TECHNOLOGICAL PROGRESS, EFFICIENCY AND ENVIRONMENTALLY ADJUSTED PRODUCTIVITY GROWTH OF INDONESIAN RICE AGRICULTURE

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Statement of Originality

I certify that this thesis is my original work except where due reference is made in the text.

Joko Mariyono

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Abstract

Rice production in Indonesia is important because it contributes more than 50 per cent of the total value of the agricultural sector. As a staple food, rice represents the largest caloric intake for more than 200 million people. The discussion of Indonesian rice development provided in Chapter 2 indicates that rice has been a priority in agricultural development. Various programs and investments in infrastructure have been undertaken to modernise rice production. Current policy still gives a priority to rice production through an agricultural revitalisation program. This thesis investigates agricultural modernisation, consisting of technological change, technical efficiency and allocative efficiency, and its impacts on productivity and the environment on rice agriculture in Indonesia.

In Chapter 3, the environmental consequences are analysed using concepts of biased technological change. Using the concept of production frontier and a data set from the Indonesian Statistical Agency and the Indonesian Centre for Agricultural Socio-economic and Policy Studies, it is clear that agriculture during 1979-1995 underwent technological regress, with environmentally biased technological change. Technological changes in intensive rice agriculture during the Green Revolution were more agrochemical using. Changing to a more environmentally sound policy reduced the intensity of agrochemical use.

Analysis of technical efficiency is provided in Chapter 4. Using the concept of the production frontier and a data set from the Indonesian Centre for Agricultural, Socioeconomic and Policy Studies, technical efficiency estimates are obtained. The results show that there is a variation in rice production due to technical efficiency. Household characteristics, composition of labour and tractor use are the sources of variation in technical efficiency. Javanese rice agriculture is the most technically efficient, and technical efficiency of rice agriculture in all regions has increased. Overall, technical efficiency is low. Therefore there is still considerable room for improvement in rice production, given state-of-the-art agricultural technology.

In Chapter 5, further analyses of efficiency related to the use of environmentally detrimental inputs and social efficiency are provided. The results show that there is an indication of low environmental efficiency, leading to significant agrochemical waste. Large-scale farms lead to greater amounts of waste because of large amounts of agrochemicals used. Rice production also fails to allocate all inputs at the correct level. Land is still under-utilised and other inputs are overused.

Chapter 6 analyses productivity growth decomposed into technological change, efficiency and scale effects. The productivity growth is also adjusted by the environmental costs associated with the use of agrochemicals. The results show that the total factor productivity growth is driven by technological change and allocative efficiency effects. This is good as the adopted technology is more advanced and the allocation of inputs more efficient. Taking environmental costs into account lowers the productivity growth. But, the environmentally adjusted productivity growth is a fair measure. Productivity growth, as well as environmentally adjusted productivity growth, has increased dramatically over time.

The policy implications of the study should ultimately contribute to sustainable increases in rice production and conservation of the agricultural environment. Environmentally friendly technology should be continually developed and applied to reduce agrochemical intensity, and the rate of efficiency improvement should be enhanced. Special attention should be paid to deal with the problem of agrochemical pollution caused by the inefficient use of agrochemical inputs. It is expected that these will bring about a sustainable increase in productivity growth.

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Chapter 1

Introduction

Agriculture and Sustainable Rural Development

The subject of development economics in general and agricultural economics in particular, has long focused on how agriculture can best contribute to growth and modernisation. Early on, Fei and Ranis (1961) highlighted agriculture because of its abundance of resources and its ability to transfer surpluses to the what was perceived to be more important industrial sector. The primary role of agriculture in the transformation of a developing economy was considered secondary to the central strategy of accelerating the speed of industrialisation. This conservative approach to agriculture's role in development gave attention to important market-mediated linkages of agriculture: providing labour for urban sectors; producing food for expanding populations with higher incomes; supplying savings for investment in industry; enlarging markets for industrial output; providing export earnings to pay for imported capital goods; and producing primary materials for agro-processing industries (Johnston and Mellor 1961).

There are good reasons for these early approaches to focus on the economic roles of agriculture as a one-way flow of resources towards the industrial sector and urban centres. In agricultural societies with a small number of trading opportunities, most resources are devoted to the provision of food. As national incomes rise, the demand for food increases much more slowly than other goods and services. New technologies for agriculture lead to expanding food supplies per hectare and per worker, and the modernising economic sectors use more intermediate inputs purchased from other sectors.

The decline in agricultural GDP share is partly the consequence of post-farm-gate activities, such as taking produce to market, that become commercialised and are taken over by specialists in the service sector, and partly because producers substitute agrochemicals and machines for labour. Producers receive a lower price and, in return, their households spend less marketing time. As a result, value added from the farm household's own labour, land and capital, as a share of the gross value of agricultural output, falls over time as purchased intermediate inputs become more important. Farmers' increasing use of purchased intermediate inputs and off-farm services adds to the relative decline of the agricultural sector in terms of overall GDP and employment (Pingali 1997).

A number of development economists have tried to point out that, while agriculture's share fell relative to industry and services, it still grew in absolute terms, evolving increasingly complex linkages to non-agricultural sectors (Adelman 1984; Singer 1979; Vogel 1994). They highlighted the interdependence between agricultural and industrial development and the potential for agriculture to encourage industrialisation. The argument was that productive agriculture and institutional links with the rest of the economy produce demand and supply incentives that promote modernisation.

This broader approach to the economic roles of agriculture suggested that the one-way path leading to resources out of the rural communities ignored the full growth potential of the agriculture sectors. Resources may need to move towards industry and urban centres, but attention had to be focused on the capital, technological, human resource and income needs of agriculture. This required policymakers to change strategies.

Agriculture and industries are convincingly connected. The growth of industries is dependent, in many ways, on agriculture and primary production. Primary production grows and progresses to reflect the demands of industry, and industries develop and grow to reflect the potential of the rural sectors (Akiyama 2004). Ignoring the large economic and social contributions of primary agriculture to these much faster-growing industrial activities presents an incomplete picture of their shared world. Ignoring the whole range of economic and social contributions of agriculture underestimates the returns to investment in the sector (Stringer and Pingali 2004).

At present, the development consensus is that a strongly performing agricultural sector is fundamental for overall economic growth. Improving agricultural performance generates income in both rural and urban areas. As incomes increase, households save more and spend more, stimulating growth and investment in other sectors (Stringer and Pingali 2004). Such positive direct and indirect cross-sectoral linkages are mediated in particular through lower food prices, labour migration and capital flows from agriculture, but there are also other channels through which growth in the sector impacts positively on economic development.

In most developing countries where agriculture is the dominant sector, measured in terms of employment of resources and of income generation, it is a source of livelihood and nourishment for the majority of people, and the agricultural growth provides the important hope of higher standard of living (Kalirajan 1990). Especially in those countries where the share of agriculture in

GDP is still significant, Timmer (2002) argues that agricultural productivity may impact on overall economic growth through various positive indirect and roundabout linkages which are classified in four categories: technology linkages; physical capital linkages; human capital linkages; and linkages through positive impacts on a number of efficiency shifters that determine the degree to which a frontier per capita income is reached. Akiyama (2004: 62) clearly proves that 'the growth rates of overall economic and non-agricultural activities are closely correlated with those of the agricultural sector'.

Thus, the widely practiced policies that had inhibited growth of the rural sector needed to give way to a less discriminatory policy atmosphere for agriculture (Krueger et al. 1991), more investment in producing technological innovations (Hayami and Ruttan 1985) and public investment in rural incomes to generate social and physical infrastructure (Adelman 1984; Vogel 1994). The strong interdependence between agriculture and the other sectors is more widely recognised. It is necessary to progressively reverse past discrimination and policy bias against developing countries' agriculture.

Agricultural productivity growth is able to bring significant opportunities for reducing poverty and hunger (de Janvry and Sadoulet 2002). Most poor people in developing countries live in rural areas and depend directly or indirectly on agriculture for their livelihoods. Growth in agricultural productivity is also capable of reducing malnutrition and improving health outcomes. Over the past three decades, agricultural productivity growth tripled food production in developing countries and contributed to a significant decline in the proportion of undernourished people. Increased food availability is central to improving food security. Agricultural productivity growth – when based on efficiency, sustainability and social equity — promotes income growth for households and communities, improving livelihoods and lifting not only farmers, but also entire communities out of poverty.

However, enhancement of agricultural productivity can, if mismanaged, result in depletion or degradation of the natural resource base. Up till now, many current agricultural practices have pressured long-term sustainability, leading to environmental degradation. The challenge for sustainable rural development is to enhance agricultural productivity while conserving the natural resource base, increasing rural incomes, generating employment and promoting the nutrition and food security status of households and individuals.

The excessive use of pesticides and fertilisers has potential consequences of poisoning soil and rendering it unusable, and causing significant human health problems. Land degradation and erosion lead to declines in agricultural productivity. Future increases in agricultural productivity will need to rely on long-term investments in order to improve knowledge on environmental degradation status, impacts and causes, promote environmentally sound practices, and encourage research and development and technology transfers to raise agricultural productivity.

Rice and Agricultural Development

The importance of rice in agriculture is verified by the fact that more than 90 per cent of the world's rice is produced and consumed in Asia, where rice is consumed three or more times every day. In 1999 for example, Asians consumed nearly 500 million tons of rice. Rice is very important to many poor who expend half to three-fourths of their incomes on it. The average consumption of rice varies from country to country with the average person in Myanmar eating about 195 kg of rice annually. In Laos and Cambodia the average per person consumption is about 160 kg. By way of comparison, the average European eats about 3 kg and the average American about 7 kg of rice per year (Runckel 2000).

Rice has been a special interest in the effort of most Asian economic development. It has shaped the economic development of the countries in the era of an agricultural development (Hayami and Ruttan 1985; Mellor 1966). This is because Asia has 250 million rice farms and mainly small peasant holdings where around 85 per cent of all farms are less than five hectares (Hayami 2004). This means that rice cultivation is also a substantial factor in Asian employment. Rice also has an important role in trade and is an important foreign currency earner for many Asian countries (Runckel 2000). Thailand has the highest net value and rice is the main factor in the economy. Rice is also a critical factor in export earnings in Vietnam, one of the largest Asian rice exporters.

Rice is not only integral to life in Asia, but also in the world. The food problem in Asia in the 1960s became a world problem. This arose not only from production shortages, but also because the population in developing countries in Asia is about half of the world population and growing. The need for more food inspired the search for new and better ways of producing rice. International research institutions such as the International Rice Research Institute (IRRI) contributed to the effort to overcome the problem.

One of the first breakthroughs was in high yielding varieties (HYVs) of rice. The first variety released by IRRI was IR8 in 1966 with higher yield capacity, shorter and stiffer straw, pest and disease resistant and adaptable to a wide geographic range. The diffusion of HVYs and the resulting agricultural transformation from traditional to modern, along with the complementary technology is called the 'Green Revolution' and describes the tremendous increase in rice production in many developing agrarian countries over the past four decades. The Green Revolution denotes a dramatic increase in crop yield resulting from the development and adoption of new agricultural technology. The increase in food production was perceived as a fundamental achievement which could provide a global solution to the Malthusian dilemma, especially in Asia.

As an Asian developing country, Indonesia pays attention to agriculture in national economic development since it occupies a leading role in the Indonesian economy. Even though the relative position of the agricultural sector has decline significantly over the past four decades, its importance to the Indonesian economy has not decreased (Kawagoe 2004). In 1981 the agricultural sector constituted 24.5 per cent of gross domestic product and in 1980 employed 54.8 per cent of the total labour force. In 1979, rice itself contributed 17.5 per cent of GDP, or 56.8 per cent of the total value into the agricultural sector. In the 1990s, agriculture still provided approximately 50 per cent of jobs and around 20 per cent of GDP (Hill 2000).

As in other Asian countries, in Indonesia rice is an important commodity. It carries great emotional and symbolic weight, being associated with the rural family, whose importance is proclaimed in Indonesia's constitution (Kawagoe 2004). It is a staple food that represents the largest nutritional caloric intake for more than 200 million people, despite the fact that corn, cassava, soybean and sweet potato are important supplementary foods. Politically, rice is a strategic product. Either a shortage of rice in domestic markets or a highly variable price has the potential to generate political instability. The shortage of supply of rice into domestic markets has become a more pressing problem in the Indonesian economy, not only because it is the main staple food, but also because the price is always a matter of public awareness on considering the people's expectations on inflation rate and economic stability (Widodo 1989).

The Problem Statement and the Research Question

There are three main problems in Indonesian rice production. First, rice farming practices have given a high environmental pressure since the Green Revolution. This environmental pressure results from a high use of agrochemicals (Fox 1991). This condition is not in line with the increasing global awareness on environmental issues and interest in sustainable agricultural development.

Second, rice production is still inefficient. This leads to a condition in which rice production is relatively low and uncompetitive compared to other rice producing countries. As a result, there is no incentive for farmers to continue operating rice farms, and imported rice will dominate the Indonesian market. It is more realistic for Indonesia to be more competitive in rice production by increasing the efficiency.

Third, increasingly intensive rice-farming for fulfilling increasing demand associated with population growth leads to environmental problems. Indonesian rice production is facing a challenge of population growth leading to an increase in demand for food. For the last decade, production of rice has not been able to match domestic demand, and consequently it has been necessary to import

(Warr 2005). This will require continual increases in agricultural productivity, despite the fact that productivity growth is slowing and the availability of land for future expansion is limited. Rice production has used chemical inputs since the introduction of the Green Revolution. Despite the fact that the Green Revolution boosts production, the use of agrochemicals leads to adverse impacts on the environment (Fox 1991). Furthermore, environmental problems associated with agriculture threaten future levels of agricultural productivity and impose severe environmental and health costs at a national level. Continued agricultural growth is therefore not an option, but a necessity instead. This growth however must not jeopardise the underlying natural resource base or impose high external cost on others.

Research questions raised in this study are:

1. Does technological change in rice production adversely affect the environment? There have been two important technologies implemented in rice production: chemical intensive technology and environmentally sound technology. There is still lack of scrutiny of the different technologies in terms of environmentally induced technological change.
2. How have rice farms performed in terms of efficiency? The efficiency level of rice farms represents a measure of their performance in rice production. The efficiency consists of technical, allocative and environmental efficiency. Combining technical and allocative efficiency gives economic efficiency, and taking environmental efficiency into economic efficiency yields social efficiency. There is limited scrutiny of technical, allocative, environmental efficiency, and the relationship between such efficiencies of current rice production.

3. What drives productivity growth in rice production, and what is the impact of negative externalities on productivity growth? Total productivity growth can be dissected into technical progress and improvement in efficiency. Analysis of decomposition of total productivity growth (where change in efficiency is separated into technical and allocative efficiency, and environmental efficiency) has almost never been conducted.

Objectives of Research

The objectives of this thesis are as follows.

1. To investigate the agricultural modernisation and productivity and its environmental impacts in rice agriculture in Indonesia. Agricultural modernisation is a representation of technological progress consisting of technological change, technical efficiency and allocative efficiency (Janssen and Ruiz de Londonõ 1994). Environmental impacts of modernisation are analysed using a concept of biased technological change resulting from agrochemical intensive farming practices and past implementation of environmentally sound technology.
2. To examine technical efficiency and sources of its variation. Technical efficiency is analysed using a stochastic production frontier of current farming practices. Sources of inefficiency to be analysed are farm characteristics, socio-economic and geographical factors.
3. To analyse environmental, allocative and social efficiency derived from technical efficiency, and measure the amounts of agrochemicals discharged into the environment. The amount of chemical waste is assumed to exceed assimilating capacity, to be detrimental to the environment and to cause

diseconomy externalities. These externalities are then valued in monetary terms using an "effect on production" approach. As stated by Fox (1991) the environmental cost of chemical use should be taken into consideration, and the monetary value internalised into the cost of production to obtain a social benefit. Thus social efficiency of rice production can be determined.

4. To examine the growth rate of productivity decomposed into technological change, efficiency and scale effects, and then productivity growth is also adjusted by the environmental costs. The environmentally adjusted productivity growth is defined as 'sustainable productivity', where costs related to the environment have been taken into account.

The results and policy implication of this thesis should ultimately contribute to sustainable increases in rice production, decreases in poverty and conservation of the agricultural environment.

Organisation and Content of the Thesis

This thesis is divided into two principal sections. The first (Chapters 2 and 3), provides descriptive and econometric analyses of the development and policy of rice agriculture in the past. Chapter 2 describes chronological development and policy and provides an analytical foundation for the thesis, drawing links among technological change in rice production and rice policies. Chapter 3 provides econometric analysis of technological change in rice production in relation to environmental impact of rice farming practices. There are two distinct programs related to environmental consequence: intensive rice and non-intensive programs. There are also two different policies that may induce environmental problems, that is, one, programs related to Green Revolution and two, environmentally sound policies. The programs and policies are expected to be different in terms of technological change. Aggregate data at provincial level are used to analyse the technological change.

The second section (Chapters 4, 5 and 6) provides an econometric analysis of the current performance of rice production. The performance is represented by efficiencies and productivity of rice production. Chapter 4 analyses technical efficiency using a primal approach, or with a production function. Realising that producers are not technically efficient, Chapter 5 analyses environmental efficiency, a recent concept of efficiency augmented from the technical efficiency where environmentally detrimental inputs are used in the production. Since the production is environmentally inefficient, an environmental adjustment of productivity growth is proposed in Chapter 6. The productivity growth is decomposed into technical change, technical and social efficiency analysed in Chapters 4 and 5. The environmental issue discussed in this thesis is the use of agrochemicals, which consist of inorganic fertilisers and synthetic pesticides. Farm level panel data from a longitudinal survey conducted by the Indonesian Centre for Agricultural, Socioeconomic and Policy Studies (CASEPS) of the Ministry of Agriculture are used in these analyses.

The thesis ends with a set of conclusions, reviewing the impact of policy in the past and the prospects for the future. Although the spectacular increases in rice productivity of the recent past might not be achievable again, environmentally sound sustained improvements in the quantity and quality of production are clearly possible. However, increased and sustainable improvements will only arise if policymakers are successful in finding an appropriate set of rice policies. Creative, innovative farmers remain ready to expand rice production in response to public incentives.

Chapter 2

Development of Indonesian Rice Production

Abstract

This chapter analyses a chronological description of agricultural development in Indonesia. It was remarkable that the agricultural sector was ignored as a result of "Dutch Disease", when the oil boom benefited the Indonesian economy. As the revenue from oil dropped significantly, the agricultural sector became important as an engine of economic growth. Rice was the top priority. Various intensification programs, coinciding with the Green Revolution, were launched, and various institutions were established to support the programs. The result was so influential that Indonesia was able to achieve rice self-sufficiency. But, along with a growing awareness over the sustainable development, the intensification programs were irrelevant. The programs were replaced with an environmentally sound policy. As industrial sectors grew, again, the agricultural sector was ignored, until an economic crisis hit Indonesia. Realising that the agricultural sector is important, the sector is developed equally with other sectors.

Introduction

Despite the abundance of land, Indonesia still imports rice to meet domestic demand (Business-in-Asia.com 2003). The magnitude of its imports varies depending on domestic production, international prices, the size of Indonesia's stocks and the government's rice import policy. With an unparalleled past performance in achieving rice self sufficiency during the late 1980s and early 1990s, Indonesia –in the middle of the current Asian crisis— was suffering from lengthy droughts and unsuccessful recent harvests. It has been estimated that Indonesia will need to import between 4.4 million and 8.0 million tons of rice in

1998, which amounts to about 25 to 40 per cent of world trade in rice (Economist 1998). Over the 4 years following the Asian financial crisis of 1997-1998, the portion of imported rice was 9.1 per cent of its total consumption of rice and 18 per cent of the world's total imports, making Indonesia the world's largest rice importer (Warr 2005). To meet this considerable challenge, the government needs to give foreign exchange reserves for financing rice imports in order to provide adequately enough food to support consumer prices.

The recent developments in rice production have energised the ongoing debate in Indonesia regarding the government's interventions in the rice market. Such interventions concerning the quantities and prices of rice imports are politically sensitive especially because rice is a staple food and accounts for a large share of both consumers' budgets and total employment. In Indonesia, rice also represents the largest nutritional caloric intake for more than 200 million people, despite the fact that corn, cassava, soybean and sweet potato are important supplementary foods (Widodo 1989). Rice represents 7.2 per cent of average consumer expenditure and its production employs 7.1 per cent of the total work force at the farm level alone. Its importance is even greater for the lowest income groups, for whom both the average share of rice in total consumption and the dependence on rice production as a source of employment far exceed the average for the whole population. For example, for that part of the workforce with only primary school education or less, the production of rice at the farm level accounts for 18 per cent of total employment (Warr 2005).

Rice economy provides benefits to many individuals and sectors because it is involved in the economic activities of most Indonesian people, in both rural and urban sectors. The supply chain from production in rural areas to consumers in both urban and rural areas involves many stakeholders (Ellis 1993). Rice production is mostly carried out by a huge number of small farms (Utami and Ihalauw 1973) employing rural labour. In rural areas where there is an abundance of labour, it is likely that rice production is labour intensive. Traditionally, '... rice harvesting takes the form of a community activity in which all or most community members can participate and receive a certain share of output' (Hayami and Hafid 1979: 95). Post harvesting activities also employ a great deal of labour including its transportation and engage many kiosks of agricultural output and inputs in rural areas (Mears 1981).

There has been a long history of agricultural development in Indonesia. The last two political phases have influenced agricultural development. The first phase is the "New Order" era under the Presidency of Soeharto. During this era, attention was given to the agricultural sector, particularly rice. Various programs were launched to enhance rice production. The milestone of this era was the ability of Indonesia to achieve rice self-sufficiency (Fox 1991), with the President being invited by the Food and Agriculture Organisation of the United Nation (UN-FAO) to address an international conference. The second phase is the "Post New Order", or "Reformation" era. This era is under three Presidents: Abdullrahman "Gus Dur" Wahid, Megawati Soekarno Putri, and Susilo Bambang Yudhoyono. Under the current president, there is a favourable environment for agriculture to grow as current policy pays attention to agriculture as one of the more important sources of economic growth.

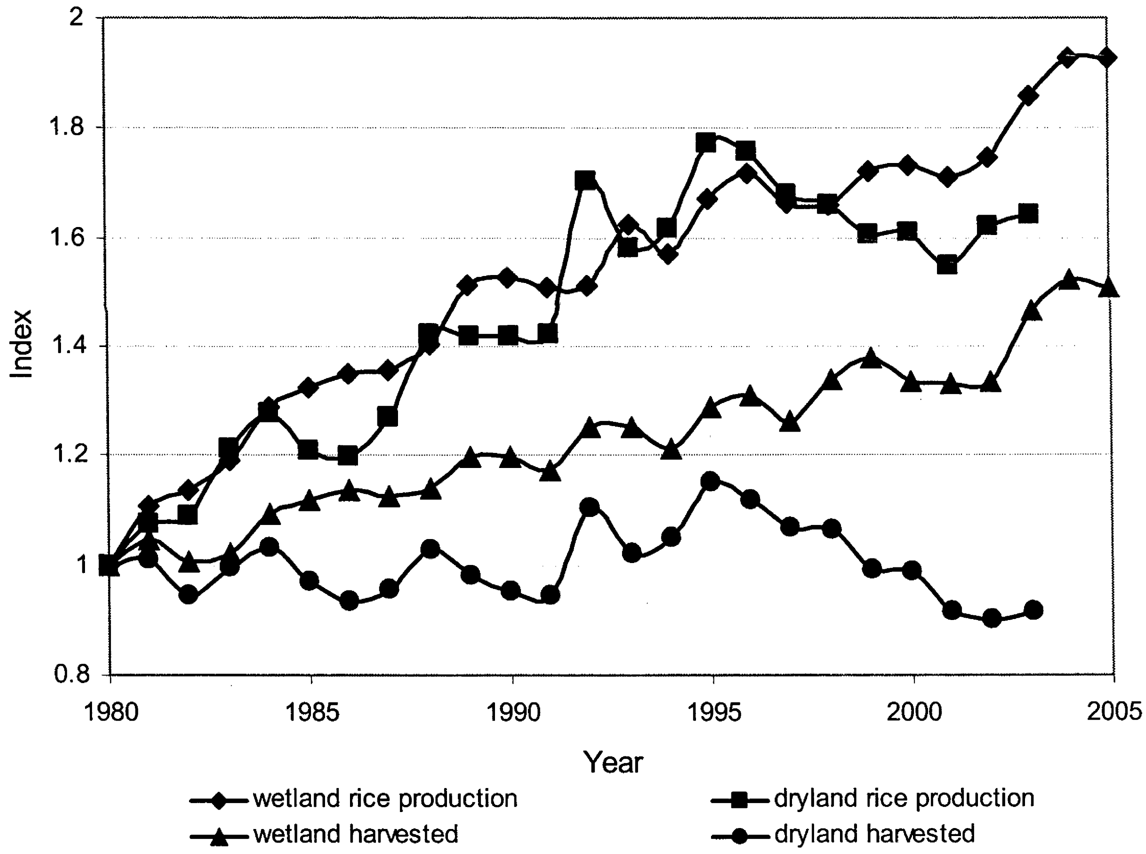
It is important to analyse the eras where agriculture has been prioritised. Let us note that experience is a good teacher. This chapter analyses descriptively the chronological development of the agricultural sector, particularly for rice development. This description gives in-depth support to the analyses of the next chapters. The next sections discuss efforts to increase rice production, intensification programs, centralised public investment and market interventions, the change to environmentally sound policy, ignorance of agriculture, and current favourable environment of agriculture.

Boosting Rice Production

In the early 1980s, the world oil price began to slide downward and by the middle of the decade had settled in a range less than half of its 1980 peak. With the end of the oil boom, the Indonesian economy sank into slow growth and a difficult period of macroeconomic adjustment. Accordingly, policymakers intensified their efforts to find activities in the economy to enable income growth to occur efficiently, with less dependence on government budgetary expenditures. Agriculture, and especially rice production, became established as a prime source of efficient growth and an essential objective of rice-food policy became efficient income growth (Pearson et al. 1991).

There is evidence of the broad success of Indonesian rice policy in encouraging growth of rice output. Between 1955 and 1965, the rate of growth in rice yields in Indonesia was some 0.2 per cent per year, while rice production grew at a rate of 1.2 per cent per year. Some efforts to improve rice production occurred, that coincided with the Green Revolution between 1965 and 1985, where productivity of land and production had annual growth rate of 4.1 per cent and 5.6 per cent respectively, with a dramatic boost of 7.2 per cent annual growth of production between 1977 and 1984. Most of this growth occurred during the second of these two decades, when average yields increased from 2.8 to 4.2 tons per hectare (Pearson et al. 1991). The effort to increase yield and production of rice has been continuing through wetland expansion as well as intensification.[1] As shown in Figure 2.1, wetland planted to rice expanded by 50 per cent during the period 1980-2005. This expansion of wetland rice is possibly because of conversion from drylands to wetland production, especially during the last decade. Since the production increases faster than land expansion, it is remarkable that most of the output gain was attributed to intensive productivity increases rather than to extensive expansion of rice land.

Figure 2.1. Rice production and land expansion



Data source: CASEPS, 2006

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[1] In some regions of Java, agricultural land has been converted to other non-agricultural businesses (Firman 1997). To some extent, there is a tendency of which wetland (sawah) is created from dryland (Mariyono 2006).

Intensification Programs

Indonesia had been facing difficulty in fulfilling food since independence of the state. In the 1960s, domestic production of food crops was low compared to the potential production of rice (Hossain et al. 2006) and actual production in other Asian neighbouring countries (IRRI 1995). Although some amount of food was imported, it was an uneasy process (van der Eng 2000). The government was required to prioritise a program to enhance domestic production of food crops, particularly rice which is the staple food for most Indonesian people. The potential for increasing rice production came from two consecutive programs undertaken by Bogor Agricultural University and the College of Agriculture from the University of Indonesia. The programs, which were the origins of BIMAS (*bimbingan masal* or mass guidance), were the joint combination of action research and DEMAS (*demonstrasi masal* or mass demonstration) implemented in West Java in 1963-1964 and 1964-1965 respectively (Roekasah and Penny 1967). Principally, the programs consisted of three major components. The first component was to encourage farmers to adopt *Panca Usahatani* (five farming efforts). The second component was to send university students to live with farmers and to be modernisation agents. The last component was to provide soft credits through the KOPERTA (*Koperasi Tani* or farmers' cooperative).

The *Panca Usahatani* was about intensive use of high yielding varieties, appropriate and timely use of fertilisers, pest and disease control, improvements in cultivation methods, and improvements in irrigation and drainage systems. The decision to let the university carry out these projects and involve the students was considered a breakthrough. This was because the project became more administratively simpler and could move faster than if it had been conducted by a governmental department. Approximately 440 university students were sent to about 220 villages covering more than ten thousand hectares of paddy fields to facilitate farmers in implementing Panca Usahatani and accessing credits from KOPERTA. Farmers obtained loans, mostly in kind, in the form of slips or release orders which were shown to assigned kiosks for the delivery of agricultural inputs such as seeds, fertilisers and pesticides. After harvesting, farmers returned their loans in kind as well (Roekasah and Penny 1967). Overall, the programs were considered successful, in spite of some cases where fertilisers were not delivered in time or repayments were problematic. There was an impressive increase in yield of rice by 50 per cent (Roekasah and Penny 1967)

In 1965, the programs were scaled up to a national program, called BIMAS and were organised by the Ministry of Agriculture. In that year, around 1200 university students were sent to regions covering 140 thousand hectares of paddy fields, and 480 thousand hectares in the following year. After that, the coverage continued to increase (Roekasah and Penny 1967). The role of the university students was gradually replaced by agricultural extension workers recruited by the Ministry of Agriculture. The credits, which were mostly extended through KOPERTA, or the head of village, were mainly provided by BRI (*Bank Rakyat Indonesia* or Indonesian People's Bank). Another source of funding for the programs was BULOG (*Badan Urusan Logistik* or national logistics agency), founded in 1966.

The programs made it more apparent that the logistics of timely and appropriate use of fertilisers and pesticides was a difficult task and intensive supervision was not necessarily available. Therefore, two modifications of the programs were made in 1967. First, the loans received by BIMAS-participating farmers, included costs of living and transportation, and secondly the loans had to be paid back in cash. Second, another intensive supervision program, called INMAS (*intensifikasi masal* or mass intensification) was established. In this program, farmers were still supervised intensively, although less than with BIMAS, and no credit facility was available. Farmers were expected to find their own source of financial support for their farms. The program would arrange for fertilisers, pesticides and sprayers to be available for cash purchase accessible by the farms. Initially, INMAS was to be a follow-up measure for successful BIMAS-participating farmers who no longer needed financial support or were capable of finding their own sources. Later on, it turned out that earlier-BIMAS participation was not the criterion for joining INMAS (Mears and Afiff 1968). This phase was called the old order under the Presidency of Soekarno.

In the new order, starting from 1967 under the Presidency of Soeharto, BIMAS was one of the top national priorities. BIMAS was then modified into BIMAS *Gotong Royong* (or Cooperative BIMAS). Seven foreign companies were contracted to supply fertilisers, pesticides and other agricultural equipment. Prices were subsidised on a one-year deferred payment basis to BIMAS-participating farmers (Pearson et al. 1991). These companies were paid a fixed price for every hectare for which they supplied production inputs. BULOG organised the payments to the companies and repayments from farmers. The main reason was that the government was running out of foreign exchange for importing needed production inputs. The program covered about 780 thousand hectares of paddy fields by the wet season of 1970 (Widodo 1989).

BIMAS Gotong Royong has been considered a failure. In this program, the approach to farmers was very strict. Instead of suggesting farmers adopt the BIMAS procedure flexibly, farmers were instructed to strictly follow the procedure. It is important to note that technological change cannot be made mandatory for farmers because it is a long process of innovation, adoption and diffusion, and institutionalisation of economic, social, legal, and political circumstances for innovation, adoption and diffusion (Jaffe et al. 2000; Knudson and Larson 1989). The entire system provided opportunity for abuse, from mark-up pricing of material inputs, cheating over the quantities and qualities of distributed inputs, and black markets selling the inputs obtained from the program. Consequently, the yield of rice during implementation was reported to be lower than that expected, and the repayment rate of loans was as low as 20 per cent (Piggott et al. 1993).

Because of the failure, by the early 1970s, Indonesia became a large importer that represented about 20 per cent of world rice trade and the world's largest rice-importing country. But, food shortage was still a problem. Hence, a new rice intensification program was established. It was called *BIMAS yang disempurnakan* (or improved BIMAS). In this program, the BRI played a much more significant role. The bank set up a number of village and mobile units to overcome problems of lending to small farmers, as well as village retailers or agricultural inputs to reduce late delivery, and village warehouses to store rice awaiting sale and so as to use the stored rice to guarantee further credits. The program increased the number of extension workers to fully replace university students and widely distributed high yielding varieties of rice, which was fertiliser-responsive and later on pest-resistant varieties. The private sector started being allowed to participate in selling fertilisers and pesticides to the

BIMAS market, under massive price subsidies. BULOG assisted by BUUD (*Badan Usaha Unit Desa* or rural semi-cooperative) and KUD (*Koperasi Unit Desa* or rural cooperative), monopolised national rice trade to establish floor and ceiling prices of rice (Mears and Moeljono 1981; Pearson et al. 1991). Throughout the 1970s, the program was considered successful. The area covered by the new BIMAS was around 4 million hectares by the mid 1970s, which was around 70-80 per cent of all the rice area in Indonesia (Mears and Moeljono 1981).

