelated regression (SUR), I estimated a system of equations composed of the restricted cost function (equation 3-14) and four cost-share equations (equation 3-17) with the full set of constraints. The iteration of the SUR, until convergence gives the maximum likelihood estimates, which is invariant to the choice of the purged equation (Kmenta and Gilbert 1968).

The elasticities of cost with respect to output and public investments are

(3-18) $\varepsilon_{CY} = \alpha_Y + \alpha_{YY} \ln Y + \sum_i \alpha_{Yi} \ln W_i + \sum_k \alpha_{Yk} \ln Z_k$, and

(3-19) $\varepsilon_{CZk} = \gamma_k + \sum_l \gamma_{kl} \ln Z_l + \sum_i \delta_{ik} \ln W_i + \alpha_{Yk} \ln Y$.

I evaluated equations (3-17), (3-18) and (3-19) using the median data. I used these elasticities and the annual exponential growth rates of cost, output, input prices, and quasi-fixed inputs to determine the TFP growth.

3.2.5. Data and Description

I obtained data on regional costs and returns of rice production from the Rice Statistics Handbook published by the Bureau of Agricultural Statistics (BAS) and PhilRice. The BAS used their 1991 and 2002 surveys as a benchmark for updating costs and returns data from 1992 to 2001, and from 2003 onwards.[16] I utilized the data from 16 regions from 1992 to 2007 for a total of 256 observations. The use of aggregate data may lead to a potential simultaneity of prices, as unobserved characteristics of each region can affect the market clearing conditions in those areas. To account for this, I implemented a "within" transformation of data prior to the estimation.[17] I assumed that the characteristics of the regional market equilibrium were time-invariant and can be eliminated by the "within" transformation.

The costs of seed, fertilizer, labor, machines, and water constituted the variable cost. For the price of labor, I utilized the average regional real daily wage rate for rice farm workers. In addition, I obtained the price of seed by dividing each region's seed cost per hectare with the average quantity of seed applied per hectare. I derived machine rental rates by adding 50% of the imputed thresher's share and 10% of the hired labor cost to the rental rates of machine in the farm budget. These items accounted for rentals of tractor and

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[16] Ideally, an annual survey is the best source of data for this analysis. Given the data limitations, I proceed with the analysis noting that the process of data-generation can impact the outcome of the analysis.

[17] I implemented the within transformation by using the *xtadata, fe* command in STATA. The process of within transformation is similar to including dummy variables for each region. However, the use of within transformed data is better because it allows the coefficients to be estimated with larger degrees of freedom, unlike including 16 regional dummy variables in the model.

threshing machines[18]. Using the quantity shares as weights, I calculated the price of fertilizer as a weighted average price per bag of different fertilizer grades.

3.2.6. Specifying Stock Variables for Public Investments

Except for the government spending on production support which has a one time-effect, public investments in R&D, extension, and irrigation yield economic services for more than one period. Thus, the stock levels of quasi-fixed inputs from R&D, extension, and irrigation in a particular time are results of investments in prior periods. To account for this in constructing the stocks of quasi-fixed inputs, I used time-shape weights to distribute the economic services of public investments over time (Evenson 2001, pp.584-588). I employed the segment-length approach in constructing public investment stocks because it allows flexibility in segment lengths while imposing a reasonable shape over time.[19]

Before generating the stock variables, I deflated all public expenditures into 2000 constant prices using the consumer price index for rice. I derived the stock of local R&D from the sum of PhilRice's expenditures and the DA-Rice Program budget allocation for R&D.

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[18] Due to small farm sizes, the use of combined harvester-thresher is still not popular in the Philippines. Paddy rice is harvested manually and threshed using a machine. Threshing activities are often contracted out, thus, the thresher's share reflects the combined returns to farm workers and machine owners. Similarly, a part of the hired labor cost is for land preparation. This activity is also often contracted out suggesting that hired labor cost reflects the return to tractor owners and wages of the operator. Assumption on the percentage of costs attributed to machine rent is based on my personal knowledge of rice production in the Philippines.

[19] Time-shape weights can be estimated through either free-form, distributed lag, or segment-length approaches. The free-form approach can be implemented by including a number of lagged public investment variables in the econometric model. On the other hand, the distributed lag approach can be applied by imposing a functional form on the time shape. The segment-length approach can be implemented by constructing stock variables using alternative time-shape weights (i.e. an inverted trapezoid to account for a lag in adoption, and depreciation) and then choosing the model with minimum mean square error. Evenson notes that the free-form approach usually have unsatisfactory results because coefficients tend to oscillate between positive and negative values. On the other hand, the distributed lag approach imposes a very strong structure on time shapes. While crude, he prefers the segment-length approach.

I used the time-shape weights set by Evenson and Quizon (1991) because it described a logical progression of the future impacts of R&D. The first segment characterized a period when no impact is realized, which implied that R&D programs did not produce immediate impacts. The second segment described a period of increasing impact, which signified the rising contributions of R&D. The third segment represented the period of constant effect. This suggested that after reaching its peak, research service impacts did not "depreciate" because new inventions "build on" the inventions that they displaced. I constructed the stock of local R&D as

$$\text{(3-20)}\quad Z_{it}^{LR\&D} = \theta_{it}\left(0.2LR\&D_{t-2} + 0.4LR\&D_{t-3} + 0.6LR\&D_{t-4}\right) + \theta_{it}\left(0.8LR\&D_{t-5} + \sum_{j=6}^{J} LR\&D_{t-j}\right),$$

where $LR\&D_t$ is the total public expenditures in R&D in period *t*, *J* corresponds to the time index for 1986, and θ_{it} is the share of region *i* in period *t* to the total value of rice production in irrigated areas. Since local R&D programs give greater emphasis on developing technology for irrigated areas, I considered only the value of total rice production in irrigated areas in calculating the share of each region.[20]

I assumed that the international R&D investment has an indirect effect on costs by improving the productivity of local R&D. To capture this spillover effect, the international R&D variable appeared in the model as an interaction with the local R&D variable. I generated the stock of international R&D for region *i* at period *t* as

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[20] The priority given to technology development for irrigated areas can be discerned from greater number of research projects and studies for favorable areas compared to unfavorable ecosystem. For more details, please see http://www.philrice.gov.ph//index.php?option=com_content&task=view&id=88&Itemid=126.

(3-21) $$Z_{it}^{IRES} = \theta_{it}\lambda_j\left(0.2IR\&D_{t-2} + 0.4IR\&D_{t-3} + 0.6IR\&D_{t-4}\right)$$

$$+\theta_{it}\lambda_j\left(0.8IR\&D_{t-5} + \sum_{k=6}^{K} IR\&D_{t-k}\right),$$

where $IR\&D_t$ refers to IRRI's expenditure in the Philippines in period *t,* and *K* refers to the time index for 1970.[21] I also used another weight, λ_j, to reflect the geographic distance of each region from IRRI's headquarters located in region 4A. Thus, the farther the region from IRRI's headquarters, the smaller the spillover effect.[22]

Similar to R&D stock, I employed the time-shape weights set by Evenson and Quizon (1991) in creating the stock for extension. I calculated the stock of extension in region *i* at period *t* as

(3-22) $$Z_{it}^{EXT} = \theta_{it}\left(0.5EXT_t + 0.25EXT_{t-1} + 0.25EXT_{t-2}\right),$$

where EXT_t corresponds to the budget allocation of the DA Rice Program to the farmers' training and extension in period *t*. Using the production subsidy component of the DA Rice Program budget, I generated the stock of production subsidy as

(3-23) $$Z_{it}^{PS} = \theta_{it}PS_t.$$

Since the DA Rice Program aims to achieve self-sufficiency, it targets farmers with access to irrigation and who have a greater probability of producing more. Because of this, I also used the share to total value of rice production in irrigated areas in allocating the stocks of extension and production subsidy in each region.

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[21] I also tried the length of the segment for international R&D that ends in 1985 but this resulted in significantly lower coefficient of determination.

[22] I use the weights 0.6 for CAR, regions 1, and, 2; 0.8 for regions 3, 4B, and 5; and 1 for region 4A. These regions are within the Luzon Island. I use the weight 0.4 for the regions in Visayas Island, and 0.2 for the regions in Mindanao Island.

Using the regional expenditures of NIA, I generated the stock of irrigation as

$$(3\text{-}24)\quad Z_{it}^{IRRIG} = 0.5NIA_{t-1} + 0.75NIA_{t-2} + \sum_{j=3}^{6} NIA_{t-j} + 0.8NIA_{t-7}$$

$$+0.6NIA_{t-8} + 0.4NIA_{t-9} + 0.2NIA_{t-10}\,.$$

I used an inverted trapezoid as time-shape weights to account for the development period and the depreciation of irrigation facilities. I assumed that the large-scale irrigation system has a ten-year usable lifespan. This considers two years of partial use during the construction period, four years of full service, and four years to allow for complete depreciation.[23]

3.3. Results and Discussion

3.3.1. Rice Production Technology in the Philippines

Table 3.1 presents the iterated SUR estimates of the parameters of the translog cost function. On average, the model explains 67% of the variation in cost of rice production in the region. The estimated cost function satisfies the properties of monotonicity, concavity and homogeneity of degree one in prices, suggesting the feasibility of reconstructing the production technology. The evaluation of the estimated cost shares at the median data showed the monotonicity in input prices of the estimated cost function. The estimated cost shares are 0.08 for seed, 0.13 for fertilizer, 0.66 for labor, 0.09 for machinery, and 0.05 for water.

The estimated elasticity of cost with respect to output is 0.93, which is significantly different from zero at 99% confidence level. This indicates that the estimated cost function

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[23] While I cannot stretch the length of the segment longer than 10 years because of data limitations, I tried four specifications of time-shape weights for irrigation. The results did not vary much from each specification prompting me to choose the one that has the highest coefficient of determination.

is monotonic in output. The 95% confidence interval (0.64, 1.22) of the estimated elasticity of cost with respect to output also shows that it is not significantly different from unity. This implies that the regional rice production is operating at a constant return to scale.

As expected, the own-price elasticities of input demands are negative and significant. The estimated own-price elasticities are -0.42 for seed, -0.33 for fertilizer, -0.20 for labor, -0.24 for machinery, and -0.38 for water (Table 3.2). This indicates that the Hessian matrix of the estimated cost function is negative semi-definite, which implies the concavity in prices of the estimated cost function at the point of verification. All estimated own-price elasticities are lower than unity in absolute terms suggesting that the demands for these inputs are inelastic. Results also show that among the inputs, the seed demand is the least inelastic with respect to its own-price. This suggests that the demand for seed in a region is highly sensitive to the changes in its price compared to other input uses. At the regional level, the greater flexibility in seed use is due to the higher quantity of seed planted per hectare compared to the recommended seeding rate. For example in 2002, the regional average seeding rates for transplanted and direct seeded rice were 95 and 146 kg/ha (PhilRice-BAS 2004). These are higher than the 40 and 60 kg/ha seeding rates recommended for transplanted and direct seeded rice. Given this, a reduction in the quantity of seed use has no significant penalty in the production of the region. In addition, the prevalence of seed-saving and seed-exchange practices may have also contributed to the greater flexibility in seed use.

Table 2 also summarizes the cross-price elasticities of input demands. The negative sign of the estimated cross price elasticities implies that seed, machine and water are substitutes for labor. Labor constitutes the largest portion of cost of rice production in the region. In addition, there is also a competing demand for labor from non-rice and non-agriculture economic activities at the regional level. Thus, producers tend to substitute away from labor as its price increases.

Table 3.3 presents the Morishima elasticity of substitution (MES) which measures the flexibility of input substitution in a technology. Formally, the elasticity of substitution measures the percentage change in the input ratio with respect to the percentage change in their price ratio (Varian 1992, p.13). I reported the MES because it captures the changes in two inputs with a change in their cross price, making it a better measure of degree of substitution compared to the partial elasticity of substitution of Allen-Uzawa, which is only a scaled version of the cross-price elasticity of demand (Blackorby and Russell 1989).

Results show that as the price of labor increases, rice production in the region has a greater degree of substitution toward seed compared to machinery, water and fertilizer. Examining the role of labor in rice production at the farm level can help us better understand the high degree of substitution between labor and seed at the regional level. Labor is the largest component of the production cost at both farm and regional levels. Transplanting, harvesting, and threshing are the most labor-intensive farm activities. While threshing is partially mechanized, transplanting and harvesting are still done manually.[24] It is a common practice for rice farmers to hire farm workers to do these tasks. For a one-hectare farm, about 23 labor-days are used for transplanting while 30 labor-days and a portable thresher

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[24] The gathering of the cut stalks and packaging of the threshed grains in sacks are still done manually. While there are existing designs of mechanical transplanter and combined harvester-thresher, these machines are not yet commercially produced and are not commonly used at the farm level.

are used for harvesting and threshing (Moya and Dawe 2006). Although transplanting is paid in cash, harvesting and threshing are paid in kind, which is a certain percentage of the gross harvest. At a high price of rice, in-kind payment creates an opportunity for farm workers to earn more from harvesting and threshing compared to the wage received from non-rice and non-agricultural employment. Because of this, it is easier for rice farmers to find seasonal workers during harvesting than in planting period. Thus, when a labor bottleneck arises during the planting period particularly in provinces near the major cities, farmers often resort to the direct seeding technique, which only requires 2-3 labor-days to broadcast seed in one-hectare land. Moya and Dawe indicated that the reduction in labor cost more than offset the increase in the costs of seed and weed control associated with direct seeding. They also indicated insignificant difference in yield between transplanted and direct-seeded rice. This can partly explain the higher degree of labor substitution toward seed compared to other variable inputs.

The use of more seed as a substitute for labor raises the demand for rice grain. Given the Philippine restrictions in the international trade of rice, a greater demand for seed may lead to an increase in the domestic price of rice. To avoid this problem and to further reduce the production cost, it might be more useful to improve the degree of substitutability of labor with machinery by providing appropriate institutional mechanisms to commercialize machine designs.