In relatively short periods, BIMAS was able to do essential tasks. BIMAS provided relatively easy access for necessary capital, when the farmers underwent financial difficulty. BIMAS also provided useful information on better agronomical practices and developing irrigation systems. Better cultivation techniques were disseminated, important modern inputs such as seeds, fertilisers and pesticides were widely adopted by farmers.

The BIMAS program was continued throughout the 1980s, despite the fact that the achievements were not as successful as in the 1960s and 1970s. Other similar programs were developed: INSUS (*Intensifikasi Khusus* or special intensification) in 1979, which was then modified into OPSUS (*Operasi Khusus* or Special effort program) in the early 1980s, and finally into SUPRA INSUS (or super special intensification) in 1987. These programs were equipped more toward developing extension activities, including farmer groups and cooperatives rather than incorporating the component of BIMAS credit.

Within the first ten years, around 45 per cent of rice areas in the country were covered by intensification programs; within the first 20 years, around 75 per cent; and more than 80 per cent after 25 years. The intensification program was either BIMAS, INMAS (*Intensifikasi Masal* or mass intensification), INSUS, OPSUS, or SUPRA INSUS (Tabor 1992; Hill, 2000). The result of this program was a significantly steady increase in yields of rice (Sawit and Manwan 1991; Pearson et al. 1991; Tabor 1992; Piggott et al. 1993). By 1983, for the first time the domestic production of rice offset the domestic demand for rice, and Indonesia was declared a rice-self-sufficient country (Widodo 1989).

Overall, the intensification programs seem to have been effective. Especially from a national point of view, the approach can be considered a success. Indonesia attained self-sufficiency in rice in 1983, after having been the world's largest importer for many years. The political turmoil coinciding with the famine in the 1960s ensured that food security remained a political priority. Price relationships were carefully managed such that most farmers continued to make a minimal living, while rice remained available at reasonable price (Resosudarmo and Yamazaki 2006).

By the mid 1980s, major issues with the intensive approach became apparent, however. The economic issue was the extremely high costs of the program which mostly came from the oil boom in the 1970s. BIMAS encouraged the use of more pesticides and fertilisers than necessary, by subsidising the inputs. In the mid 1980s the rate of subsidy for fertilisers and pesticides accounted for more than 50 and 80 per cent of their market prices, respectively. As reported by Barbier (1989) the total fertiliser and pesticide subsidy in 1986/87 was around US$ 725 million. This was around 66 per cent of total budget of agricultural development for the fiscal year.

A political issue was related to the involvement of high ranking officers of the Ministry of Agriculture in the chemical companies. The fact that the intensification programs made farmers use fertilisers, which were typically inorganic, and synthetic pesticides, benefited suppliers of these chemical products, in this case agrichemical companies. In a way, the programs guaranteed a fixed amount of sales each year for these companies (Tabor 1992). The involvement of high ranking officers made it possible for the intensification program to force farmers to apply more and more chemical inputs (Resosudarmo and Yamazaki 2006).

An agronomical issue was related to excessive use of agrochemicals, particularly pesticides. One of the features of BIMAS was the intensive use of pesticides. When the initial new varieties of rice, which were fertiliser responsive, were released, there were susceptible to pests. Thus without intensive use of fertilisers and pesticides, the yields were lower than traditional varieties (Cleaver 1972). Even though the pest-resistant varieties were released later on, pesticide use did not recede (Fox 1991) as there was a belief that pesticides were an effective measure to protect plants from pest infestations (Irham 2001; Resosudarmo and Yamazaki 2006). Overuse of pesticides resulted in pesticide-resistant pests, pest resurgence and secondary pest outbreak, while overuse of fertilisers, particularly Nitrogen, was supposed to make rice more attractive for pests (Untung 1996). The first secondary pest outbreak was the case of the brown planthopper, destroying more than 450 thousand hectares of paddy fields in 1976-77. At the time, pesticide use was addressed to control rice stem borers, which were major pests, not to control brown planthopper, which was not a major pest. The estimated yield lost to the pest outbreak was equivalent to 364,500 tons of milled rice, which could have fed three million people for an entire year (Settle et al. 1996; Resosudarmo and Yamazaki 2006). However, the reaction to the pest outbreak was to encourage farmers to use more pesticides, instead of reducing the use of pesticides. Another brown planthopper outbreak was in 1986, which was hypothesised to be a pest resurgence resulting from excessive us of pesticides (Barbier 1989; Settle et al. 1996; Useem et al. 1992). After the outbreak, there was a belief that some pesticides were the cause of pest resurgence (Rola and Pingali 1993).

Human and ecological health issues were related to poisonous pesticides and environmentally detrimental fertilisers. When intensive agriculture was used world-wide as has been argued by Cleaver (1972), the technology would raise ecological problems. Byerlee (1992) has identified some cases of adverse impacts associated with intensive agriculture over the world. After the publication of Silent Spring by Rachel Carson in 1963, the global communities became aware much about the practices of intensive agriculture (Pretty et al. 2000; Pretty and Hine 2005).

In response to the unexpected outcomes of intensification, the overuse of agrochemicals should be addressed. Along with a decline in oil revenue in the early 1970s that resulted in an economic recession in Indonesia, the credit package was eliminated. In 1986, 57 brands of pesticides were banned from rice cultivation (Fox 1991; Rolling and van de Fliert 1994). The pesticide subsidies started to be reduced in 1987 and were totally eliminated in 1990 (Useem et al. 1992). Thus the early 1990s coincided with the end of the intensification program, and the turning point of environmentally related policy in the agricultural sector, particularly rice.

Public Investments and Market Intervention

High yielding varieties of rice

In Indonesia, the hybrid technology in rice production has been widely applied in the lowlands of Java, Bali and Sumatra since 1967. This technology is based on modern rice varieties that are high yielding varieties (HYVs), were used with inorganic fertilisers, improved pest control and other practices which were supported by rehabilitation and expansion of irrigation infrastructure. Local scientists together with many Dutch scientists who worked in the country, and collaborated with international institutions had developed techniques to improve rice cultivation (Mears and Moeljono 1981). Starting in 1941, the Central Research Institute of Agriculture (CRIA) began to release improved rice varieties such as Bengawan, Fajar and Peta, and then followed by releasing Syntha and Sigadis and others in 1952. These varieties were called national improved varieties. In 1967 the varieties of IR8 and IR5 were released in Indonesia and the BIMAS, which required a higher quantity of fertilisers. In the dry season of 1968, IR5 and IR8 were planted on 21,300 hectares. The IR5 spread more rapidly than IR8 because of its intermediate height and slightly greater resistance to several diseases and ability to adapt to diverse environments (Widodo 1989).

Since 1969 C4-63 was introduced and soon rapidly spread because the variety matures early and is superior in eating quality to Indonesian tastes. With the release of IRRI varieties which are fast maturing, stiffer-stalked and nitrogen responsive, the CRIA altered its breeding objective and subsequently developed new types of modern varieties which were highly responsive to fertilisers. These types were named Pelita I/1 and Pelita I/2, and were released in 1971 (Fox 1991). The types were accepted by farmers because they performed well across a wider range of environments, the taste satisfied Indonesian people and the price was relatively higher. Both Pelitas are similar to IR5 in terms of agronomic performance, but to some extent have stronger bacterial leaf blight resistance. Consequently, Pelitas replaced IR5 in most areas (Widodo 1989).

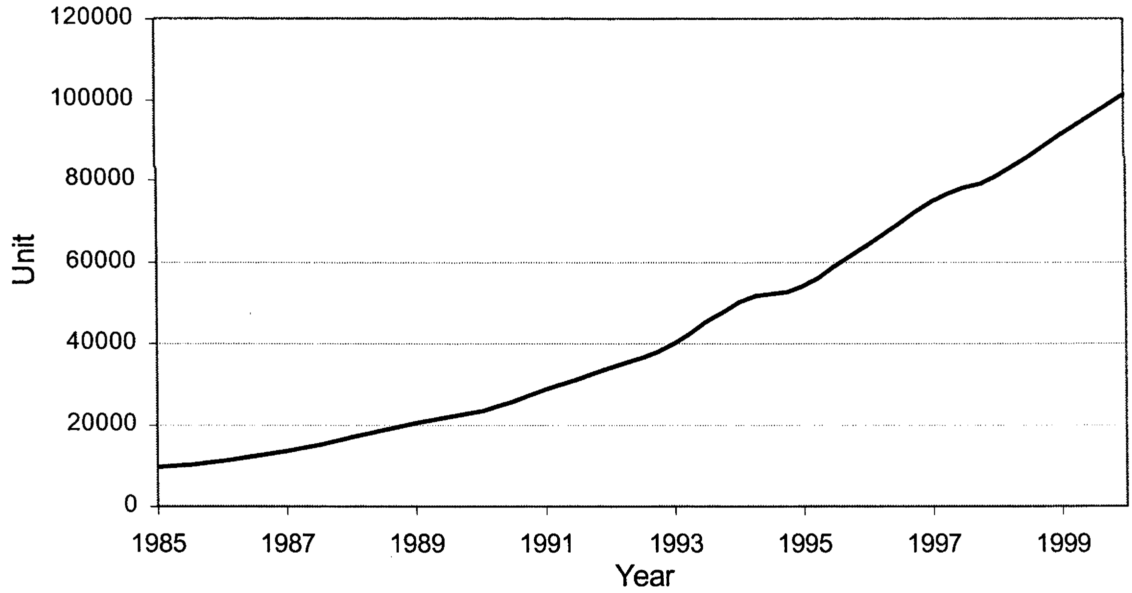
Unfortunately, Pelitas, IR5 and IR8 are susceptible to diseases of blast, tungro and grazy stunt viruses, and brown planthopper. A series of IRs, such as IR36, IR38 and IR42 were released to overcome brown planthopper infestations, particularly for biotype I and biotype II. Many new varieties with better taste such as IR64 Cisadane and Membramo have been released in response to the development of pest resistance (Widodo 1989). A particular focus was on the biotype development of brown planthopper (Fox 1991), a fast breading invader pest (Gallagher et al. 2005). The research and development continues to find new varieties in keeping with the resistance of pests.

Mechanisation

In Indonesia, mechanisation of rice production mostly relates to land preparation and harvesting. However, there has been little mechanisation except for widespread adoption of rice mills. Four techniques: hand hoes, draught animals, two-wheel tractors, and four-wheel tractors, are mostly used for land preparation. On Java, only hand tractors are used on rice land, but off Java the smaller four-wheel tractors are also used. In general however, the level of tractorisation is very low (Heytens 1991b), despite the fact that the number of hand tractors, as given in Figure 2.2, has increased substantially.

The most likely reason for the limited mechanisation is because of topographic and plot-size constraints, mechanical problems, and different factor endowments of farmers. Very small plots are likely to be prepared using hand hoes. When farmers have their own draft animals, they are likely to use them on their rice fields. Farmers who do not own animals generally use whichever technology is most cost-effective. The presence of large rocks or steep slopes sometimes prevents farmers from using tractors and draught animals. In many areas of Java, hand hoes are still used alongside animal traction or tractors, particularly to repair bunds and to turn corners difficult to reach with animals or machines.

Figure 2.2. Number of hand tractors



Data source: CASEPS, 2006

Some studies explain the low level of tractor use in Indonesia. There are no agronomic reasons a priori (Binswanger 1978) and no empirical evidence in Indonesia (Lingard and Bagyo 1983) that using tractors for land preparation provides any yield advantage over other techniques. On Java, the generally low level of wages and technical factors, especially related to small plot size and the impracticality of using tractors in hilly areas, are the main constraints on mechanisation of land preparation. Government policy has not promoted the use of tractors. Tractors are not cheap in Indonesia. High costs of assembly because of tariffs on imported parts and high-priced domestic parts, and large distribution costs because of supply monopolies, contribute to high prices. Domestic price of hand tractors was estimated to have been roughly 25 per cent above world prices in 1988 (Heytens 1991b).

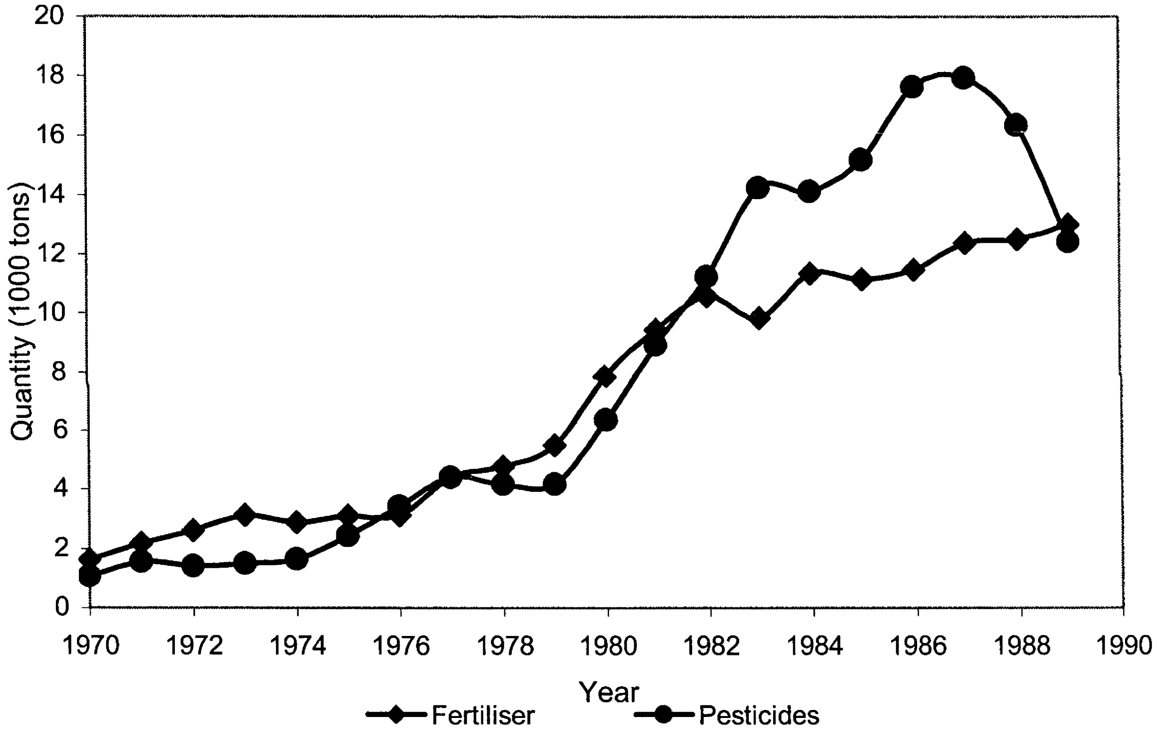
Chemical inputs

Chemical inputs, consisting of inorganic fertilisers and synthetic pesticides, have been the keystones of the rice development programs in Indonesia. The use of fertilisers per hectare is high in comparison with other rice-producing countries in Southeast Asia. The application of fertiliser has also increased dramatically since the late 1960s and nutrient sources have become more diversified in recent years. Urea constitutes a large input, but has declined as a portion of total use. Triple super phosphate (TSP) accounts for a good portion of the remainder (Heytens 1991b).

The yield advantages from applying chemical fertilisers were clear to farmers. The yields had risen in response to higher fertiliser applications. Among surveyed farmers, fertiliser use was greater on the higher-productivity systems with good water control; fertilisers applied in a more stable and fertile crop environment were considered more likely to pay off and less risky than fertilisers applied in a variable environment. In the well-controlled paddy field, farmers tend to apply less fertiliser during the wet season to reduce the risk of falling down, which is typically not a problem during the dry seasons (Heytens 1991b).

In almost all of Indonesia's wetlands, fertilisers are applied by broadcasting onto the rice paddy. Fertilisers generally are applied three times in a season at the time of transplanting, 20 to 30 days and 30 to 45 days afterward. Farmers usually use family labour to broadcast fertilisers. An average fertiliser application per hectare can easily be finished in a day by two or three people. Hence family labour usually is sufficient, particularly on the small farms that characterise wetland rice production on Java.

Figure 2.3. The use of fertilisers and pesticides



Data source: Pemerintah Indonesia (1991)

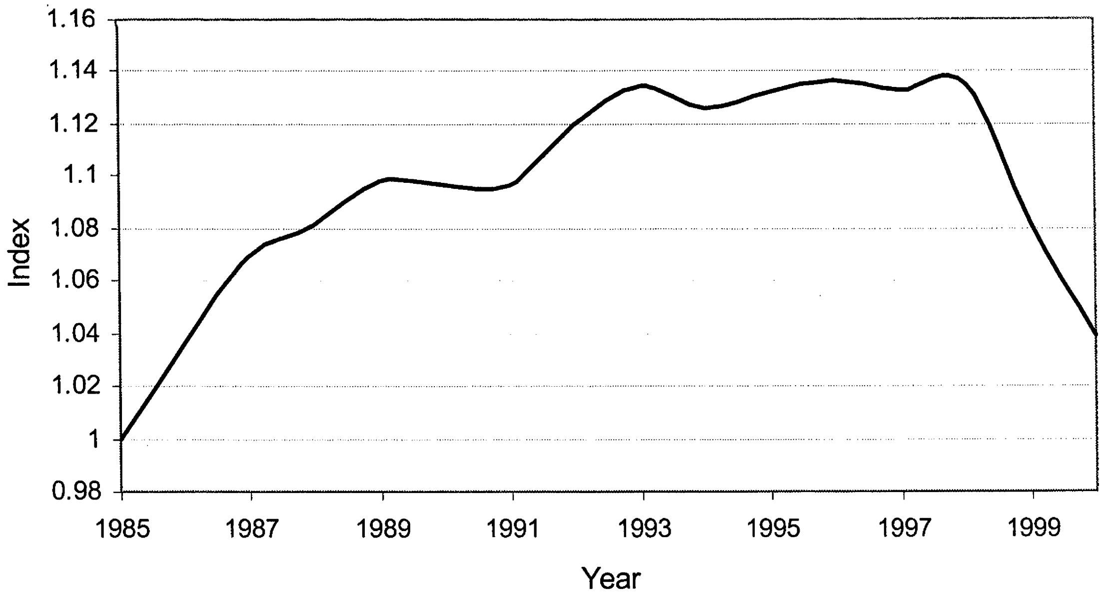
Pesticides have accompanied the use of fertilisers. First releases of new varieties of rice are not only responsive to fertilisers, but unfortunately also susceptible to pest infestations. Pesticides were used to protect rice from pests to guarantee promising yields as high as in research stations. As shown in Figure 2.3, the uses of nitrogenous fertilisers and pesticides at the national level increased substantially. The use of pesticides however, started dropping in

1987 when the subsidy was gradually reduced. But the use of fertilisers continued to increase.

Irrigation systems

The dissemination of advanced rice technologies has been facilitated by investments in public infrastructure and irrigation systems, especially on Java. Investments in irrigation have been particularly significant to the success in the adoption of HYVs because the new seed varieties were specifically adapted for irrigated systems. Lowland areas with existing irrigation systems, including many regions on Java, were favoured by the initial investments in irrigation between 1968 and 1975 (Heytens 1991a). The expansion of irrigated area continued to increase.

Figure 2.4. Expansion of irrigated areas



Data source: CASEPS (2006)

Figure 2.4 indicates a marked increase in investment in irrigation and expansion in area during the early 1980s, that levelled off in the mid 1990s, and fell in the late 1990s. This pattern of reduced public spending on irrigation resulted from a fall in the total development budget and a decline in the share of that budget devoted to agricultural investment.

Price stabilisation

Indonesia has had a policy to develop a domestic buffer stock intended to achieve stable rice prices and thereby enhanced food security. The fundamental concepts underlining the stability of price for rice are based on four major policy objectives. They are, to set the floor price high enough to stimulate production, to establish a ceiling price which assures a reasonable price for consumers, to maintain a sufficient range between these two prices to provide traders and millers reasonable profit after holding rice between crop seasons, and to keep an appropriate price relationship between domestic and international markets (Mears 1984).

BULOG, the National Food Logistics Agency established in 1974, has been successfully implementing price stabilisation since that time. BULOG protected a floor price to farmers by offering to buy rice at the village cooperative (KUD) level at the announced floor price, storing purchased grain in government warehouses, and selling rice from stocks when the wholesale price approached the desired ceiling level. The band between the floor price and the urban retail price was maintained reasonably enough to allow for active private participation in the storage and distribution of rice.

Subsidies on fertilisers and pesticides

Government subsidies on fertiliser had also been an important instrument of rice policy in Indonesia. Since the late 1960s, fertiliser subsidies had been given to farmers by setting the wholesale prices of urea, triple super phosphate (TSP), and ammonium sulphate (ZA). Village cooperatives (KUD) and traders have been allowed to distribute fertilisers to farmers at the official retail price level. Domestic fertiliser manufacturing plants have been constructed since the mid-1970s to ensure adequate supplies. The success in expanding its rice production in Indonesia is attributable to the contribution of output and input price policies that improved the profitability of rice cultivation (Timmer 1990).

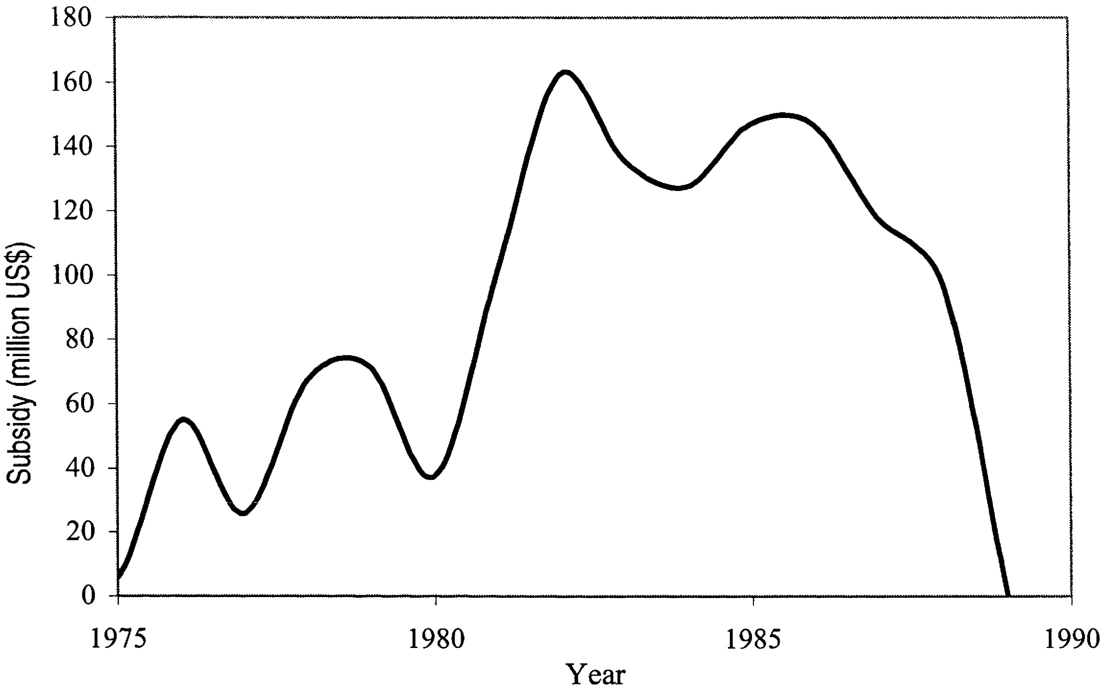
Since 1968, the prices of all bio-chemical inputs in rice production have been influenced directly by government policy. The costs of seeds, water, fertiliser, pesticides, fuel, and machinery have been reduced at various times by specific price or credit subsidies. As estimated by Timmer (1990), the growth in rice production from 1968 to 1984 was attributed to improved incentives to farmers created by the fertiliser subsidy and stable rice prices. Officially reported expenditures on the fertiliser subsidy as a proportion of total development expenditures peaked at over seven per cent in 1984-85, when the fertiliser subsidy was Rp 732 billion.

Along with fertilisers, the use of pesticides was also subsidised since the pesticides were imported. Pesticides were used to guarantee the promising high yield of new varieties of rice, which were susceptible to pest infestation. Even though the new pest-resistant varieties of rice were disseminated later on, the subsidy on pesticides continued to increase.

As shown in Figure 2.5, pesticides started being subsidised in 1975, and the amount increased substantially to more than US$ 150 million in 1982. Subsidies on pesticide were eliminated in 1989 when the massive use of pesticides became apparently problematic. Meanwhile, subsidies on fertilisers were gradually reduced. From the beginning of 1994, only urea was subsidised.

However, because of the deep economic and financial crisis, at the end of 1998 the government eliminated the fertiliser subsidy.

Figure 2.5. Subsidy on pesticides



Data source: Pemerintah Indonesia (1991)

Shifting to Environmentally Friendly Technology

Based on the unexpected outcomes of intensification, by the end of the 1970s Indonesian scientists had learned from their own various studies and worldwide reports of many more problems associated with the use of pesticides in agriculture (Antle and Pingali 1994; Bond 1996; Pimentel et al. 1992). Based on these findings and information from the international community on agriculture, Indonesian scientists concluded that Indonesia had to stop relying solely on pesticides and needed to utilise several control techniques, including synchronised planting, crop rotation and natural enemies, with pesticides as the last alternative. This strategy was commonly known as integrated pest management (IPM). In the Agro-Chemical Report (2002) it is stated that

Indonesia has been one of the leaders in the use of IPM in Asia. Since 1989, a national IPM program has helped farmers in Indonesia to reduce their dependence on pesticides and increase their harvests. It has also dramatically reduced the incidence of pesticide related illnesses and environmental pollution. Pearson et al. (1991) point out that the development and dissemination of new varieties of rice are significant to the success of IPM and the continued expansion of rice output.

The IPM movement was not smooth as expected. There was political intrigue in which the promoters of intensive use of pesticides and producers of pesticides received benefits through massive subsidies. Resistance to moving from intensification to an IPM strategy was very strong in the Ministry of Agriculture (MOA). Many officials in the MOA still believed synthetic pesticides to be the simplest, most reliable and effective method of pest control. Several high ranking officials in the MOA were suspected to be closely associated with pesticide companies that still desired to campaign for the intensive use of pesticides. At the grassroots level, farmers had been accustomed to use pesticides to control pest infestations.

The second national brown planthopper outbreak in 1986 caused concern in BAPPENAS (*Badan Perencanan Pembangunan Nasional* or National Planning Agency). This agency, the most powerful government agency at the time, quickly sought advice from scientists in the MOA and leading universities who suggested the implementation of the IPM at a grassroots level. With intensive consultations concerning the need to implement the IPM program with the president, the INPRES No. 3/1986 (Presidential Decree No. 3/1986) was launched to support the implementation of the IPM.

The Presidential Decree introduced an impressive arrangement of policy measures that provided an important support for the extension effort, including: prohibition of fifty-seven broad-spectrum insecticides for rice, leaving ten brands (with only four different active ingredients) of narrow-spectrum insecticides, most of them considered especially effective against brown planthoppers; recruitment of 1,500 new pest observers posited within the Directorate of Crop Protection of MOA, bringing the total up to 2,900; enforced use of resistant rice varieties; enforced introduction of one (dry) secondary food crop after two irrigated rice crops, prohibiting continuous wet rice farming in several irrigated areas; and specific action through so-called POSKO (*Pos Komando* or commando post) involving specially trained farmers to give mass applications of narrow-spectrum insecticides, if necessary. A second major policy measure with regard to pest control was the gradual removal of the 85 per cent subsidy on the price of pesticides.

The first reaction to INPRES 3/86, was the dissemination of IPM implemented through the Training and Visit extension system, which was the method used in the intensive program (Matteson et al. 1993). The Government proposed to the World Bank to amend US$ 4.19 million remaining for the second phase of the National Agricultural Extension Project (NAEP II) to be used for IPM training. Senior pest observers were trained as IPM master trainers, and the new pest observer recruited and selected village extension workers were given a six-day specific training program. The trained pest observers and extension workers, in turn, had to train farmers. The FAO's Inter-country IPM Program provided technical assistance. In this crash program, a remarkable endeavour was made to train a cadre of master trainers, and to develop training materials distributed by NAEP II. Travel money, honoraria, vehicles, subsistence and pocket money for farmers, and other moneys were paid. The entire budget was spent in seven months, which would have totalled US$ 7 million if calculated on an annual basis.

Though the activities had Presidential priority and were facilitated by the Ministries of Finance and Planning, and Economic Affairs, only 8.5 per cent of the allocated resources were delivered to the field to train less than 10 per cent of the targeted farmers (10,300 persons). Where farmers were reached, trainers used instruction approaches and did not use the field or farmers' own experience. Only 25 per cent of the training groups actually entered a rice field. Farmers reported not to have learned many new things, and the decision-making was mostly dependent on the officials.

The rigid system equipped to move simplistic messages to a large number of passive farmers could not absorb the principles of IPM. A transformation from within was needed to meet the new challenges from outside. Despite the insufficient result from this crash IPM training program, the policy measures resulting from INPRES 3/86 were enough to: end the threat to food security from brown planthopper outbreaks, induced by the destruction of natural enemies (Settle et al. 1996); save on annual expenditure for the pesticide subsidies of between US$ 110-120 million a year; vastly reduce pesticide imports; and make farming more cost-effective.

In contrast to popular belief fanned by the pesticide companies, careful field experiments had shown that yields were unaffected by the reduction in pesticide use. Environmental and health effects at farm and macro levels were less easily measurable, but assumed to be substantial. In 1989, the National IPM Program was approved to start the large-scale implementation of a revised IPM extension approach in major irrigated rice growing areas.

The second reaction was to start on a new course, with respect to both technology and training, after having learned from ten years of experience in IPM training and implementation in various Asian countries. The dissemination of IPM shifted from mechanical instructions for field sampling and spraying based on centrally determined economic threshold levels to more ecological principles. These different principles required a different approach to extension, called SLPHT (*sekolah lapangan pengendalian hama terpadu* or IPM farmers' field school).

SLPHT, a process of learning by doing, was at the heart of the IPM program in Indonesia. The World Bank, along with a number of development agencies promoted SLPHT since it was a more effective method to extend science-based knowledge and practices (Feder et al. 2004a). SLPHT used a participatory approach to provide assistance for farmers to develop their capability in analytical skills, critical thinking and creativity, such that farmers could make better decisions. In short, the objective of SLPHT was to enhance human resource development, in which farmers become experts of IPM in their paddy fields. Farmers were expected to be able to conduct observations, to analyse agro-ecosystems, to make decisions, and to implement pest control strategies based on the results of their field observations. In reality, IPM addressed not only pest control but also other aspects of farming such as balanced and efficient fertilising, efficient use of water, crop rotation and soil conservation. The following IPM principles were central to the SLPHT: growing healthy crops;

conserving and utilising natural enemies; carrying out regular field observations; and developing farmers as IPM experts in their own fields (Untung 1996).

Three steps were taken to achieve the nationwide goal: training for trainers; training for farmers by these trainers; and training for farmers by trained-farmers. The steps were performed in two phases. The first phase (1989-1992) was sponsored by the FAO with funding from USAID. Realising that it was very hard to expect the MOA actively to implement IPM training and extension workers, BAPPENAS was asked to carry out this role, even though BAPPENAS is supposed to be concerned solely with planning. This phase was considered a large-scale attempt to systematically introduce sustainable agricultural practices as a public sector effort at national level. IPM was introduced into an irrigated rice farming system, in which the Green Revolution has been successful during the past twenty years. Locations of FFS were deliberately selected with criteria of easy accessibility and the presence of active farmer groups. Farmers participating in the school were also expressly selected for the program. More prosperous and better informed farmers in the selected villages were encouraged to be participants of the school. During the first phase around 200,000 farmers had been trained intensively, and many more by other methods. About ten per cent of these trained farmers were selected to train other farmers after obtaining special training.

The second phase (1993-1999) was sponsored by the World Bank. In this phase the program was expanded. In the nationwide scale, BAPPENAS were no longer capable of dealing with the complexity of the projects because of not having representatives at the local levels (Resosudarmo and Yamazaki 2006). Since 1994, the National IPM Training Project had been taken over by the MOA with 70 per cent funding from the World Bank. The project promoted IPM and improved crop cultivation of not only rice, but also other food and horticultural crops (World Bank 1993).

More regions had been covered and more actors had been involved. However, the target was not to reach all Indonesian farmers. The strategy of the program was to train a fraction of farmer communities, instead of training all farmers in the community. Thus, the spread of IPM knowledge relied on farmer-to-farmer diffusion. During implementation of the second phase of the project, villages where SLPHTs were carried out were still subjectively selected with the same criteria by the project management in collaboration with Agricultural Services officials both in provincial and district levels. With the assistance from the agricultural office at sub-district level and farmer group leaders, farmers were also selected with certain criteria, for instance: rice farmer, literacy, and ability to actively discuss.

This second phase underwent difficulties associated with a complex administrative obstacle (Pretty and Waibel 2005), such as the delay in the transfer of funding (Feder et al. 2004a). As a result, training was not fully synchronised with the calendar of rice-agronomic development and supplies of meals and training material for participants were irregular. Further, there was a relatively large rate of farmer absenteeism in school sessions during the period. Some effort had been made to improve the SLPHT through a monitoring and evaluation system, and training quality could be enhanced during the last two years of the project (Mariyono 1999).

In 1997, there was a massive drop in the country's income because of an economic crisis. The number one priority of the government as well as foreign donors was to structure the financial sector. The agricultural sector, including the IPM program, was no longer a national priority (Resosudarmo and Yamazaki 2006). In spite of the fact that 'the [IPM] program both reduces the number of pesticide-related illnesses [and]... all households are better off, especially those in the agricultural sector' (Resosudarmo and Thorbecke 1998: 156), and has 'substantial positive impacts on agricultural productivities' (Yamazaki and Resosudarmo 2007: 18), the program was suddenly terminated at the end of 1999, a year after elimination of fertiliser subsidies.

Deconstruction of Agriculture

The priority of agriculture in national economic development has fluctuated. Agriculture became a top national priority during the mid 1960s to mid 1980s. After that, along with the industrialisation era, the priority gradually declined. As reported by Mellor et al. (2003), the period 1986-1997 marked a significant difference in Indonesian agriculture, particularly after the achievement of rice self-sufficiency in 1985. As the agricultural sector suffers seriously from ignorance of policy priorities, agricultural GDP grew at only 3.4 per cent per year. The slow rate of agricultural growth was associated more with the policy shifts in the labour-intensive exporting commodities, starting from the mid 1980s.

The regress of agriculture went faster in the early 1990s, as both scientists and policy makers ignored the real roles of agriculture in economic development. Agriculture was only treated as a sub-ordinate sector that could make contribution to economic growth and development. This ignorance was also caused by a remarkable achievement in the manufacturing and industrial sectors, which recorded two-digit growth. Other sectors in the economy such as the banking, trade and service sectors also grew very rapidly, which then misled many economists and policy makers to the conclusion that structural transformation had been completed. Foreign aid neglected agriculture during this period, reinforcing the government's urban bias.

Politics and markets underestimated the agricultural sector, and even ignored the major contribution of agricultural progress in the structural transformation of the Indonesian economy. No major agricultural policies were introduced to improve efficiency level and market-oriented strategies in agriculture. If anything, agricultural policies only benefited urban consumers and traders, but undermined farmers and rural people as the ultimate group of society, even contributing to the political system. The floor price policy in rice is the most well regarded public policy despite being biased to urban consumers and traders, although often cited as very important for poverty alleviation.

Food crop sectors suffered from the policy environment, and Indonesia was importing rice again in the 1990s. The most crucial component of structural transformation is actually to strengthen the basis of the economy, where agriculture and the rural sector in general should receive closer attention. Improvement in the links between the agricultural sector and the rest of the economy would influence the flow of labour and resources between the traditional and modern sectors. The negative effects were apparent when the accumulated burden of the agricultural sector increased very rapidly in the 1990s. For the sake of economic efficiency, the conglomeration process occurred under land acquisitions previously managed by small-scale farmers or by traditional groups of society. In the deficiency of property rights and poor setting of institutional arrangements, the agricultural sector is really in the process of a regressive phase. Agricultural policies often result in accrued benefits for large-scale companies, and the economy as a whole suffers from higher level of inequality. In addition to such inequality, Indonesian agriculture has also suffered from resource degradation in almost every single part of the country. Externality impacts of resource degradation in agricultural production appear more dominant than the positive income transfer created by intensification decisions and land investment made for conservation purposes. The food sub-sector, once again, had to depend on import, where Indonesia imported rice, corn, soybean, etc, either for domestic consumption or for meeting the demand from agro-based industries.

During the economic crisis of 1997-2000, the agricultural sector suffered from high inflation. Low-skilled urban workers flocked into rural areas because of massive lay-offs in urban sectors. Both formal and informal workers had to find some jobs in rural areas, as the crisis hit some sectors in urban areas more severely. As a result, the growth rate of agricultural GDP in the period of 1997-2000 was quite small, about 1.6 per cent per year, along with a severe contraction in the rest of the economy.

Current Position of Agriculture

Agriculture is the backbone of the Indonesian economy. Along with an ongoing decentralisation program, where the local governments are empowered to take ownership of their own development paths, current policy is now revitalising agricultural sectors (Sinukaban 2005). With agricultural decentralisation, including decentralisation of rural services and agricultural research, it is expected to provide a favourable environment for the agricultural revitalisation. Based on the past experience that government interventions in credit markets have taken the form of directed allocations of loans, subsidised interest rates and state ownership of rural banks had generally been dismal (Lai and Cistulli 2005). The decentralisation of agricultural research efforts has been identified in some countries as a necessary step for improving the performance of research by making services and research outputs more accessible and relevant at regional or local levels (AARD-ISNAR 2002).

Revitalisation of agriculture is a wise strategy. This is not primarily because the President is an agricultural economist, but is based on the past experience that agriculture was a significant contributor to economic growth and the fact that agriculture was the only growing sector during the economic crisis. As stated by the President of Indonesia, Susilo Bambang Yudhoyono,

> 'Realising the sustaining importance on agriculture in Indonesian economy, Indonesia committed to reinvigorate its role by launching policy so-called agriculture revitalisation as one of the national economic development priorities. This policy would be a general strategy to reduce unemployment, poverty and unbalanced development in some areas' (Yudhoyono 2006: 4).

Revitalisation of agriculture means that agriculture should be positioned proportionately and contextually, to revive its strength and to enhance its ability and performance in national development without ignoring other sectors. Las et al. (2006) point out that the agricultural revitalisation also should not jeopardise the environment.

In the revitalisation of agriculture, rice has the top priority since it has played an important role in maintaining economic stability, and social and national security. With more than 200 million people relying on rice as the staple food, Indonesia faces a high susceptibility to the availability of rice. The fulfilment of rice demand through domestic production is an essential part of national development. Rice contributes 66 per cent of food crop sub-sector to GDP, and still provides jobs for more than 21 million households.

Current constraints faced by agricultural development are the stagnancy of technological innovation, agricultural land conversion, agricultural land degradation resulting from decline in environmental quality and shortages in irrigation (Las et al. 2006). Rice policy is aimed to achieve significant increases in production and productivity of existing harvested areas, and development of new rice bowl areas and regional buffers to increase farmers' income and the foundation of food security and food safety.

Establishment of new irrigation networks, rehabilitation of existing irrigation, creation of paddy-land, conservation of land and water resources, and financial assistance, are still the main priorities. Those are supported by stabilising prices, and establishing institutional marketing in order to shorten the supply chain from farmers to consumers. It is expected that rice based development is aimed to improve efficiency through innovation and adoption of technology, to utilise natural resources optimally, and to empower farmers and rural societies.

Conclusion

To sum up, it is remarkable that the agricultural sector, particularly rice, has been dynamically up-and-down. Agricultural development has been dependent on the dynamics of political change and global concern of sustainable development. Agriculture was able to contribute to economic growth during the new order through intensification programs coinciding with the promotion of the Green Revolution. Irrigated land was expanded and irrigation infrastructure was established. The programs utilised HYVs of rice supported by high levels of agrochemical use under huge subsidies. Productivity of rice increased dramatically and this triggered significant economic growth.

However, intensive programs became less relevant with the growing concern over sustainable development, that economic development should not degrade the quality of the environment. Indonesian agricultural policy shifted from the agrochemical-intensive programs to more environmentally sound practices. A number of problematic pesticides were prohibited, fertiliser use was rationalised and farmers were empowered. Agriculture was the only sector resistant to the economic crisis. This sector still grew, whereas other sectors such as manufacturing and banking collapsed during the crisis. Based on that fact, current policy pays close attention to the agricultural sector through a revitalisation program.

Chapter 3

Technological Change and Environmental Consequences of Rice Agriculture

Abstract

Agricultural technological change plays an important role in the development of a country's agriculture. This study analyses technological change in rice agriculture. Using a primal approach, movements of the production frontier are considered technological change. The production frontier is modelled as simplified translog technology that captures non-neutral technological change. Different schemes of rice agriculture are accounted for to determine the non-neutral technological change. Data are compiled from the Indonesian Statistical Agency. The results show that rice agriculture during 1979-1995 underwent technological regress, with non-neutral technological change. The technological change was capital saving and labour augmenting. Technological changes in intensive rice agriculture during the Green Revolution were more chemical using. Changing to a more environmentally sound policy reduced intensity of chemical use.

Keywords: rice agriculture, non-neutral technological change, Green Revolution, environmentally friendly policy.

Introduction

The importance of technological change in determining the enhancement of productivity and economic growth cannot be disputed (Nin et al. 2003) and the vital role of technological change in economic development has been identified (Kosempel 2004). In the agricultural sector, technological change 'can be a powerful force in reducing poverty' (de Janvry and Sadoulet 2002: 1) and has a multiplier effect on a whole economy (Khan and Thorbecke 1988). The responsibility of government for establishing an appropriate climate for technological development through a framework of market oriented macro and microeconomic policies, the provision of efficient and effective infrastructures, and the coordination of policies over the range of issues influencing technology needs elaboration.

Changes in agricultural technology have always been an important component in the progress of human societies, from the times of traditional farming, and more recently in the development of modern agriculture that makes use of biological technology (Huang et al. 2004). However, since the Green Revolution, the extent and pervasiveness of the role played by technological change has experienced a qualitative change. This rapidly increasing role of technological change was noticed by scholars of socioeconomic development at the time, but not quite in the same way in which it is perceived nowadays.

In order to know the genesis of past changes in the structure of agriculture, and to appreciate the likely future path of structural change and the implications of government policies, it is imperative to understand the nature and the causes of technological change and its linkages with agricultural support policies. An important issue is to what extent agricultural policies have influenced past technological change, and therefore, what the role of government should be, in the context of agricultural policy reforms, in influencing agricultural productivity growth. There is a considerable and growing interest in research on technological change. Interest in technological change, however, has not been constant throughout history and perceptions of technological change have undergone very massive variations in the course of time. These variations are possibly related to the changing role of technological change in economic development (OECD 1995).

In agrarian countries, the use of new techniques and technology of production has given rise to unprecedented growth, but these developments have also exerted increasing environmental pressure (Coxhead 1997; Cleaver 1972). The implications of technological change, together with its often ambiguous effects on the environment have given rise to critical assessment of the role of technological change in the structural evolution of the agricultural sector.

In the last decade, discussions on environmental economics and policy have become progressively more permeated by issues related to technological change (Jaffe et al. 2000). An understanding of the process of technological change is important for two broad reasons. First, the environmental impact of socioeconomic activity is overwhelmingly affected by the rate and direction of technological change. New technology may create or facilitate increased contamination, or may alleviate or replace existing contaminating activities. Further, because many environmental problems and policy responses are evaluated over time horizons of decades or centuries, the cumulative impact of these technological changes on the severity of environmental problems is likely to be large. Indeed, uncertainty about the future rate and direction of technological change is often an important factor in baseline forecasts of the severity of environmental problems.

Second, interventions in environmental policy themselves create new constraints and incentives that may affect the process of technological change. These induced effects of environmental policy on technology may have deep impacts on the normative analysis of policy decisions. They may have important consequences in the context of cost-benefit or cost-effectiveness analyses of such policies. They may also have broader implications for welfare analyses, because the process of technological change is characterised by externalities and market failures with important welfare consequences beyond those associated with environmental issues.

In spite of general acknowledgment of the central role of technological change in influencing economic growth, productivity and competitiveness, there is a lack of unanimity in identifying it. The manner in which the economic climate influences technological change in agriculture is still largely unexplored. Technological change can be influenced by a variety of factors (Martin and Warr 1994), but the knowledge of its determinants is rather incomplete. The development and adoption of new techniques and technology leading to gains in agricultural productivity have been related to public and private investment in agricultural research and development. The levels and types of agricultural support given by government may also have important effects on the development and adoption of new production technology, and eventually have specific impacts on technological change. One important feature is that technological change is locally specific, since there is variation in economic, social and cultural climates; and therefore the process of institutionalisation of new technology in one place is different from others.

The scope of the present study focuses on technological change in Indonesian rice agriculture in which there are two episodes where different technology, related to environmental problems, is implemented. The first episode is called the Green Revolution. During the episode, seed technology which resulted in new varieties of rice was widely introduced to farmers (Cleaver 1972). The introduction of new varieties of rice was, accompanied by massive campaigns and huge subsidies on chemical inputs (Barbier 1989). Various intensification programs such as BIMAS, INSUS and SUPRA INSUS have been implemented to support the Green Revolution. Government expenditures, to some extent, have been allocated to agricultural infrastructures such as irrigation and agricultural extension.

The second episode is called ecological technology. Ecological technology was launched because of the unexpected experience that chemical use, particularly pesticides, was no longer effective and caused the natural balance of agro-ecosystems to become unstable. The explosions of secondary pests and pesticide-resistant pests leading to failure of harvests had the most significant unfavourable economic impacts of intensive use of agrochemicals (Settle et al. 1996). The introduction of ecological technology coincided with the growing concern with sustainable agricultural development. The ecological technology was introduced through training packages from which farmers learned ecological processes. This training was totally different from past training in which farmers were supplied with packages of technology.

Both episodes have been applied widely in Indonesian rice agriculture. The technological change, 'especially in agriculture, can be influenced by policy towards research, extension and education' (Matin and Warr 1994: 219). But, there is still a lack of scrutiny on the impact of both episodes on the direction of technological change related to environmental issues. Better understanding the extent to which policy reforms in agriculture have implied environmental concerns are required. The objective of this study is to examine the neutrality of technological change in rice agriculture in relation to different kinds of intensification programs. In addition, promotion of ecological technology is examined to understand whether the promotion is capable of influencing the neutrality of technical change.

Literature Review

Technological change is the application of previously unknown and unavailable techniques of production. Measurement of technological change refers to the concept of the production frontier (Janssen and Ruiz de Londonõ 1994). Empirical evidence shows that agricultural technological change in developing countries was remarkable during the implementation of the Green Revolution, but could not be sustained (Teruel and Koruda 2004). Dramatic increases in production of rice and other crops are due mostly to improvement in agricultural technology. Seed technology, resulting in high yielding varieties responsive to inorganic fertilisers, is the major source of growth (Hossain et al. 2006; Settle et al. 1996).

Many studies of production technology are mostly estimated with Cobb-Douglas production functions (for example Che et al. 2006; Trewin et al. 1995), meaning that technological change is neutral. Michl (1999) reveals that technical change is not always typically neutral. As cited by Kidane and Abler (1994), technological changes are typically factor augmenting. This means that technology leads to increases in input use in order to increase the level of output. Umetsu et al.'s (2003) study on technical change of the Philippine rice sector indicates that change in productivity of rice is related to the intensification caused by the Green Revolution, which promotes chemical use. This is different from by a study by Villano and Fleming (2006) that rice agriculture in the Philippines experienced technological progress, with fertiliser-saving technological change. A study by Coelli (1996a: 89) on Australian agriculture finds that 'material and services and labour were Hicks-saving relative to other input groups'. O'Neill and Matthews (2001) who study technical change in Irish dairy production show that there is technological regress, with input-intensive technical change. The sources of variation in the non-neutrality of technological change are government policies and level of development of the countries. In developing countries, technological change tends to be input augmenting including labour, whereas in developed countries, technological change tends to be labour saving.

There are various outcomes of technological change resulting from different studies. Technological change, which can be neutral, input saving or input using, is affected by technology, the political situation and government policies. Generally, in developing countries where the agricultural sector plays an important role in the economy, it is likely that policy makers promote technology which results in input augmenting technological change to boost economic growth in the agricultural sector. As stated by Umetsu et al. (2003), technological change is intended to intensify use of packages of technology that strongly substitute for land. However, in developed countries where the agricultural sector is less important than other sectors, it is likely that technological change is input saving. Usually, this is because environmental problems resulting from agricultural inputs have been accounted for.

Theoretical Framework

Terminology of technological change

The terms 'technical change' and 'technological change' are almost interchangeably used in analyses of economic development. Technological change refers mainly to advances in the state of knowledge from which production possibilities can be enhanced. The origin of technological change is technology, which is defined as a stock of available techniques or a state of knowledge that concern the relationship between inputs and a given physical output. Technical change relates to the addition of a technique to a stock of techniques that are already in use. A technique itself is any single method of production, that is, a precise combination of inputs used to produce a given output (OECD 1995). Regarding availability, Mundlak (2000) defines that available technology is a collection of all available techniques; and technical change is a change in the technology set.

Technological change allows the substitution of knowledge for resources, or inexpensive and abundant resources for scarce and expensive resources, or it relaxes the constraints on growth imposed by inelastic supply for resources. In agricultural sectors, positive technological change enables farmers to produce more output with the same level of inputs, or the same level of output from a smaller level of inputs. When technological change makes use of existing capital and existing labour to produce more of the same output, it is called disembodied technological change. But, if the technological change requires some adjustments of existing processes, it is called embodied technological change.

Technological change in agricultural production is largely often embodied in new short-lived and durable inputs, by means of improved quality. High quality of fertilisers, agrochemicals, seeds or varieties, and feeds are examples of short-lived (variable) inputs that embody technological change. Likewise, machinery and tractors that carry out a wider array of tasks more rapidly, and genetically improved animal stocks, are examples of durable (capital) inputs that embody technological change.

Technological change can be neutral or non-neutral. Technological change is neutral if it leads to savings of all production inputs in the same proportion. If technological change results in greater savings of one factor over others, such change is called biased or non-neutral technological change. Non-neutrality of technological change permits substitution of one input for other inputs. Biased technological change can be input-saving or input augmenting.

Technological change is a process in which new technology is invented and institutionalised in production. In general, technological change consists of three inter-linked components: the research and development component that involves the creation and application of knowledge; the adoption and diffusion component that pertains to firms and consumers who decide to adopt innovation; and institutional components, the economic, social, legal, and political circumstances for the first two components (Knudson and Larson 1989). But, the relationship among the three components is symbiotic rather than sequential as there are many responses which make the boundaries between various stages indistinct.

Measure and neutrality of technological change

Technology is an abstract concept whose effects are obvious but not easily measured. Inference about the effect of improvement in technology is indirect, and is generated by making comparison of changes in inputs and outputs. As far as these effects are concerned, technology is able to increase output from a given level of inputs, or decrease inputs for a given level of output (Mundlak 2000). A measure of technology can be used as a variable in the production function and by this means allow a better estimate of the contribution of inputs to output. A frequent representative measure of changes in technology is the use of a time trend, which is an associative variable that quantitatively summarises changes over time. Such a measure provides valuable information on the rate of technological change and its factor bias.

The concept of the transformation function is formulated as:

$$T(\mathbf{Y},\mathbf{X},t)\leq 0 \qquad (3.1)$$

where $\mathbf{Y}$ represents a vector of outputs, $\mathbf{X}$ represents a vector of inputs, and t is time index associated with the modelling of technological change (Jaffe et al. 2000). Equation (3.1) describes a production possibility frontier, that is, a set of combinations of inputs and outputs that are technically feasible at a point in time. Technological change is represented by movement of this frontier that makes it possible over time to use given input vectors to produce output vectors that were not previously feasible.

In most applications, an assumption of separability and aggregation has been made such that it is possible to characterise production technology in the economy with a production function:

$$Y = F(K, L, E; t) \tag{3.2}$$

where Y is now a single measure of aggregate output. The list of inputs on the right-hand side of the production function can be made arbitrarily long. For illustrative purposes, let us visualise output as being made from a single composite of capital goods, K, a single composite of labour inputs, L, and a single composite of environmentally affecting inputs, E. In this case, the technological change means that the relationship between these inputs and possible output levels changes over time. Taking a logarithm and differentiating Equation (3.2) with respect to time yields:

$$\dot{Y}_t = \dot{A}_t + \beta_{Lt}\dot{L}_t + \beta_{Kt}\dot{K}_t + \beta_{Et}\dot{E}_t \tag{3.3}$$

in which a dot (.) over the variable represents the growth rates of the corresponding variable; the βs represent the corresponding logarithmic partial derivatives from Equation (3.2); and the subscript t indicates that all quantities and parameters may vary over time.

The term A_t corresponds to what is called "Hicks-neutral" technological change. In this sense, it represents the growth rate of output if the growth rate of all inputs is zero. Nevertheless the possibility that the βs can vary over time permits what is called "non-neutral" technological change, that is, changes over time in productivity of the various inputs. Equation (3.2) is easily interpreted in the case of process innovation and diffusion of technology, in which firms discover more efficient ways to make existing products, allowing output to grow at a rate that is faster than the rate of input growth.

To some extent, it is difficult to make a distinction between the effects of innovation and diffusion. Improvements in productivity are observed, but there is no underlying information necessary to separate such improvements between movements of the production frontier, and movements of existing firms towards the frontier. A related issue, and one that is frequently significant for environment-related technological change, is that innovation can be undertaken either by the manufacturers or the users of new modern inputs. In the former case, the innovation must characteristically be embodied in new capital goods, and must then diffuse through the population of users via the purchase of these goods, in order to affect productivity or environmental performance. In the latter case, the innovation may take the form of changes in practices implemented with existing inputs. Alternatively, firms may modify new inputs for their own use, which they then may or may not sell to other firms. The fact that the locus of activity that generates environment-related technological change can be in supplying firms, using firms, or both, has important consequences for modelling the interaction of technological change and environmental policy.

The embodiment of new technology in new capital goods creates an ambiguity regarding the role played by technology diffusion with respect to Equations (3.2) and (3.3). One of the interpretations is that these equations represent best practice, that is, what the economy would produce if all innovations made to date had been fully diffused. In this interpretation, innovation would drive technological change captured in Equation (3.3); the issue of diffusion would then arise in the form of the presence of firms producing at points inside the production possibility frontier. The stochastic frontier production function model introduced by Aigner et al. (1977) can be used to estimate the extent to which such sub-frontier behaviour is occurring. In this formulation, observed movements of the frontier — measured technological change — encompass the combined impacts of the invention, innovation and diffusion processes.

Methodology

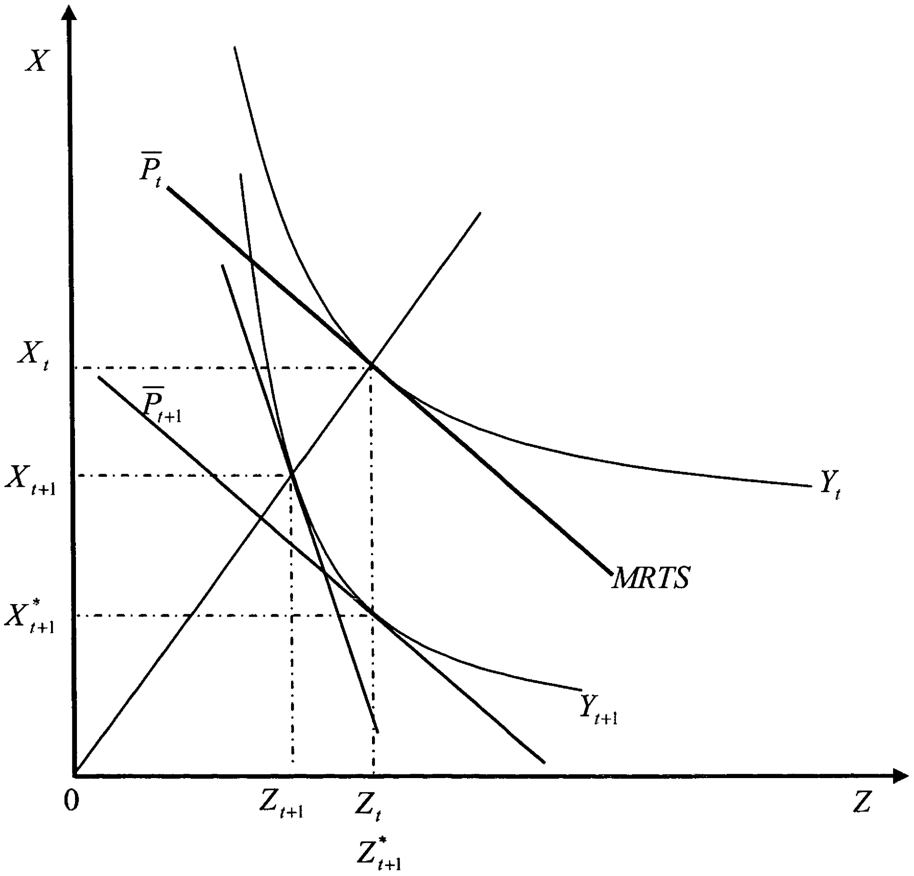
Econometric modelling

Movements in the production function. Solow (1957: 312) states that technological change is '... a shorthand expression for any kind of shift in the production function. Thus slowdowns, speedups, improvement in the education of the labor force, and all sorts of things will appear as "techn[olog]ical change."' Chambers (1988) and Antle and Capalbo (1988) propose that the dominant approach in economic analysis of production technologies has been to identify technological change with movements in the production function. Nishimizu and Page (1982) point out that technological change is represented by the movement of the production frontier. In this framework, the production function changes over time, but at a certain point in time, there is only one production function.

Non-neutrality of technological change. Suppose Y is produced using environmentally detrimental input X and usual input Z with production technology $Y_t = f_t(X_t, Z_t, t; \beta)$. Distinguishing both inputs is required to understand environment-related technological change. In agricultural practices, the environmentally detrimental input is agrochemicals, which consist of inorganic fertilisers and synthetic pesticides (Bond 1996; Reinhard et al. 2000).

Definition 3.1: Technology is regarded as`environmentally friendly if it is capable of reducing the use of environmentally detrimental inputs. Processes of innovation, dissemination and adoption of such technology can be represented by input-*X*-saving technological change.

Figure 3.1. Input-X-saving technological change



This phenomenon can be diagrammatically expressed in Figure 3.1. At time *t*, a certain level of output, represented by isoquant Y_t, is produced with some level of input X_t and Z_t. In this case, profit maximisation holds because the marginal rate of technical substitution, $MRTS$, is equal to (coincides with) the price ratio of both inputs, $\overline{P}_t$. Now, suppose there is an exogenous improvement in technology, or technological progress at time $t+1$. At time $t+1$, the same level of output, $Y_{t+1} = Y_t$, can be produced with lower level of input X_{t+1} and Z_{t+1}. Both inputs decrease proportionately. With the same proportion of both inputs, the $MRTS$ at time $t+1$ is steeper than before, or the absolute value of $MRTS$ becomes higher. Keeping the price ratio constant, the proportion of input no longer yields maximised profit, because $MRTS$ is not equal to $\overline{P}_t = \overline{P}_{t+1}$. Profit maximisation will be the case if input X is reduced from X_{t+1} to X^*_{t+1} and input Z is increased from Z_{t+1} to Z^*_{t+1}, which is equal to the initial level. The new proportion of inputs is less of input X and more of input Z. This is a kind of input-X-saving technological change, that is, improvements in technology that enable the proportion of input X to decrease to maintain maximised profit.

It can be mathematically modelled with the production function as follows. Let the production function be:

$$Y_t = \beta_0 X_t^{\beta_1+\beta_3 t} Z_t^{\beta_2+\beta_4 t} e^{\beta_5 t+\beta_6 t^2} \qquad (3.4)$$

where β_is are technology parameters including total factor productivity (tfp), which is represented by β_0.[2] This production function is able to capture two distinct technological changes: non-neutral technological change and pure technological change. Non-neutral technological change is represented by β_3 and β_4, and pure technological change is represented by β_5 and β_6. The pure technological change results in the same level of output which can be produced with a lower level of inputs where the proportion of inputs is constant. The non-neutral technological change allows the $MRTS$ to vary over time. A proposition that can be drawn is:

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[2] Taking the log on both left and right hand sides of the production function specified in equation (3.4) gives: $\ln Y_t = \ln\beta_0 + \beta_1 \ln X_t + \beta_2 \ln Z_t + \beta_3 t \ln X_t + \beta_4 t \ln Z + \beta_5 t + \beta_6 t^2$. This expression is translog production technology with a restriction of which inputs are separable from each other but not from time (Fan 1991). Ahmad and Bravo-Ureta (1996) suggest that this model is able to overcome multicollinearity problems of the translog model.

Proposition: Technological change is said to be input-X-saving if $\beta_3 << \beta_4$ such that the marginal rate of technical substitution, dX/dZ, at the same proportion of input use increases in modulus.

Proof:

Let us assume that producers attempt to maximise profit over time.

$$MRTS = -\frac{\partial Y_t/\partial Z_t}{\partial Y_t/\partial X_t} = -\frac{(\beta_2+\beta_4 t)\beta_0 X_t^{\beta_1+\beta_3 t} Z_t^{\beta_2+\beta_4 t-1} e^{\beta_5 t+\beta_6 t^2}}{(\beta_1+\beta_3 t)\beta_0 X_t^{\beta_1+\beta_3 t-1} Z_t^{\beta_2+\beta_4 t} e^{\beta_5 t+\beta_6 t^2}}$$

$$= -\frac{(\beta_2+\beta_4 t)X_t}{(\beta_1+\beta_3 t)Z_t} \qquad (3.5)$$

The impact of technological change on $MRTS$ is given by partially differentiating with respect to time trend, that is:

$$\frac{\partial}{\partial t} MRTS = -\frac{\beta_4 X_t(\beta_1+\beta_3 t) - \beta_3 X_t(\beta_2+\beta_4 t)}{(\beta_1+\beta_3 t)^2 Z_t}$$

$$= -\frac{(\beta_1\beta_4 - \beta_2\beta_3)X_t}{(\beta_1+\beta_3 t)^2 Z_t} \qquad (3.6)$$

With constant proportions of X and Z, technological change will increase $MRTS$ if $\beta_3 < 0$ and $\beta_4 \geq 0$, or in general $\beta_3 << \beta_4$ since $\beta_3 \in (0,1)$.

Functional form of production technology. Consider a farm using inputs land A, capital K, labour L, material M, and agrochemicals X, to produce a single output Y. The technology is characterised by a production function:

$$Y = F(A,K,L,M,X,t) \qquad (3.7)$$

The inclusion of t in time series econometric models of production is to measure smooth technological change over time (Millan and Aldaz 1998). Most agricultural production functions using aggregate data in developing countries exhibit constant returns to scale (Hayami and Ruttan 1985). Thus, the production function can be expressed in an intensive form of the production function or yield function as:

$$y = f(k, l, m, x, t) \tag{3.8}$$

where $y = Y/A$, $k = K/A$, $l = L/A$, $m = M/A$ and $x = X/A$. Estimating yield function that uses aggregate data can overcome a multicollinearity problem, which commonly happens in estimating a production function involving aggregate time-series data in agriculture. This is because the input uses increase proportionately with the increase in area under cultivation. To overcome the problem, the production function is estimated using data per hectare. Dividing both right and left hand sides by land results in a yield function where land disappears in the model.

Using the functional form specified in Equation (3.4) with these inputs, and taking natural logarithm give:

$$\ln y = \ln \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_x \ln x + \beta_{tk} t \ln k + \beta_{tl} t \ln l$$
$$+ \beta_{tm} t \ln m + \beta_{tx} t \ln x + \beta_t t + \beta_{tt} t^2 \tag{3.9}$$

In this case, the technological change does not only affect total factor productivity, but also affects the elasticity of production with respect to all inputs. The technological change is considered non-neutral since the passage of time affects the marginal rate of technical substitution between inputs (Heshmati 1996). The rate of technological change is:

$$d \ln y / dt = \beta_{tk} \ln k + \beta_{tl} \ln l + \beta_{tm} \ln m + \beta_{tx} \ln x + \beta_t + 2\beta_{tt} t \tag{3.10}$$

It can be seen that the rate of technological change consists of two components. The first is pure technological change expressed by $\beta_t + 2\beta_{tt}t$; and the second is non-neutral technological change expressed by $\beta_{tk}\ln k + \beta_{tl}\ln l + \beta_{tm}\ln m + \beta_{tx}\ln x$. The non-neutral technological change allows time-varying marginal rate of factor substitution. If $\beta_{tk}, \beta_{tl}, \beta_{tm}$ and β_{tx} are positive, the technological change is said to be input augmenting (O'Neill and Matthews 2001).

Technological change for different policies

Indonesian rice agriculture is divided into an intensification program, called BIMAS/INMAS and a non-intensification program.[3] Related to environmental issues, there are two major distinct periods of Indonesian rice policy. The first is the period of implementation of the Green Revolution in 1970-1988. The second is the period of dissemination and implementation of ecological technology in 1989-1999. During the Green Revolution, technological change in rice agriculture is expected to be chemical using. On the other hand, during implementation of ecological technology, technological change in rice agriculture is expected to be chemical saving. The objective of the latter policy is to use detrimental inputs at a reasonable level. Both policies are expected to promote different types of technological change.

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[3] Rice production in Indonesia also occurs in dryland, tidal, and swamp environments. However, these environments have not been an important focus of government intensification programs and often are found in remote areas poorly serviced by transportation and marketing infrastructure. Consequently, production is characterized by tiny percentages of marketed output, low yields and modest or zero levels of modern inputs. A rough estimate of the shares of rice area and production contributed by each of the main rice systems is only 5 and 6 per cent of total rice production (Heytens 1991). Because of such conditions this study does not pay attention on the particular case for such lands.