Table 3.4 shows the impacts on input demands of investments in local R&D, extension, production support, and irrigation. A rise in the local R&D investment reduces the demands for seed and labor. This can be attributed to the crop management practices developed by the local R&D, such as 20 and 40 kg/ha seeding rate for hybrid and inbred rice production, direct seeding, and designs of small farm machinery. In contrast, an increase in the extension investment raises the demand for seed, labor, and machinery although it reduces the fertilizer demand. Expenditure on production support increases the demand for all inputs except water. Public investment in irrigation is neutral to input demands.

3.3.2. The Shadow Shares of Public Investments

I found the elasticity of cost with respect to local R&D investment to be negative and significant (Table 3.5). In general, a percent increase in the stock of the local R&D will lead to a 0.24% decrease in cost. This is not surprising since the local R&D investment generates knowledge and applied technology that improves productivity. The negative cost elasticity of R&D indicates a positive shadow share, which means the over-utilization of the local R&D stock in the region. This suggests an inadequate amount of location-specific technologies for rice production. Hence, incremental investment in the local R&D is necessary to generate more location-specific varieties, machine designs, crop management practices, and integration of farming systems. However, the amount of public resources that should be invested to R&D should be guided by the principle of efficiency. In particular, a cost-benefit analysis can be useful in comparing government investment to rice R&D with other alternative public investments.

Extension services connect the flow of technology from research organizations to farmers. Unfortunately, I found a positive and significant elasticity of cost with respect to extension. This suggests that a percent increase in the stock of extension will raise the cost of rice production in the region by 0.15%. This further implies a negative shadow share of extension, which suggests the desirability of reducing the current level of investment. While there is no doubt about the importance of extension in agricultural development, investing in extension, given its present state, is wasteful.

The resulting cost-increasing effect may be a reflection of the inefficiencies in the extension system. For the investment in extension to be effective, problems in the current system should be addressed first. Recalling the discussion earlier, one of the weaknesses of the extension system is the lack of coordination between the national agencies and among the local extension offices. There is an immediate need to coordinate the highly dispersed extension activities of the different local government units. To do this, the ATI should be reorganized and its functions be realigned from merely providing training to more relevant activities such as strategic planning, funding, coordination of training, dissemination of information, and setting-up a system of monitoring and evaluation (M&E) (Gapasin 2006, p.31). As the ATI strengthens its capacity in extension management, the national government should provide funding so that the ATI can carry-out its new functions. The establishment of an extension coordinating agency and M&E system should improve the efficiency, transparency, and accountability of the flow of extension resources from the national to the local government. This will be beneficial not only for the rice sector but also for the whole agriculture sector.

There is also an urgent need to improve the competence and efficiency of local extension workers. Their skills on knowledge management, particularly the use of information and communication technologies (ICTs), need immediate improvement. With

ICTs, extension workers can have better access to information and carry-out extension functions more effectively and efficiently (Gapasin 2006). Led by the ATI, extension workers all over the country should be trained to take advantage of the emerging technology and information websites.[25] Technical training should also be complemented with proper investments in equipment, specifically computers with Internet hook-ups.[26]

Aside from extension, the investment in production subsidy has also a cost-increasing effect. Results show that a percent increase in production subsidy raises the regional cost of production by 0.09%. The regional cost of production increases when hybrid seed and certified seed of inbred varieties are adopted because the subsidized prices of these inputs are still more expensive than the opportunity cost of seed, which is the farmgate price. The regional cost is further increased when farmers in the region use more than necessary amount of seed per hectare. The positive elasticity of cost with respect to production subsidy suggests the desirability of reducing its public investment. Although the intent of the DA-Rice Program is to improve the adoption of technology, the result of this study implies that subsidy is not the proper way of doing technology transfer. This study offers empirical evidence that supports the phase-out of the subsidy for inputs including hybrid seed. In addition, although hybrid seed technology may have increased rice production at

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[25] One important site is the www.openacademy.ph, which is managed by the Open Academy for Philippine Agriculture (OPAPA). This a consortium of research agencies involving PhilRice, DA, Department of Science and Technology, IRRI, International Crops Research Institute for Semi-Arid Tropics, University of Southern Mindanao, Pampanga Agricultural College, Central Luzon State University, Isabela State University, Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development, Advance Science and Technology Institute, DA-Information and Technology Center for Agriculture and Fisheries, Bureau of Post-harvest Research and Extension, Philippine Carabao Center, and DA-Bureau of Agricultural Research.

[26] Many of the provincial, cities and municipal extension offices have not yet benefit from a computerized operation system. Many of the devolved extension personnel are computer illiterate and needs training.

the farm level, the difficulty in bringing this technology to the proper place at the right time through government intervention can be too costly.

I found insignificant elasticity of cost with respect to the stock of large-scale irrigation systems. The failure of the irrigation investment to generate cost-savings at the regional level implies the need for better strategies of delivering irrigation services to farms. Farmers’ participation in irrigation management is important in increasing timeliness of water delivery and the better resolution of conflicts that relates to water scheduling (Inocencio and Barker 2006). Thus, the turnover policies from public organizations to water-users’ associations has been a part of the conditions for the loan packages extended by the World Bank and the Asian Development Bank to the Philippine government for the development of irrigation facilities. However, the program for establishing local water-users’ associations collapsed since mid-1980s due to the lack of political support and the limitations in budget for maintenance (Korten and Siy Jr. 1988). Inocencio and Barker emphasized the importance of conducting site-specific case studies to determine the best incentive for creating collective action.

The signs of the estimated interaction terms between stocks of different public investments also provide important policy implications. The estimated coefficient of the interaction between the local and the international R&D stocks is negative and significant (-0.014 with standard error of 0.005). This signifies that an increase in the international R&D stock augments the cost-reducing effect of local R&D stock. Thus, the local R&D can benefit further from the international R&D by implementing more collaborative research, sharing research output through integrated information systems, taking advantage of IRRI-sponsored training, and accessing advanced laboratories if needed.

Similarly, the estimated coefficient of the interaction between the local R&D and extension stocks is negative and significant (-0.078 with standard error of 0.017). This implies that an increase in the extension stock also improves the cost-saving effect of the local R&D stock. Extension can improve the productivity of the local R&D by providing feedback about the technology needs of producers. On the other hand, the local R&D can enhance the productivity of the extension by developing a system of knowledge management through ICT, increasing the extension workers' access to information on latest technologies for rice production. Exploring the use of the Internet, continuous updating of rice technology websites, and setting-up of some technology support call and text messaging centers are potential means of improving extension workers' access to information.

In contrast to the stocks of international R&D and extension, public expenditure in production subsidy minimizes the cost-reducing effect of the local R&D as shown by the positive and significant coefficient of the interaction term (0.046 with standard error of 0.02). The negative impact of investment in the production subsidy to the productivity of local R&D can be attributed to the diversion of financial human resources from R&D activities to the management of the production subsidy program. An example is the deployment of researchers to act as resource persons and perform extension work during the early stage of the hybrid rice commercialization program. Back then, attendance to a hybrid rice technology briefing is a requirement to receive subsidized hybrid seeds. Though the intention of the DA Rice Program is well-meaning, this undertaking has diverted the limited human resources from their more relevant R&D work.

3.3.3. Decomposition of Total Factor Productivity

Rice TFP in the Philippines has grown at an average rate of 5.3% yearly from 1992 to 2007 (Table 3.6). This estimate is higher than the annual growth in rice output for the same period, which is 3.3%. This implies that increases in output are achieved with less variable inputs. As shown in Chapter 2, all input uses except for fertilizer have declined from 1996 to 2007. The estimated annual growth rate of rice TFP is 6.8% in 1992-1999 period and 4.3% in 2000-2007 period. These estimates look more optimistic than the TFP growth measure I found in Chapter 2. However, it should be noted that I separated the production impacts of non-conventional inputs including those of technology variables from the TFP measure in Chapter 2 whereas the impacts of R&D are included in the TFP measure in this current chapter. To be consistent, only the rate of technical change, which is 2.7%, should be compared to the TFP measure in the previous chapter.

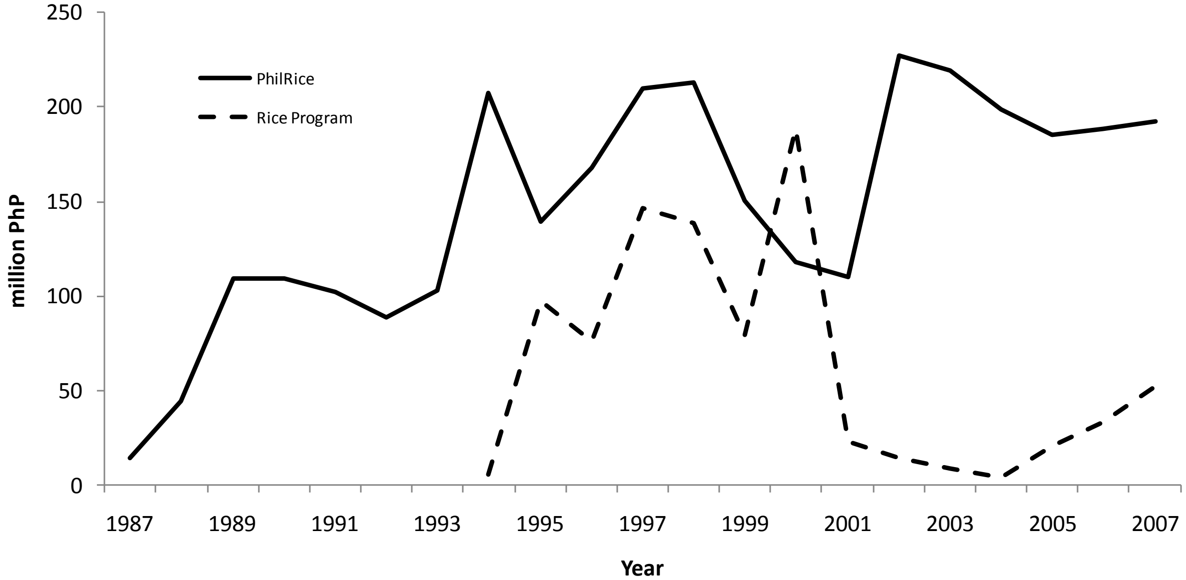
Nevertheless, my estimated rate of technical change is still higher than the estimates reported in previous studies. Estudillo and Otsuka (2006) and Umetsu, et al. (2003) reported an estimate of a 1% and 1.8% annual TFP decline in the 1990-1999 and 1986-1990 periods, respectively. Both studies measured the growth rate of rice TFP using the primal approach, which did not consider the short-run changes in capacity utilization due to public investment. I recognize that one of the limitations of my study is the data-generation process, which may have driven my optimistic results. Nevertheless, the directions of the productivity impacts of public investments, specifically in R&D, are consistent with the present state of the rice sector in the Philippines.

3.4. Policy Implications

Using a cost framework, I measured the direct cost-effects of public investments in R&D, extension, production subsidy and irrigation. Among these investments, only R&D has generated cost-savings and has improved the productivity of rice. However, the declining contribution of R&D to the rate of TFP growth should be a cause for alarm. This implies that further investment in rice R&D is essential, though a cost-benefit analysis of this is still needed to compare the returns to alternative public investments. I found that the investment in production subsidy is counterproductive even if it means to increase the adoption of technology. Given this, phasing-out of input subsidies will be beneficial for the whole agricultural sector. I also found inefficiencies in extension and irrigation investments. Thus, reforms in the current extension system and a reorientation of the irrigation development strategies should be implemented in order to reap the potential benefits from these investments.

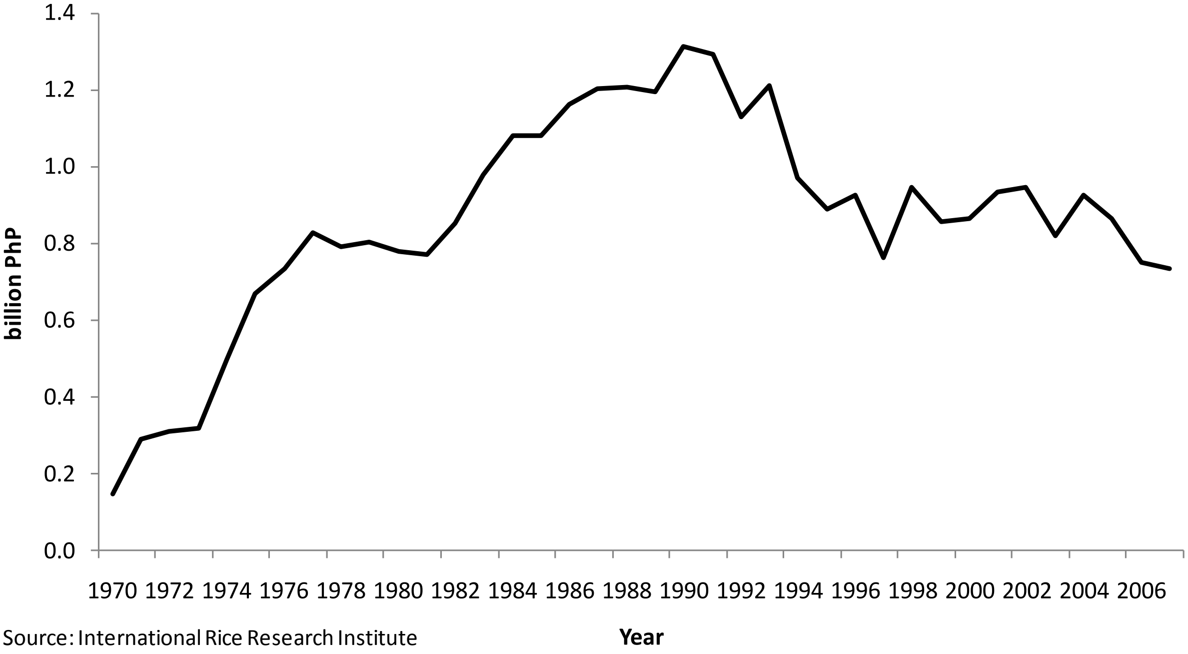
3.5. Figures and Tables

Figure 3.1. Public rice R&D expenditures in the Philippines, in 2000 constant prices, 1987-2007



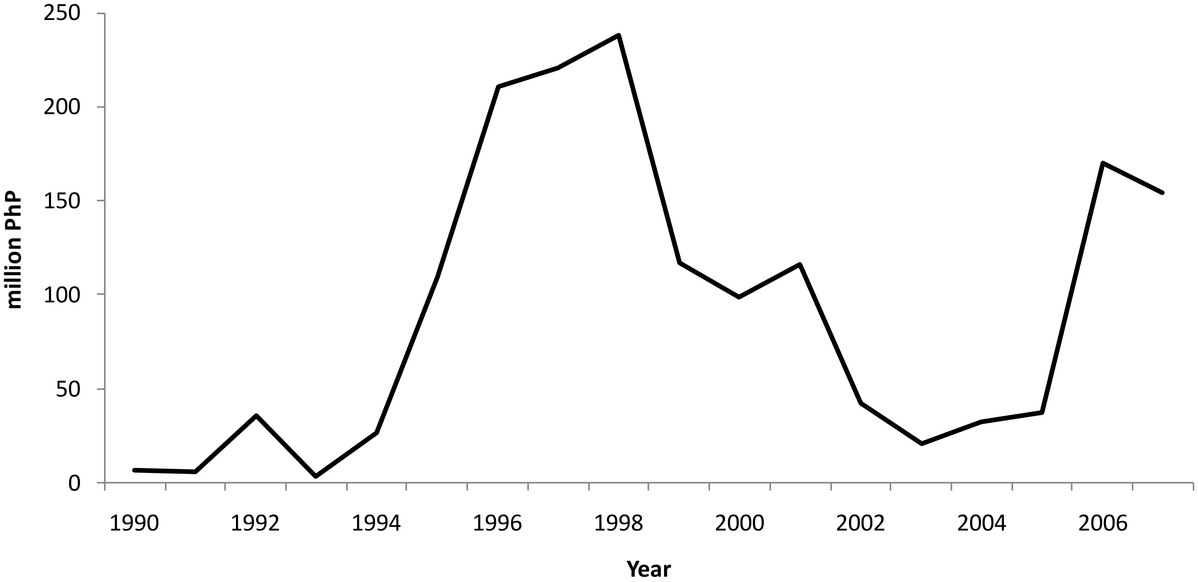
Source: Philippine Rice Research Institute and DA Rice Program

Figure 3.2. IRRI's R&D expenditure in the Philippines, in 2000 constant prices, 1970-2007



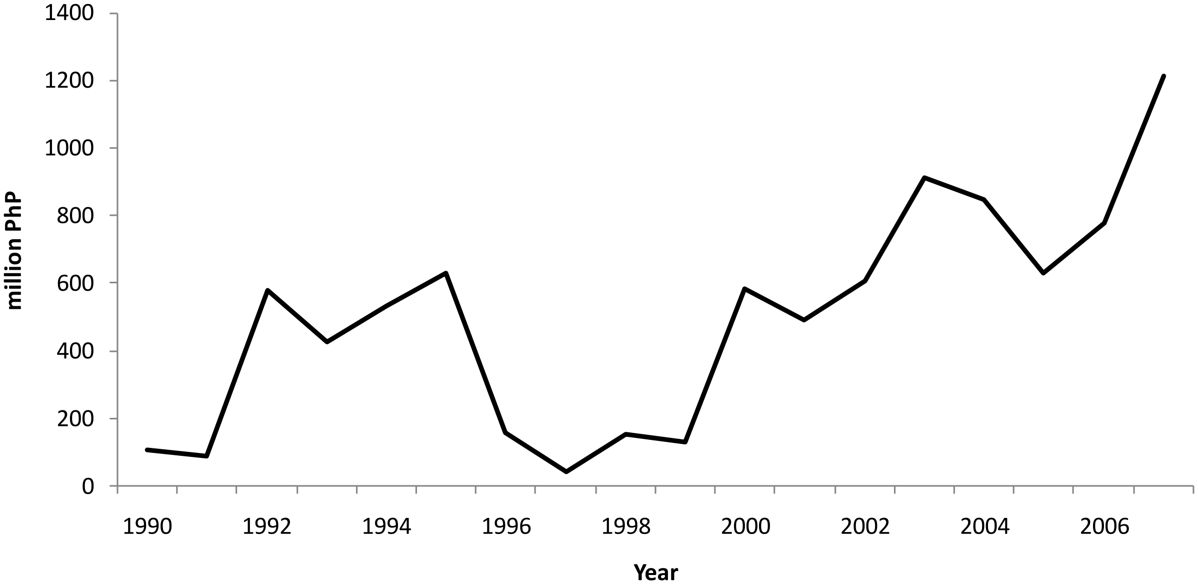
Source: International Rice Research Institute

Figure 3.3. Extension expenditure, in 2000 constant prices, 1990-2007



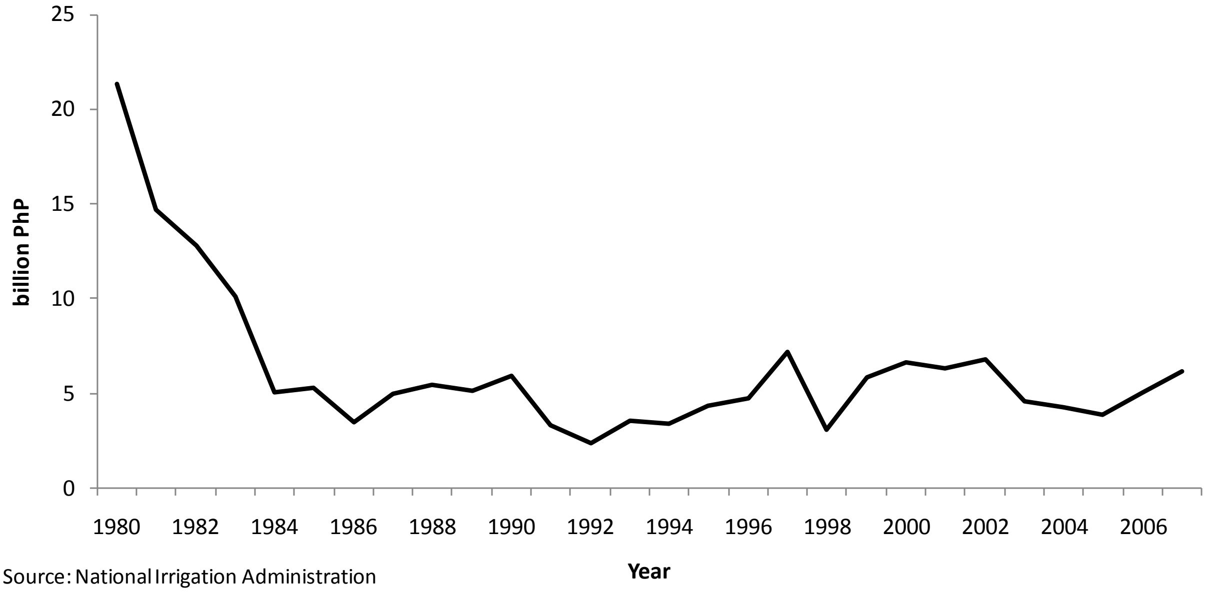
Source: Department of Agriculture Rice Program

Figure 3.4. Production support expenditure, in 2000 constant prices, 1990-2007



Source: Department of Agriculture Rice Program

Figure 3.5. Actual irrigation expenditures in the Philippines, in 2000 constant prices, 1980-2007



Source: National Irrigation Administration

Table 3.1. The iterated seemingly unrelated regression estimates of the translog variable cost function for the Philippine rice sector, 1992-2007

Variable	Coefficient		Standard Error
Output	1.968	***	0.546
$Output^2$	-0.149	***	0.053
Output x Seed Price	0.012	***	0.003
Output x Fertilizer Price	0.038	***	0.012
Output x Labor Price	-0.068	***	0.015
Output x Machinery Price	0.012	***	0.003
Output x Water Price	0.007	***	0.002
Output x Local R&D Expenditure	0.055	**	0.021
Output x Irrigation Expenditure	-0.018		0.011
Output x Production Subsidy Expenditure	-0.003		0.020
Output x Extension Expenditure	0.021		0.021
Seed Price	0.248	***	0.038
Fertilizer Price	-0.276	**	0.137
Labor Price	1.241	***	0.174
Machinery Price	-0.144	***	0.034
Water Price	-0.070	***	0.024
Seed $Price^2$	0.039	***	0.003
Seed Price x Fertilizer Price	-0.005	*	0.003
Seed Price x Labor Price	-0.012	***	0.002
Seed Price x Machinery Price	-0.016	***	0.002
Seed Price x Water Price	-0.006	***	0.001
Fertilizer $Price^2$	0.067	***	0.009
Fertilizer Price x Labor Price	-0.045	***	0.009
Fertilizer Price x Machinery Price	-0.015	***	0.002
Fertilizer Price x Water price	-0.002		0.002
Labor $Price^2$	0.086	***	0.011
Labor Price x Machinery Price	-0.018	***	0.002
Labor Price x Water Price	-0.010	***	0.001
Machinery $Price^2$	0.058	***	0.002
Machinery Price x Water Price	-0.009	***	0.001
Water $Price^2$	0.027	***	0.001
Local R&D Expenditure	-0.338	*	0.177
Irrigation Expenditure	0.181		0.132
Production Subsidy Expenditure	-0.017		0.146
Extension Expenditure	0.217		0.154
Local R&D $Expenditure^2$	-0.023		0.026
Local R&D Expenditure x International R&D Expenditure	-0.014	***	0.005
Local R&D Expenditure x Irrigation Expenditure	0.006		0.006
Local R&D Expenditure x Production Subsidy Expenditure	0.046	**	0.020
Local R&D Expenditure x Extension Expenditure	-0.078	***	0.017
Irrigation $Expenditure^2$	-0.022	***	0.005

Table 3.1. (cont.)

Variable	Coefficient		Standard Error
Irrigation Expenditure x Production Subsidy Expenditure	0.013	**	0.005
Irrigation Expenditure x Extension Expenditure	-0.005		0.006
Production Subsidy Expenditure^2	-0.057	***	0.017
Production Subsidy Expenditure x Extension Expenditure	0.018		0.017
Extension Expenditure^2	0.068	***	0.022
Seed Price x Local R&D Expenditure	-0.004	***	0.001
Seed Price x Irrigation Expenditure	-0.003	***	0.001
Seed Price x Production Subsidy Expenditure	-0.001		0.001
Seed Price x Extension Expenditure	-0.004	***	0.001
Fertilizer Price x Local R&D Expenditure	0.030	***	0.005
Fertilizer Price x Irrigation Expenditure	-0.006	**	0.002
Fertilizer Price x Production Subsidy Expenditure	-0.004		0.004
Fertilizer Price x Extension Expenditure	-0.035	***	0.003
Labor Price x Local R&D Expenditure	-0.034	***	0.006
Labor Price x Irrigation Expenditure	0.009	***	0.003
Labor Price x Production Subsidy Expenditure	0.008	*	0.005
Labor Price x Extension Expenditure	0.049	***	0.004
Machinery Price x Local R&D Expenditure	0.005	***	0.001
Machinery Price x Irrigation Expenditure	-0.001		0.001
Machinery Price x Production Subsidy Expenditure	-0.002	***	0.001
Machinery Price x Extension Expenditure	-0.007	***	0.001
Water Price x Local R&D Expenditure	0.050	***	0.013
Water Price x Irrigation Expenditure	0.015	**	0.006
Water Price x Production Subsidy Expenditure	-0.035	***	0.012
Water Price x Extension Expenditure	-0.031	***	0.006
Time Trend	-0.026	***	0.007
Constant	-1.067		3.532
R-Squared	0.68		

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 3.2. Own and cross-price elasticities of input demand

Variable	Seed	Fertilizer	Labor	Machinery	Water
Seed Price	-0.41 ***	0.04	0.06 ***	-0.11 **	-0.05
	(0.10)	(0.03)	(0.01)	(0.05)	(0.08)
Fertilizer Price	0.06	-0.35 *	0.06	-0.04	0.09
	(0.05)	(0.21)	(0.04)	(0.04)	(0.07)
Labor price	0.51 ***	0.31	-0.21 ***	0.45 ***	0.44 ***
	(0.07)	(0.22)	(0.06)	(0.09)	(0.10)
Machinery price	-0.12 *	-0.03	0.06 ***	-0.24 **	-0.11
	(0.06)	(0.03)	(0.01)	(0.10)	(0.07)
Water price	-0.03	0.03	0.03 ***	-0.06	-0.38 ***
	(0.05)	(0.03)	(0.01)	(0.04)	(0.08)

Bootstrapped standard errors in parenthesis

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 3.3. Morishima elasticities of substitution of input demand

Variable	Seed	Fertilizer	Labor	Machinery	Water
Seed Price		0.46 ***	0.47 ***	0.31 ***	0.36 **
		(0.11)	(0.11)	(0.12)	(0.16)
Fertilizer Price	0.42 *		0.42 *	0.29	0.45 **
	(0.23)		(0.25)	(0.20)	(0.21)
Labor price	0.72 ***	0.52 *		0.64 ***	0.65 ***
	(0.09)	(0.27)		(0.13)	(0.14)
Machinery price	0.12	0.21 *	0.30 ***		0.13
	(0.12)	(0.11)	(0.11)		(0.15)
Water price	0.35 ***	0.41 ***	0.41 ***	0.32 ***	
	(0.10)	(0.10)	(0.08)	(0.10)	

Bootstrapped standard errors in parenthesis

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 3.4. The elasticities of input demands with respect to public investments

Variable	Seed	Fertilizer	Labor	Machinery	Water
Research and Development	-0.29**	-0.01	-0.29**	-0.18	0.81
	(0.12)	(0.14)	(0.13)	(0.12)	(0.78)
Extension	0.10***	-0.12**	0.22***	0.07***	-0.50
	(0.03)	(0.05)	(0.02)	(0.02)	(0.40)
Production Subsidy	0.08***	0.06**	0.10***	0.06**	-0.66
	(0.03)	(0.03)	(0.03)	(0.03)	(0.39)
Irrigation	-0.05	-0.06	0.00	-0.02	0.31
	(0.04)	(0.04)	(0.03)	(0.03)	(0.33)

Bootstrapped standard errors in parenthesis

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 3.5. The elasticities of cost with respect to public investments

Public Investment	Cost Elasticity	Standard Error[1]
Research and Development	-0.24 **	0.12
Extension	0.15 ***	0.02
Production Subsidy	0.09 ***	0.03
Irrigation	-0.01	0.03

[1] Bootstrapped standard errors

*, **, and *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 3.6. Decomposition of annual TFP growth (%) in the Philippines, 1992-1997

Components	1992-1999	2000-2007	1992-2007
Economies of Scale	0.22	0.19	0.22
Research & Development	6.88	2.62	5.14
Extension	-3.94	0.07	-1.74
Production Subsidies	1.15	-1.24	-0.92
Irrigation	-0.10	0.00	-0.04
Technical Change	2.64	2.64	2.64
Primal TFP Growth	**6.84**	**4.29**	**5.30**

Chapter 4

THE USE OF CROP MODELS IN INVESTIGATING WELFARE CONSEQUENCES OF TECHNOLOGY: THE CASE OF HYBRID RICE IN THE PHILIPPINES

The economic surplus approach in a partial equilibrium setting has been the most commonly used and widely accepted framework in evaluating the economic consequences of investments in agricultural research. In this framework, the magnitude of the welfare impacts of R&D largely depends on the nature of the research-induced shift in the supply curve. Despite its importance, the nature of shift in supply is commonly assumed in the analysis and not thoroughly investigated due to the limitations in data and economic analytical tools. This results in a wide range of estimated rate of returns to agricultural R&D which obscures its positive impacts to the society.