To be capable of identifying the non-neutrality of technological change on intensification programs and policies, dummy variables need to be incorporated in the model. The simplified translog production technology is modelled as:

$$\begin{aligned}\ln y = \ln \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_x \ln x + \beta_B B + \\ \beta_{tk} t \ln k + \beta_{tl} t \ln l + \beta_{tm} t \ln m + \beta_{tx} t \ln x + \beta_t t + \beta_{tt} t^2 \qquad (3.11)\end{aligned}$$

Where B is a dummy variable for BIMAS/INMAS. But, the different programs are not only hypothesised to affect neutral technological change, but also to influence the non-neutral technological change. To capture the effect of intensification on non-neutral technological change, the production function is modelled as:

$$\begin{aligned}\ln y = \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_x \ln x + \beta_B B \\ + \beta_{tk} t \ln k + \beta_{tl} t \ln l + \beta_{tm} t \ln m + \beta_{tx} t \ln x + \beta_{Btk} Bt \ln k + \beta_{Btl} Bt \ln l \\ + \beta_{Btm} Bt \ln m + \beta_{Btx} Bt \ln x + \beta_t t + \beta_{tt} t^2 \qquad (3.12)\end{aligned}$$

The intensification programs will lead to rice agriculture being more input augmenting if $\beta_{Btk}, \beta_{Btl}, \beta_{Btm}$ and β_{Btx} are positive.

The Green Revolution applied in both programs during the period 1979-1989 is hypothesised to promote chemical use. To examine the non-neutral technological change in the Green Revolution, the production function is modelled as:

$$\begin{aligned}\ln y = \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_x \ln x + \beta_B B + \\ \beta_{tk} t \ln k + \beta_{tl} t \ln l + \beta_{tm} t \ln m + \beta_{tx} t \ln x + \beta_{Gtk} Gt \ln k + \beta_{Gtl} Gt \ln l \\ + \beta_{Gtm} Gt \ln m + \beta_{Gtl} Gt \ln x + \beta_t t + \beta_{tt} t^2 \qquad (3.13)\end{aligned}$$

where G is a dummy variable for the Green Revolution. The Green Revolution will lead to rice agriculture being more input augmenting if $\beta_{Gtk}, \beta_{Gtl}, \beta_{Gtm}$ and β_{Gtx} are positive, and vice versa.

Stochastic production frontier

A stochastic production frontier model for panel data (Kumbhakar and Lovell 2000), will be used in this study. It can be expressed as:

$$y_{it} = f(k_{it}, l_{it}, m_{it}, x_{it}, t; \beta)\exp\{v_{it} - u_{it}\} \tag{3.14}$$

The disturbance term in a stochastic frontier model is assumed to have two components. One component, u_{it}, is assumed to have a strictly non-negative distribution and the other component, v_{it}, is assumed to have a symmetric distribution. In the econometrics literature, u_{it}, is often referred to as the inefficiency term and v_{it} is often referred to as the idiosyncratic error.

Following Battese and Corra (1977) and Battese and Coelli (1993), variance terms are parameterized by replacing σ_v^2 and σ_u^2 with

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \tag{3.15}$$

and

$$\gamma = \sigma_u^2 \big/ \sigma^2 \tag{3.16}$$

Stochastic production frontier models for panel data permit two different parameterisations of the inefficiency term u_{it}: a time-invariant model and the Battese and Coelli (1992) parameterisation of time-effects. In the time-invariant model, the inefficiency term is assumed to have a truncated-normal random distribution, which is constant over time within the panel. That is:

$$u_{it} = u_i \tag{3.17}$$

In the parameterisation of time effects (time-varying decay model), the inefficiency term is modelled as a truncated-normal random variable multiplied by a specific function of time. That is:

$$u_{it} = u_i \exp\{\eta(t - \Gamma)\} \tag{3.18}$$

where Γ corresponds to the last time period in each panel, η is the decay parameter to be estimated, and u_{it} are assumed to have a $N(\mu, \sigma_u^2)$ distribution truncated at zero. In both models, the idiosyncratic error term is assumed to have a normal distribution with mean 0, $N(0, \sigma_v^2)$. The only panel-specific effect is the random inefficiency term. The time-invariant model is obtained from the time-varying model by setting $\eta = 0$.

Testable hypotheses

There are four hypotheses related to this analysis: (1) non-existence of the production frontier, (2) non-existence of technological change, (3) neutrality of technological change, and (4) no different technological change for different lands, intensification programs and polices. Non-existence of the stochastic production frontier should be tested since technological change is represented by its movement. This test allows the production frontier to be different from the average production function estimated using ordinary least square (OLS). Following Battese and Coelli (1992), the formal test for the hypothesis of non-existence of the production frontier is formulated as:

H$_0$: $\gamma = \mu = \eta = 0$

H$_1$: at least $\gamma > 0$ (H3.1)

If H_0 is not rejected, the production frontier will be the same as the average production function.

Technological change is practically represented by movement in the production frontier. A formal test for the hypothesis of absence in technological change is formulated as:

H_0: $\beta_t = \beta_{tt} = 0$

H_1: H_0 is not true (H3.2)

If H_0 is true, there is no technological change.

When the technological change exists, the neutrality of technological change needs to be tested to account for the possibility of biased technological change. Neutral technological change implies a Cobb-Douglas production technology in which technological change is represented by change in intercepts over time. A formal test for the hypothesis of neutral technological change is formulated as:

H_0: $\beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0$

H_1: H_0 is not true (H3.3)

If H_0 is true, the technological change is neutral.

In the case of non-neutral technological change, a further test is needed to examine the non-neutral technological change for different intensification programs and policies. A formal test for the hypothesis of no impact of different intensification programs is formulated as:

H_0: $\beta_{Btk} = \beta_{Btl} = \beta_{Btm} = \beta_{Btx} = 0$

H_1: H_0 is not true (H3.4)

A formal test for the hypothesis of no impact of the Green Revolution on rice agriculture under intensification and non-intensification is formulated as:

H$_0$: $\beta_{Gtk} = \beta_{Gtl} = \beta_{Gtm} = \beta_{Gtx} = 0$

H$_1$: H$_0$ is not true (H3.5)

Related to attention to environmental issues, a particular hypothesis will be based on chemical input, x. It is expected that β_{Btx} and β_{Gtx}, are positive, meaning that chemical-augmenting technological change has been occurring in rice agriculture under intensification programs and rice agriculture during the Green Revolution. A formal test for the hypothesis of solely chemical-augmenting technological change is formulated as:

H$_0$: $\beta_{Btx} = 0$, $\beta_{Gtx} = 0$

H$_1$: $\beta_{Btx} > 0$, $\beta_{Gtx} > 0$ (H3.6)

Testing for those hypotheses is conducted using a likelihood ratio (*LR*-test) as described in Verbeek (2003). That is:

$$LR = 2(LL_{H_1} - LL_{H_0}) \qquad (3.19)$$

where LL_{H_1} is log-likelihood obtained from a model where the alternative hypothesis is true, and LL_{H_0} is log-likelihood obtained from a model where the null hypothesis is true. The value of LR follows the distribution of χ^2 with a degree of freedom the same as the number of the parameters specified in the null hypothesis.

FRONTIER 4.1, a computer program created by Coelli (1996b) is used to estimate the parameters of the stochastic frontier production function. It does a maximum likelihood estimation (MLE) involving a three-step procedure. The first stage involves the ordinary least square (OLS) estimation of β and σ^2. All estimators are unbiased except for the intercept term and σ^2 if $\gamma>0$. The second stage involves the evaluation of the likelihood function for a number of values of γ in the range zero to one, and the adjustment of the OLS estimates for σ^2 and the intercept for use in the final stage. Finally, the largest log-likelihood values from the second stage are used as starting values in an iterative maximisation routine, which obtains the maximum likelihood estimates.

Data, source and variables

This study uses detailed farm level annual surveys of rice cultivation costs conducted and published by the Indonesian Statistical Agency (BPS). The data are the average variables for rice agriculture operating in one hectare of paddy land in each region across time. The data are therefore expected to be sufficiently representative of one hectare of rice agriculture. Variables are aggregated based on type and function. The aggregation is done to avoid many missing variables.[4]

Particular emphasis is on chemical inputs because it strongly relates to analysis of the Green Revolution and environmentally friendly policies. The definitions and units of measurement are provided in Table 3.1, and the summary statistics for those variables are given in Table 3.2 to Table 3.4. It can be seen from the tables above that standard deviations of rice yield, uses of capital, labour,

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[4] In agricultural production, it is common that producers do not use chemical inputs. It is also the case that some farms do not employ capital because it is substitutable with labour. By definition, for a simplified translog production function, using zero chemical input leads to undefined function. In fact, without using chemical inputs, the production is not zero. Furthermore, estimating the production function using zero input is impossible because taking the logarithm of zero will result in negative infinity. One of the ways of dealing with such a problem is to replace no use of chemical inputs with a positive very small value (Trewin et al. 1995).

materials and chemical inputs within and between regions are relatively high. The standard deviations of such variables are also relatively high over time. These indicate that such variables vary considerably. These variations are expected to provide good conditions for estimating frontier production functions. Note that observations are mostly from Sumatra because the number of provinces in the region dominates other regions. For Java, despite the fact that the region is considered a rice bowl in Indonesia, the number of observations is not as many as Sumatra, because the number of provinces in Java, at the time, was only four. It is important to note that tests for co-integration show that each variable (in logarithm) including time trend is co-integrated. This means that there will be no spurious regression results (Greene 2003; Gujarati 2003).

Table 3.1. Definitions and units of measurement of variables

Variable	Description
Yield (y)	Production of rice per hectare in each province (kg)
Capital (k)	Machinery and animals hired and employed per hectare of land (thousands IDR at constant price of 1983)
Labour (l)	Labour hired per hectare of land (thousands IDR at constant price of 1983),
Material (m)	Values of seed, irrigation, compost, and other costs used per hectare of land (thousand IDR at constant price 1983)
Chemical (x)	Inorganic fertilisers consisting of Urea, KCl, TSP and ZA and chemical pesticides consisting of insecticides, herbicides, and fungicides in various formulations used per hectare of land (thousand IDR at constant price 1983)

Note: Since all inputs are measured in monetary values, the coefficients of the estimated production function may differ slightly from those when the inputs are measured in physical terms. Using agricultural deflation is expected to reduce the variation of the monetary values. The higher value of inputs may represent the larger amount and/or the better quality of inputs.

Source: Central Bureau of Statistics (BPS).

Table 3.2. Summary statistics for variables, by major region

Regions		Intensification program					Non-intensification program				
		Yield	Capital	Labour	Material	Chemical	Yield	Capital	Labour	Material	Chemical
Sumatra (133 obs)	mean	3822.01	5.42	70.22	25.74	431.25	2915.41	2.99	37.75	21.27	15.89
	s.d.	474.78	6.20	33.23	17.56	147.71	425.68	4.29	22.10	13.16	28.19
	min	2800.00	0	4.49	0.05	83.19	1872.00	0	2.81	0.05	0
	max	4818.00	39.21	169.93	93.26	770.50	4027.00	20.44	156.53	82.91	222.84
Java& Bali (85 obs)	mean	5015.78	11.70	131.32	27.94	694.99	3245.34	5.74	75.07	19.61	73.29
	s.d.	381.55	7.01	44.48	9.93	111.89	587.56	5.06	45.76	14.59	133.05
	min	3975.00	2.17	58.15	9.05	406.08	1620.00	0	0.95	0.93	0
	max	5915.00	36.38	342.87	51.96	897.06	4900.00	21.30	200.00	73.27	668.02
Kalimantan (64 obs)	mean	2788.38	0.63	51.06	17.10	274.74	2198.75	0.44	32.88	19.40	7.54
	s.d.	325.29	1.00	56.97	14.31	119.46	327.83	1.07	20.78	10.38	12.71
	min	2067.00	0	2.92	0.10	0.00	1448.00	0	3.83	1.66	0.00
	max	3602.00	5.13	379.39	94.96	616.80	3298.00	6.62	92.43	69.11	74.52
West Nusa Tenggara (34 obs)	mean	3792.85	19.38	65.85	21.13	456.71	3089.47	10.51	32.79	14.59	28.39
	s.d.	558.48	7.14	30.42	9.52	174.48	402.88	5.76	18.86	6.72	73.17
	min	2131.00	6.20	13.94	5.30	93.34	2435.00	0	9.22	3.82	0
	max	4584.00	35.60	118.18	45.46	821.14	3928.00	26.83	70.43	31.34	419.59
Sulawesi (68 obs)	mean	3822.12	13.61	73.54	35.30	398.98	2802.04	9.67	47.43	25.67	13.35
	s.d.	489.60	12.58	39.42	17.31	105.35	346.16	7.08	25.35	17.79	25.36
	min	2664.00	0	8.78	7.83	215.33	2185.00	0	6.19	3.13	0
	max	4679.00	53.80	202.03	72.03	642.40	3803.00	28.48	115.16	100.13	154.95
Indonesia (384 obs)	mean	3911.42	8.70	80.75	26.07	460.08	2833.21	4.96	44.14	20.87	24.15
	s.d.	826.25	9.34	49.82	15.92	190.04	535.55	6.01	30.71	13.78	64.64
	min	2067.00	0	2.92	0.05	0.00	1448.00	0	0.95	0.05	0
	max	5915.00	53.80	379.39	94.96	897.06	4900.00	28.48	200.00	100.13	668.02

Note: See Table 3.1 for units of measurement
Source: Author's calculation

Table 3.3. Summary statistics for variables in intensification program, by year

Year		Yield	Capital	Labour	Material	Chemical
1979	mean	4019.33	16.60	81.34	13.51	336.47
	s.d.	736.32	14.52	73.92	9.77	164.86
1980	mean	4348.91	15.54	103.71	21.93	396.95
	s.d.	877.01	13.41	72.12	18.25	182.11
1981	mean	3492.73	16.45	98.97	18.30	483.01
	s.d.	645.81	13.48	79.21	13.23	129.21
1982	mean	3754.41	12.85	92.76	16.84	488.12
	s.d.	639.47	12.48	47.40	7.53	136.90
1983	mean	3807.18	12.79	90.23	18.55	513.30
	s.d.	737.94	9.37	45.98	10.39	144.02
1984	mean	3746.65	8.57	61.47	18.76	401.88
	s.d.	755.84	6.54	39.86	9.17	224.24
1985	mean	3743.39	8.57	71.65	27.12	402.74
	s.d.	771.17	6.54	38.66	11.78	194.96
1986	mean	3838.65	8.57	68.90	29.89	434.89
	s.d.	770.26	6.54	33.97	14.44	184.08
1987	mean	3771.96	2.96	67.22	26.37	459.60
	s.d.	907.95	3.74	38.19	15.90	194.86
1988	mean	3833.00	5.52	80.94	38.82	489.93
	s.d.	846.64	4.87	42.02	23.48	215.69
1989	mean	3881.74	7.40	81.60	33.59	499.27
	s.d.	934.36	6.34	36.85	16.59	223.74
1990	mean	3944.61	4.10	76.20	23.32	480.45
	s.d.	813.81	4.67	41.82	14.02	206.98
1991	mean	4054.35	6.03	78.33	32.84	516.69
	s.d.	869.14	5.45	45.59	16.86	166.34
1992	mean	4081.31	7.83	86.58	32.87	515.17
	s.d.	866.56	8.59	52.47	20.76	184.90
1993	mean	4063.87	6.38	80.13	26.24	468.77
	s.d.	892.03	7.19	41.45	12.18	191.36
1994	mean	4060.13	5.01	76.17	31.45	453.30
	s.d.	899.00	5.69	43.27	13.63	200.79
1995	mean	4069.78	4.68	80.37	30.32	469.16
	s.d.	903.67	5.53	49.06	10.90	204.98
Indonesia	mean	3911.42	7.16	80.75	26.07	460.08
	s.d.	826.25	9.55	49.82	15.92	190.04

Note: See Table 3.1 for units of measurement. Dickey-Fuller test for residual -4.436, $p>0.01$

Source: Author's calculation

Table 3.4. Summary statistics for variables in non-intensification program, by year

Year		Yield	Capital	Labour	Material	Chemical
1979	mean	3340.00	6.04	40.21	12.34	27.97
	s.d.	566.00	6.25	38.77	10.47	35.04
1980	mean	3511.24	6.50	65.49	17.54	38.52
	s.d.	579.27	6.67	47.94	13.83	52.54
1981	mean	2710.91	5.79	47.53	15.19	38.97
	s.d.	368.38	6.78	34.45	6.27	37.32
1982	mean	2766.18	5.65	55.94	13.92	25.99
	s.d.	394.61	7.95	29.88	5.91	31.85
1983	mean	2834.55	5.88	42.00	13.48	29.54
	s.d.	378.41	7.05	24.77	7.51	39.18
1984	mean	2858.50	4.98	31.75	15.02	12.19
	s.d.	412.90	4.69	19.47	5.68	33.21
1985	mean	2832.18	4.98	42.85	23.84	7.66
	s.d.	399.12	4.69	24.51	10.94	10.64
1986	mean	2669.18	4.98	43.56	24.56	7.46
	s.d.	620.25	4.69	19.43	17.05	17.09
1987	mean	2541.78	2.77	44.25	27.26	39.00
	s.d.	433.19	3.50	27.11	14.90	138.20
1988	mean	2835.59	4.22	51.95	29.44	36.49
	s.d.	379.20	4.80	31.95	18.93	79.51
1989	mean	2841.50	4.38	49.11	31.07	13.34
	s.d.	481.55	7.35	29.47	20.55	21.79
1990	mean	2803.86	3.95	40.79	20.23	93.47
	s.d.	534.62	5.55	22.35	11.97	164.74
1991	mean	2758.55	4.09	45.79	25.62	3.61
	s.d.	508.33	4.96	35.11	15.19	8.32
1992	mean	2633.50	6.24	42.73	25.21	3.86
	s.d.	496.20	8.86	39.58	13.68	4.03
1993	mean	2674.47	5.64	35.91	19.27	4.60
	s.d.	541.36	6.41	25.03	12.34	4.48
1994	mean	2735.72	4.29	34.36	23.24	5.56
	s.d.	698.74	5.09	25.63	9.97	6.24
1995	mean	2730.73	3.71	28.32	17.68	7.92
	s.d.	458.79	4.88	13.85	6.37	11.13
Indonesia	mean	2833.21	4.04	44.14	20.87	24.15
	s.d.	535.55	5.99	30.71	13.78	64.64

Note: See Table 3.1 for units of measurement. Dickey-Fuller test for residual -3.192, $p>0.05$

Source: Author's calculation

Results and Discussion

We test for the non-existence of the stochastic frontier function and non-neutral technological change, which is given in Table 3.5. We can see that the restriction of $\gamma = \mu = \eta = 0$ is rejected, meaning that the production function estimated using the frontier exists. As well, the restriction of $\beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0$ is rejected, meaning that technological change is not Hicks-neutral. Further tests are directed to show whether intensification was different from non-intensification programs, and whether the Green Revolution was different from the environmentally sound policies in terms of non-neutrality of technological changes. The estimated models accounting for the differences are given in Table 3.6.

The tests show that $\beta_{Btk} = \beta_{Btl} = \beta_{Btm} = \beta_{Btx} = 0$, is rejected, as well as $\beta_{Gtk} = \beta_{Gtl} = \beta_{Gtm} = \beta_{Gtx} = 0$. These mean that there were different biases in technological changes between intensification and non intensification programs; and Green Revolution and environmentally sound policies. Since β_{Btx} is significantly positive, rice agriculture under intensification programs was more agrochemical-augmenting.

With respect to the Green Revolution, β_{Gtl} is significantly negative and β_{Gtx} is significantly positive, technological change of rice agriculture under environmentally friendly policies was less labour-saving and more agrochemical-saving than under the Green Revolution.

The dummy variable for intensification programs is positive and significant. This means that total factor productivity under the intensification program was about 24-37 per cent higher than that under the non-intensification program. When the intensification program is normalised to one, Figure 3.2 shows the comparison between both programs. We can see that given different levels of input use, yield of rice under intensification programs was on average 28 per cent higher than that under non-intensification. The gap in yield was mostly driven by gaps in input use. The uses of capital and labour for intensification were almost double those of non-intensification programs. The use of agrochemicals in both programs differed almost 20 fold, whereas the use of material differed only 20 per cent.

Table 3.5. Frontier yield functions, neutral and non-neutral models

$\ln y$	Hicks-neutral		Biased	
	coefficient	t-ratio	coefficient	t-ratio
tfp	8.3897	130.47^a	8.5018	110.61^a
$\ln k$	0.0005	0.99	0.0022	2.01^b
$\ln l$	0.0142	1.90^b	-0.0216	-1.79^c
$\ln m$	0.0193	3.18^b	0.0136	1.36
$\ln x$	0.0002	0.13	0.0000	-0.02
B	0.0669	1.52^c	0.1585	1.97^b
$t \ln k$			-0.0002	-1.91^b
$t \ln l$			0.0048	3.52^a
$t \ln m$			0.0008	0.61
$t \ln x$			0.0001	0.24
t	-0.0192	-5.00^a	-0.0447	-5.44^a
t^2	0.0016	7.51^a	0.0015	7.23^a
γ	0.8804	60.39^a	0.8355	30.05^a
μ	0.5132	8.43^a	0.4242	4.21^a
η	-0.0277	-7.94^a	-0.0177	-2.41^b
Log-likelihood		595.48^a		603.97^a
LR-test for $\gamma = \mu = \eta = 0$		683.78^a		655.02^a
LR-test for $\beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0$				16.98^a

Note: Dependent variable is rice production per hectare (in logarithmic form). Statistical test is based on Table 1 of Kodde and Palm (1996); ^{a}) significant at 1%; ^{b}) significant at 5%; ^{c}) significant at 10% level.
Source: Author's calculation

Table 3.6. Frontier yield functions, full models

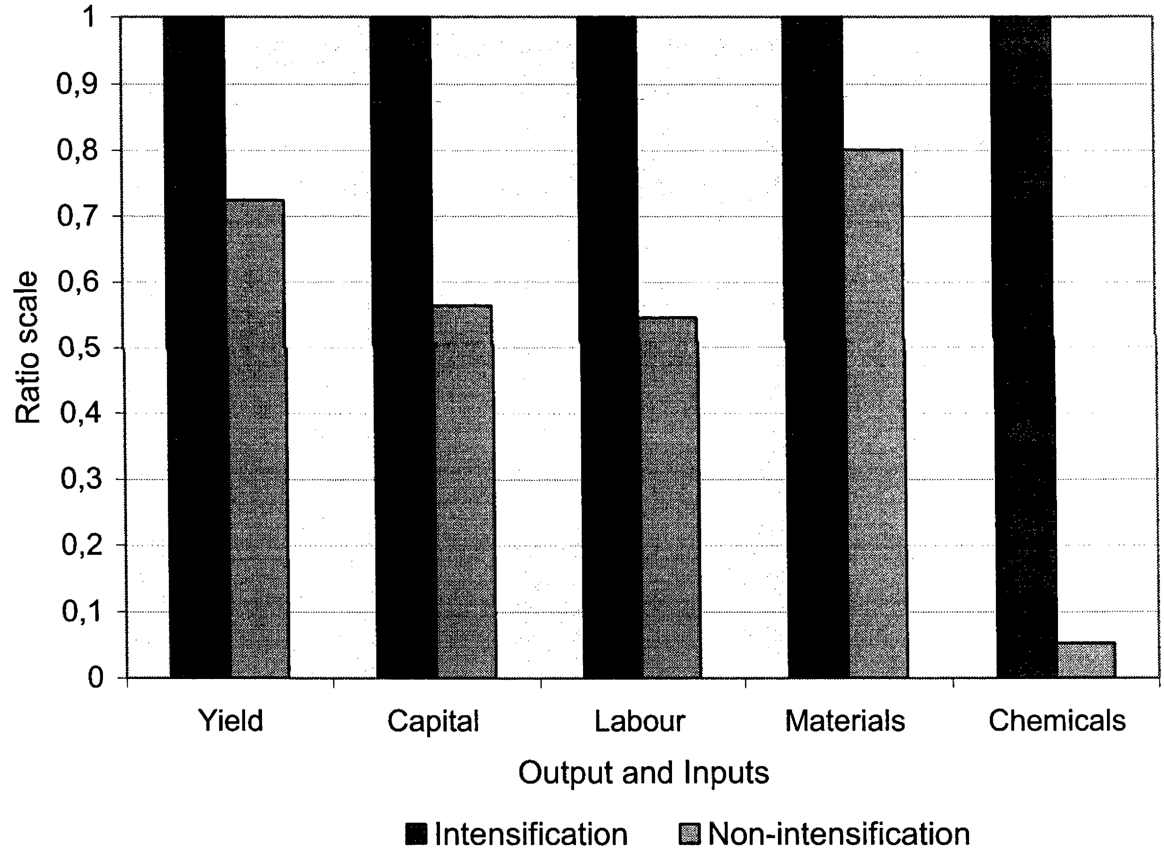
$\ln y$	Different intensification		Different policy	
	coefficient	t-ratio	coefficient	t-ratio
tfp	8.2487	156.24[a]	8.3375	153.80[a]
$\ln k$	0.0018	1.84[c]	0.0008	0.54
$\ln l$	-0.0048	-0.42	-0.0168	-1.31
$\ln m$	0.0125	1.29	0.0124	0.94
$\ln x$	0.0052	1.94[c]	-0.0079	-2.73[b]
B	0.2479	7.85[a]	0.3771	9.61[a]
$t\ln k$	-0.0002	-1.55	-0.0001	-0.83
$t\ln l$	0.0028	1.95[b]	0.0053	4.46[a]
$t\ln m$	0.0013	0.87	0.0008	0.54
$t\ln x$	-0.0007	-2.56[b]	0.0006	2.53[b]
$Bt\ln k$	0.0000	-0.30		
$Bt\ln l$	-0.0009	-0.57		
$Bt\ln m$	-0.0010	-0.64		
$Bt\ln x$	0.0035	3.38[b]		
$Gt\ln k$			-0.0001	-0.85
$Gt\ln l$			-0.0032	-2.08[b]
$Gt\ln m$			0.0006	0.31
$Gt\ln x$			0.0009	3.18[b]
t	-0.0448	-6.82[a]	-0.0503	-7.83[a]
t^2	0.0014	7.30[a]	0.0011	5.30[a]
γ	0.9014	17.97[a]	0.8798	14.98[a]
μ	0.1132	0.75	0.1060	0.73
η	-0.0152	-2.87[b]	0.0021	0.33
Log-likelihood		628.31[a]		619.11[a]
LR-test for $\gamma=\mu=\eta=0$		674.13[a]		670.28[a]
LR-test for $\beta_{tk}=\beta_{tl}=\beta_{tm}=\beta_{tx}=0$				48.68[a]
LR-test for $\beta_{Gtk}=\beta_{Gtl}=\beta_{Gtm}=\beta_{Gtx}=0$				30.28[a]

Note: Dependent variable is rice production per hectare (in logarithmic form). B is dummy variable = 1 for intensification program and = 0 otherwise; G is dummy variable = 1 for Green Revolution and = 0 otherwise. Statistical test is based on Table 1 of Kodde and Palm (1996); [a]) significant at 1%; [b]) significant at 5%; [c]) significant at 10% level.

Source: Author's calculation

The considerable gap in agrochemical use between both programs was because farmers joining intensification programs received in-kind credit of agricultural inputs, mostly fertilisers and pesticides. But, it did not immediately mean that if the use of inputs was the same, the yield would be the same. The main reason is that intensification programs were implemented in locations where agricultural infrastructure, fertile lands and educated and cooperative farmers were available (Rolling and van de Fliert 1994; Feder et al. 2004a).

Figure 3.2. Comparisons of output and inputs



Source: Author's calculation

Since β_t is significantly negative and β_{tt} is significantly positive, rice agriculture underwent negative technological progress at a decreasing rate. Keeping the use of inputs constant, the rate of negative technological progress was, on average, 3.63 per cent a year.[5] This is in line with the case in the Philippines where rice productivity grew impressively but cannot be sustained (Teruel and Koruda 2004). One possible cause is resource degradation (Kalirajan et al. 2001). It has been technically shown that the Green Revolution in Pakistan brought about land degradation (Ali and Byerlee 2002). The use of high yielding varieties enabled farmers to grow rice more than once a year. Lands were over exploited because they were rarely fallowed to allow lands to recover naturally.

This chapter focuses on the biased technological changes related to environmental issues. In this case, it is represented by the use of agrochemicals in intensification programs and the Green Revolution. It has been significantly shown in the estimated model above that technological changes in rice agriculture under both schemes were agrochemical augmenting. This implies that the dynamics of rice yield and agrochemicals in both schemes were different. The dynamics for different intensification programs and different sets of rice policies can be descriptively analysed with graphical representations.

The first policy is the Green Revolution during the period of the 1979-1989. After 1989 policy is considered more environmentally sound because of dissemination of environmentally friendly technology and elimination of pesticide subsidies (Rolling and van de Fliert 1994). In this descriptive analysis, the first policy is represented by periods 1979-89 and the second policy is represented by the period after 1989 (shaded areas). Changes in temporal patterns of rice agriculture after the Green Revolution are partially considered as the impacts of the environmentally sound policy that implemented environmentally friendly technology. The technology is called integrated pest

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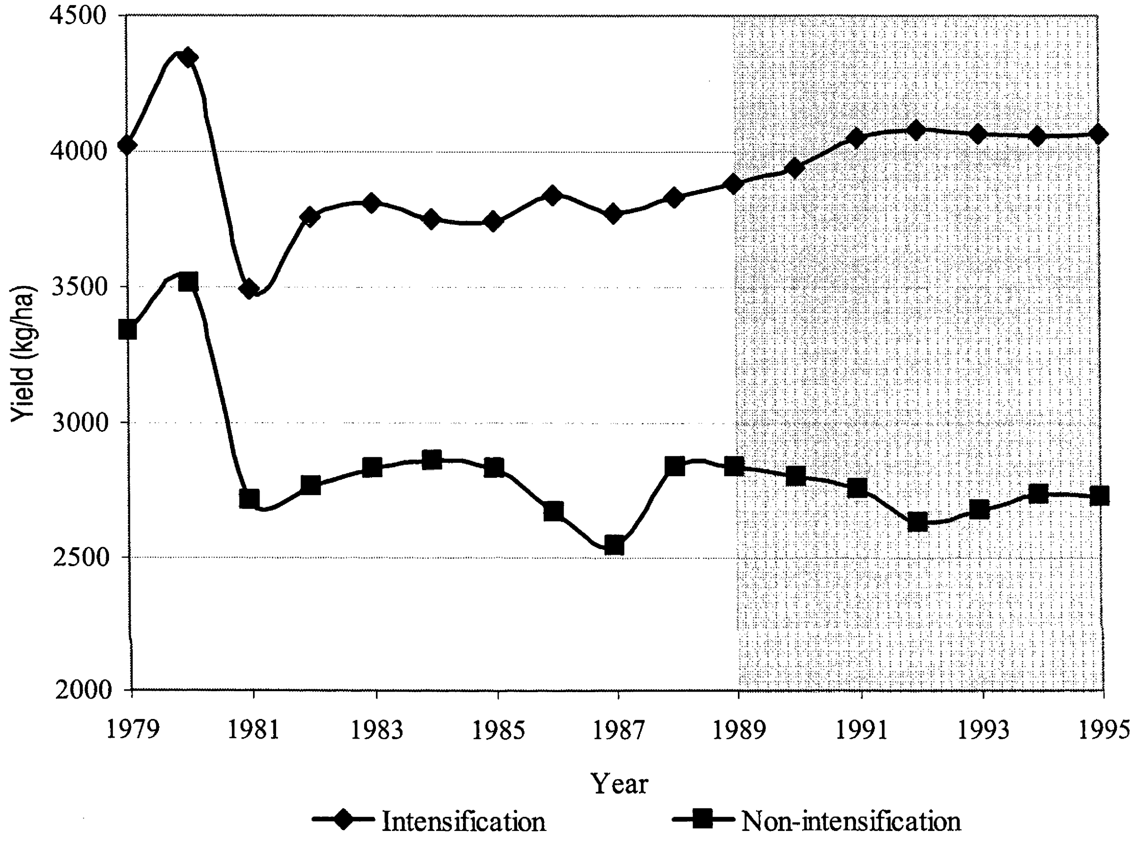
[5] The value of 3.63 per cent (0.0363) is obtained from $0.0448-0.0014\bar{t}$, where $\bar{t}$ is the average time index.

management and was institutionalised through a national program. The descriptive movements in yield of rice and use of agrochemicals are given in Figure 3.3 and Figure 3.4.