In this paper, I intend to narrow this gap by capitalizing on the developments of crop simulation models over the last two decades. The development of the computing capacity in the recent years enable crop models to dynamically simulate growth and production of crops by integrating information about crop bio-physical processes, environment, and management conditions. Through the aid of crop models, the true production technology is not as unknown as before.

To showcase the method, I chose the Decision Support System for Agrotechnology Transfer (DSSAT) to investigate the effect of adopting hybrid seed technology on rice production in the Philippines. The DSSAT is a microcomputer software package that provides a shell program for the interface of crop-soil simulation models, data for soil and weather, and programs for evaluating management strategies. The DSSAT uses the CERES-

Rice model to simulate and predict the growth and yield of rice given certain weather, genetic, soil, water, nutrient and management conditions (Jones, Tsuji, et al. 1998; Jones, Hoogenboom, et al. 2003). Table 4.1 shows the minimum set of data required to operate the DSSAT model. I selected the DSSAT program because of its good predictive capability in simulating various crops including rice (Cheyglinted, Ranamukhaarchchi and Singh 2001; Timsina and Humphreys 2006; Sarkar and Kar 2006).

Using experimental data, the DSSAT model is calibrated and validated to find a set of genetic coefficients that appropriately describe a specific rice cultivar. As a manifestation of the seed technology, these genetic coefficients govern the growth stages of rice and its interaction with inputs, management practices, soil and weather. Once the DSSAT is calibrated to adequately simulate the real world scenario for a particular location, computer experiments can be performed to determine yield difference between the new and control technology under different input levels and management practices. Using this method, I can investigate the production behavior of low-cost producers, and consequently the nature of technology-induced shift in supply.

I applied this model to hybrid rice because of the important implications on the current rice production program of the Philippine government. The ongoing debate is focused on whether to continue or withdraw government support on hybrid rice in the Philippines. On one hand, proponents argue that the country is set to benefit from hybrid rice after years of capacity building in terms of research and development of new hybrid rice varieties, development in farmers' human capital, and the keen interest of the private sector in seed production. Gonzales and associates (2007) outlined the benefits of adopting hybrid rice at the farm level. The authors found that the yield advantage of hybrid varieties over inbred ones is 8% to 13% and 11% to 14% during wet and dry cropping seasons. They also found that the production cost per unit of hybrid rice was not significantly different from that of inbred rice, even when the price of seed was not subsidized. This led to a higher net income from hybrid rice compared to inbred rice production.

On the other hand, critics believe that hybrid rice is not a commercially viable technology, and that the government subsidy on hybrid seed is distorting the farmers' incentives in choosing between inbred and hybrid rice varieties. David (2006), and Cororaton and Corong (2009) provided a detailed critique of the hybrid rice commercialization program (HRCP) of the government. These authors recommended the abandonment of the HRCP and a redirection of the scarce research resources from hybrid to inbred rice. With the use of the DSSAT model in improving the economic surplus analysis, I hope to give more insight about the effect of hybrid technology on the supply of rice in the Philippines.

4.1. The Economic Surplus Analysis

Since the pioneering works of Griliches (1958), Peterson (1967), and Schmitz and Seckler (1970), a huge volume of literature on the economic impacts of agricultural research has been written using the economic surplus approach. Until recently, this framework was employed to evaluate the economic impacts of biotechnology products such as Bt corn (Hyde, et al. 1999; Demont and Tollens 2004), Bt cotton (Pray, et al. 2001; Traxler, et al.

2001), round-up ready soybeans (Moschini, Lapan and Sobolevsky 2000), or transgenic crops in general (Falck-Zepeda, Traxler and Nelson 2000; Marra, Pardey and Alston 2002).

To quantify the benefits from research, some studies explicitly measured the shift in supply, and the corresponding changes in surplus of economic agents in the society. Other studies applied simplifying assumptions to measure the economic surplus implicitly. These studies either valued the research-induced increase in production at a single market price or valued cost savings at the existing production level, which corresponded respectively to a vertical or a horizontal shift in the supply curve. Both explicit and implicit approaches employed a procedure to account for the time value of the streams of costs and benefits. The economic impacts of agricultural research are often reported in terms of rate of return. Alston, Norton, and Pardey (1998) discussed in detail the state of the art on these methods.

Despite the huge volume of literature written on returns to agricultural research, questions persist about the meaning, accuracy, and use of these estimated returns. Alston and associates (2000) made a meta-analysis of studies on research evaluation to determine factors that affect differences in estimated returns. They reviewed 292 studies and their results showed that the estimated rate of return to agricultural research ranged from -7.4% to 5645%. Their study also indicated that only 21% of the published estimated returns fall within the range of the conventional wisdom of 40% to 60% a year. In addition, there was also a huge disparity between the average return (100%) and the median return (48%) indicating skewness in the distribution of the estimated returns. Alston and associates also indicated the importance of the assumption on the nature of the research-induced shift in supply to the magnitude of the estimated returns.

The huge impact of the assumed nature of the research-induced shift in supply on the distribution and size of research benefits was already known (Duncan and Tisdell 1971; Lindner and Jarrett 1978; Miller, Rosenblatt and Hushak 1988). If the demand is perfectly inelastic, the producers' surplus may decrease, increase or not change, depending upon the nature of the supply shift (Figure 4.1, Panel 1). In particular, producers' surplus would fall if the supply shift were pivotal and divergent, suggesting that high-cost producers experienced a greater cost reduction than do low-cost producers. On the other hand, producers' surplus would increase with pivotal and convergent shifts in the supply curve, indicating a lesser reduction in cost at the margin than infra-marginally. However, producers' surplus would remain the same for a parallel supply shift though it would generate larger total research benefits compared to a pivotal shift in supply. Given a perfectly elastic demand, producers would always gain with any type of supply shift though the magnitude of the measured surplus would vary with the nature of the shift (Figure 4.1, Panel 2).

Unfortunately, it is impossible to make an *a priori* generalization about the nature of the industry supply shift (Lindner and Jarrett 1978). This would depend on the effect of technological innovation on the cost structure of existing producers. On one hand, some innovations may affect the low-cost producers more than the high-cost ones. This implied greater cost reduction in infra-marginal units (those near the price axis) compared to marginal units (those located at the top end of supply curve), leading to a convergent shift in supply. On the other hand, a technological innovation affecting the high-cost producers more than the low-cost ones may result in a divergent supply shift. Thus, determining the nature of shift in supply warrants a close examination of the effect of technological innovation on the cost of producing marginal and infra-marginal units. Examining the production cost of infra-marginal units implies the need to extrapolate the functional form of the supply curve to the price or quantity axes.

In economics, the true production technology is generally regarded as an unknown. Given this, the effect of technological change on supply is approximated through econometric estimation of a production, cost or profit function. The estimated marginal product of research or the marginal cost reduction brought about by research is used as a basis for the magnitude of the supply shift. Depending upon availability of data, economic models of crop production may include variables on lagged research expenditures to capture the effects of technological change. In many economic analyses however, time is commonly used as a proxy variable for technological progress in the absence of data. In some special cases when uses of two technologies can be observed, separate production or cost functions can be estimated to represent each technology. Some studies include a dummy variable in the specification to act as a shifter. However, this procedure leaves several unobserved variables as part of the error term that creates problems in the estimation. In particular, this can lead to an endogeneity bias of the estimated coefficients if explanatory variables are correlated with those unobserved variables. Some econometric techniques can handle this problem but only when panel data is available. In the end, the econometric techniques lead to an average estimate of a production increase or cost reduction. Unfortunately, this does not yield enough information to discern the nature of the research-induced shift in supply.

Examining the cost of infra-marginal units is difficult to resolve econometrically since most available data lack observations corresponding to the lower part of the supply curve.

Hence, assumptions about the nature of the research-induced supply shift are inevitably made, and often the researcher's choice of functional form is dictated by analytical convenience. For example, Alston, Norton and Pardey (1998, p. 64) encouraged the use of a parallel shift in the absence of greater information. While the use of a parallel shift simplified the calculation of research benefits and encouraged consistency in evaluation, it has diminished the incentive to look for innovative ways of investigating the true nature of the shift in supply. This, in turn, might have led to biased and highly variable estimates of returns to research, which up to present remained a major gap in the literature. It is in this aspect that this paper draws its significance.

4.2. Data and Methods

4.2.1. Site Description

I used field data from the PhilRice central experiment station in Maligaya, Muñoz, Nueva Ecija, Philippines. Situated in the central plain of Luzon, Nueva Ecija is one of the top rice-producing provinces in the country, which produced about 1.2 million tons of paddy rice in 2008. It has about 286,000 hectares of rice area harvested of which 86% are irrigated. The project site is located at 15^{o} 40' 21" north latitude and 120^{o} 53' 26" east longitude. It has a slope of less than 1% and an elevation of 48 meters above sea level. The project site is fully irrigated allowing rice to be planted in both dry (January to May) and wet (June to October) seasons. Derived from alluvium parent material, the soil in the area is poorly drained and is classified as fine, montmorillonitic, isohyperthermic Ustic Epiaquerts, commonly known as Maligaya clay (Corton, et al. 2000). Table 4.2 shows the physicochemical characteristics of the Maligaya clay soil that were used in the study.

I also used data from the weather station in the project site.[27] From 2005 to 2007, the project site had a mean temperature and annual rainfall of 27.6°C and 1900 mm. Monthly average maximum temperature showed April and May as hottest months (Figure 4.2). On the other hand, the monthly average minimum temperature was quite consistent all year round. Since the project site has a low elevation, the observed temperature was well within the range of optimal temperature for different growth stages of rice reported by De Datta (1981, p.26). The dry months were from January to April, indicating the importance of irrigation water in this period. On the positive side, less cloudiness during this period implied higher solar radiation, which encourages plant photosynthesis. The rainy months were from June to October. While water was more available during this period, greater cloudiness led to a lower amount of solar radiation available for photosynthesis. In this site, there seems to be greater opportunities for higher rice yield during the dry season, as long as water is not limiting.

4.2.2. Rice Genetic Coefficients

In this study, I considered two rice cultivars namely PSBRc72H and PSBRc82 to represent hybrid and inbred varieties. Both varieties were bred by the International Rice Research Institute. PSBRc72H and PSBRc82 were approved for release in 1997 and 2000.

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[27] The weather data at PhilRice Agro-Metereology Station were compiled by the database management team under the supervision of Mr. Jovino de Dios of the Agronomy, Soils, and Plant Physiology Division of PhilRice. I would like to express my gratitude to Dr. Eduardo Jimmy P. Quilang, the head of this division, for allowing me to use their data.

Since these varieties are commonly planted in the Philippines, they are used as controls for the National Coordinated Test on Multi-Adaptation Trials (NCT-MAT) of rice varieties in the country. PhilRice implements the NCT-MAT project to test which lines from different breeding institutes have stable yield across the country and can be approved for national release. I obtained data on varietal characteristics (i.e. dates of panicle initiation, anthesis, maturity, grain weight and yield) of the two varieties from the NCT-MAT project for 2005 and 2006 dry and wet planting seasons.[28] Ideally, there are 18 varietal characteristics that can be used in the calibration but I was only able to use 5 due to the limited availability of data.[29]

Using data on varietal characteristics during dry and wet seasons of 2005, I was able to calibrate the sets of genetic coefficients for PSBRc72H and PSBRc82. With the help of the GenCalc tool of DSSAT v.4.0, I was able to calibrate for each variety the growing-degree days (in ^{o}C-day units) for the vegetative phase (P1), the beginning of grain filling to physiological maturity (P5), the critical day length for flowering in hours (P2O), and the photoperiod sensitivity coefficient (P2R). These P coefficients enabled the model to predict the growth stages. The data from NCT-MAT also allowed me to calibrate each cultivar's potential spikelet number coefficient (G1), single grain weight in grams (G2), tillering coefficient relative to the variety IR64 (G3), and temperature tolerance coefficient (G4). These G

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[28] I obtained the experimental data from NCT-MAT project, which is implemented by the team of Mrs. Thelma Padolina , the head of Plant Breeding and Biotechnology Division of PhilRice. I also obtained the data on growth stages of the rice varieties from Dr. Rolando Cruz. I would like to acknowledge their generosity for letting me use their data in this study.

[29] These characteristics include dates of panicle initiation, anthesis and maturity, yield at harvest, grain weight, number of panicles per unit area, number of grains per panicle at maturity, leaf area index, tops weight at anthesis, tops nitrogen at anthesis, tops weight at maturity, by-product produced (stalks) at maturity, harvest index at maturity, grain nitrogen at maturity, tops nitrogen at maturity, stem nitrogen at maturity, and percentage of grain nitrogen at maturity.

coefficients facilitated the model's simulation of grain yield (Ritchie, et al. 1998). Table 4.3 lists the calibrated genetic coefficients for PSBRc72H and PSBRc82.

4.2.3. Field Data

Table 4.4 shows the details of NCT-MAT field experiments for 2005 and 2006. The two varieties were transplanted at 22 and 26 days after sowing (DAS) in dry and wet seasons of 2005 and 2006. The experimental data indicated that 120 kilogram of nitrogen was applied per hectare (kg/ha) in 3 and 4 splits during the dry seasons of 2005 and 2006. A smaller amount of nitrogen at 90 kg/ha was applied in 3 splits during the wet seasons of 2005 and 2006. The timing of application usually coincided with the basal stage, active tillering, and panicle initiation. Since there was no information on irrigation dates, I assumed that water was not limiting in the computer simulations. I assumed that during dry seasons, fields were irrigated every 10 days starting from the date of planting until 100 DAS at a 5 cm depth each time to avoid water stress. The crop was assumed to be free from any pest or disease stress in the simulation process.

4.2.4. Model Validation

To validate the model, I used the planting information from the dry and wet seasons of 2006, and the calibrated genetic coefficients to predict the panicle initiation, anthesis, maturity and grain yield of the two varieties. To compare the simulated to the observed data, the root mean square error (RMSE) is calculated as

(4-1) $$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(S_i - O_i)^2}{n}}$$

where S and O were the simulated and observed characteristics. Willmott et al. (1985) suggested the use of RMSE to validate model performance as it summarizes the mean difference in the same units of predicted and observed values. I also used the relative or the normalized RMSE to express the mean difference as a percentage of the average of the observed values. The normalized RMSE is calculated as

(4-2) $$nRMSE = \frac{RMSE}{\sum_{i=1}^{n} \frac{O_i}{n}}$$

Table 4.5 summarizes the simulated and observed characteristics of PSBRc72H and PSBRC82. The calculated nRMSE for grain yield were 9% and 4% for PSBRc72H and PSBRc82. These values were better than most of the nRMSE for grain yield reported in various studies reviewed by Timsina and Humphreys (2006), which ranged from 3% to 32%. The nRMSE for anthesis and maturity that I found were similar to the reported values in that review. This implies good predictive capacity of the model considering that only 5 out 18 possible characteristics were used in the calibration process. This suggests that the model would have even better predictive capacity if more information were available.

4.2.5. Model Application

Using the calibrated genetic coefficients, the average weather data from 2005 to 2007, and the soil characteristics of the project site, I performed several computer experiments to determine the hybrid and inbred rice yield responses to varying amounts of water and nitrogen. Later, I included potassium among the variable inputs and also examined its effect on yield. I performed the computer experiments for the dry season to capture better the response of rice yield to irrigation. The choice of water, nitrogen, and potassium as variable inputs was due to their perceived importance to the growth of rice plants.[30]

De Datta (1981, pp.297-300) described rice as a semi-aquatic plant, indicating that it grows better and produces higher yields when grown in flooded soil. He stressed that water influences the physical characteristics of rice (i.e. plant height, tiller number and culm strength), and acts as a solvent to increase availability of nutrients. Flushing rice field with water also reduces soil toxicity, which can retard root development, inhibit absorption of nutrients, and cause root rotting. The presence of standing water also serves as a method of weed control particularly in the early vegetative stage of the rice plant.

De Datta (1981, pp.350-351) also expressed the importance of major nutrients such as nitrogen, and potassium in the growth of rice plants. Nitrogen increases height, promotes production of tillers, and increases the sizes of leaves and grains. Nitrogen absorption can also lead to a greater number of spikelets per panicle, a higher percentage of filled spikelets in panicles, and in an increased protein content of grains. Potassium increases the size and weight of the grains. It also plays an important role in physiological processes of rice, including opening and closing of stomata, and improves tolerance to unfavorable weather conditions.

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[30] Phosphorus is another major nutrient that affects the growth of rice plants. It stimulates root development, and promotes active tillering, which enables rice plants to recover faster after being subjected in an unfavorable condition. Phosphorus is also good for grain development. However, the DSSAT software was not configured to assess the phosphorus balance for rice, although it can in other crops. Due to this limitation, I was not able to include phosphorus among the variable inputs.

For the two-input case, I combined thirty nitrogen and five water application rates to form a hundred and fifty treatments.[31] To constitute the three-input case, I replicated the two-input treatments for five application rates of potassium resulting in a total of 750 computer simulations for each variety. Figure 4.3 shows the DSSAT-generated yields of hybrid and inbred varieties at various levels of nitrogen and water. Theoretically, generating enough yield data through DSSAT would allow us to create a nonparametric representation of the technology frontier for a particular rice variety. However, it may not be easy to identify the profit-maximizing levels of inputs from this nonparametric form without intensive calculation techniques.

For the purposes of demonstrating the DSSAT model, I estimated a parametric form of the hybrid and inbred yield responses to simplify the optimization process and the derivation of the supply curve. Using the DSSAT-generated yield data, I estimated a quadratic yield response function to simplify the calculation of the analytical solution for the profit maximization. The yield response function to be estimated is written as

$$\text{(4-3)} \quad y_k\left(X;\bar{t}_k,\bar{c},\bar{z},\bar{m}\right)=\alpha_0+\sum_{i=1}^{3}\alpha_i x_i+\sum_{i=1}^{3}\sum_{j=1}^{3}\alpha_{ij}x_i x_j, k\in\left\{\text{Hybrid, Inbred}\right\}.$$

In equation (4-3), y_k is the hybrid and inbred rice production per hectare, X is a vector of variable inputs per hectare (nitrogen, potassium, and water), $\bar{t}_k$ is the vector of genetic coefficients for hybrid and inbred cultivars, $\bar{c}$ is a vector of spatial characteristics (i.e. soil, topography, initial field conditions), $\bar{z}$ is a vector of weather variables (i.e. maximum and minimum temperatures, rainfall, evaporation rate, solar radiation), and $\bar{m}$ is a vector of

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[31] I considered different application rates from 5 to 150 kg/ha/season for nitrogen, from 20 to 60 kg/ha/season for potassium, and from 200 to 1000 mm/ha/season for water.

management variables (i.e. method of planting, age of seedlings, plant population, timing of fertilizer and water applications). Since yields were generated using the same weather conditions, soil properties, and crop management practices, the OLS estimates of the coefficients of yield response functions should not be subject to the endogeneity bias.[32]

Using the estimated yield response functions, the profit maximization problem of a firm can be written as

(4-4) $\underset{X>>0}{\text{Max}}\ py\left(X;\bar{t},\bar{c},\bar{z},\bar{m}\right)-wX,$

where p is the output price, and w is a vector of input prices. The input vector $X^{*}\left(p,W;\bar{t},\bar{c},\bar{z},\bar{m}\right)$ maximizes the profit if it satisfies the following first order conditions,

(4-5) $p\dfrac{\partial y}{\partial x_i}\left(X;\bar{t},\bar{c},\bar{z},\bar{m}\right)\leq w_i$, with equality if $x_i^{*}>0.$

This implies that the value of the marginal product of each input is equal to their respective prices if the level of the profit-maximizing input is positive. The convexity of the production set guarantees that the first order conditions are not only necessary but also sufficient conditions for the existence of a solution to the profit-maximization problem (McFadden 1978; Mas-Collel, Whinston and Greene 1995)[33]. However, a non-convex production set is also possible, leading to a corner solution. Substituting the profit-maximizing input levels

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[32] This problem in estimation of a production function was usually encountered when some unobserved variables (i.e. i.e. weather, soil, and management) are omitted from the analysis. Griliches and Mairesse (1998) provided a good discussion.

[33] The production set would be convex if the estimated yield response functions were concave. The estimated hybrid and inbred yield response functions would be concave if their respective Hessian matrices (*H*) were negative-semidefinite, or mathematically $v'Hv\leq 0$ for any positive column vector v.

back to the original production function (equation 4-4) would lead to the recovery of the output supply function (S). Formally, this could be written as

$$(4\text{-}6)\quad S(p,W)=f\left(X^{*}(p,W;\bar{t},\bar{c},\bar{z},\bar{m});\bar{t},\bar{c},\bar{z},\bar{m}\right).$$

By comparing the derived supply functions for hybrid and inbred rice, I would be able to examine the nature of the supply shift induced by adopting hybrid rice technology.

4.3. Results and Discussion

4.3.1. Two-input Case

Under the two-input case, only nitrogen and water are varied while other nutrients like phosphorus and potassium are considered non-limiting. Table 4.6 summarizes the estimated hybrid and inbred yield response functions for the two-input case. The estimated coefficients of determination (R^2) are 0.96 and 0.95 for hybrid and inbred yield response functions, indicating a good fit. All estimated coefficients are found significant at the 99% confidence level, and have the appropriate signs.

Figure 4.4 demonstrates the estimated hybrid and inbred yield responses to nitrogen at different water levels. The figure shows that the marginal product of nitrogen was positive but diminishing as expected. Similarly, water also had a positive marginal product as shown by the upward shift in the production function as the assumed water level increased. Hybrid and inbred varieties had very similar yield responses at lower levels of nitrogen application. However, when large amounts of nitrogen were applied, the hybrid variety had a greater yield response compared to the inbred variety. The figure also shows a pivoting of the estimated hybrid and inbred yield responses at combination with low nitrogen and high water levels. The pivoting of the yield responses can be interpreted as a sign of stress due to excess water. It can also be due to the inability of the rice plant to take advantage of high water levels at limiting nitrogen levels. However, the pivoting can also be a reflection that the DSSAT model is not calibrated well under very low input scenarios.

Using the estimated coefficients and fixed prices of inputs, I recovered the demands for nitrogen and water as a function of output price.[34] Figure 4.5 displays the behavior of these input demand functions. As expected, the input demands increase with the increase in output price. The figure also shows that for a given output price, farmers who plant hybrid rice would use greater amounts of fertilizer and water compared to those who plant inbred rice. It would also take a positive output price before farmers use nitrogen and water.

The recovered supply functions of hybrid and inbred rice under the two-input case were given by

$$(4\text{-}7) \quad S_H\left(p;\bar{W}\right)=\frac{13504.1\left(p^2-3.76^2\right)}{p^2}, \text{ and}$$

$$(4\text{-}8) \quad S_I\left(p;\bar{W}\right)=\frac{8593.07\left(p^2-3.83^2\right)}{p^2}.$$

Since these functions are derived from a potential yield, these can be interpreted as the highest possible supply that can only happen under circumstances of no pest and disease stress, and non-limiting amounts of nutrients other than nitrogen. Figure 4.6 exhibits the supply responses of hybrid and inbred rice to changes in price. As expected, hybrid and

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[34] The price of nitrogen was PhP 40.00 per kilogram. This was derived from the price of urea, which was PhP 18.60 per kilogram. Each kilogram of urea has 46 % nitrogen concentration. The price of potassium was PhP 34.00. I derived this from the price of Triple-14 fertilizer (with concentration 14%N, 14%P_2O_5, and 14%K_2O), which was PhP 15.60 per kilogram. On the other hand, the opportunity cost of water was based on the value of fuel (diesel) required to pump-out water and increase the flood depth in the field by one millimeter. Using the ratio of 1.5 liter of diesel per 1 millimeter flood depth, the price of water used was PhP 51.00 per millimeter.

inbred supplies were increasing in price, and a positive price was required for a positive amount of rice to be supplied. At very low prices, both hybrid and inbred rice producers would supply the same amount though more hybrid rice would be supplied compared to inbred rice at higher prices. For example, in 2008, at the average price of PhP 14.00 per kilogram, a farmer who planted PSBRc72H would supply 50% more rice than when he or she planted PSBRc82. This would be true only if the farmer's field had the same soil characteristics as in the experimental station, the same crop management was used, and no stress due to disease or pests was experienced.

This exercise predicts that the use of a hybrid rice variety induces a pivotal but divergent shift in the rice supply of an individual producer. I consider this result as an important contribution in the literature because this is the first time that a study specifically predicts the nature of a technology-induced supply shift. The new method I have presented here, which is the first of its kind, is a major improvement over previous methods that merely extrapolate the supply curve back to the price axis based on observed data. With this new approach, I was able to definitively show the behavior of the individual supply curve near the price axis. Given more information, this study could be replicated for various soil classes that characterize the rice areas in the Philippines and it might be possible to generate an industry supply curve.

4.3.2. Three-input Case

In addition to nitrogen and water, I also ran simulations that varied potassium and examined the corresponding yield responses of hybrid and inbred varieties. In this case, other nutrients except for nitrogen and potassium are considered non-limiting. Table 4.7 summarizes the estimated coefficients of the yield response functions of PSBRc72H and PSBRc82 under the three-input case. The estimated R^2 for hybrid and inbred yield response functions were 0.90 and 0.89, which were still high but slightly lower compared to those obtained under the two-input model.[35] Interestingly, the estimated coefficients of potassium and its squared term were negative in both hybrid and inbred yield responses. This suggests a negative marginal product for potassium at low levels of nitrogen and water application. This result can be explained by assuming the incorporation of organic materials from rice straw in the field. Dobermann and Fairhust (2002) stressed that rice straw, which was the only organic material available in significant quantities to most rice farmers, is a rich source of potassium. About 14 to 20 kg of potassium oxide (K_2O) can be recovered from a ton of straw residue. In the model, I assumed that 600 kg of organic material was incorporated in the soil. Given that fair amounts of organic residue were already in the soil, further application of potassium might not yield additional value.[36] Because of this, a zero application of potassium would maximize the profit.

Using the corner solution for potassium, I calculated the profit-maximizing levels of nitrogen and water. Figure 6 displays the hybrid and inbred demand for nitrogen and water

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[35] Note that I used different yield data sets for the two- and three-input scenarios. Under the two-input case, I generated yield data in DSSAT assuming that potassium is non-limiting. Under the three-input case, I varied potassium while generating yield data in DSSAT. Because of the difference in data sets, the resulting R-squared was lower even when I added a new variable in the second regression.