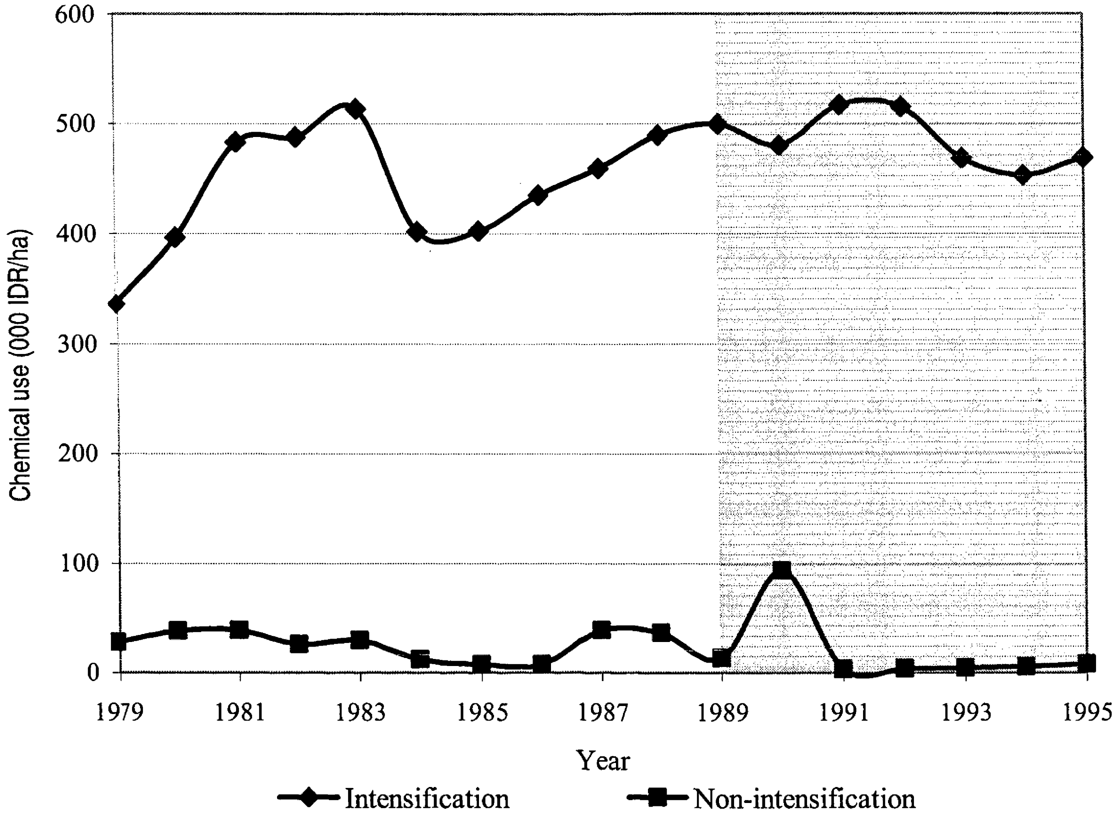
Figure 3.3. Trend of rice yield for different programs



Source: Author's calculation

Figure 3.3 shows the time series for rice yield. Overall, the yield of rice falls at the beginning period. The most likely cause was the sporadic pest out-breaks in 1980-81 resulting from pest resurgence. In addition, there was a transition program in which BIMAS/INMAS was modified into OPSUS (Sawit and Manwan 1991). After that, the yield of rice under intensification increased steadily, whereas that under non-intensification tended to fall continually. Beyond the Green Revolution, yield of rice under intensification levelled off two year after the change in policy.

Figure 3.4. Trend of agrochemical use for different programs



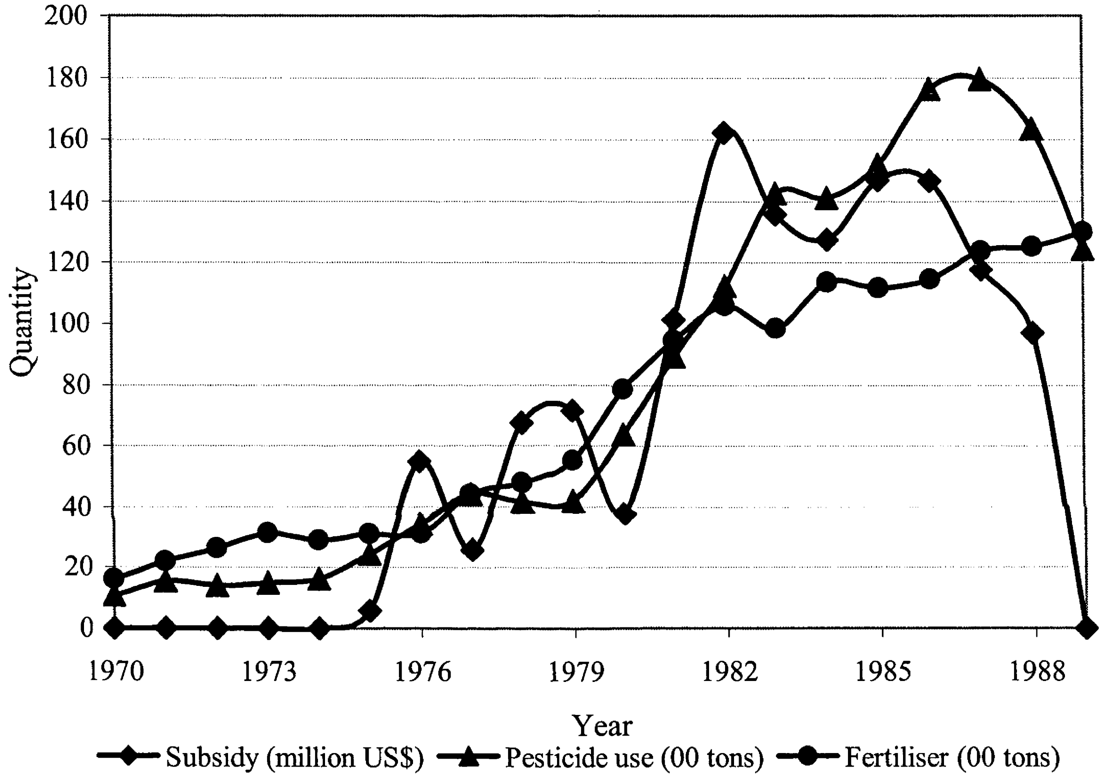
Source: Author's calculation

Figure 3.4 shows the time series for agrochemical use. Overall, the use of agrochemicals for intensification increased, in contrast to that under non-intensification programs. The fall in 1984 was due possibly to the modification of the program where new agrochemicals were introduced and the uses were rationalised. After that, the agrochemical use continued to increase until the subsidy of pesticides was totally discontinued in 1989. The slight increase after discontinuing the subsidy was due to resistance of high ranking officials in the Ministry of Agriculture to move the priority of pesticide use from the top to the bottom in coping with pest infestations (Tabor 1992). The involvement of high ranking officers of the Ministry of Agriculture in the agrochemical companies forced farmers to apply more and more agrochemicals in the intensification program. This also led to a black market of pesticides when a number of problematic pesticides were prohibited in 1986. A sharp decline in 1993 coincided with the wide dissemination of IPM technology.

The movements in agrochemical use confirm the econometric results indicating that technological change in intensive rice agriculture was agrochemical augmenting. The phenomenon is technically logical. In the intensification program, high yielding varieties of rice, which were fertiliser responsive, were widely grown. The varieties were initially susceptible to pest infestation, such that they had to be protected with high use of pesticides. Without use of agrochemicals, superiority of the varieties would not appear (Cleaver 1972). Despite the fact that pest-resistant varieties were introduced later on, pesticides were still used because they had been considered the most powerful measure for controlling pests. During the Green Revolution, the technological change was also agrochemical augmenting, because technological packages for rice agriculture were exactly the same as those in intensive rice agriculture. All actions of the intensification policy during the Green Revolution were reflected by more agrochemical-using technological change. In general, this finding confirms the statement of Murgai (2001) that technological change is biased. In relation with the Green Revolution, the condition is in line with a case in the Philippines where rice productivity relates to the intensification caused by the Green Revolution, which promoted agrochemical use (Umetsu et al. 2003).

When the magnificence of intensification and the Green Revolution ended, a new environmentally oriented policy was applied in 1989. The policy was able to reduce the intensiveness of agrochemicals, despite a delay in effective impact of the policy. The delay was mostly because of political intrigues in the Ministry of Agriculture in accepting the environmentally friendly technology. The other relevant reasons are that the policy only waived pesticide subsidies, and continued to subsidise fertilisers. In this analysis, agrochemicals consist of inorganic fertilisers and synthetic pesticides. There was a strong relation between pesticide use and the subsidies on pesticides as depicted in Figure 3.5.

Figure 3.5. Uses of fertilisers and pesticides; and subsidy of pesticides



Source: Author's analysis. Data from Pemerintah Indonesia (1991)

Pesticide use dropped when the subsidy decreased, but fertilisers steadily increased. The elimination of the pesticide subsidy provided a good atmosphere for adoption of IPM technology (Rolling and van de Fliert 1994). The technology did not only address the use of pesticides but also fertilisers (Untung 1996). The technology applied a reasonable level of inorganic fertilisers at the right time –synchronised with agronomical development of rice —, and synthetic pesticides when necessary. Thus, dissemination of the technology was able to reduce the use of agrochemicals. The reduction in agrochemicals is expected to increase welfare impacts on the whole community as quality of the environment and human health related to agrochemicals can be improved, as mentioned by Resosudarmo and Thorbecke (1998) and Resosudarmo (2001) that the IPM technology reduces the number of pesticide-related illnesses and increases agricultural output resulting households better off, especially those in the agricultural sector. Since the technology needed regular observation of agro-ecosystems to control pests (Untung, 1996) more labour was needed, and this led to more labour augmenting technological change.

The impact was apparent three years after the introduction. The delay was due largely to two conditions. First, in the first two years of dissemination, there were only 200,000 farmers, which were very small compared to the total number of Indonesian farmers, in the pilot project (Rolling and van de Fliert 1994). Second, the rate of diffusion of technology among farmers was low (Feder et al. 2004b). The massive dissemination began in 1994 when the project was taken over by the Ministry of Agriculture. The program was considered a nationwide policy (Untung 1996). The program was backed up by local governments, at provincial, district, sub-district and village levels (Rolling and van de Fliert 1994). Several non-government organisations concerned with environmental issues, particularly in agricultural and rural developments, supported the policy by disseminating the ecological technology in some regions not covered by the program.

Conclusion

The technological change driving rice production plays an important role in Indonesia, because rice is one of the important commodities as its politically and economically strategic position in economic development. Technological change has been shaped by various policies related to the importance of rice in the country's economy. There have been at least two policies related to environmental impact: the Green Revolution and the environmentally sound policies. Progress and direction of technological change is different for both policies.

Using a frontier production approach, rice agriculture underwent technological regress at a decreasing rate while technological change was not neutral. Changes in agricultural technology over time affected the productivity of certain inputs used per hectare of land. The type of technological change was not the same in both spatial and temporal aspects. Spatially, technological change in rice agriculture under intensification was different from that under non-intensification programs. Temporally, technological change in rice agriculture during the implementation of the Green Revolution was different from that during the implementation of environmentally sound technology.

Technological change under intensification programs was more agrochemical-using than under non-intensification programs. Temporally, technological change during the Green Revolution was less labour-saving and more agrochemical-using. More agrochemical-using technological change during the Green Revolution and intensification programs was mostly driven by development of seed technology which was responsive to fertilisers and susceptible to pest infestation. Intensive rice agriculture and the Green

Revolution were indeed considered to have serious environmental consequence because of agrochemical augmenting technological change over time. This implies that intensification and the Green Revolution policies were obviously not beneficial to the environment because agrochemicals are environmentally detrimental.

In terms of environmental aspects, the technological change improved after 1989 when the Green Revolution and intensification policies were replaced by an environmentally sound policy. The policy consisted of two major components: waiving pesticide subsidies and introducing IPM technology, which is considered a environmentally sound technology. The policy led to more agrochemical-saving technological change, by means of a decrease in the intensity of agrochemical use. With the reduction in use of agrochemicals, there will be positive welfare impacts as the quality of environment and human health can be improved. Because the political environment was not conducive at the beginning of policy change, the expected impact of the policy was not immediately apparent. The impact became apparent three years after the change in policy.

Chapter 4

Technical Efficiency and Sources of Inefficiency

Abstract

One cause of low productivity of Indonesian rice agriculture is, to some extent, technical inefficiency. This study measures the technical efficiency of rice production in five regions, and examines factors determining its variability. To estimate technical efficiency and inefficiency effects, this chapter uses stochastic frontier production functions, which reflect the best practice of production given certain levels of input use and technology. Unbalanced panel data on input-output rice production consisting of 358 farms in 1994, 1999 and 2004 are employed for estimating frontier production function. The results indicate that variation in rice production is due to technical inefficiency. Household characteristics, composition of labour and tractor use are the sources of variation in technical efficiency. Spatially, rice agriculture on Java is the most technically efficient and, dynamically, technical efficiency of rice agriculture in all regions increases. Overall, technical efficiency is low. Therefore there is still considerable room for improvement in productivity of rice agriculture, given state-of-the-art technology for rice production.

Keywords: technical efficiency, stochastic production frontier, farm level panel data, rice agriculture

Introduction

Indonesia needs to increase productivity of rice agriculture. Adopting new technology is one of the options. However, if farmers have not used existing technology efficiently, Shapiro (1983) and Belbase and Grabowski (1985) argue that efforts to improve technical efficiency may be more cost effective than introducing new technologies as a means of increasing agricultural productivity. It is wasteful to introduce new technology or to upgrade the existing technology if the technology has not been used to its full potential (Kalirajan et al. 1996). Therefore, an efficiency study is selected as a way of exploring the reasons that suppress productivity in Indonesian rice agriculture.

This part of the thesis attempts to analyse the efficiency of Indonesian rice production. Understanding the achievement of technical efficiency will be useful for agricultural policy makers to decide whether or not the efforts of upgrading the existing technology as well as introducing new technology are needed to increase rice production. If the level of technical efficiency is still low, the efforts are not necessary, and the increase in rice production can be achieved by improving technical efficiency with the existing state-of-the-art technology. The analysis utilises a stochastic frontier production technique, to estimate technical efficiency and to determine sources of inefficiency. The next section of this paper gives an overview of stochastic production function theory, including a definition and techniques used. It is followed by explanations of variables and the data set used. Discussion of the results from the model leads us to interpretations and conclusions.

Literature Review

Measurement of technical efficiency refers to the concept of the production frontier. The large number of frontier models that have been developed can be categorised into two main types: parametric and non-parametric. The former relies on a specific functional form and can be sub-divided into deterministic and stochastic models. The deterministic model holds the assumption that any deviation from the frontier is because of inefficiency, while the stochastic model allows for statistical error. Dhungana et al. (2004) analysing production efficiency of rice in Nepal, and Widodo (1989) in Indonesia, are examples of production frontiers which are estimated deterministically.

The latter is independent of functional form, and there is no specific functional form required in estimating technical efficiency. Umetsu et al. (2003) analyse agricultural performance in the Philippines using a Malmquist index of production derived from aggregate regional level data. Coelli (1996a) analyses Australian agriculture using a Tornqvist index of production and cost functions derived from aggregate regional data. Llewelyn and William (1996) analyse technical efficiency of Indonesian agriculture using farm level data. These studies are examples of non-parametric approaches.

For a stochastic production frontier there are two approaches. The first approach is an error component model that incorporates a composed error structure with a two-sided symmetric term and a one-sided component (Aigner et al. 1977; Meeusen and van den Broeck 1977). The one-sided component reflects inefficiency, while the two-sided error captures the random effects outside the control of the production unit, including measurement errors and other statistical noise typical of empirical relationships. The second approach, proposed by Kalirajan and Obwona (1994) is called a varying coefficients' model that allows different coefficients among firms. This approach has been used to estimate technical efficiency and productivity growth of Indian agriculture (Kalirajan 2004), the Chinese economy (Kalirajan et al. 1996), and the Taiwanese manufacturing industry (Sun 2004).

The main difference between the error component and the varying coefficient models is the coefficients of production technology. In the error component model, all firms are assumed to have the same coefficients of technology but have different productivity (intercepts) which represent inefficiency. The frontier production technology is a representation of firms with the lowest inefficiency. In contrast, in the varying coefficient model, all firms are assumed to have both different productivity and coefficients of technology. The frontier production technology is the representation of the combination of best productivity and coefficients of technology in each firm. For the case of Australian dairy farm, Kompas and Che (2006: 73) empirically find that 'the results for estimates of the stochastic frontier were confirmed using a random coefficient approach ... allowing for the possibility of 'non-neutral' shifts in the production frontier'.

Econometric techniques for the estimation of efficiency can be separated into primal and dual approaches that depend on the underlying behavioural assumptions made. The primal approach, or the direct estimation of the production function, has been the more common route used for frontier estimation. The dual approach is based on a cost function derived from the production function. Greene (1993) argues that the technical inefficiency measures derived from the dual models are not interpreted straightforwardly.

According to the type of data, the econometric estimation of frontier functions can also be sorted into cross-section or panel data analyses. The cross-section data correspond to the observation of different objects at one point in time, whereas the panel data consist of observations of some or all units across different time periods. The ability to observe each unit more than once may result in more accurate estimates of efficiency than single cross-section observations (Greene 1993; Lovell 1993).

The stochastic frontier methodology has become widely used as an analytical tool in applied production economics in many sectors since the work of Aigner et al. (1977) and Meeusen and van den Broeck (1977). This is due largely to its consistency with the definition of production, profit or cost function theories. Its reputation is shown by the large number of methodological and empirical frontier analyses of various sectors over the last two decades over many countries: Taiwanese manufacturing industries (Sun 2004); United States first class railways (Kumbhakar 1988a; 1988b) and airlines (Bauer 1990); Australian dairy farms (Kompas and Che 2006) and fisheries (Kompas et al. 2004); Spanish agro-food industries (Apezteguia and Garate 1997); Chinese state-owned enterprises (Kong et al. 1999); and the United States banking industry (Bauer and Ferrier 1996).

Battese (1992) and Bravo-Ureta and Pinheiro (1993) review the applications of frontier methodology to examine technical efficiency in agriculture. These reviews highlight the efforts that have been devoted to measuring efficiency in developing countries where agriculture plays a key role, using the broad collection of available frontier models. In the agricultural sectors of developing economies, efforts to enhance agricultural performance have been through improving efficiency. Amaza and Olayemi (2002) in Nigeria, Tadesse and Krishnamoorthy (1997) and Battese and Tessema (1993) in India estimate technical efficiency using farm level cross-sectional data with Cobb-Douglas frontier production technology, while Kumbhakar (1994) in India uses translog frontier production technology. Bravo-Ureta and Evenson (1994) in Paraguay analyses secondary crops using farm-level data. Ahmad and Bravo-Ureta (1996) try to compare technical efficiency with different functional forms. The studies use both primal and dual approaches with various functional forms. Thiam et al. (2001) conclude that the primal approaches with less restricted functional forms are likely to provide better estimates of technical efficiency.

Technical efficiency also has been used for specific goals. Villano and Fleming (2006) analyse rice agriculture in relation to risks in the Philippines. Che et al. (2006; 2001) analyse rice agriculture associated with market reforms in Vietnam. Reinhard et al. (1999; 2000; 2002) analyse technical efficiency to measure environmental performance in Dutch dairy farms. These imply that analysis of technical efficiency is applicable in various sectors in both developed and developing economies.

Many studies on technical efficiency of Indonesian agriculture have been conducted using various methods and data. Widodo (1989) estimates efficiency of rice farmers on Java by using cross-sectional farm-level data. The production technology used is a Cobb-Douglas production function. The main outcome is that small farms are more technically efficient than large ones. Esparon and Sturgess (1989) analyse rice production in West Java. By using stochastic production frontier estimates with cross-sectional farm-level data, the main result shows that rice farmers are technically efficient. This is not a surprising outcome because West Java is considered as a “field laboratory” for rice production. The new agronomical technology is almost always introduced and applied in these areas. One unique feature of the study is stochastic linear production technology. In this sense, assumptions on profit maximisation do not hold, and this does not match the goal of achieving efficiency (Farrell 1957).

Another study conducted by Squires and Tabor (1991) uses a stochastic production frontier to estimate translog production functions with panel farm-level data. In terms of coverage, this study is wider than those before it, and the results more accurately represent Indonesian rice agriculture. The main outcome is that there is no relation between achievement in technical efficiency and size of farms.

This outcome is different from Widodo's (1989) finding. A possible source of the difference is the coverage. On Java, it is more likely that small farmers are more technically efficient. It has been argued that farmers operating small farms might pay closer attention to their tasks and could use more fine-tuned agronomical cultivation. Trewin et al. (1995) use a stochastic production frontier with a translog production function estimated using rice-farm level panel data. The results indicate that West Javanese farmers are not technically efficient. This contradicts the outcome of Esparon and Sturgess (1989) that these farmers are technically efficient, even though both studies use the same source of data. A possible explanation of the gap is the linear production technology used by Esparon and Sturgess (1989).

Note that all studies on technical efficiency of Indonesian rice agriculture analyse technical efficiency of rice agriculture before 1990. In terms of time, these results are quite out of date and there is a possibility of change in technical efficiency resulting from various polices recommended by those studies. One disadvantage of these studies is that sources of variation in technical efficiency are estimated using a two-step procedure. This procedure has been criticised as being inconsistent (Battese and Coelli 1995).

Recent studies on technical efficiency of rice agriculture have been conducted by Utama (2005) in one location of West Sumatra, and Sumaryanto et al. (2003) in one location of East Java. In terms of techniques and sources of data, both studies improve the previous studies because both estimate sources of variation in technical inefficiency using a one-step procedure which is better than a two-step and the data are collected from a survey in the late 1990s. But the coverage is inferior compared with the previous studies. Both studies find that technical efficiency is affected by some producer characteristics. Age and education are the main sources of variation in technical efficiency. Size of farm is also identified as a factor. These studies, however, do not provide information on temporal patterns of technical efficiency because most of them use cross-sectional data. Up to now, the information on temporal patterns of technical efficiency in Indonesian rice agriculture is still limited.

This current study will be different from the previous ones in some respects. First, this study uses panel data sets at farm level. Using panel data can reduce specific characteristics embodied in each farm and farm operator. According to Greene (1993), models that rely on panel data are likely to yield more accurate efficiency levels given that there are repetitive observations on the same object. This condition is expected to provide answers for previous studies on technical efficiency of rice agriculture that use cross-sectional data.

Second, this study uses stochastic frontier production functions. Some previous studies on technical efficiency in Indonesian agriculture used non-parametric and parametric deterministic methods. The non-parametric technical efficiency models, which are referred to as data envelopment analysis (DEA), are based on mathematical programming techniques. In the case of steel industries where production technology is much less stochastic, the deterministic model is empirically superior to the stochastic one (Sahoo et al. 1999). The methods have a major disadvantage, that is, they are deterministic and consequently influenced by extreme observations. The parametric deterministic model assumes that any deviation from the frontier is due to inefficiency, while the stochastic approach allows for statistical noise. Therefore, a basic problem with deterministic frontiers is that any measurement error, and any other source of stochastic variation in the dependent variable, is set in the one-sided component making the resulting technical efficiency estimates sensitive to outliers. The stochastic frontier production model is capable of dealing with this sensitivity problem by incorporating a composed error structure (Greene 1993). In agricultural production, Sharma et al. (1999) make a comparison between parametric stochastic frontiers and deterministic frontiers. Using the same data on swine production and functional form, it is shown that the stochastic frontier is superior in estimating technical efficiency.

In most cases studying technical efficiency of rice agriculture, efforts have been made to obtain sources of technical inefficiency. The reason is that once the sources of inefficiency are determined, relevant polices can be applied to reduce inefficiency. Many factors affecting inefficiency of rice agriculture have been studied. Each study tries to find the source of inefficiency based on locally specific factors. In most cases, managerial characteristics of farm operators are of interest, as reported by Munroe (2001), for example, age that represents farmer's experience, and level of education that represents capability of adopting technology. In the case of Indonesian rice agriculture, Sumaryanto et al. (2003) examine farm characteristics and income. A study by Utama (2004) is another example of a case study that investigates technical inefficiency of rice agriculture related to management training. Another significant feature of this study is that it improves the previous studies by examining additional aspects – labour composition, mechanisation and geographical characteristics — which have not been examined before.

Last, this study uses relatively new data, and is expected to provide updates on efficiency in Indonesian rice agriculture.

Theoretical Framework

Efficiency of a production unit is defined as how effectively a producer uses variable resources for the purpose of profit maximisation, given the best production technology available, the level of fixed factors, and product and factor prices (Sadoulet and de Janvry 1995). Technical efficiency is defined as the ability of the producer to produce maximum output given a set of inputs and technology (Kumbhakar and Lovell 2000; Sadoulet and de Janvry 1995). Consider a firm with technology, $Y = f(X, Z)$, that shows the maximum output attainable from various input vectors, suppose that the firm produces Y^0 level of output using inputs X^0 and Z^0. The firm is then said to be technically efficient if $Y^0 = f(X^0, Z^0)$, and technically inefficient if $Y^0 < f(X^0, Z^0)$ (Kumbhakar 1988a). The presence of technical inefficiency implies that productivity of one or more inputs is lower than what it would be with technical efficiency, which is dependent on functional form of the technology.

Studies employing a stochastic frontier production model incorporate a composed error structure with a two-sided symmetric term and a one-sided component. The one-sided component reflects inefficiency, while the two-sided error captures the random effects outside the control of the production unit including measurement errors and other statistical noise typical of empirical relationships. Furthermore, the stochastic frontiers also make it possible to estimate standard errors and to generate test hypotheses.

From an econometric perspective, the estimation of stochastic frontiers with panel data analysis has some advantages, compared with cross-sectional estimation. A major feature of panel data is the ability to decompose productivity growth into technological change and technical efficiency. Another key element is that consistent estimates of technical inefficiency are provided when adding more observations on the same subject, whereas adding more units to a given cross-sectional data set still has a problem of consistency. The panel data analysis also has an advantage in that it opens up an opportunity for computing efficiency by estimating the fixed effects model. This eliminates the need for imposing distributional assumptions on the one-sided error term and also avoids the assumption that the inefficiency term is uncorrelated with the independent variables (Schmidt and Sickles 1984). Moreover, technical efficiency can be modelled as time-varying or time-invariant and suitable statistical tests can be applied to determine which alternative is consistent with the data at hand (Ahmad and Bravo-Ureta 1996). But, a recent study by Druska and Horrace (2004: 196) argues that

> 'if T [time] is somewhat large, the usually time-invariant unobserved heterogeneity models (e.g., FE) may not be applicable, since it is widely held that heterogeneity may change in long-run, dynamic economic systems (particularly when it is viewed as technical inefficiency)'.

Econometrics of the stochastic frontier

Aigner et al. (1977) and Meeusen and van den Broeck (1977), define a stochastic frontier production function model in which the disturbance term (ε) is composed of two parts, a systematic component (v) and a one-sided component (u). In relation to panel data, a functional form of a stochastic production function is specified as:

$$Y_{it} = f(\mathbf{X}_{it}, \beta, t)\exp\{\varepsilon_{it}\} \tag{4.1}$$

i = 1,2, ... and t = 1, 2, ...

where Y is output, $\mathbf{X}$ is a vector of inputs t is time trend to capture technological change and β is a vector of parameters to be estimated. The error term (ε) is, then defined as:

$$\varepsilon_{it} = v_{it} - u_{it} \tag{4.2}$$

The systematic component v_{it}, which captures random variation in output due to factors outside the control of the farmer, is assumed to be independently and identically distributed (*iid*) as $N(0, \sigma_v^2)$, independent of u_{it}, which specifies the technical inefficiency relative to the stochastic frontier. Most of the empirical literature assumes that, u_i has a non-negative (one-sided) half-normal distribution with $N(0, \sigma_u^2)$. Consider σ_u^2 is the variance of the inefficiency effect, and σ_v^2 is the variances of the systematic error (v) respectively, and define:

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \tag{4.3}$$

and

$$\gamma = {\sigma_u^2}/{\sigma^2} \tag{4.4}$$

which is attributed to technical efficiency (Battese and Corra 1977). Thus, based on the assumption that u_i and v_i are independent, the parameters of the production frontier can be estimated using a maximum likelihood method and econometric software. Furthermore, given a multiplicative production frontier for which the production function is specified, the farm-specific technical efficiency of the i^{th} farm in the t^{th} period is defind as the ratio of the conditional expectation of output, given the inefficiency effect, relative to its expectation if the inefficiency effect is zero, as shown by Battese and Coelli (1988). That is:

$$\varphi_{it} = \frac{E(Y_{it} \mid u_{it}, \mathbf{X}_{it})}{E(Y_{it} \mid u_{it} = 0, \mathbf{X}_{it})} = \exp\{-u_{it}\} \qquad (4.6)$$

It is shown that the technical efficiency lies between zero and one. When technical efficiency is equal to one, the actual output lies on the stochastic production frontier.

Temporal pattern of technical inefficiency

Technical inefficiency can be considered as unobserved effects embodied in producers. In a cross-sectional econometric analysis, the existence of these effects may make the estimate biased if the effects are correlated with one or more independent variables.. With panel data, technical inefficiency can be modelled as time-invariant or time-varying (Ahmad and Bravo-Ureta 1996). However, when time is somewhat long, the technical efficiency may vary over time together with the change in other characteristic of producers which may affect inefficiency (Druska and Horrace 2004).

Model of time-varying technical inefficiency can be divided in two groups, which are dependent on whether assumptions of distributional technical inefficiency are imposed on the temporal patterns of inefficiency. In the one group, it is assumed there is no functional specification of the temporal pattern, a distributional assumption on u_{it} is made and non-linear formulations are used to separate the time trend effect into technical inefficiency change. Several temporal patterns have been modelled in this fashion. Kumbhakar (1990) suggests that:

$$u_{it} = \left[1 + \exp\left(\delta_1 t + \delta_2 t^2\right)\right]^{-1} u_i \qquad (4.7)$$

where u_i is assumed to have a half normal distribution, and δ_1 and δ_2 are parameters to be estimated. Battese and Coelli (1992) propose the temporal pattern of inefficiency as an exponential function of time, that is:

$$u_{it} = u_i \exp(-\eta(t - \Gamma)) \qquad (4.8)$$

where Γ corresponds to the last time period in each panel, u_i is assumed to be independently and identically distributed as a truncation of the normal distribution, and η is a parameter to be estimated. The main drawback of this model is that once the technical inefficiency increases, it will increase exponentially and will never fall.

The common disadvantage of models proposed by Kumbhakar (1990) and Battese and Coelli (1992) is that the temporal pattern of inefficiency is assumed to be identical for all producers. Battese and Coelli (1995) overcome this shortcoming by modelling:

$$u_{it} = \sum\nolimits_k \delta_k C_{kit} + \mu_{it} \qquad (4.9)$$

where C_{kit} is a vector of producers' characteristics that explain technical inefficiency and μ_{it} is defined by the truncation of the normal distribution with mean zero. In this model technical inefficiency is no longer identically distributed since it is affected by some factors. But, technical inefficiency effects specified in the stochastic frontier model are assumed to be independently but not identically distributed non-negative random variables.

In the other groups, in which there is no assumption on distribution of technical efficiency, Lee and Schmidt (1993) propose a model of temporal pattern of technical inefficiency as:

$$u_{it} = u_i \delta_t \tag{4.10}$$

where δ_t is time-effect which is represented by a dummy of time. Although it is non-linear, it is a striking specification, because it does not impose any functional form on the temporal pattern of inefficiency. Cornwell et al. (1990) make a model of time-varying technical inefficiency in a quadratic form of time, that is:

$$u_{it} = \delta_{0i} + \delta_{1i} t + \delta_{2i} t^2 \tag{4.11}$$

where $\delta_{0i}, \delta_{1i}, \delta_{2i}$ (i=1, 2, ...,n) are the producer-specific parameters to be estimated. This model has advantages, that is, the model is flexible and it allows inefficiency to vary across time and producers. In this model, the average rate of change in technical inefficiency across time can be identified.

Econometric estimation of technical inefficiency effect

In general, there are two major approaches to analyse the source of inefficiency: two step and one step estimations. In the two-step process, the production frontier is first estimated and the technical efficiency of each firm is derived. These are subsequently regressed against a set of variables, C_{kit}, which are hypothesised to influence rice agriculture's efficiency (Bravo-Ureta and Evenson 1994). This process has a problem with inconsistency in the assumptions about the distribution of the inefficiencies. In the first stage, the inefficiencies are assumed to be independently and identically distributed in order to estimate their values. But, in the second stage, the estimated inefficiencies are assumed to be a function of a number of firm specific factors, and therefore are not identically distributed (Coelli et al. 1998). In the one-step procedure, the inefficiency effects are defined as a function of the farm specific factors (as in the two-stage approach) but they are then incorporated directly into the maximum likelihood estimation (Coelli 1996).