[36] It could be possible that the yield response of rice crop to potassium was not captured properly in the coefficients of the DSSAT model. As mentioned earlier, the DSSAT model was not configured to assess the yield response of rice to phosphorus. If there are significant interactions between phosphorus and potassium, as suggested by De Datta (1981, p. 351), then having phosphorus fixed in the analysis might be the cause of the negative coefficients of potassium and its squared term. This hypothesis could be validated if experimental data are available. However, validating the coefficients of the DSSAT model is beyond the scope of my study.

when zero application of potassium is assumed. This shows that the demands for nitrogen and water increase as the output price increases. For any given output price, the demands for nitrogen and water were lower when zero application of potassium was assumed compared to the case of non-limiting amount of potassium.

The recovered hybrid and inbred rice supply were given by

$$\text{(4-9)} \quad \tilde{S}_H\left(p;\bar{W}\right)=\frac{4394.73\left(p^2-4.66^2\right)}{p^2}, \text{ and}$$

$$\text{(4-10)} \quad \tilde{S}_I\left(p;\bar{W}\right)=\frac{2658.95\left(p^2-5.80^2\right)}{p^2}.$$

Again, these should be interpreted as the highest possible rice supply under no pest or disease stress conditions. Due to a lower input application, the resulting hybrid and inbred supplies under the three-input scenario were lower compared to the two-input case (Figure 4.8). However, the pivotal and divergent nature of the shift in the supply curve was preserved. At lower prices of paddy rice, the supply of hybrid and inbred rice were not largely different. As price increases, the gap between the supplied quantity of hybrid and inbred rice also increases. For example, at 2008 average price of PhP14.00 per kilogram, the hybrid rice producer would supply 3.9 tons per hectare while the hybrid producer would only supply 2.2 tons per hectare given the assumed prices of inputs.

4.4. Limitations and Implications for Future Research

In this study, I demonstrated the use of the DSSAT model in investigating the nature of the shift in supply when a hybrid rice variety was used. The method that I have presented here is the first of its kind. Though far from perfect, this study has demonstrated the use of the DSSAT model in examining the effect of adopting a new technology on input demand and output supply. The use of this crop simulation model has enriched the economic analysis by considering in detail just how the change in technology affects the supply curve, rather than treating this process as a black box.

Aside from applications in assessing the economic impacts of new agricultural technology, the method presented can also be applied to evaluating the environmental effects of adopting a technology. Evaluations of the environmental impacts of over-fertilization, nitrogen loss to denitrification, and methane emission from rice are only some of the potential applications of the DSSAT model. The use of this model can also encourage greater collaboration between various disciplines, such as agricultural sciences and economics, leading to more holistic policy recommendations.

I consider the use of crop models as an approach complementary to econometric analysis. Ordinarily, the use of survey data in estimating a production function leads to an endogeneity bias in the estimated coefficients because of the correlation of input variables to unobserved variables such as technology, weather, soil, and management. The use of DSSAT circumvents this problem because it generates yield data under the same technology, weather, soil, and management variables. This makes the use of OLS in estimating yield response functions feasible even without panel data. In turn, this enables an analyst to isolate and econometrically investigate the true relationship between the output and variable inputs without worrying about endogeneity. Additionally, if the crop model is calibrated well, especially for extreme amounts of inputs, the parts of the production function and the individual supply curve can be examined closely without relying on the observed levels of input use. Given this, the supply function can be extrapolated back to the price axis with greater confidence than when using survey data and econometric methods alone.

While the presented method can be useful, there are major issues and challenges that need to be addressed to optimize the use of the DSSAT model as a complementary analytical tool in assessing the welfare effects of a new agricultural technology. First, the DSSAT model requires huge amounts of data to run simulations. Adequate data on weather conditions, soil properties, existing crop management practices, and plant characteristics may not be available for many desired studies. Fortunately, this problem can be addressed by improving and standardizing data collection and database management for different experiment stations of research organizations (i.e. universities, public research institutes, private research organizations). For example, the NCT-MAT project could be used as a platform to increase availability of data for testing more hybrid and inbred varieties in various production environments in the Philippines. Through this, a better way of examining the effect of adopting hybrid rice varieties on the industry supply curve may be possible.

The second issue centers on the calibration process, which affects how well the DSSAT model predicts real production at extremely low and high levels of input application. This study has shown the pivoting of the hybrid and inbred yield response functions at combinations of very high water level and low nitrogen applications, which could be a reflection of a poorly calibrated model. It is also interesting to note that the model finds potassium as an insignificant input from the economic point of view, though this nutrient is known to have an important role in production. In fact, there is a significant reduction in the output level when a zero potassium application is assumed compared to the scenario where it is assumed to be non-limiting. This calibration issue can be investigated further with the availability of data from experiments that use extremely low and high input applications.

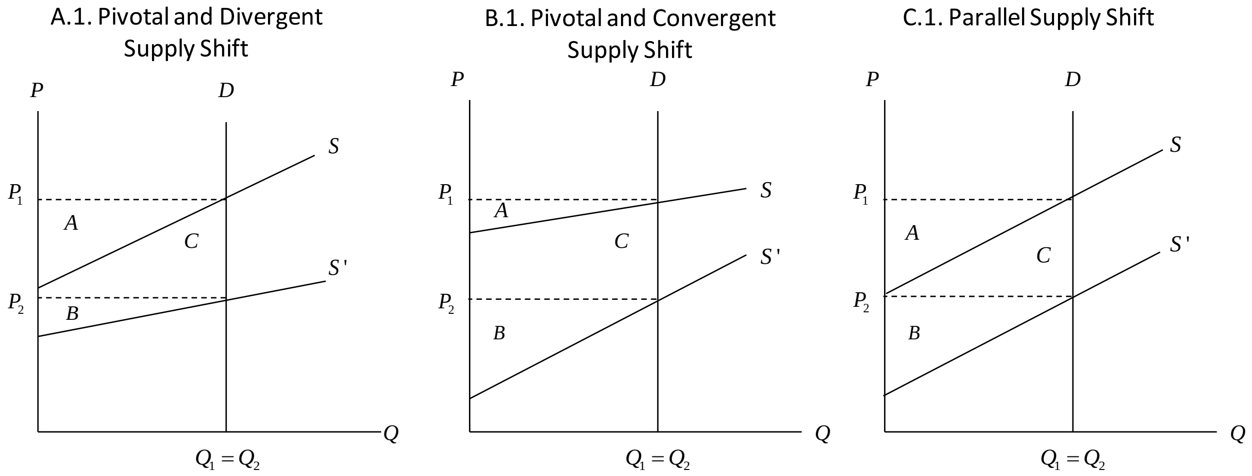
The third issue is the use of a parametric representation of the yield responses. The magnitude of the welfare changes is not only affected by the nature of the shift in supply but also by the assumed functional form. In this study, the choice of the quadratic functional form partly drives the resulting behavior of the derived supply functions. In the future, it may be useful to explore nonparametric techniques to identify the individual supply curve directly from the DSSAT-generated yield data.

This study confirms that hybrid rice technology can generate a greater economic surplus for the society though it cannot fully answer whether the generated benefits could outweigh the costs of R&D of hybrid rice varieties, including the associated cost spent by the government in promoting it. However, the method that I have presented here provides a step towards a better measurement of benefits from adopting hybrid rice technology, and consequently to the measurement of returns to hybrid rice R&D.

4.5. Figures and Tables

Figure 4.1. Nature of supply shifts

Panel 1**:** Perfectly inelastic demand

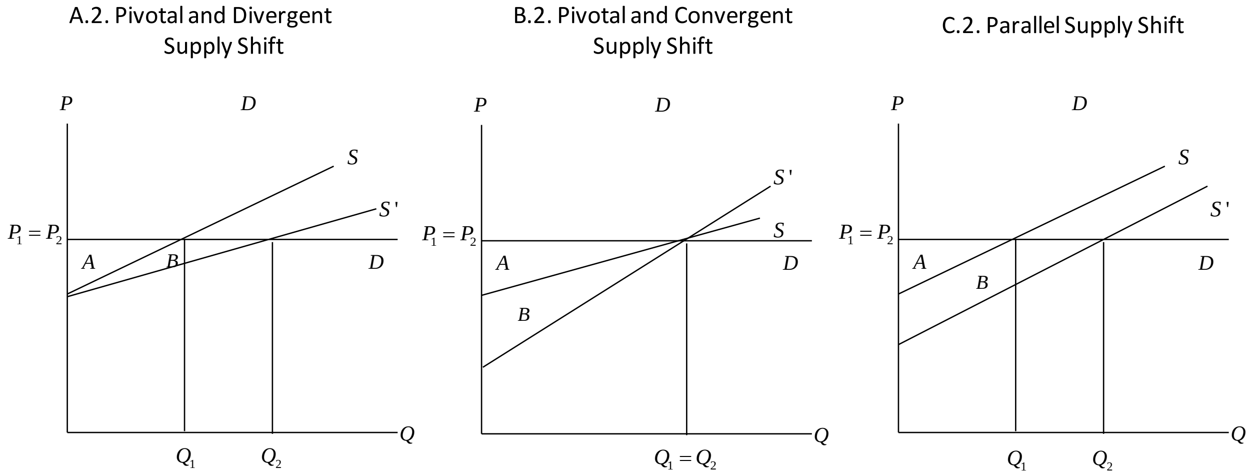


A.1. Pivotal and Divergent Supply Shift

B.1. Pivotal and Convergent Supply Shift

C.1. Parallel Supply Shift

Panel 2: Perfectly elastic demand

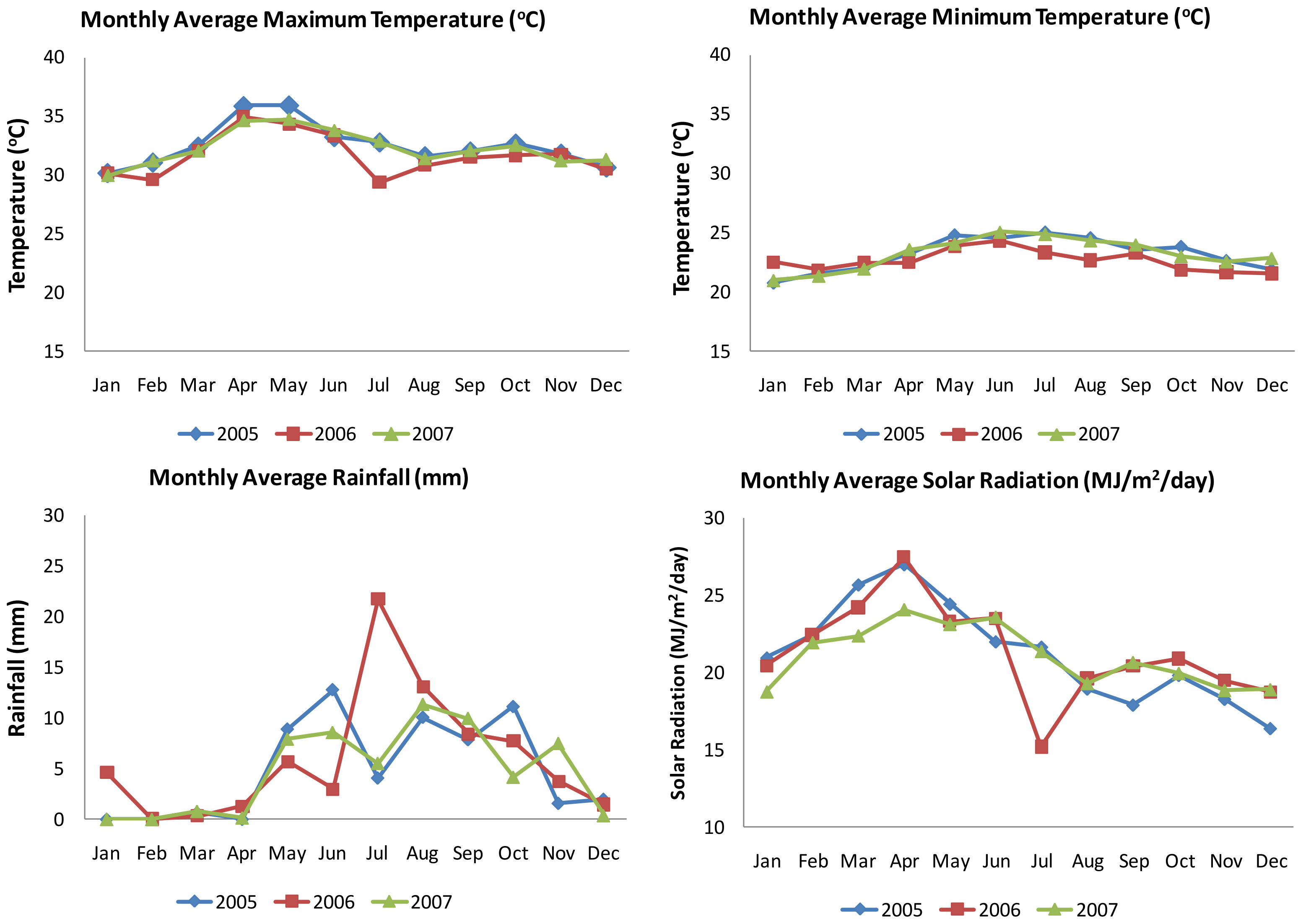


A.2. Pivotal and Divergent Supply Shift

B.2. Pivotal and Convergent Supply Shift

C.2. Parallel Supply Shift

Figure 4.2. Monthly average temperature, rainfall and solar radiation at PhilRice Station, Science City of Munoz, Nueva Ecija , Philippines, 2005-2007



Source: Agronomy, Soils, and Plant Physiology Division, PhilRice, Science City of Munoz, Nueva Ecija, Philippines

Figure 4.3. Hybrid and inbred yield responses to nitrogen at different water levels, two-input case