Methodology

Model specification

This study uses a primal approach, or the direct estimation of the production functions, with functional form of a transcendental logarithmic (translog) production technology introduced by Christensen et al. (1973).[6] The translog, in this study, is specified as:

$$\ln Y_{it} = \beta_0 + \sum_{k=1}^{5} \beta_k \ln X_{kit} + 0.5 \sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} \ln X_{kit} \ln X_{jit}$$

$$+ \sum_{k=1}^{5} \beta_{kt} t \ln X_{kit} + \beta_t t + \beta_{tt} t^2 + v_{it} - u_{it} \qquad (4.12)$$

where (k, j)=1, 2, ...,5 for land, capital, labour, material and agrochemicals respectively, $\beta_{kj} = \beta_{jk}$ for $k \neq j$, t is the time index, $\ln$ represents the natural

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[6] The work of Thiam et al. (2001) concludes that using more flexible functional forms results in more accurate technical efficiency estimate. More flexible functional forms reduce the error terms $(\varepsilon_{it} = v_{it} - u_{it})$, which means higher estimates of technical efficiency. Considering that a higher rate of efficiency represents a better estimate, a primal approach is also more accurate than the dual, because 'studies using the primal approach leads to significantly higher TE estimates than those obtained from dual frontiers' (Thiam et al. 2001: 241).

logarithm. Time trend is included in the model to account for smooth technological progress (O'Neill and Matthews 2001).[7]

The elasticity of production with respect to input X_i is expressed as:

$$\theta_{X_k} = \frac{\partial \ln Y_i}{\partial \ln X_k} = \beta_k + \sum_{j=1}^{5} \beta_{kj} \ln X_{jit} + \beta_{kt} t \tag{4.13}$$

The output elasticity with respect to agrochemicals is not constant, and is dependent on the level of its input, other inputs and time trends. The output elasticity with respect to agrochemicals is then evaluated at the average level of each input and time period.

The translog has become an integral tool for examining production structure of many production systems in various sectors. Kim (1992) states that the translog production function is non-homothetic and it does not impose any restrictions on production technology related to the elasticity of substitution and returns to scale. Homotheticity of the translog production function implies that the marginal rate of technical substitution is homogenous of degree zero in inputs if $\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} = 0$ is satisfied. The production function is homogenous of degree one, or has linear homogeneity if $\sum_{k=1}^{5} \beta_k = 1$, $\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} = 0$ and $\sum_{k=1}^{5} \beta_{it} = 0$. This condition shows that the production function exhibits constant returns to scale.

Inefficiency is modelled as:

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[7] Another model is specified as $\ln Y_{it} = \cdots + \beta_{D94} D_{94} + \beta_{D99} D_{99} + \cdots$, where D_{94} and D_{99} are dummy variables for 1994 and 1999 respectively. The dummy accounts for natural conditions and policies at the time. The dummy variable and time trend cannot be analysed in one production function because of exact multicollinearity in the study sample.

$$\mu_{it} = \delta_0 + \delta_1 AG + \delta_2 ED + \delta_3 FM + \delta_4 NP + \delta_5 ST$$
$$+ \delta_6 SZ + \delta_7 SH + \delta_8 MC + \delta_9 JV \qquad (4.14)$$

where AG is age of farmers, ED is education, FM is number of family members, NP is the number of plots, ST is status of land, SZ is size of total area, SH is share of hired labour, MC is a dummy for mechanisation, and JV is a dummy for Java.

The underlying principles for including those variables as sources of efficiency are as follows. Age represents experience of farmers, older farmers being more experienced, and thus less inefficient. Education represents human capital and skill, and thus more educated farmers are expected to be less inefficient. Family member represents the size of households. Larger households are expected to be more capable of dealing with problems in farming, and thus less inefficient. The number of plots represents land fragmentation. More fragmented land will be more difficult for farmers to manage, and thus are expected to be more inefficient. Hired labour represents professionalism, and thus more hired labour employed on farms is expected to result in less inefficiency. Mechanisation represents the adoption of technology, and thus farms are expected to be less inefficient if mechanisation is used. Java is included in the model as a source of inefficiency because Java is a “rice laboratory” of Indonesia. New technology and policies related to rice agriculture have been implemented on Java, and thus farms located on Java are less inefficient. A time trend is not included in the model because technical inefficiency has been affected by age of the farmer, which increases over time at the same rate as time trend. Level of education and number of family members are also likely to increase overtime when the period is long enough. Time trend will be strongly correlated with those variables if time trend is included in the model.

To capture the time-varying technical inefficiency, the temporal pattern of technical inefficiency needs to be modelled. Following Cornwell et al (1990), the temporal pattern of technical inefficiency is modelled as a quadratic function of time, that is:

$$\hat{\varphi}_{it} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 \qquad (4.15)$$

where $\hat{\varphi}_{it} = 1 - \hat{u}_{it}$ is predicted inefficiency (Villano and Fleming 2006). Compared with Battese and Coelli (1992) according to whom technical efficiency either exponentially increases or decreases continually, the advantage of this specification is its flexibility of technical efficiency across producers and time. Importantly, there is no inconsistency in this approach of a two-stage estimation, as in the second stage predicted efficiency is not dependent on a number of producer characteristics, but merely on time trend which is identically distributed among producers. The technical efficiency estimated in the first stage has been predicted with the producer characteristics under the first-stage assumption of Battese and Coelli (1995). Thus, this model is consistent with a method in which technical efficiency is independently and identically distributed in the stochastic frontier (Karagiannis et al. 2002).

Data and variables

This study uses a database which is established from a longitudinal survey conducted by the Indonesian Centre for Agricultural, Socioeconomic and Policy Studies (CASEPS) of the Ministry of Agriculture. The database is unbalanced panel data consisting of 358 farm operations in Indonesia during 1994, 1999 and 2004. The sample is collected from five regions. Some villages are selected in each province and farmers cultivating rice are sampled randomly. Once farmers are selected, they become respondents of the survey and are interviewed every five years. The total number of observations used is 817.

Table 4.1. Number of observations

Regions	Year			By region
	1994	1999	2004	
Lampung	74	79	54	207
West and East Java	36	33	19	88
West Nusa Tenggara	126	121	63	310
N. Sulawesi	21	21	0	42
S. Sulawesi	84	50	36	170
By year	341	304	172	817

Source: Author's calculation

Table 4.2. Time periods within panel

Panel	Period			
	1994&99	1994&04	1999&04	1994, 99&04
Lampung	4	29	9	41
West and East Java	6	20	3	10
West Nusa Tenggara	9	67	4	50
N. Sulawesi	0	21	0	0
S. Sulawesi	35	49	1	0
Total	54	186	17	101

Source: Author's calculation

Table 4.1 and Table 4.2 show detailed descriptions of observations related to the panel data. Table 4.3 shows the variables and units of measurement. In those tables, most observations are made in 1994 and 1999. One major cause of the reduction in observations in 2004 is the fact that some farmers are no longer cultivating rice, and some had died and the family did not continue to cultivate rice. In 2004, farmers in North Sulawesi were no longer interviewed.

Because of lack of continuity, the data become an unbalanced panel, which is shown in Table 4.2, indicating that most farmers are interviewed in the periods 1994 and 2004, and 1994, 1999 and 2004. In addition, more than two thirds of total sampled farmers are interviewed twice with five-year and ten-year intervals, and the rest are interviewed three times with five-year intervals.

The number of variables observed in the data collection done with interviewing sampled farmers varies widely. This is because the survey is accommodating variations in which farming is very spatially and temporally specific. For example, certain fertilisers are not used in one place and always used in another place. In some regions, it is usual that there is voluntary labour during early planting and harvesting seasons, but this not the case in others. As well, some farmers are able to separate expenses of rice agriculture in some detail, but some others are not. For the purpose of this study, however, the data are then aggregated to avoid problems of missing data.[8]

The description and measurement of aggregated variables of input-output and technical inefficiency models from individual observations are given in Table 4.3, and Table 4.4.

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[8] In agricultural practice, including rice agriculture, it is typical that farmers do not use fertilizers, pesticides and tractors. In the absence of such inputs the production is still positive. However, if the functional form is a translog production technology, the production with no such input will be zero and econometric estimation will be impossible as logarithm of zero is undefined. Trewin et al. (1995) suggest that the problem can be handled by adding the individual fertilisers and replacing the zero level of input use with a small positive value. This way has been used by Villano and Fleming (2006). Instead of using a translog model, they also use a quadratic functional form to overcome such problem. The results show that both ways give very close measures of output elasticity with respect to inputs and estimates of technical efficiency. But, the translog model provides more precise estimates than the quadratic model as the log-likelihood for the translog model is much greater than that for the quadratic model, and the variance of the technical inefficiency effects in the stochastic frontiers for the translog model is also greater than that for the quadratic model.

Table 4.3. Data on input and output of rice agriculture

Variable	Description	Unit
Rice production	un-husked production	kilogram
Area (A)	Total rice-sown area	hectare
Labour (L)	Total labour comprises family, voluntary and hired labour, used for six stages of farming	man-working day
Capital (K)	Capital consists of tractors and animals mainly used in land tillage	tractor-working day
Materials (M)	Total material used in rice production comprises seed, water irrigation, and green manure	monetary term*
Chemicals (X)	Chemical fertilisers and pesticides. Fertilisers consist of Urea, Triple Super Phosphate (TSP), Ammonium Sulphate (ZA) and Potassium Chloride (KCl). Pesticides comprise solid and liquid formulations	monetary term*

Note: *) Monetary value is at 1993 constant price

Table 4.4. Data on technical inefficiency model

Variable	Description	Unit
Age	Age of farmer	year
Education	Education of farmer, years spent in formal education	year
Member	Number of household members, including the farmer	persons
Plot	Number of blocks of land cultivated with rice	unit
Status of land	Fraction of privately owned land cultivated with rice. = 1 if totally owned land, = 0 if purely rented land	[0,1]
Area	Total area of rice cultivation	hectare
Share of hired labour	Share of hired labour, = 100 if fully hired, = 0 if fully unpaid labour	[0,100]
Mechanisation	Dummy for using tractor, = 1 if using tractor, = 0 otherwise	dummy
Java	Dummy location, = 1 if located on Java, = 0 otherwise	dummy

Table 4.5 shows the summary statistics for key variables across time. Table 4.6 shows summary statistics for key variables sorted by region. On average, production increases over time. Area, along with materials and agrochemicals grow over time. But there is a considerable slowdown in capital use. Labour increases almost two-fold in 1999, but decreases in 2004. It is important to note that standard deviation of each variable in each region is relatively high, indicating that there is considerable variation in such variables. We can see that, on average, the highest rice production is in West Nusa Tenggara, with the largest area of rice-sown land.

Table 4.5. Summary statistics for key variables, by year

	1994		1999		2004	
	mean	standard deviation	mean	standard deviation	mean	standard deviation
Production	1,856	1,751	2121	2866	3,445.11	3,972
Area	0.55	0.53	0.62	0.60	0.88	0.95
Capital	8.19	17.12	1.45	2.59	0.44	2.26
Labour	41.69	35.34	78.99	59.79	57.77	70.29
Material	35,503	39,247	58,580	60,884	81,322	109,758
Chemical	52,414	54,709	64,896	71,210	254,891	2,255,989
Age	45.56	12.50	50.05	12.07	52.70	11.44
Education	3.79	2.09	4.93	3.21	5.24	3.17
Member	5.30	2.07	4.67	1.79	4.44	1.79
No. Plots	1.00	0.00	1.33	0.68	1.54	0.87
Status of Land	0.91	0.28	1.00	0.00	0.80	0.39
Share of hired labour	14.47	24.27	47.87	33.57	23.63	31.26
Mechanisation	0.22	0.41	0.30	0.46	0.02	0.13

Note: See Table 4.3 and Table 4.4 for units of measurement.
Source: Author's calculation

Table 4.6. Summary statistics for key variables, by region

	Lampung	Java	West Nusa Tenggara	North Sulawesi	South Sulawesi
Production	2477	1341	2482	1284	2445
	(3989)	(1318)	(2365)	(1645)	(2574)
Area	0.5825	0.2650	0.8038	0.5569	0.6554
	(0.6163)	(0.2295)	(0.8020)	(0.6573)	(0.5295)
Capital	1.0346	2.6686	7.3441	2.5437	2.8108
	(2.9914)	(3.4090)	(17.01)	(4.3999)	(9.0604)
Labour	61.65	42.39	60.74	30.56	68.02
	(67.57)	(44.12)	(47.79)	(24.45)	(62.59)
Material	26,676	23,712	77,028	32,634	64,968
	(32,297)	(30,368)	(76,000)	(36,157)	(90,548)
Chemical	62,884	44,294	158,399	37,013	81,588
	(79,700)	(45,151)	(168,134)	(43,612)	(84,620)
Age	47.9324	56.06	48.169	46.48	47.51
	(12.7826)	(13.46)	(11.88)	(10.298)	(11.80)
Education	4.9227	3.8636	4.1194	5.1190	4.9412
	(2.5455)	(2.8170)	(2.8276)	(2.7158)	(3.1599)
Member	4.7198	4.4432	4.8065	4.1190	5.6471
	(1.8924)	(1.6530)	(1.8472)	(1.5492)	(2.1904)
No. Plots	1.2415	1.3409	1.1968	1.0476	1.3000
	(0.6071)	(0.8826)	(0.4927)	(0.2155)	(0.7121)
Status of Land	0.8647	0.9205	0.9761	0.8333	0.9132
	(0.3428)	(0.2721)	(0.1503)	(0.3772)	(0.2680)
Share of hired labour	20.5697	30.2559	38.0494	37.1434	19.2654
	(28.7976)	(30.6614)	(35.9918)	(36.8157)	(27.3419)
Mechanisation	0.1498	0.2955	0.2839	0.0952	0.1176
	(0.3577)	(0.4589)	(0.4517)	(0.2972)	(0.3231)

Note: Figures in parentheses represent standard deviations. See Table 4.3 and Table 4.4 for units of measurement.
Source: Author's calculation

Testable hypotheses

There are three groups of test of hypotheses. The first is testing for model specification, which is needed to determine the correct functional form of production technology. It is formally formulated as below.

Testing for Cobb-Douglas technology without technical change is formulated as:

H_0: $\beta_{kj} = \beta_{kt} = \beta_t = \beta_{tt} = 0$

H_1: H_0 is not true (H4.1)

Testing for Cobb-Douglas with Hicks-neutral technical change is formulated as:

H_0: $\beta_{kj} = \beta_{kt} = 0$

H_1: H_0 is not true (H4.2)

Testing for Simplified Translog (Ahmad and Bravo-Ureta 1996) is formulated as:

H_0: $\beta_{kj} = 0$

H_1: H_0 is not true (H4.3)

Translog with Hicks-neutral technical change is formulated as:

H_0: $\beta_{kt} = 0$

H_1: H_0 is not true (H4.4)

Testing for Translog without dummy year (from equation (4.12)) is formulated as:

H_0: $\beta_{D94} = \beta_{D99} = 0$

H_1: H_0 is not true (H4.5)

Translog without time trend (from equation (4.13)) is formulated as:

H_0: $\beta_t = \beta_{tt} = 0$

H_1: H_0 is not true (H4.6)

The second test is for the presence of a production frontier and technical inefficiency effect. The formal test for the production frontier is formulated as:

H_0: $\gamma = \delta_0 = \delta_1 = \cdots = \delta_9 = 0$

H_1: H_0 is not true (H4.7)

Test for source of inefficiency is formulated as:

H_0: $\delta_0 = \delta_1 = \cdots = \delta_9 = 0$

H_1: H_0 is not true (H4.8)

Following Kompas and Che (2006), it is also important to test whether the technical inefficiency effect is constant. The test is formulated as:

H_0: $\delta_1 = \cdots = \delta_9 = 0$

H_1: H_0 is not true (H4.9)

The last test is for returns to scale of the production function.[9] Given that that inputs are separable from each other and from time, the test is formulated as:

H_0: $\sum_{k=1}^{5} \beta_k = 1$

H_1: $\sum_{k=1}^{5} \beta_k \neq 1$ (H4.10)

H_0: $\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} = 0$

H_1: $\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} \neq 0$ (H4.11)

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[9] The test is conducted separately, instead of joint single test, to know the source of non-constant returns to scale. If the separate test indicates non-constant returns to scale, the joint test will indicate the same case.

H$_0$: $\sum_{k=1}^{5}\beta_{kt}=0$

H$_1$: $\sum_{k=1}^{5}\beta_{kt}\neq 0$ (H4.12)

Testing for those hypotheses is conducted using a likelihood ratio test (LR-test) as described in Verbeek (2003). That is,

$$LR = 2\left(LL_{H_1} - LL_{H_0}\right) \tag{4.16}$$

where LL_{H_1} is log-likelihood obtained from a model with the specification of a null hypothesis applied, and LL_{H_0} is log-likelihood obtained from a model with a null hypothesis. The value of LR asymptotically has a chi-square distribution if the null hypothesis is true. *FRONTIER 4.1*, a computer program created by Coelli (1996b), is used to estimate the parameters of the stochastic frontier production function.

Results and Discussion

For convenience, the outcomes of analyses are presented in three sub-divisions: results of testing for the hypotheses, production technology and output elasticity; technical efficiency and sources of inefficiency; and profiles of rice agriculture grouped by level of technical efficiency.

Model specification, inefficiency effect and returns to scale

Testing for model specification is given in Table 4.7. The joint test rejects $\beta_{ij}=\beta_{it}=\beta_t=\beta_{tt}=0$, indicating that Cobb-Douglas technology is not suitable with farm level data. This means that technological change is not neutral; the output elasticity with respect to each input is not constant across time, and dependent on the level of its uses and use of other inputs. This finding differs from a statement of Hayami and Ruttan (1985) that agricultural production technology in Asian developing countries with aggregate data fits with Cobb-Douglas production technology. The source of the difference is the type of data, which is farm-level in this study.

Table 4.7. Testing for model specification

	Hypothesis	Formulation	Statistical test	
	Functional form:			
H4.1	CD with no technical change	$\beta_{kj}=\beta_{kt}=\beta_t=\beta_{tt}=0$	132.52	reject
H4.2	CD with Hicks-neutral technical change	$\beta_{kj}=\beta_{kt}=0$	115.55	reject
H4.3	Simplified translog (Ahmad and Bravo-Ureta 1996)	$\beta_{kj}=0$	94.93	reject
H4.4	Translog with Hicks-neutral technical change	$\beta_{kt}=0$	70.14	reject
H4.5	Translog with no dummy year	$\beta_{D94}=\beta_{D99}=0$	26.93	reject
H4.6	Translog with no trend	$\beta_t=\beta_{tt}=0$	26.97	reject

Source: Author's analysis

The joint test also rejects $\beta_{kj}=\beta_{kt}=0$, indicating that there is interaction among inputs. The output elasticity with respect to each input is indeed dependent on the level of its use and use of other inputs.

With respect to time trend, the test rejects $\beta_{kt}=0$, meaning that the output elasticity with respect to each input definitely varies over time. In other words, technical change is not Hicks-neutral (O'Neill et al. 1999; O'Neill and Matthews 2001). The last test rejects $\beta_t=\beta_{tt}=0$, meaning that the production frontier changes over time.

Table 4.8. Testing for production frontier and inefficiency effects

	Hypothesis	Formulation	Statistical test	
H4.7	Frontier production with no technical efficiency effect	$\gamma = \delta_0 = \delta_1 = \cdots = \delta_9 = 0$	137.47	reject
H4.8	Source of inefficiency	$\delta_0 = \delta_1 = \cdots = \delta_9 = 0$	27.29	reject
H4.9	Constant effect	$\delta_1 = \cdots = \delta_9 = 0$	5.71	reject

Source: Author's analysis

Related to the presence of a production frontier, Table 4.8 shows tests for the technical efficiency model. The hypothesis of $\gamma = \delta_0 = \delta_1 = \cdots = \delta_9 = 0$ is rejected. This means that production estimated using maximum likelihood with technical inefficiency effects is significantly different from the production function estimated using OLS. The hypothesis that $\delta_0 = \delta_1 = \cdots = \delta_9 = 0$ is rejected. This indicates that inefficiency is dependent on producer's characteristics. The test also rejects $\delta_1 = \cdots = \delta_9 = 0$, meaning that the constant of the effect of inefficiency should be included in the model of the technical inefficiency effect.

Table 4.9. Testing for returns to scale

	Hypothesis	Statistical test	Implication
H4.10	$\sum_{k=1}^{5} \beta_k = 1$	z (1)= 0.72	do not reject
H4.11	$\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} = 0$	z (1)= 0.79	do not reject
H4.12	$\sum_{k=1}^{5} \beta_{kt} = 0$	z (1)= 2.72	reject

Note: Statistical test is based on Table 1 of Kodde and Palm (1996).

Source: Author's analysis

Results of testing for returns to scale are shown in Table 4.9. It shows that the translog production function does not exhibit constant returns to scale, because of the non-neutral technical change. The implication is that non-neutrality of technological change matters, and the returns to scale of production technology vary over time.

Production technology and output elasticity

The test for functional form of production technology shows that translog production technology with non-Hicks neutral technological is assumed to be true model related to the farm-level data of Indonesian rice agriculture. The magnitudes and signs of all estimated coefficients of the translog production frontier in the two models are given in Table 4.10. We can see some of the coefficients are positive and others negative.

With respect to time trend, Indonesian rice agriculture undergoes input augmenting technical change, except for the use of material input, and there is technological regress at an increasing rate. Referring to the dummy years of 1994 and 1999, it is clear that there is gradual increase in total factor productivity.

This indicates no significant fluctuation in natural conditions, and the increase in total factor productivity mainly represents technological progress.[10] Note that the signs and statistical inferences of the coefficients on variables are identical and the magnitudes do not vary much. For consistency, the discussion is based on Model 1, in which technological progress is smooth.

Some coefficients are not individually significant. This is common in estimating translog production technology (Ahmad and Bravo-Ureta 1996). The output elasticity is estimated at the average level of input uses and time trend during the period. The mean output elasticities are shown in Table 4.11.

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[10] Natural conditions are likely to be controlled by the survey, because all rice farms were observed in the most favourable season.

Table 4.10. Parameter estimates of stochastic frontier production function

		Model 1		Model 2	
		Coefficient	z-ratio	Coefficient	z-ratio
TFP	β_0	8.0538	7.1^{a}	10.2332	10.45^{a}
Area (A)	β_1	1.2286	3.33^{a}	1.5053	3.70^{a}
Capital (K)	β_2	0.1513	2.81^{b}	0.1464	2.93^{a}
Labour (L)	β_3	-0.057	-0.19^{n}	-0.2241	-0.80^{n}
Material (M)	β_4	-0.1096	-0.98^{n}	-0.2063	-1.73^{c}
Chemicals (X)	β_5	0.0774	1.38^{n}	0.0713	1.30^{n}
0.5 A*A	β_{11}	0.051	1.61^{c}	0.0668	2.04^{b}
0.5 K*K	β_{22}	0.0076	3.49^{a}	0.0076	3.48^{a}
0.5 L*L	β_{33}	-0.0106	-0.62^{n}	-0.0098	-0.56^{n}
0.5 M*M	β_{44}	0.0051	1.72^{c}	0.0046	1.85^{c}
0.5 X*X	β_{55}	0.0057	6.97^{a}	0.0056	6.88^{a}
A*K	β_{12}	-0.006	-1.20^{n}	-0.0067	-1.38^{n}
A*L	β_{13}	-0.0158	-0.45^{n}	-0.0300	-0.83^{n}
A*M	β_{14}	-0.0602	-2.06^{b}	-0.0754	-2.62^{b}
A*X	β_{15}	0.0216	3.11^{a}	0.0213	3.11^{a}
K*L	β_{23}	0.0015	0.44^{n}	0.0015	0.45^{n}
K*M	β_{24}	-0.0095	-2.18^{b}	-0.0090	-2.22^{b}
K*X	β_{25}	-4.66E-05	-0.08^{n}	-0.0001	-0.09^{n}
L*M	β_{34}	0.0134	0.56^{n}	0.0281	1.29^{n}
L*X	β_{35}	-0.0042	-0.88^{n}	-0.0038	-0.80^{n}
M*X	β_{45}	-0.0104	-2.10^{b}	-0.0098	-2.04^{b}
t*A	β_{1t}	0.0217	0.44^{n}	0.0055	0.12^{n}
t*K	β_{2t}	0.0252	4.81^{a}	0.0245	4.84^{a}
t*L	β_{3t}	0.0276	0.82^{n}	0.0251	0.76^{n}
t*M	β_{4t}	-0.0548	-1.32^{n}	-0.0361	-0.96^{n}
t*X	β_{5t}	0.0891	7.32^{a}	0.0880	7.26^{a}
t	β_t	-0.3387	-0.67^{n}		
t^2	β_{tt}	0.2955	5.48^{a}		
D_{94}	β_{D94}			-1.2736	-1.51^{n}
D_{99}	β_{D99}			-0.9278	-2.14^{b}
	σ^2	1.097	5.92^{a}	1.0788	6.03^{a}
	γ	0.8811	38.48^{a}	0.8774	35.1^{a}
Log-likelihood		-645.56		-645.58	
LR-test		137.47a		137.43a	

Note: Dependent variable: output (kg); all variables are logarithmic form; ^{a}) significant at 1%; ^{b}) significant at 5%, ^{c}) significant at 10 %; ^{n}) not significant
Source: Author's analysis

Output elasticity with respect to land is very high. In many cases of agricultural production technology, output elasticity with respect to land is likely to be very high. Estimates using Cobb-Douglas technology show that output elasticity with respect to land is high compared with other inputs (Trewin et al. 1995). In Sumaryanto et al. (2003), output elasticity with respect to land is around 0.8. By using translog and quadratic forms, the same case of output elasticity of land being the highest happens in rice farming in the Philippines (Villano and Fleming 2006). In China, the output elasticity of land is 0.9 (Yao and Liu 1998). For the case of Vietnamese rice production, however, the highest output elasticity is not with respect to land (Che et al. 2001) but with respect to material inputs (Che et al. 2006).

Table 4.11. Mean output elasticities with respect to different inputs

Inputs	Year			Total
	1994	1999	2004	
Land	0.7207	0.6969	0.7432	0.7166
Capital	0.0343	0.0487	0.0315	0.0443
Labour	0	0	0	0
Material	0.1043	0.1028	0.1229	0.1077
Agrochemicals	0.0013	0.0884	0.1920	0.0923
Scale elasticity	0.8605	0.9368	1.0896	0.9608

Note: The output elasticity is evaluated at the average of all input use in 1994, 1999, 2004 and total. Labour has zero elasticity because of insignificance of labour input.
Source: Author's calculation

Output elasticity with respect to capital is very small. One possible reason is that capital use is less suitable in Indonesian rice agriculture in which the size of farms is very small. Tractors, which are a component of capital, are likely to be suitable in large-scale agriculture (Heytens 1991a). As we can see, farm size is, on average, less than one hectare, and on Java the average size of farms is even less, 0.2 hectare. Output elasticity with respect to labour is zero. This is an indication that rice production is labour intensive. During economic crisis, low-skilled urban workers have flocked to the agricultural sector because of huge numbers of lay-offs in urban sectors (Mellor et al. 2003). Output elasticity with respect to material is relatively large, and tends to increase. On limited land, it is quite easy to increase output by increasing material input. Output elasticity with respect to agrochemicals is relatively small but progressively increases over time. The formulation of agrochemicals, consisting of inorganic fertilisers and pesticides, has been developed to provide nutrients that are easily absorbed by plants and to give specific protection from pest attack.

Technical efficiency of rice agriculture

Table 4.12 shows parameters of technical inefficiency effects estimated with two models. The signs, magnitudes and statistical inferences of the coefficients on variables affecting technical inefficiency seem to be identical. Individually, factors that reduce inefficiency significantly are age, education, share in hired labour, size, mechanisation and location. The sign of the coefficient of age of the household head is negative. This means that older farmers are more experienced and have more knowledge of rice growing activities than younger ones. The older farmers are more willing to embrace better agricultural production practices that increase technical efficiency. They are also more reliable in performing production tasks. Consequently, technical inefficiency is lower.

The sign of the coefficient of education is negative. This means that a higher level of educational attainment results in lower technical inefficiency. As in many studies on productivity and growth (for example: Lucas 1988; Mankiw et al. 1992), educational attainment is a proxy for human capital.

The sign of the coefficient associated with the number of family members of the household is negative. More members in the household mean more labour is available for carrying out farming activities in a timely fashion and therefore the production process is more efficient.

Table 4.12. Parameter estimates of technical inefficiency model

		Model 1		Model 2	
		Coefficient	z-ratio	Coefficient	z-ratio
Constant	δ_0	2.4751	4.44^a	2.3923	4.50^a
Age	δ_1	-0.0252	-3.64^a	-0.0247	-3.64^a
Education	δ_2	-0.0718	-2.57^b	-0.0683	-2.39^b
Member	δ_3	-0.0464	-1.33^n	-0.0443	-1.28^n
No. Plots	δ_4	-0.9066	-2.95^b	-0.8980	-3.06^a
Status of Land	δ_5	-0.0761	-0.32^n	-0.0516	-0.22^n
Size	δ_6	-0.6181	-1.88^c	-0.5889	-1.81^c
Share labour	δ_7	-0.0055	-2.05^b	-0.0056	-2.10^b
Mechanisation	δ_8	-1.3739	-3.48^a	-1.3634	-3.55^a
Java	δ_9	-1.7632	-3.50^a	-1.7498	-3.66^a
	σ^2	1.0970	5.92^a	1.0788	6.03^a
	γ	0.8811	38.48^a	0.8774	35.1^a
Log-likelihood		-645.56		-645.58	
LR-test		137.47^a		137.43^a	
Mean technical efficiency		0.6755		0.6785	
Corr. coeff. Model 1&2		0.999^a			

Note: Dependent variable: output (kg); all variables are logged; ^{a}) significant at 1%; ^{b}) significant at 5%, ^{c}) significant at 10 %; ^{n}) not significant
Source: Author's calculation

The sign of the coefficient associated with the number of plots is negative. The number of plots represents land fragmentation, which is expected to have a positive effect on inefficiency. In fact, the coefficient is negative, meaning that having more plots leads to higher technical efficiency. It is possible that more plots do not immediately mean that each plot is small, such that the more plots farmers have the larger the farms are. This condition corresponds to the negative sign on the coefficient of farm size. This means that a large farm is less technically inefficient than a small one. It is easier to operate a larger farm, which could be either of more plots or larger single plots.

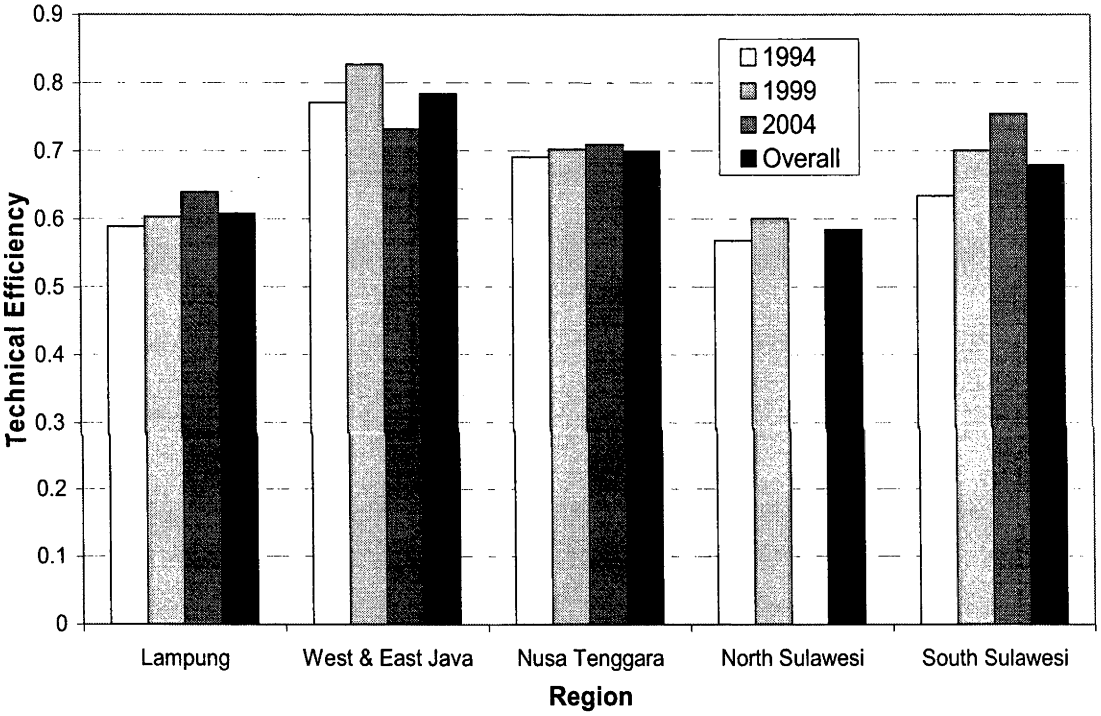
The sign of the coefficient of land status is negative, although individual tests show insignificance. The status of land represents the proportion of privately owned land to total farm land. This means that farms operating on privately owned land are less inefficient than farms operating on rented land. This is a common phenomenon where farmers may rent out the less fertile land and operate on their more fertile land. Consequently, farms operating on less fertile land will be less technically efficient. This is in line with the finding of Acharya and Ekelund (1998) showing that share tenancy brings about less efficient farming.

The sign of the coefficient of labour share is negative. This share represents the proportion of hired labour to total labour employed on the farm. The employed labour that is not paid consists of family, exchange and voluntary labour. Farms with a high proportion of hired labour are less technically inefficient. Farmers are able to supervise the hired labour such that it works effectively and efficiently. However, farmers are not capable of controlling the exchange and voluntary labour, and consequently this labour does not provide effective and efficient work.

The sign of the coefficient of mechanisation is negative. This means that if farmers hire tractors, their farms will be more efficient. The condition of whether the output elasticity with respect to capital is negative, does not contradict the fact that using tractors leads to more technically efficient farms. This is because the tractor is mostly used in large farms, which are more technically efficient.