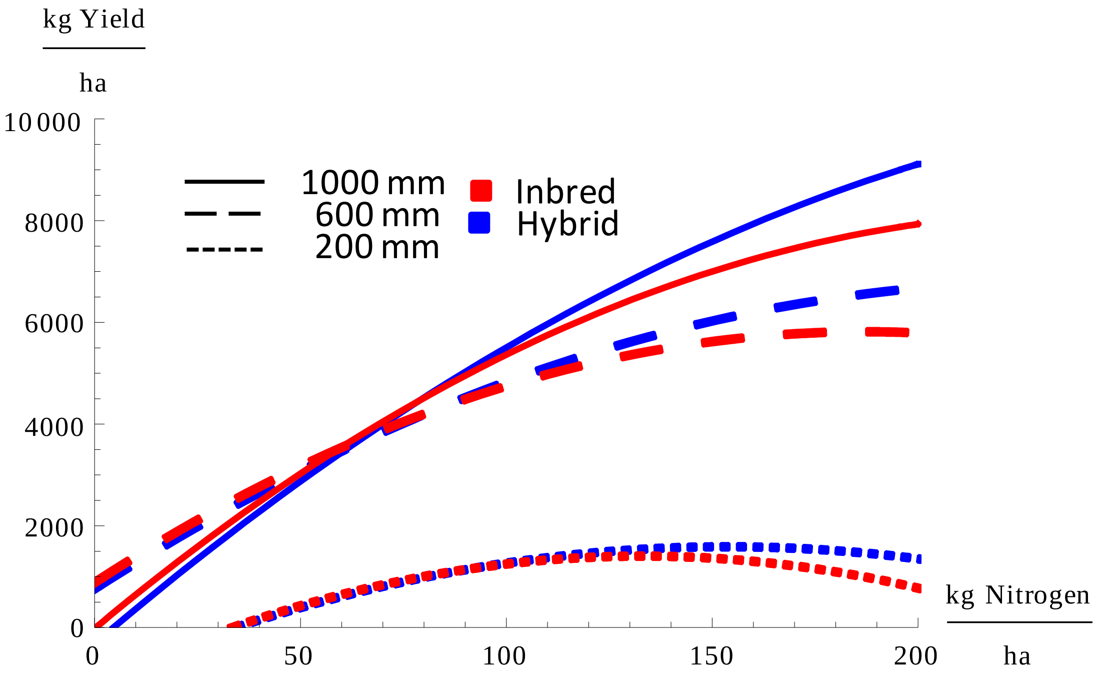


Figure 4.4. DSSAT-generated hybrid and inbred yield responses, two-input case

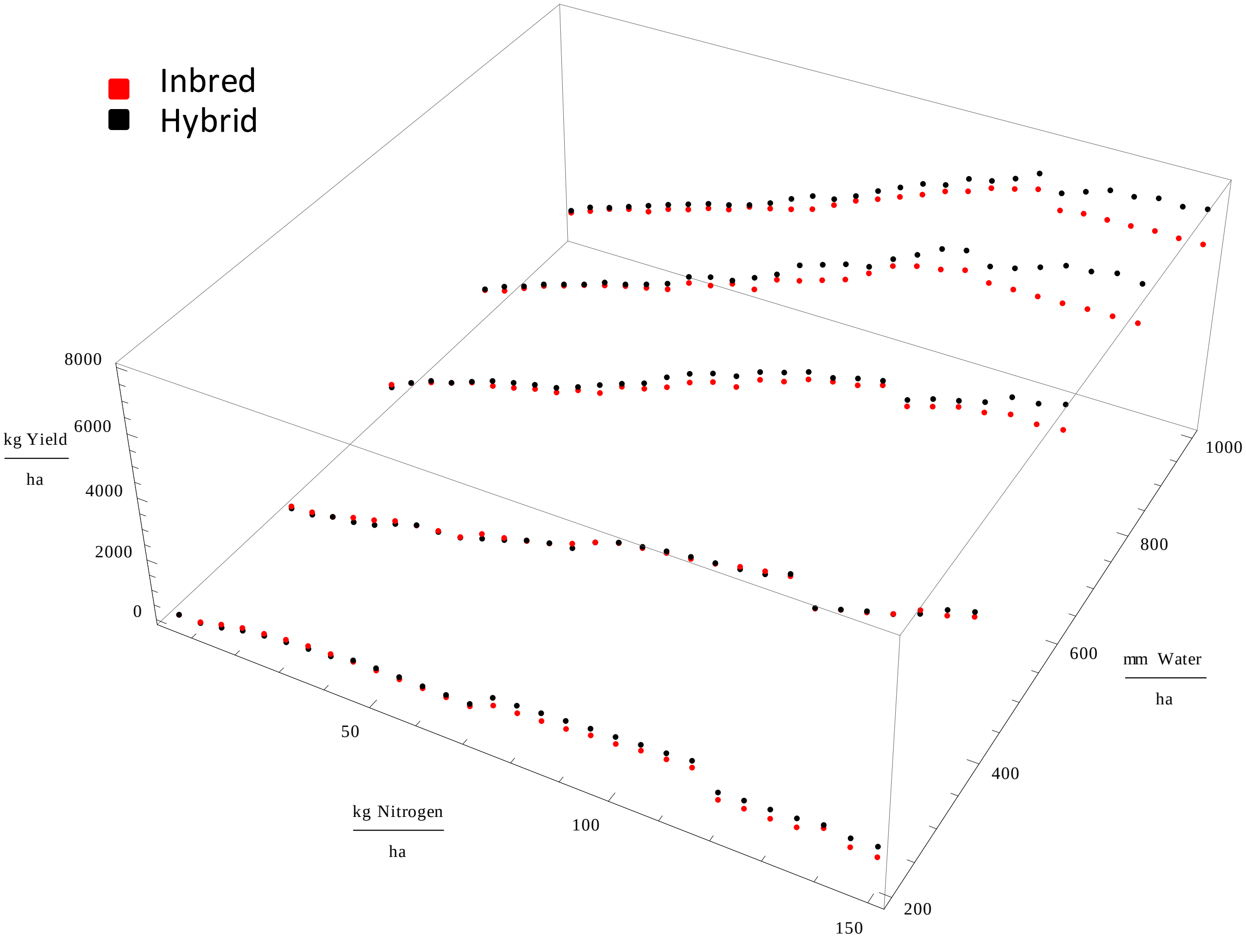


Figure 4.5. Hybrid and inbred demands for nitrogen and water, two-input case

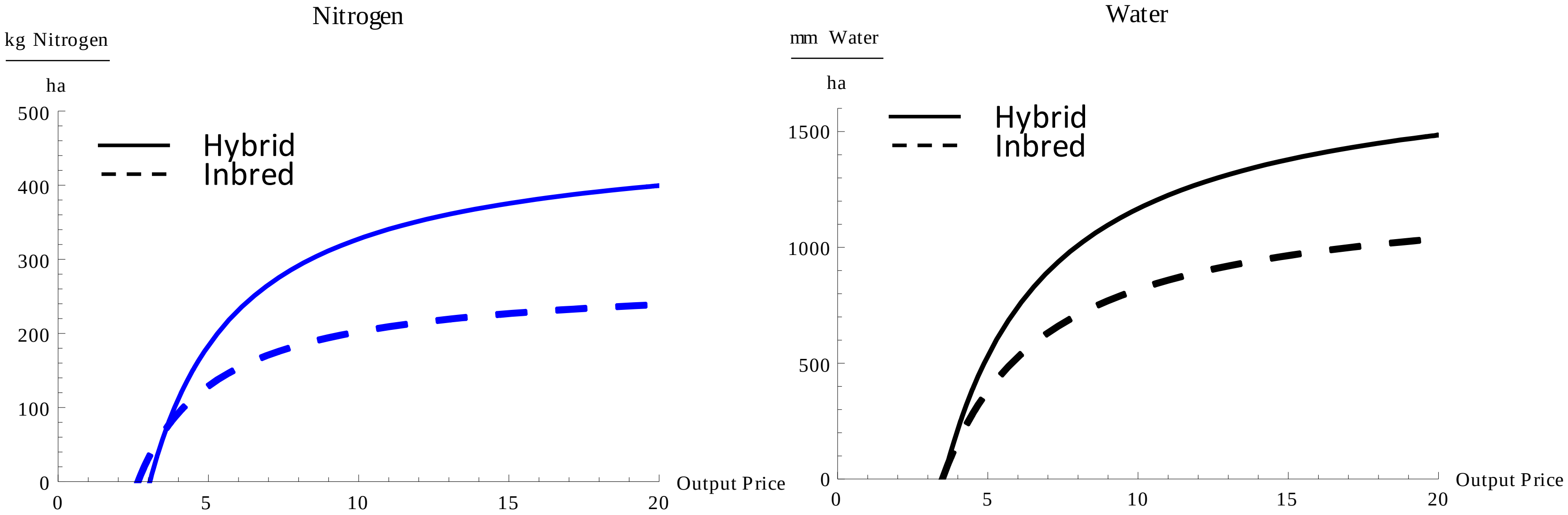


Figure 4.6. Hybrid and inbred supply functions, two-input case

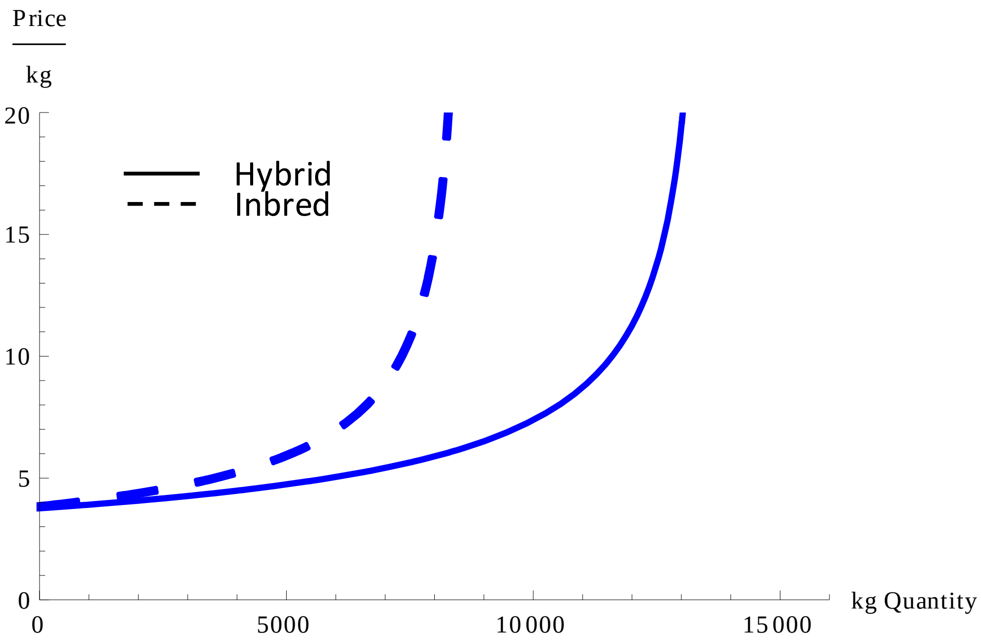


Figure 4.7. Hybrid and inbred demands for nitrogen and water, three-input case

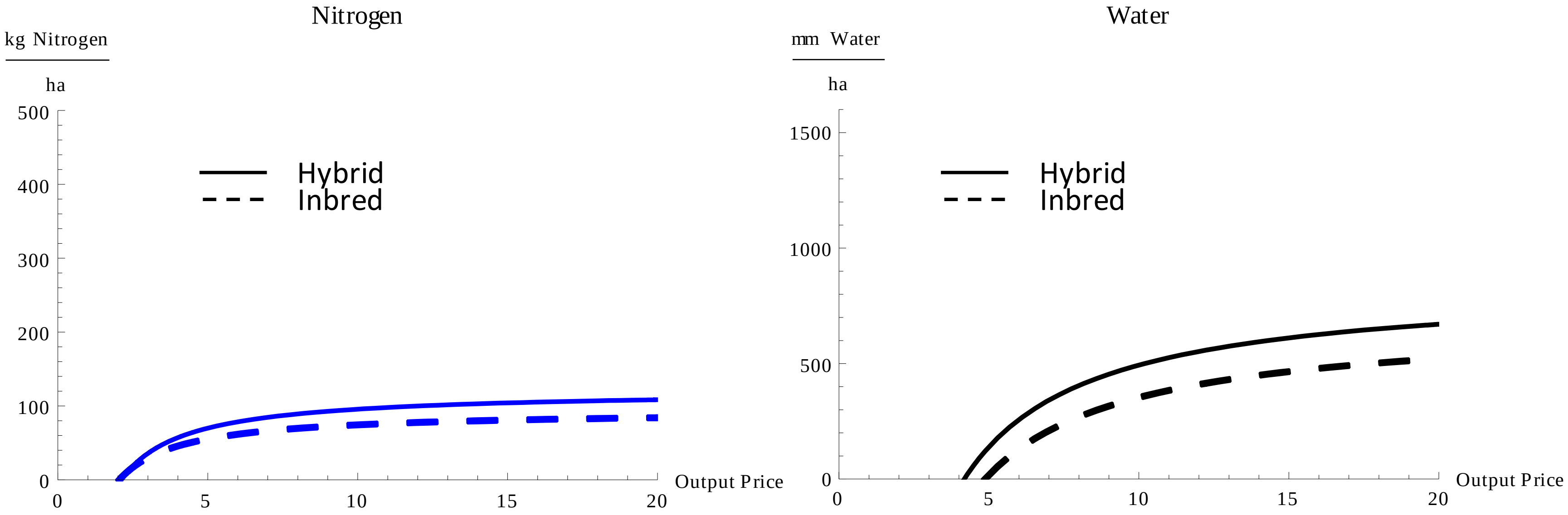


Figure 4.8. Hybrid and inbred supply functions, three-input case

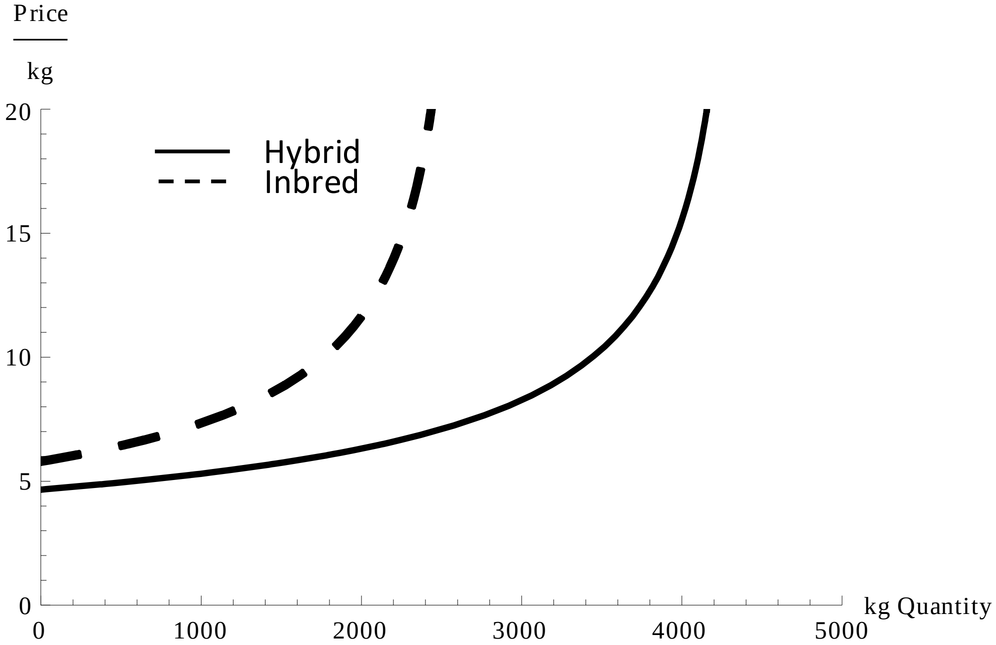


Table 4.1. Minimum data requirements to operate DSSAT model

(a) For Calibration of Model	
Site	Latitude and longitude, elevation; average annual temperature; average annual amplitude in temperature; slope and aspect; major obstructions to the sun (e.g. a mountain nearby); drainage (type, spacing and depth); surface stones (coverage and size)
Weather	Daily global solar radiation, maxium and minimum air temperatures, precipitation
Soil	Classification using the local system and (to family level) the USDA-NRCS taxonomic Basic profile characteristics by soil layer: in situ water release curve characteristics (saturated drained upper limit, lower limit); bulk density, organic carbon; pH; root growth factor; drainage coefficient
Initial conditions	Previous crop, root and nodule amounts, numbers and effectiveness of rhizobia (nodulating crop) Water, ammonium and nitrate by soil layer
Management	Cultivar name and type Planting date, depth and method; row spacing and direction; plant population Irrigation and water management, dates, methods, and amounts or depths Fertilizer (inorganic) and inoculant applications Residue (organic fertilizer) applications (material, depth of incorporation, amount and nutrient concentrations) Tillage Environmental (aerial) adjustments Harvest schedule
(b) For Validation of Model	
	Date of emergence Date of flowering or pollination (where appropriate) Date of physiological maturity Leaf area index (LAI) and canopy dry weight at three stages during the life cycle Canopy height and breadth at maturity Yield of appropriate economic unit (e.g. kernels) in dry weight terms Canopy (above ground) dry weight to harvest index (plus shelling percentage for legumes) Harvest product individual dry weight (e.g. weight per grain, weight per tuber) Harvest product number per unit at maturity (e.g. seeds per spike, seeds per pod) Soil water measurementsvs. Time at selected depths interval Soil nitrogen measurements vs. time Soil C measurements vs. time, for long term experiments Damage level of pest (diseases, weeds, etc.) infestation (recorded when infestation was first, and at maximum) Number of leaves produced on the main stem N percentage of economic unit N percentage of non-economic parts

Source: Jones et al. 2003.

Table 4.2. Properties of Maligaya clay soil at PhilRice Station, Science City of Munoz, Nueva Ecija, Philippines

Soil Properties	Soil Depth	
	0-8 cm	8-23 cm
% Clay[a]	6	6.8
% Silt[a]	36.9	37.1
% Sand[a]	57.1	56.1
Bulk density (g/cc) [a]	1.3	1.38
Saturated Hydraulic Conductivity (cm/sec)[a]	2.8×10^{-5}	4.6×10^{-7}
Total Nitrogen (%)[a]	0.106	0.04
Organic Carbon (%)[a]	1.52	0.63
pH (H_2O)[b]	6.88	
Olsen Phosphorus (mg/kg) [b]	3.1	
Exchangeable Potassium (cmol/kg) [b]	0.1	

[a] Personal communication with Mr. Wilfredo Collado, soil scientist at the Agronomy, Soils, and Plant Physiology Division, PhilRice, Maligaya, Munoz, Nueva Ecija, Philippines

[b] Corton, et al. (2000)

Table 4.3. The calibrated genetic coefficients of PSBRc72H and PSBRc82

Variety	P1	P2R	P5	P20	G1	G2	G3	G4
PSBRc72H	418.4	42.86	525.0	8.123	81.67	0.027	0.88	1.00
PSBRc82	323.0	60.37	544.5	9.975	71.28	0.026	1.02	1.00

Table 4.4. Management practices for NCT-MAT field experiments

	DS 2005	WS 2005	DS 2006	WS 2006
Date of planting	20-Jan-05	19-Jul-05	17-Jan-06	25-Jul-06
Method of planting	Transplant	Transplant	Transplant	Transplant
Age of seedlings (days after sowing)	22	22	26	26
Fertilizer application				
Nitrogen				
1st application (kg)	60 (22 DAS)	30 (22 DAS)	30 (26 DAS)	30 (26DAS)
2nd application (kg)	30 (45 DAS)	30 (32 DAS)	30 (30 DAS)	30 (36 DAT)
3rd application (kg)	60 (60 DAS)	30 (55 DAS)	50 (50 DAS)	30 (55 DAS)
4th application (kg)	-		40 (65 DAS)	
Phosphorus				
1st application (kg)	60 (22 DAS)	30 (22 DAS)	30 (26 DAS)	30 (26 DAS)
2nd application (kg)	-	30 (32 DAS)	30 (30 DAS)	30 (30 DAS)
Potassium				
1st application (kg)	60 (22 DAS)	30 (22 DAS)	30 (26 DAS)	30 (26 DAS)
2nd application (kg)	-	30 (32 DAS)	30 (30 DAS)	30 (30 DAS)

Source: NCT-MAT project

WS - wet season; DS - dry season

Table 4.5. Comparison of simulated and observed grain yield, anthesis, and maturity dates, 2006

Data/ Variety	DS 2006		WS 2006		RMSE	nRMSE
	Observed	Simulated	Observed	Simulated		
Grain Yield (kg/ha)						
PSBRC72H	7435	7368	4358	5069	505	0.09
PSBRC82	6791	7009	4749	5008	239	0.04
Anthesis (days after planting)						
PSBRC72H	67	64	61	65	4	0.06
PSBRC82	52	56	59	58	3	0.05
Maturity (days after planting)						
PSBRC72H	97	97	95	100	4	0.04
PSBRC82	82	91	93	94	6	0.07

Table 4.6. Estimated hybrid and inbred yield response functions, two-input case

Variables	Two-Input	
	Hybrid (PSBRc72H)	Inbred (PSBRc82)
nitrogen	25.35***	29.95***
	[5.207]	[5.261]
water	11.70***	12.15***
	[0.822]	[0.867]
$nitrogen^2$	-0.111***	-0.141***
	[0.025]	[0.025]
nitrogen_water	0.0228***	0.0194***
	[0.002]	[0.002]
$water^2$	-0.008***	-0.009***
	[0.001]	[0.001]
Constant	-3018***	-3165***
	[362.261]	[386.564]
Observations	150	150
R-squared	0.958	0.952

*, **, *** indicate significance at 90%, 95%, and 99% confidence levels.

Table 4.7. Estimated hybrid and inbred supply functions, three input case

Variables	Three-Input	
	Hybrid (PSBRc72H)	Inbred (PSBRc82)
nitrogen	37.11***	32.85***
	[2.790]	[2.488]
water	10.89***	9.714***
	[0.442]	[0.403]
potassium	-16.29***	-7.981**
	[4.404]	[4.009]
$nitrogen^2$	-0.230***	-0.227***
	[0.014]	[0.013]
nitrogen_water	0.011***	0.007***
	[0.001]	[0.001]
nitrogen_potassium	0.104***	0.125***
	[0.010]	[0.010]
$water^2$	-0.008***	-0.008***
	[0.000]	[0.000]
water_potassium	0.013***	0.016***
	[0.001]	[0.001]
$potassium^2$	-0.056*	-0.151***
	[0.033]	[0.031]
Constant	-2470***	-2225***
	[210.557]	[191.319]
Observations	750	750
R-squared	0.899	0.887

*,**,*** indicate significance at 90%, 95%, and 99% level of confidence.

Chapter 5

CONCLUSION

Rice is an important part of the Filipino diet and is an integral component of the household food security. However, I believe that food security is not equivalent to and should not be equated to rice self-sufficiency. Rice policies alone cannot solve the food insecurity at the household level. But still, raising productivity of rice is critical in ensuring that enough supply is available to meet the increasing demand of a growing population. Improving productivity can also increase income of small rice producers and landless farm workers, which may contribute in poverty reduction in rural areas. Furthermore, enhancing productivity is crucial in helping the domestic producers become cost-competitive compared to the international producers. This, in turn, can serve as an impetus for liberalizing the rice trade in the Philippines making the supply available to consumers at an affordable price.

Rice R&D plays a valuable role in improving productivity. In this dissertation, I have shown the various impacts of R&D in the Philippine rice industry. In Chapter 2, I have demonstrated how much technology such as hybrid rice varieties, inbred rice MVs, and the use of certified seed have increased the production at the farm level. I have also shown the contributions of irrigation and farmers' training in increasing rice production per farm. This implies that improving the farmers' access to these non-conventional inputs can further increase the rice production at the farm level. To increase the farmers' access to these non-conventional inputs, the government has implemented an active fiscal policy to lead the nation towards the achievement of food security by investing in R&D, extension, and irrigation, and subsidizing hybrid and certified inbred seed. In the next chapter, I investigated the efficiency of these investments at the aggregate level.

In Chapter 3, I have shown that only R&D investments have reduced the cost of production at the regional level. This emphasizes the importance of investing in R&D to generate more location-specific technologies that are relevant to each region. Development of location-specific rice varieties and decision support systems for better crop management are examples of R&D activities that need to be supported. This is consistent with the results in Chapter 2 that indicates the production-increasing effect of these technology products. However, while it might be optimal to invest in rice R&D, the allocation of public resources to rice R&D must be guided by principles of efficiency. In particular, cost-benefit analysis can be useful in comparing the returns to rice R&D investments to other alternative public investments.

The cost-increasing effects of investments in extension and irrigation at the regional level seem to contradict the production-increasing impacts of irrigation and farmers' training at the farm level. However, I would like to emphasize that increases in the public investments in irrigation and extension at the regional level do not necessarily translate to increases in their services at the farm level. As discussed in the previous chapters, farmers' training is a responsibility of the extension offices in the LGUs. However, the local extension offices usually have a weak support from the local government managers and have inadequate coordination with research organizations. In addition, extension workers at the local government level have low morale, outdated skills, and lack the modern equipment that can make their extension job more efficient. On the other hand, the failure of irrigation investments in generating services can be attributed to the low participation of farmers in irrigation management. Probably due to these institutional weaknesses, public investments in extension and irrigation have failed to generate enough economic services that lead to cost reduction in the region. Thus, in order to benefit from these investments, the current extension and irrigation systems must be reformed.

Chapters 2 and 4 document the success of adopting hybrid rice and certified inbred seed. However, Chapter 3 shows inefficient public spending on subsidies to these inputs indicating that subsidizing these technologies may not be the best way to increase their adoption. The government intervention in the seed market has been ineffective in bringing these technologies to the producers to the right place and at the right time. This subsidy has distorted the incentives for farmers to choose the appropriate technology for their production. In addition, the provision of subsidy has siphoned the government's limited financial and human resources away from more productive R&D and appropriate extension activities. Based on these findings, I support the phasing-out of these input subsidies.

Instead of subsidies, a better way to encourage farmers to adopt technology is by breeding better varieties and development of decision support systems so that farmers can appropriately manage their crops. This can only be achieved through continuous research. In addition, a revitalized extension system that provides better services to farmers in terms of improved technical assistance can also increase the adoption of seed technology. The government can also encourage the participation of the private sector to make these technology inputs available to farmers. These points emphasize the need for government to focus on providing public goods while promoting the participation of the private sector in the development process.

As an economist myself, I recognized that the economics profession has contributed to the growing cynicism on the ability of R&D to improve the welfare of the society. Though many economic studies assessed the returns to agricultural R&D and found positive rate of returns, the wide variability of these estimates has planted the seed of doubt regarding the economic efficiency of R&D. This may have transpired due to the lack of a better economic tool for investigating agricultural technology.

In Chapter 4, I have presented a new approach of using the DSSAT model in investigating the nature of a technology-induced shift in supply. In this chapter, I have demonstrated the potential of this methodology by predicting the pivotal and divergent shift in the individual supply of rice when a hybrid variety is adopted. The methodology has the potential to be applied at the aggregate level. In particular, the method can be used in predicting the nature of technology-induced shift in the industry supply if the appropriate data is available. This can be addressed by having a greater collaboration between the disciplines of economics and crop sciences, and by standardizing the data collection and database management in different research agencies.

To optimize the use of the DSSAT model as a complementary tool for economic analysis, further research must be done in terms of the proper calibration of the model. This entails the use of more data from field experiments, which may already exist but needs to be repurposed. The use of nonparametric approaches is also worth exploring in identifying the supply curve from the DSSAT-generated yield data to extract more information.

Additionally, a comparison of the use of the DSSAT model and the traditional use of survey data and econometric techniques can also yield important information. Despite its limitations, the method I presented is a big step toward a better measurement of the benefits from adopting technology in particular and returns to R&D in general.

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