The sign of the coefficient of Java is negative. This means that rice agriculture on Java is less technically inefficient than other regions. One of the factors is that Java is considered as a rice-bowl area, in which the government has conducted a lot of intensification programs, and agricultural infrastructure has been well developed (Barbier 1989). The average technical efficiency is described in Figure 4.1 and Table 4.13.

Figure 4.1. Comparison of technical efficiency among regions



Source: Author's analysis

In each region and year, the standard deviation of technical efficiency is somewhat smaller than the average of technical efficiency. This indicates that the variation of technical efficiency in each region and year does not give much variation. In Lampung, the standard deviation of technical efficiency is greater than that in other regions, meaning that there is more variation in technical efficiency. On average, technical efficiency of rice agriculture on Java is the highest. It is not surprising that rice agriculture on Java is the most technically efficient becasue the quality of land on Java, in terms of soil fertility and climate, is the highest and considered the most suitable for non-tree cultivation including rice (Strout 1983). In fact the technical efficiency of Javanese rice production is 0.78 which is just around 0.14 higher than that other regions. With agricultural facilities available and highly fertile paddy fields, the efficiency achievement of 0.78 is considered low.

The rice agriculture in the other regions does not vary much in terms of technical efficiency. In all regions, the technical efficiency tends to increase over time. The differences in technical efficiency among regions and years are given in Table 4.14. Most coefficients are significantly negative, meaning that rice agriculture on Java is the most technically efficient.

Table 4.13. Average technical efficiency among regions and year

Regions	Year			By region
	1994	1999	2004	
Lampung	0.5894 (0.2193)	0.6039 (0.2510)	0.6402 (0.2336)	0.6082 (0.2353)
West and East Java	0.7716 (0.1340)	0.8268 (0.0819)	0.7325 (0.1429)	0.7839 (0.1235)
West Nusa Tenggara	0.6912 (0.1454)	0.7034 (0.1623)	0.7102 (0.1431)	0.6998 (0.1515)
North Sulawesi	0.5685 (0.2123)	0.6013 (0.1787)	N/A	0.5849 (0.1945)
South Sulawesi	0.6344 (0.1364)	0.7012 (0.1282)	0.7550 (0.0986)	0.6795 (0.1352)
By year	0.6560 (0.1748)	0.6835 (0.1916)	0.7001 (0.1743)	0.6755 (0.1818)

Note: Number in parentheses is standard deviation, N/A: no observation
Source: Author's estimation

Based on the estimated technical efficiency, the rank order from most to least technical efficiency of rice agriculture is: Java, West Nusa Tenggara, South Sulawesi, Lampung and North Sulawesi. In 1994, rice agriculture outside Java was inefficient compared with that on Java. The declining rank order of rice agriculture is: Java, West Nusa Tenggara, South Sulawesi, Lampung and North Sulawesi. In 1999, the rank order was still the same as that in 1994.

However, in 2004 the rank order dramatically changed. The coefficients for West Nusa Tenggara and South Sulawesi were not significant, and even positive for South Sulawesi. This means that rice agriculture in both regions was as technically efficient as that on Java. In other words, the technical efficiency of rice agriculture in both regions has been catching up with that on Java. The rank order becomes South Sulawesi, Java, West Nusa Tenggara, and Lampung.

Table 4.14. Regression of technical efficiencies on dummy regions

Regions	1994	1999	2004	Overall
Constant (=Java)	0.7716 (27.94)[a]	0.8268 (26.32)[a]	0.7325 (18.76)[a]	0.7839 (42.37)[a]
Lampung	-0.1822 (-5.41)[a]	-0.2229 (-5.96)[a]	-0.0923 (-2.03)[b]	-0.1757 (7.95)[a]
West Nusa Tenggara	-0.0803 (-2.56)[b]	-0.1234 (-3.48)[a]	-0.0223 (-0.50)[n]	-0.0840 (-4.01)[a]
North Sulawesi	-0.2031 (-4.46)[a]	-0.2255 (-4.48)[a]	N/A	-0.1990 (-6.11)[a]
South Sulawesi	-0.1372 (-4.16)[a]	-0.1257 (-3.11)[a]	0.0224 (0.46)[n]	-0.1043 (-4.58)[a]
R^2	0.1122	0.1244	0.0632	0.0928
F-stat	10.62[a]	10.62[a]	3.78[b]	20.77[a]
No. Obs.	341	304	172	817

Note: number in parentheses is t-ratio, [a]) significant at 1%; [b]) significant at 5%, [c]) significant at 10%; [n]) not significant; N/A: no observation
Source: Author's estimation

In Figure 4.2, it is clear that technical efficiencies of rice agriculture in all regions have continually increased, except on Java. In 2004, technical efficiency of rice agriculture on Java dropped because of a sharp decrease in capital use. Capital has been substituted by non-agriculture-experienced labour. As reported by

Mellor et al. (2003), the agricultural sector suffered from economic crisis in 1997. A huge number of lay-offs in the low-skilled urban sector flocked to the agricultural sector. As has been mentioned, capital consisting of mechanisation is an important factor in determining technical efficiency, where farms with mechanisation are more technically efficient. The catch up of technical efficiency in West Nusa Tenggara and South Sulawesi comes from two sources. The first is a fall in technical efficiency of rice agriculture on Java in 2004. The second is continual increase in technical efficiency in South Sulawesi and West Nusa Tenggara.

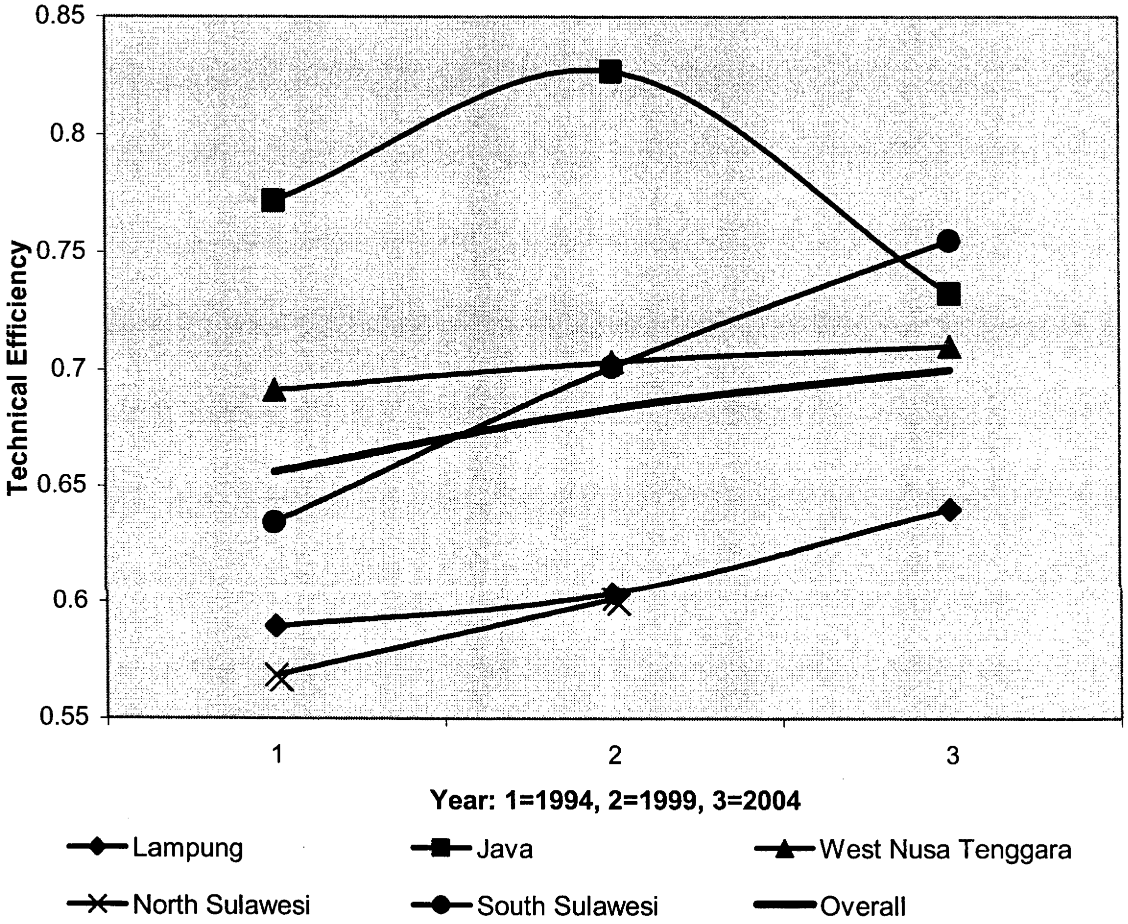
Table 4.15. Regression of technical efficiency on time trend

Variable	Linear		Quadratic 1		Quadratic 2	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
Constant	0.6348	39.32^a	0.6543	63.93^a	0.6177	13.72^a
t	0.0227	2.75^b			0.0438	0.83^n
t^2			0.0056	2.65^b	-0.0054	-0.41^n
R^2	0.01		0.01		0.01	
F-test	7.54^b		7.00^a		3.85^b	

Note: ^{a}) significant at 1%; ^{b}) significant at 5%, ^{c}) significant at 10%; ^{n}) not significant
Source: Author's estimation

Table 4.15 shows the dynamics of technical efficiency. Estimated with a linear form, technical efficiency significantly increases at a constant rate of 0.0227 every five years. However, technical efficiency significantly increases at an increasing rate when it is estimated using purely quadratic form. As described in Figure 4.2, overall technical efficiency is increasing at a decreasing rate, so it is reasonable to estimate the dynamics of technical efficiency in the form of a general quadratic function. The result indicates that the coefficient of the linear time trend is positive and the coefficient of the quadratic time trend is negative. This is an indication that technical efficiency increases at a decreasing rate. It is important to note that both coefficients are individually insignificant, but jointly significant. This is because the time trend is small and data are unbalanced panel, such that both linear and quadratic time trends are highly correlated and cause a multicollinearity problem.

Figure 4.2. The dynamics of technical efficiency



Source: Author's analysis

Profile of rice agriculture by efficiency rankings

The average technical efficiency of producers does not vary by region, but the individual technical efficiency among producers varies considerably. This indicates that within regions there is a large variation in technical efficiency. This is likely since rice agriculture is sensitive to ecological situations such as weather and pest infestations. The ecological situation also varies among regions and across time. For instance, when there is a pest outbreak in the middle or late stage of rice cultivation, rice production will be very low. In such a case, large amounts of inputs have been used and, as a consequence, the technical efficiency is low. Following Kompas and Che (2006), it would be uncomplicated to analyse technical efficiency rankings. Since the range of individual technical efficiencies is wide, the rankings are grouped into 'very low' (less than 0.60), 'low' (0.60 to 0.75), 'high' (0.76 to 0.85) and 'very high' (greater than 0.85). The number of rice producers in each group is 219, 235, 280 and 83 respectively. The characteristics of rice agriculture indicated by average values in each technical efficiency group are given in Table 4.16.

There are a number of features that arise from these profiles of rice agriculture. First, high and very high technical efficiency groups of producers are more educated and more experienced operators. Second, rice agriculture in both groups operates at a large scale either in single or multiple plots of land. The larger scale operations are the more technically efficient. The larger scale of rice agriculture means that the levels of use of all inputs are higher, except for irrigation and organic materials.

Third, the use of a high proportion of hired labour dominates these groups. This is an indication that hired labour is more effective than voluntary labour. Finally, a high level of use of capital with a high proportion of tractors tends to be associated with high and very high technical efficiency. It is obvious that use of tractors is more effective than animals, particularly in large-scale rice agriculture.

Table 4.16. Summary characteristics by efficiency groups

Average value of farm characteristics	Unit	Efficiency group				Correlation with tech. efficiency
		<0.60 (219)	0.60-0.75 (235)	0.76-0.85 (280)	>0.85 (83)	
Farmer						
Age	year	45.66	46.69	51.51	53.27	0.189[a]
Education	year	4.28	4.35	4.76	4.78	0.090[c]
Family member	#	4.90	4.92	4.85	4.86	0.021[n]
Output						
Total output	kg	784	1707	2859	5989	0.450[a]
Land						
Area	ha	0.50	0.58	0.70	1.04	0.211[a]
Number of plots	#	1.08	1.10	1.28	1.89	0.273[a]
Owned land	%	0.89	0.93	0.92	0.97	0.051[n]
Capital						
Total capital	day	2.00	3.57	6.03	4.19	0.126[a]
Animal	day	1.63	2.41	2.52	2.01	0.074[b]
Tractor	day	0.41	1.15	3.51	2.19	0.142[a]
Labour						
Total labour	day	50.45	48.26	62.91	98.32	0.181[a]
Family labour	day	39.75	34.89	40.86	41.43	0.045[n]
Unpaid labour	day	1.00	0.38	0.44	0.51	-0.049[n]
Hired labour	day	9.70	12.99	21.61	56.39	0.254[a]
Share hired labour	%	18.73	25.11	32.63	53.13	0.229[a]
Material						
Total material	Rp	20679	27453	38514	46638	0.224[a]
Seed	kg	28.56	38.19	49.52	59.86	0.178[a]
Irrigation	Rp	952	39594	10967	26119	0.252[a]
Organic materials	Rp	3796	135	134	70.48	-0.033[n]
Agrochemicals						
Total agrochemicals	Rp	36656	55023	178838	125422	0.053[n]
Fertilisers	kg	83.15	124.63	205.59	322.30	0.197[a]
Pesticides	Rp	7610	12964	11820	21046	0.357[a]

Note: [a]) significant at 1%; [b]) significant at 5%; [c]) significant at 10%; [n]) not significant

Source: Author's calculations

Most of coefficient correlations are positive except for unpaid labour and organic materials. The positive coefficient indicates that more technically efficiency farms occur with high level of farm characteristics. Employing volunteer labour leads to low technical efficiency because, as mentioned above, workers are unlikely to be controlled by farm managers. Consequently, the workers are ineffective. The use of organic materials also leads to low technical efficiency because the land actually receives organic material regularly from the biomass of plants at harvesting. Farmers usually leave dried rice stalks in the paddy field. Technically, there is no need for additional organic materials.

Conclusion

Productivity of Indonesian rice agriculture is still low, particularly in areas outside of Java. Because of the fact that most Indonesian people rely on rice for dietary energy requirements, it is important to raise productivity. There are two choices for achieving this, adopting new technology and raising the level of technical efficiency. Adopting new technology will be effective if the process of production with existing technology is technically efficient. However, if the production with the existing technology is still technically inefficient, improving technical efficiency will be an appropriate instrument. Thus, estimating technical efficiency of rice agriculture is an appropriate choice. After the technical efficiency is determined, then factors affecting the differential technical efficiency can be found, and, subsequently technical efficiency can be raised using such factors.

Use of stochastic frontier production functions indicates that technical efficiency still has a key role in affecting Indonesian rice production. The average of technical efficiency is around 0.68. The important factors that significantly increase technical efficiency are: farmer's experience, educational attainment, size and number of plots, hired labour and mechanisation. More experienced and educated farmers can increase technical efficiency because they will be more capable of implementing the existing technology. Mechanisation and hired labour lead to high technical efficiency because using tractors is less costly, and hired labour works more effectively. Regional characteristics that have positive effects on technical efficiency on Java are intensification programs and irrigation management. This appears where various extension programs have been implemented, and, as a result farmers in this region operate with more technical efficiency than those in other regions.

Technical efficiency is increasing at a decreasing rate. The implication is that the average production function is getting closer to the production frontier. Since rice agriculture is still technically inefficient, there is enough room for improvement in the productivity of rice farms, by increasing technical efficiency given state-of-the-art agricultural technology for rice production. Rice agriculture on Java, which is the rice-bowl of Indonesia, is mostly considered for possible improvement because in it has good agricultural infrastructure and institutions, as well as soil fertility of paddy fields. Despite the highest technical efficiency, this achievement is considered low, and there is a tendency of decreasing technical efficiency.

Further Analysis

In this analysis, it has been demonstrated that technical efficiency of rice agriculture has not been fully achieved. In other words, if the technical efficiency can be improved, either output can be increased with the same level of inputs, or inputs can be reduced while keeping output unchanged. Polices related to the enhancement of technical efficiency need to be wisely formulated. With global concern on the environment, it is ecologically wise to reduce environmentally detrimental chemical inputs. The next chapter will analyse the inefficiency of chemical inputs, and estimate the waste of agrochemicals, that is, chemical inputs not fully absorbed by the production system.

Chapter 5

Environmental Efficiency, Chemical Waste and Social Efficiency

Abstract

Intensive agricultural practices are strongly related to natural resources and the environment. It is therefore necessary to analyse agricultural performance. The performance is measured by environmental efficiency that gauges how efficient the farm uses environmentally detrimental inputs; and social efficiency that gauges how efficiently the farm allocates inputs when environmental cost associated with chemical use is taken into account. Environmental efficiency is derived from technical efficiency and scale elasticity with respect to all inputs. Both are estimated using farm level panel data on rice production. The results indicate low environmental efficiency, leading to some chemical waste. Large-scale farms lead to greater amounts of waste because of large amounts of agrochemicals used. Rice production also fails to allocate all inputs at the correct level. Land is still under-utilised; and other inputs are overused. This makes sense since the agricultural technology is intended to substitute scarce lands.

Keywords: environmentally detrimental inputs, environmental efficiency, agrochemical waste, social efficiency

Introduction

Much of the earth's surface has been modified for the purpose of agriculture. As a consequence, it is reasonable to raise fundamental issues between environmental conservation and intensive agriculture. The early 1960s, when the Green Revolution was being introduced, was the time of agricultural scientific euphoria. During the mid 1970s, there was rapid growth in global food production, thus reducing the threat of increasing gap between supply and demand for food. The concern that growth of agricultural production would not be capable of keeping pace with the rising need for food by the world population has not materialised. However, since the late 1980s, optimism has been tempered due largely to the persistent problem of insufficient supply for food in major parts of the world, and environmental and social concerns about intensive agriculture methods (Nijkamp and Vindigni 2000). As reported by the United Nations (1997) there is a greater recognition of the problem of food security in the medium and long terms of depletion of natural resources, and of environmental and land degradation.

Evidence indicates that agriculture indeed leads to non-point source pollution and that this leads to high external cost.[11] Houndekon and de Groote (1998) report that the external cost of controlling migratory locust pests during 1992-1996 in Niger was around US$ 416,607, the value of livestock poisoned by insecticides. In Thailand, Jungbluth (1999) reports that the external costs of agrochemical use in 1992 reached about US$ 43 million, coming from the market value of chemical-contaminated vegetables and fruits. In terms of health cost, each Pilipino farmer must spend approximately an extra US$ 24 for recovering health associated with 1 kg of pesticide application (Rola and Pingali 1993).

Some studies also report that not only developing countries suffer from agricultural pollution problems. Agrochemical-pollution resulting in external cost also occurs in many developed countries. Germany estimates the amount of external costs related to the unintended undesirable side effects of

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[11] Non-point source pollution is a form of pollution whose source and quantity are very difficult to identify (Grafton et al. 2004).

agrochemical application. Every year, at least US$ 164 million should be spent to deal with water contamination, residues in food, plants destroyed by herbicide, and loss in honey production. The ratio of such external costs to pesticide expenses is 23 per cent. Compared with the benefit value of pesticides, there is a net welfare loss of US$ 587 million, which is equivalent to five per cent of net domestic agricultural product (Fleischer 1999). Pincus et al. (1999) note that the net welfare loss related to agrochemical use also happens in the United States. Pretty et al. (2000: 118) estimate the value of negative externalities of the modern farming practices that use agrochemicals in the UK. They conclude that

> 'Modern farming clearly results in substantial external costs per hectare and per kilogram of non-renewable input. These per hectare costs are substantially greater than those estimated in other studies, probably reflecting the more comprehensive nature of the framework and range of impacts measured. Nonetheless, we believe them to be a conservative estimate of the true costs.'

Additionally, the accompanying environmental and social costs of decreasing efficiency in agriculture are undervalued or even ignored. Agricultural practices with chemical intensive technologies are so dominating that they suppress serious debate of alternatives.

Since the publication of *Silent Spring* by Rachel Carson in 1963, issues of environmental problems related to intensive agriculture have been raised. A number of publications raising concerns over the sustainability of intensive agriculture have continued to increase since the late 1970s, (for example Barbier 1989; Conway and Barbier 1990). Demand for a clean and healthy environment is greater today than it has ever been because of growing property rights of people to a better environment. The expression of greater demand for a better environment is seen in several ways. The existence of organisations that lobby for environmental regulations and policies is one of the expressions.

The demand for a better environment has grown because of two main elucidations. First, as people have increasing income, the demand for a wider range of goods and services is increasing as well. One of these goods and services is a high quality environment. Second, as knowledge of the effect of human actions on the environment grows, people show they are capable of taking measures that improve the environment. For instance, it is well known that agrochemicals poison wildlife through a food chain process, and kill beneficial organisms. In principle, people are able to design measures that limit such problems.

In Indonesia, environmental degradation related to intensive agricultural practices had been recognised well during the Green Revolution (Barbier 1989; Conway and Barbier 1990). Land degradation is associated with chemical use which has damaging effects on the environment (Bond 1996). In the practice of rice agriculture, land degradation associated with chemical use seems to be more serious because of the use of a lot of chemicals. There is still lack of scrutiny in the use of agrochemicals in agricultural practices, particularly rice production in Indonesia.

This study aims to examine rice agriculture efficiencies related to use of agrochemicals at farm level. The efficiency measures cover environmental, allocative and social efficiencies. The externality cost related to inefficiency of chemical use will be estimated, and social efficiency will be obtained by taking environmental cost into account. The chemical inputs are considered as environmentally detrimental materials (Bond 1996).

Literature Review

Many studies on efficiency of agriculture have been conducted over the world, but most focus on technical efficiency and allocative efficieny. For example: Amaza and Olayemi (2002) in Nigeria, Tadesse and Krishnamoorthy (1997) and Battese and Tessema (1993) estimate technical efficiency in India using farm level cross-sectional data with Cobb-Douglas frontier production technology, while Kumbhakar (1994) uses translog frontier production technology. Bravo-Ureta and Evenson (1994) in Paraguay analyse secondary crops using farm level data. Ahmad and Bravo-Ureta (1996) try to compare technical efficiency with different functional forms. Concern over intensive agriculture that uses environmentally detrimental inputs has been raised in many discussions (for example: Byerlee 1992; Ali and Byerlee 2002; Apel et al. 2002; Pujara and Khanal 2002; Singh 2002; Schumann, 2002; Toryanikova et al. 2002), but, there are still limited discussions on agricultural efficiency that take environmental impact into account. Only a few studies pay close attention on the efficiency of chemical use by integrating technical, economic and environmental performance measures using stochastic and deterministic approaches.[12]

Hadri and Whitaker (1999) try to analyse the relationship between technical efficiency of dairy farms and environmental pollution related to agrochemicals that are potential environmental contaminants. The study uses a stochastic

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[12] Coelli et al. (2007) review several existing methods that use a deterministic approach and propose an alternative method that improves the previous one by introducing a materials balance condition. As discussed in Chapter 4 however, this study uses a stochastic approach because of the nature of agricultural production, and therefore we only review the existing literature that uses the stochastic method.

production frontier to estimate technical efficiency, which is dependent on some farmer characteristics and the use of chemical inputs. The important outcome of this study is that the more efficient farms use more chemical inputs. Related to the concern on environmental pollution, this is an interesting finding to analyse further, because farms will use more chemical inputs to increase technical efficiency. A study conducted by Roche (1994) in Indonesian rice production shows that the use of Nitrogenous fertilisers determines technical efficiency. In this case, neither low nor high use of such fertilisers leads to high technical efficiency. The most technically efficient farms are determined by a range of level of fertiliser use recommended by extension services. There is a tendency that Javanese farmers overuse fertilisers, contrasted to those off Java.

The need for further analysis is to answer a question of whether more technically efficient farms will result in lower pollution or not. Reinhard et al. (1999; 2000) make an effort of studying efficiency related to the use of environmentally detrimental inputs in dairy farming. The study uses two approaches to estimate environmental efficiency, a new concept of efficiency associated with the use of environmentally detrimental inputs. Environmental efficiency is defined as the ratio of minimum attainable environmentally detrimental input use to actual use given actual level of output and other inputs at the existing state of technology. By definition, the amount of chemical input surplus representing pollution can be determined. The first approach uses the method of data envelopment analysis to estimate a deterministic production frontier. Environmental efficiency is then derived from the production frontier. The second approach uses an econometric method to estimate a stochastic production frontier. The same next step is to derive environmental efficiency using the estimated the production frontier. The functional form of production technology is a flexible transcendental logarithmic (translog), which has a strict requirement for environmental efficiency to be derived from a production function. The requirement is related to monotonicity of the estimated production function with respect to environmentally detrimental inputs.[13] The important statement of this estimation of environmental efficiency is that a technically efficient producer is a necessary condition for environmental efficiency, but a highly technically efficient producer does not immediately lead to environmental efficiency.

Methodologically, both calculations of environmental efficiency have the same disadvantage, that is, the monotonicity of the production function. In other words, the producer is assumed to operate the firm under conditions of production increasing at a decreasing rate. When the condition does not hold, it is unlikely to calculate environmental efficiency.

In the deterministic approach, in which monotonicity is imposed on the production function, the study is able to calculate environmental efficiency of two environmentally detrimental inputs, that is, nitrogenous and phosphate fertilisers. Meanwhile, in the stochastic approach, the study fails to calculate environmental efficiency of phosphate use. The failure is because of the non-monotonic production frontier with respect to phosphate.[14]

Using a stochastic method with the same object, Reinhard et al. (2002) re-estimate environmental efficiency of Dutch dairy farms and examine the sources of variation in environmental inefficiency. A two-step estimation is used

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[13] Monotonic curvature guarantees that there is a unique solution in which the observable output can be feasibly produced with a minimum level of inputs at the frontier. If the input is environmentally detrimental, the ratio of the minimal level to the observable level will represent the rate of environmental efficiency.

[14] When the curvature is not monotonic, there will be more than one level of inputs given an observable level of output at the frontier.

to account for some producer characteristics which are assumed to have impacts on environmental efficiency. In the first step, environmental efficiency is calculated from a production frontier. In the second step, environmental efficiency is regressed with the producer characteristics hypothesised to have strong relations to environmental performance. The two step estimation does not violate independence of technical inefficiency as stated by Coelli et al. (1998). This is because environmental inefficiency is not only dependent on technical inefficiency, but also dependent on the level of environmentally detrimental input use and the acquisition of production technology. It is likely that each producer will be different in acquiring levels of technology, use of environmentally detrimental inputs, and levels of technical inefficiency. Because environmental efficiency is calculated using the same procedure as before, the environmental efficiency of each producer will not be found when the individual production technology is not monotonic in environmentally detrimental inputs.

Both studies do not proceed with the calculation of waste discharged into the environment. The rank of the producer is made using environmental efficiency level. This rank may be misleading because high environmental efficiency does not immediately reflect the amount of waste. The rank of the producer based on the amount of waste is likely to be a suitable indicator of environmentally sound performance. The amount of waste therefore needs to be calculated. A recent study on environmental efficiency conducted by Gang and Felmingham (2004) calculates the potential reduction of environmentally detrimental material. The potential reduction can be regarded a chemical waste. The study uses a similar method to Reinhard et al. (2002) to calculate environmental efficiency.

Based on the above reviews, the objective of this present study is to analyse the environmental efficiency in rice agriculture, with particular attention to the use of agrochemicals. The analysis utilises a stochastic frontier production technique. This paper gives an overview of the definition of environmental efficiency and its derivation from stochastic production function theory. These then are followed by explanations of variables and the data collection. Finally the results and discussion of estimated models lead us to interpretations and conclusions.

Theoretical Framework

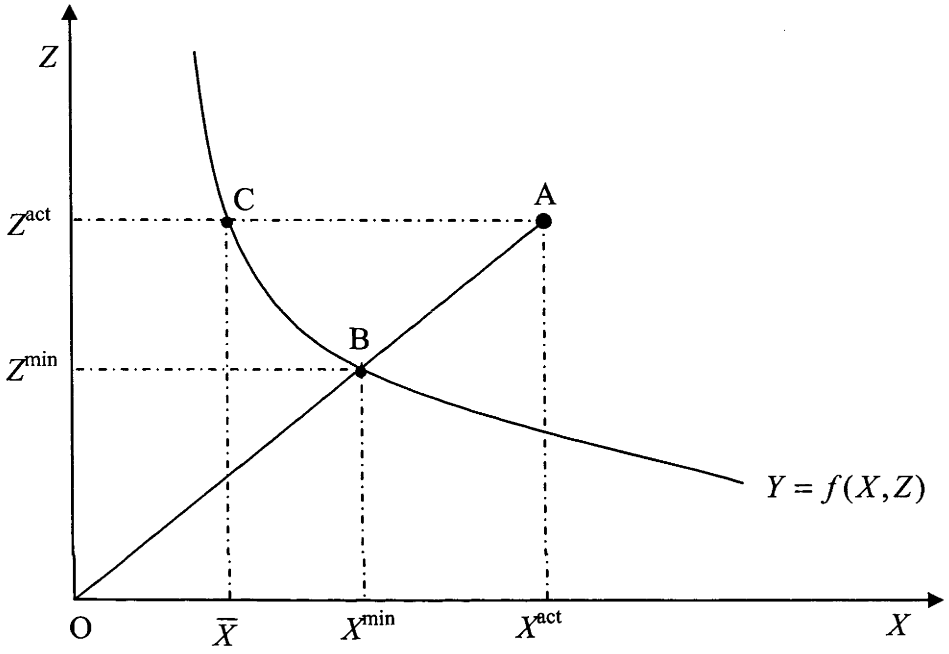
Environmental efficiency

In modern agricultural practices, including rice production, chemical inputs are commonly used. The inputs are considered environmentally damaging. Dealing with damaging inputs in agricultural practices is associated with what is called non-point source pollution, i.e. a form of pollution whose source and quantity are difficult to identify (Grafton et al. 2004). The pollution happens because the chemical inputs used are not perfectly used by the production system, and are to some extent discharged into the environment (Cacho 1999). Based on the fact above, it is relevant to use a concept of environmental efficiency to analyse agricultural practices that use damaging inputs. Starting with the concept of a stochastic production frontier, the environmental efficiency is defined as:

Definition 5.1: environmental efficiency is defined as the ratio of minimum attainable environmentally detrimental input use to actual use given the actual level of output and other inputs at the existing technology (Reinhard et al. 2002).

A technically efficient farm is a necessary condition for environmental efficiency, meaning that if a farm is technically efficient, the farm will automatically be environmentally efficient. Figure 5.1 describes the definition of environmental efficiency.

Figure 5.1. Environmental efficiency, input oriented



At point B, suppose Y^{pot} is a potential production level which is produced through a frontier production technology $f(X,Z)$ with level of $X^{\min}$ and $Z^{\min}$, where X is an environmentally detrimental input and Z is a usual input. Because of being a technically inefficient producer, the same level of Y is produced with actual level of X^{act} and Z^{act}, at point A. In this case the rate of technical efficiency, φ, is the ratio of Y^{act} to Y^{pot} or OB/OA (Sadoulet and de Janvry 1995).

Improvement in technical efficiency is represented by a shift in actual production from A to B, such that both inputs can be reduced in the same proportion to produce the potential output. This is a kind of Hicks-neutral shift in actual production toward frontier production (Huang and Liu 1994). By definition, environmental efficiency is represented by the ratio of $O\overline{X}/OX^{act}$. This implies that to be environmentally efficient, producers should reduce input X from X^{act} to $\overline{X}$ to produce the potential output. This means that there is a shift in actual production from point A to point C. This is particularly true if the shift in actual production is not Hicks-neutral.[15] In fact, the definition is based on a Hicks-neutral shift. Thus the definition of environmental efficiency above violates the concept of a stochastic production frontier with which the definition starts. The definition of environmental efficiency needs to be revised as follows.

Definition 5.2 (revised): environmental efficiency is the ratio of minimum feasible environmentally detrimental input to actual use, given the actual level of output and efficient level of other inputs.

In Figure 5.1, the environmental efficiency is represented by the ratio of $OX^{\min}/OX^{act}$. Thus, to be environmentally efficient, producers should reduce input X from X^{act} to $X^{\min}$ to produce the potential output. In the output oriented approach, environmental efficiency can be depicted in Figure 5.2.

At point B, potential output can be produced with actual inputs $(X,Z)^{act}$. Because of technical inefficiency, the actual output at point A can be efficiently produced with minimum feasible inputs $(X,Z)^{\min}$. As defined above, the rate of technical efficiency, φ, is the ratio of Y^{act} to Y^{pot} (Sadoulet and de Janvry 1995), and environmental efficiency, ψ, is the ratio of $X^{\min}$ to X^{act}.

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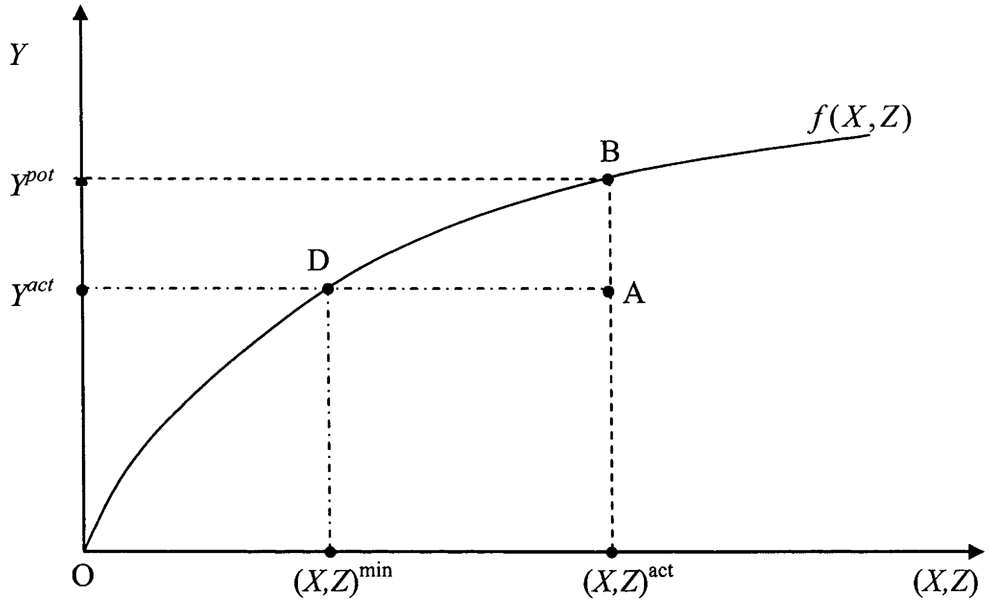
[15] The kind of non-neutral shift in actual production to frontier production has been introduced by Kalirajan and Obwana (1994). But, this study does not use the approach as an analytical tool.

Figure 5.2. Environmental efficiency, output oriented



The relation of technical efficiency and environmental efficiency can be explored in a mathematical approach. In an input oriented approach, the actual level of output can be represented by:

$$Y^{act} = f(\psi X, \psi Z) \tag{5.1}$$

In an output oriented approach, the actual level of output can be represented by:

$$Y^{act} = \varphi Y^{pot} \tag{5.2}$$

Let the kernel deterministic frontier production function taking a functional Cobb-Douglas form technology be:

$$Y^{pot} = AX^{\alpha}Z^{\beta} \tag{5.3}$$

Substituting (5.1) into (5.2) with the functional form of (5.3) gives:

$$\varphi AX^{\alpha}Z^{\beta} = A(\psi X)^{\alpha}(\psi Z)^{\beta} \tag{5.4}$$

and solving for ψ results in:

$$\psi = \varphi^{\frac{1}{\alpha+\beta}} \tag{5.5}$$

Equation (5.5) shows that environmental efficiency can be indirectly estimated in two steps. First, estimate technical efficiency and technology parameters using the production frontier. Second, measure environmental efficiency, derived using the estimated technical efficiency and the output elasticity with respect to inputs. It can be seen that there are two conditions that make environmental efficiency exactly the same as technical efficiency. The first is when the firm is operated at full technical efficiency $(\varphi = 1)$ and the second when production exhibits constant returns to scale, that is, $(\alpha + \beta = 1)$.

In the case of Cobb-Douglas production technology, output elasticity with respect to all inputs is constant over time and not dependent on the use of inputs. This is a very restrictive condition where environmental efficiency of each producer has a similar pattern to technical efficiency. For example, when technical efficiency of a producer is high, the environmental efficiency is high as well. Thus, using Cobb-Douglas technology will be meaningless in estimating variation of environmental efficiency.

Output elasticity is expected to vary among producers, and it could be the case that producers with high technical efficiency have more output elasticity; and vice versa. Consequently, producers with high technical efficiency are likely to have a similar measure of environmental efficiency to producers with low technical efficiency. It is therefore more informative to estimate environmental efficiency using more flexible production technology to capture variation in output elasticity with respect to each input.

Chemical waste and environmental costs

Intensive agricultural practices have been known as one of the sources of pollution, particularly non-point source pollution resulting from chemical waste. The amount of agricultural waste is defined as the use of environmentally detrimental inputs not totally used by the production system and partially discharged into the environment (Cacho 1999). From the estimated environmental efficiency, ψ, the amount of non-point source pollution from each producer can be calculated as:

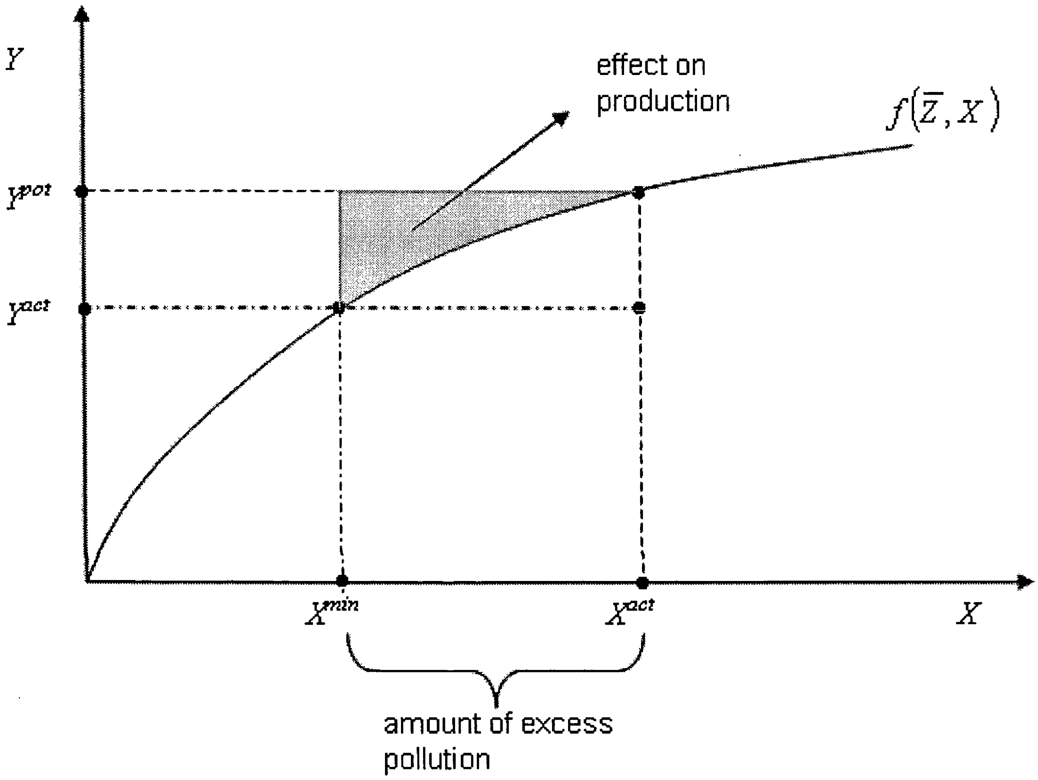
$$AW = (1-\psi)X \tag{5.6}$$

where AW is the amount of agricultural waste, and X is the use of environmentally detrimental inputs.

In the era in which society has property rights to a clean environment, the existence of agricultural waste reduces amenity, and the society normatively should have compensation from disutility due to "consuming" a contaminated environment. The amount of compensation is dependent on the level of chemical waste discharged into the environment. Therefore, environmental impact of chemical waste needs to be valued in monetary terms. The value is then called an environmental cost.

Monetary valuation of that pollution is difficult because it is a non-marketed good, and there is no general method because every case needs a specific approach as a consequence of different states of nature. To some extent, due to lack of information, there is little agreement on the economic costs of externalities in agriculture. Some authors suggest that the current system of economic calculations grossly underestimates the current and future value of natural capital (Costanza et al. 1997). Such valuations of ecosystems are still debatable because of methodological and measurement problems, and because of their role in affecting public opinions and policy decisions (Hanley et al. 1998; Carson 2000). However, this does not mean that valuation of externalities should be neglected.

Figure 5.3. Valuation of externality using an “effect on production” approach



Some approaches have been proposed and examined in the literature to value the environmental cost associated with certain pollution. One of the approaches suitable to this study is “effect on production” (Garrod and Willis 1999) which suggests that the existence of additional pollution will affect production such that the level of output will be different from the production with existing pollution. The difference of monetary value of output represents the environmental cost. Since using the environmentally detrimental inputs provides benefits to producers in terms of increased output for a given level of inputs

(Paul et al. 2002), it is reasonable to make an inverse statement of the effect on production as follows: environmental cost is the monetary value of output that must be given up in order to maintain minimum pollution.

Figure 5.3 shows the valuation of environmental cost using the effect on production approach. Given the estimated production function, the minimum environmental cost associated with the amount of environmentally detrimental input discharged into the environment can be calculated as:

$$EC = P\{f(X^{act}, Z) - f(X^{\min}, Z)\} \tag{5.7}$$

where P is prevailing price of output.

Efficient level of resource use

In the framework of static equilibrium analysis, the study of resource use efficiency has been a popular field of research for agricultural economists. Efficient level of resource use relates to profit maximisation. In a production process that results in externalities, there are two efficiency levels. The first is private efficiency in which the producers do not take the externality into account. The second is social efficiency in which the producers take the externality into account (Grafton et al. 2004). In the case of negative externalities, social efficiency will be obtained when the producers reach maximum profit at which the external costs have been internalised into production costs. The mathematical explanation of private and social efficiencies is as follows.

Let the profit identity be:

$$\Pi \equiv P_Y \cdot f(\bullet) - P_X \cdot X - P_Z \cdot Z \tag{5.8}$$

where Π is profit, $Y_{it} = f(\bullet) = f(X_{it}, Z_{it}, t; \beta)\exp\{\varepsilon_{it}\}$ is production technology that produces single output Y using environmentally detrimental input X and usual input Z, P_Y is prevailing market prices of output, P_X and P_Z are prevailing market prices of input X and input Z respectively, t is time index, β is the coefficient of technology, and ε represents the composite disturbance terms. Note that the production technology should be strictly concave to guarantee profit maximisation. The first-order conditions that are necessary for profit maximisation are:

$$P_Y \frac{\partial f(\bullet)}{\partial X} = P_X \tag{5.9a}$$

$$P_Y \frac{\partial f(\bullet)}{\partial Z} = P_Z \tag{5.9b}$$

In terms of elasticity, the conditions can be expressed as:

$$V_Y \theta_X = W_X \tag{5.10a}$$

$$V_Y \theta_Z = W_Z \tag{5.10b}$$

where θ_X and θ_Z are output elasticity with respect to input X and Z respectively, $W_X = P_X \cdot X$ and $W_Z = P_Z \cdot Z$ are costs of input X and Z respectively, and $V_Y = P_Y f(\bullet)$ is value of product.

Let us denote $V_Y \theta = V_Y \theta_X + V_Y \theta_Z$ and $W = W_X + W_Z$, and then the first-order conditions that are necessary for profit maximisation can be arranged as:

$$\frac{\theta_X}{\theta} = S_X \tag{5.11a}$$

$$\frac{\theta_Z}{\theta} = S_Z \qquad (5.11b)$$

where $S_X = \frac{W_X}{W}$ and $S_Z = \frac{W_Z}{W}$. The notation of θ_X/θ and θ_Z/θ are called normalised output elasticity with respect to input X and Z respectively. A firm is said to be allocatively efficient if and only if normalised output elasticity with respect to each input is equal to the share of cost of each respective input. The conditions will hold if:

$$|\Omega_X| + |\Omega_Z| = 0 \qquad (5.12)$$

where $\Omega_X = \frac{\theta_X}{\theta} - S_X$ and $\Omega_Z = \frac{\theta_Z}{\theta} - S_Z$. This represents marginal rate of technical substitution ($MRTS$) between both inputs that is equal to the price ratio of both inputs (Kumbhakar et al. 2000). When the conditions do not hold, representing deviation of $MRTS$ from the price ratio, implying the use of one input must be excessive relative to other inputs. The closer the value of $|\Omega_X| + |\Omega_Z|$ is to zero the higher allocative efficiency.

Pretty and Waibel (2005) suggest that environmental costs resulting from chemical use should be taken into account to obtain social efficiency. Social efficiency can be determined by internalising the environmental cost associated with the environmentally detrimental input, X, that is:

$$\frac{\theta_X}{\theta} = \hat{S}_X \qquad (5.13a)$$

$$\frac{\theta_Z}{\theta} = \hat{S}_Z \qquad (5.13a)$$

where $\hat{S}_X = \frac{W_X + EC}{W + EC}$, $\hat{S}_Z = \frac{W_Z}{W + EC}$ and EC is environmental cost associated with the use of X. A firm is said to be socially efficient if and only if normalised output elasticity with respect to each input is equal to the share of social cost of each respective input. The conditions will hold if:

$$|\Phi_X| + |\Phi_Z| = 0 \tag{5.14}$$

where $\Phi_X = \frac{\theta_X}{\theta} - \hat{S}_X$ and $\Phi_Z = \frac{\theta_Z}{\theta} - \hat{S}_Z$. The closer the value of $|\Phi_X| + |\Phi_Z|$ is to zero the more social efficiency.

Methodology

Environmental efficiency

This study employs translog production technology as specified in Chapter 4. The output elasticity with respect to agrochemicals is not constant, and is dependent on the level of use of their input, other inputs and the time index. The individual output elasticity with respect to agrochemicals is then evaluated at the actual level of each input and the time involved, instead of the average level of input uses. Environmental efficiency is then calculated using the formula:

$$\psi = \varphi^{1/\sum_k \theta_k} \tag{5.15}$$

where $\varphi = \exp\{-u_i\}$ is technical efficiency, θ_k is output elasticity with respect to input k, for k=1,2,...,5. The estimation of environmental efficiency using this formula is expected to overcome the problem when a producer uses zero level of an environmentally detrimental input.[16]

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[16] At the micro level of agricultural practices, it is likely that a producer does not use fertilisers and/or pesticides.

Allocative and social efficiencies of resource use

Analysis is needed to find the proportionality of input use, which can be specified as:

$$\frac{\theta_k}{\theta} - S_k = \Omega_k \tag{5.16}$$

for $k =$ land, capital, labour, materials and agrochemicals. The firms are allocatively efficient when Ω for all inputs are not statistically different from zero, and that non-zero Ω represents allocative inefficiency in the use of respective inputs. If Ω_k is positive, the use of input k is excessive relative to other inputs. Likewise, the social efficiency is analysed as:

$$\frac{\theta_k}{\theta} - \hat{S}_k = \Phi_k \tag{5.17}$$

When Φ for all inputs are not statistically different from zero, the firms are socially efficient, and non-zero Φ represents social inefficiency in the use of input. Overall allocative and social efficiencies are shown by the value of $\sum_k |\Omega_k|$ and $\sum_k |\Phi_k|$ which show that $MRTS$ of inputs is not equal to the price ratio.

Results and Discussion

Environmental efficiency, chemical waste and environmental costs

Environmental efficiency is determined by two factors: technical efficiency and scale elasticity. The scale elasticity is dependent on the parameters and functional form production technology, levels of input use and technological change. The frontier production technology that is assumed to be the true model is translog with non neutral smooth technological change.[17]

When the frontier production function is estimated, the technical efficiency of each producer can be determined. Output elasticity with respect to each input is calculated from the estimated production function evaluated at the farm level of input use. The environmental efficiency is calculated using equation (5.5) with estimated values of technical efficiency and scale elasticity.[18] The results are given in Table 5.1. On average, the rate of environmental efficiency is 0.64, which is low. This result corresponds to Roche's (1994) finding of low N-uptake efficiency in rice production.

Table 5.1. Average environmental efficiency among regions over time

Region		Year			By region
		1994	1999	2004	
Lampung	Mean	0.5461	0.5927	0.6691	0.5960
	S.D	0.2373	0.2501	0.2217	0.2420
Java	Mean	0.7442	0.8136	0.7396	0.7692
	S.D	0.1486	0.0867	0.1475	0.1317
West Nusa Tenggara	Mean	0.6162	0.6637	0.7066	0.6531
	S.D	0.1593	0.1788	0.1435	0.1673
North Sulawesi	Mean	0.5095	0.5661	N/A	0.5378
	S.D	0.2256	0.1990		0.2120
South Sulawesi	Mean	0.5726	0.6454	0.7527	0.6322
	S.D	0.1517	0.1655	0.0953	0.1613
By year	Mean	0.5972	0.6518	0.7081	0.6409
	S.D	0.1895	0.2023	0.1669	0.1944

Source: Author's calculation

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[17] The formal test for functional form and the discussion on estimates of the frontier production technology have been conducted in Chapter 4.

[18] For comparison, the environmental efficiency is also calculated using a formula proposed by Reinhard et al. (2002). Environmental efficiency of 189 producers is undefined. Most of them use zero level of environmentally detrimental inputs, and some others use very low levels of the same inputs. Using equation (5.5), the case of zero use of such inputs shows that environmental efficiency is slightly greater than technical efficiency. This is because the scale elasticity is greater than unity, or the individual producer shows increasing returns to scale.

Given, in Table 5.2, the correlation between technical efficiency and environmental efficiency is close to unity, means that both have similar patterns. We can see that environmental efficiency increases over time, which is similar to technical efficiency, as discussed in Chapter 4.

It is clear that technically inefficient rice agriculture that uses environmentally detrimental input leads to environmental inefficiency. To some extent, this condition indicates inability of rice agriculture to use the detrimental input efficiently and consequently, the detrimental input is discharged into the environment. In technical terms, rice agriculture leads to non-point source pollution. The volume of non-point source pollution resulting from each producer will be dependent on the level of environmental efficiency and the level of use of environmentally detrimental inputs. This study emphasises chemical waste as a consequence of environmentally inefficient farms. Because environmental efficiency is low, a significant quantity of agrochemicals applied to rice production system is simply wasted.

Table 5.2. Correlation between environmental efficiency and other variables

	Technical Efficiency	Environmental Efficiency	Chemical Waste	Environmental Cost	Use of Chemicals
Environmental Efficiency	0.9709^a	1			
Chemical Waste	-0.0763^b	-0.0777^b	1		
Environmental Cost	0.0697^b	0.0966^a	0.1464^a	1	
Use of Chemicals	0.0532^n	0.0536^n	0.0301^n	0.0738^n	1
Farm size	0.2107^a	0.1916^a	0.3573^a	0.4543^a	0.1428^a

Note: ^{a}) significant at 1%; ^{b}) significant at 5%; ^{n}) not significant
Source: Author's calculation

As expected, the correlation between environmental efficiency and chemical waste is very low, meaning that environmentally inefficient farms do not necessarily lead to high level of chemical waste. Consequently, the rank of farms based on environmental and technical efficiency will be different from those based on level of chemical waste.

Table 5.3. Regression of chemical waste on dummy regions

Regions	Year			
	1994	1999	2004	Overall
Constant (=Java)	879.25	691.79	1335.01	907.36
	0.42[n]	0.72[n]	1.39[n]	0.94[n]
Lampung	2323.85	2665.12	1061.34	2143.99
	0.90[n]	2.32[b]	0.95[n]	1.86[c]
West Nusa Tenggara	3949.54	3309.59	1773.16	3248.80
	1.65[c]	3.04[a]	1.61[c]	2.97[a]
North Sulawesi	3871.12	2810.03	(dropped)	3218.74
	1.11	1.82		1.90
South Sulawesi	4306.02	2567.22	5870.74	4139.24
	1.71[c]	2.07[b]	4.93[a]	3.48[a]
R^2	0.011	0.030	0.182	0.017
F-stat	0.44[n]	2.32[c]	12.47[a]	3.52[a]
No. Obs.	341	304	172	817

Note: [a]) significant at 1%; [b]) significant at 5%, [c]) significant at 10 %; [n]) not significant
Source: Author's estimation

In Table 5.3, we can see that the highest level of chemical waste results from rice farms in South Sulawesi. In fact, the region is not the least environmentally efficient. Another factor that affects chemical waste is farm size. The correlation shows that the greater size of rice farms leads to a higher level of chemical waste. On average, the size of rice farms in South Sulawesi is relatively larger than that in other regions. West Nusa Tenggara, which has the largest size of rice farms, is in the second ranking in terms of chemical waste level. Since the use of agrochemicals does not significantly correlate with the level of chemical waste, the logical explanation is that the bigger farms lead to higher rates of technical as well as environmental efficiencies.

The chemical waste is an externality which is an unexpected outcome of the production system. Since the society ideally has property rights to the dirt-free environment, the externality needs to be valued in monetary terms, which are used to provide monetary compensation. Using a concept of effect on production approach, the monetary value of externalities, or environmental costs, can be estimated. The comparison of environmental costs among regions is given in Table 5.4.

Table 5.4. Regression of environmental cost of dummy regions

Regions	Coefficient	t-ratio
Constant (=Java)	15161	0.23^n
Lampung	34483	0.43^n
West Nusa Tenggara	139335	1.84^c
North Sulawesi	-13895	-0.12^n
South Sulawesi	202958	2.47^b
R^2	0.014	
F-stat	2.92^b	

Note: ^{b}) significant at 5%, ^{c}) significant at 10 %; ^{n}) not significant
Source: Author's estimation

We can see that environmental costs in West Nusa tenggara and South Sulawesi are significantly greater than those on Java, statistically not different from Lampung and North Sulawesi. The cause of higher environmental costs in both regions is large size of rice farms.

Allocative and social efficiencies

Overall, allocative inefficiency here is indicated by the sum of absolute values of deviation in share of input cost to the normalised output elasticity with respect to particular inputs. The output elasticity and the normalised elasticity are given in Table 5.5. The normalised output elasticity is then subtracted from the share of private and social input costs to indicate whether or not the farms are allocatively and socially efficient respectively. The private and social costs of inputs are given in Table 5.6.

Table 5.5. Output elasticity with respect to each input

Input	Elasticity			Normalised elasticity		
	1994	1999	2004	1994	1999	2004
Land	0.7207	0.6969	0.7432	0.8375	0.7439	0.6821
Capital	0.0343	0.0487	0.0315	0.0399	0.0520	0.0289
Labour	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Material	0.1043	0.1028	0.1229	0.1212	0.1097	0.1128
Chemicals	0.0013	0.0884	0.1920	0.0015	0.0944	0.1762
Scale elasticity	0.8605	0.9368	1.0896	1	1	1

Note: Discussions on output elasticity has been given in Chapter 4
Source: Author's calculation

Table 5.6. Share in private and social costs

Input	Private share			Social share		
	1994	1999	2004	1994	1999	2004
Land	0.0439	0.0121	0.1230	0.0439	0.0120	0.0901
Capital	0.0604	0.1049	0.2030	0.0604	0.1046	0.1660
Labour	0.2603	0.4669	0.4047	0.2602	0.4655	0.3175
Materials	0.2799	0.2173	0.1237	0.2798	0.2156	0.0904
Chemicals	0.3555	0.1988	0.1456	0.3557	0.2023	0.3360

Source: Author's calculation

With respect to the share of private costs generally, labour and agrochemicals have a higher share of costs of production. In small-scale rice agriculture, this condition is reasonable. Small-scale rice agriculture is usually labour and chemical intensive. Chemicals are used to increase productivity of land, and labour is more suitable than tractors. This corresponds to the lowest share in cost of capital which is a less suitable input in small-scale rice agriculture. Land has the smallest share in cost, because most farmers studied here produce rice on their privately owned land. The cost related to land is land tax, which is relatively low in rural areas. The shares of land, labour and capital costs tend to increase, whereas the shares of agrochemicals and materials tend to decease. The dynamics of shares of cost is dependent on the price of inputs and the level of use of these inputs.

With respect to share of social cost, it is theoretically expected that the share of chemical cost increases and the share of other input costs decrease. This is because the environmental cost associated with agrochemicals is internalised into the cost of chemical input. In the first two points in time, the impact of internalisation of environmental cost is very low. But, in the last point in time, there is considerable change in those shares. This is an indication that in the last point in time, the environmental cost associated with chemical input is significant.

Overall allocative and social efficiencies hold if normalised output elasticity with respect to each input is equal to shares in private and social costs of each respective input. It can be identified by the sign and magnitude of differences between normalised elasticity of output with respect to each input and share in cost of each respective input, indicating allocative inefficiency, and the differences between such elasticity and the share of social cost of input indicating social inefficiency. The differences are given in Table 5.7.

Table 5.7 shows that allocative and social efficiencies of rice agriculture are not the case because producers fail to equalise the normalised output elasticity of all inputs to share of all costs of inputs. These indicate that one or more inputs are allocated in incorrect amounts such that the *MRTS* among inputs are not equal to their price ratio, and that this leads to economically incorrect proportions in allocating inputs.

Table 5.7. Differences between normalised elasticity and share in input costs

Year	Inputs	$\frac{\theta_X}{\theta}-S_X=\Omega_X$		$\frac{\theta_X}{\theta}-\hat{S}_X=\Phi_X$	
		mean	Sd	mean	Sd
1994	Land	0.7936^{a}	0.0581	0.7937^{a}	0.0581
	Capital	-0.0205^{a}	0.0760	-0.0205^{a}	0.0759
	Labour	-0.2603^{a}	0.1976	-0.2602^{a}	0.1975
	Materials	-0.1587^{a}	0.1959	-0.1586^{a}	0.1958
	Chemicals	-0.3540^{a}	0.1971	-0.3542^{a}	0.1971
		$\sum\lvert\Omega\rvert = 1.5871$		$\sum\lvert\Phi\rvert = 1.5872$	
1999	Land	0.7318^{a}	0.0145	0.7319^{a}	0.0144
	Capital	-0.0529^{a}	0.1211	-0.0526^{a}	0.1208
	Labour	-0.4669^{a}	0.2658	-0.4655^{a}	0.2652
	Materials	-0.1075^{a}	0.2151	-0.1059^{a}	0.2133
	Chemicals	-0.1045^{a}	0.1729	-0.1079^{a}	0.1747
		$\sum\lvert\Omega\rvert = 1.4636$		$\sum\lvert\Phi\rvert = 1.4638$	
2004	Land	0.5591^{a}	0.1381	0.5920^{a}	0.0928
	Capital	-0.1741^{a}	0.1962	-0.1371^{a}	0.1616
	Labour	-0.4047^{a}	0.2486	-0.3175^{a}	0.2233
	Materials	-0.0109^{a}	0.1215	0.0224^{a}	0.0962
	Chemicals	0.0306^{a}	0.1282	-0.1598^{a}	0.2203
		$\sum\lvert\Omega\rvert = 1.1794$		$\sum\lvert\Phi\rvert = 1.2288$	

Note: ^{a}) significantly different from zero tested at 1% significance level

We can see that the gap between normalised output elasticity with respect to land and share of cost of land is the highest and the sign is positive. This is a robust indication that the utilisation of land is far below allocative efficiency. The cause is that the observed cost of land is represented by land tax, which is very low in rural areas; meanwhile the output elasticity with respect to land is very high. In other words, the value of marginal product of land is much greater than the "price" of land for rice production. This means that expanding land for rice production can improve allocative efficiency, and profit can be enhanced. But, it is not an easy task because of limited amount of land suitable for rice production. Particularly on Java, where fertile paddy land exists, the amount of such land decreases over time due mostly to land conversion (Ashari 2003; Firman 1997; Mariyono 2006; Mariyono et al. 2007).

The other gaps for other inputs are negative, meaning that the uses of capital, labour, materials and agrochemicals are relatively excessive compared with the use of land. In spite of relatively little mechanisation in rice agriculture, except for rice mills (Widodo 1989), capital is still relatively overused. This indicates capital is less suitable for rice farming. Topography and plot-size are the main constraints. It is much easier to hand-hoe very small, steep sloped and rocky plots. In many areas of Java, hand hoes are always used to repair bunds and to turn corners difficult to reach with animals or machines.

Overused labour is indicated by zero elasticity of output with respect to labour. This is a common phenomenon, because there is an abundance of labour in the rural sector. Institutional and cultural forms in rural areas enable rice farming, which is mostly small in size, to employ excessive labour. For example, the existence of voluntary and exchange labour has possibly caused very small farms to employ more labour than necessary. When the economic crisis hit Indonesia, the condition was more rigorous since there was a massive flow of unskilled labour from the urban sector to rural areas (Mellor 2003). From an economic point of view, Widodo (1989) explains that overuse of labour is because the farmer's valuation on output and input is not equal to the prevailing market price. The labour market in farming and non-farming may not provide equal employment opportunities to every peasant. There is a common assumption that agricultural workers are considered as uniform labour without skill differentiation and that farming skill is the most appropriate for work in farming. In small farms, the subjective marginal value product is not equal to the market price. Farmers holding small farms value production of rice as the main staple food more than they value market price. Farmers would not sell their entire product, unless they suddenly have an unexpected need for cash.

The overuse of materials and agrochemicals is reasonable because both inputs are likely to be complementary. Materials mainly consist of seed and irrigation. It seems that the source of overuse is seed. Modern varieties of rice need sufficient water irrigation (Las et al. 2006). Rice seed is not directly planted on paddy fields, but it is firstly grown in seedling plots, and then transplanted. Seedlings are not totally transplanted. The healthy ones are selected to be transplanted, and some of them are reserved for replacement. So the amount of required seed will be greater. With respect to irrigation, the overuse of water is because of relatively low costs of irrigation. During the wet season in irrigated areas, water for irrigation is usually abundant. We can see from Table 5.7 that allocative efficiency of materials increases over time.

Overuse of agrochemicals is due largely to seed technology developing fertiliser-responsive varieties. During the Green Revolution, agrochemicals were used excessively (Barbier 1989; Fox 1991). The impact on farmers' behaviour still existed until 1994. But, after 1994, there is an impressive improvement in allocation of agrochemicals. This is understandable because the use of agrochemicals has been rationalised (Rolling and van de Fliert 1994; Winarto 2004; Resosudarmo and Yamazaki 2006). Pesticides will be used when serious pest infestation exists, and timely and correct dosage of fertilisers is applied, based on the agronomical development of rice. This finding is in line with a study by Roche (1994) indicating excessive use of fertilisers in Javanese rice farming. The overuse is due mostly to intensification programs, which is not the case outside Java, where most rice farms are not covered by the programs. It contradicts a study by Widodo (1989) showing that the use of fertilisers and pesticides is at less than an allocatively efficient level. It is explained that apparent low level of chemical use is due mostly to simultaneous equation bias in the production function. The bias leads to marginal product of such inputs being overestimated. But, this problem has not been the case since Coelli (2002) shows that production function provides unbiased estimators under expected profit maximisation as stated by Zellner et al. (1966).

Overuse of such inputs relative to land use is sensible when farm size is small. In Indonesia, the size of rice farm is small and the availability of land for expansion is limited. With limited availability of land and 'when extremely small landholdings are the primary basis for providing a rural family's staple food supply, the households' expected welfare may be optimised by a strategy that maximises yields' (Roche 1994: 80). Agricultural technology mostly covers high yielding varieties of rice and fertilisers. The technology can work properly if it is supported by good irrigation systems. The technology is a substitute for land (Hayami and Ruttan 1985) that enables higher production of rice on limited land. Murgai (2001) calls this phenomenon 'land-saving technological change'.

Internalisation of environmental cost into cost of input slightly changed efficiency and this became apparent in 2004 the cost became higher that year. Internalisation of environmental cost, in this case, causes farms to be less allocatively efficient, meaning that the rate of allocative efficieny is greater than that of social efficiency. We can see that allocative efficiency increases over time, and so does social efficiency.

Conclusion

Chemical inputs are considered environmentally detrimental and lead to negative externalities. Such inputs have been used in Indonesia since the Green Revolution to improve productivity in rice agriculture. Along with the growing concern over sustainable agricultural development, the externalities of chemical inputs need to be taken into account. This study aims to estimate environmental efficiency associated with the use of agrochemicals and to calculate chemical waste. The waste or externality, is then valued in monetary terms and internalised in the production costs.

Using a production approach, the study shows that environmental efficiency is low. The most environmentally efficient rice farms are on Java, and the least efficient are in North Sulawesi. Environmental efficiency has slightly increased over time. Since environmental efficiency is strongly correlated with technical efficiency, factors affecting technical efficiency automatically influence environmental efficiency.

Low environmental efficiency means that there are agrochemicals applied in the rice production system that cannot be absorbed effectively, and this results in significant chemical waste. The highest level of chemical waste is in South Sulawesi and the lowest is in Java. The waste leads to externalities that impose costs on society. In terms of monetary value, or the cost of externalities, the highest values are in South Sulawesi and West Nusa Tenggara where the average farm size is relatively large compared to other regions.

Allocative efficiency is another measure of farm efficiency. The results show allocatively inefficient rice agriculture. The cost of land is relatively much lower than costs of other inputs, such that the use of land is much less than the efficient level. In contrast, capital, labour, materials and agrochemicals are relatively overused compared to land, with too much labour devoted to rice production. This became more serious after economic crises hit Indonesia because of re-urbanisation. In general, there is economically sub-optimum allocation of input. Internalisation of environmental costs associated with chemical use slightly changes the allocative efficiency. Efficiency taking environmental cost into account is called social efficiency. Both allocative and social efficiencies increase over time. Social efficiency is a good measure because it has taken environmental problems into account. Along with growing concern on sustainable development, it is recommended that the policy should address improving social efficiency, instead of allocative efficiency.

Further analysis

In this analysis, it has been demonstrated that rice agriculture has not been environmentally efficient. In other words, some agrochemicals are discharged into the environment, leading to environmental cost and economically inefficient use of agrochemicals. The next chapter analyses the productivity of rice agriculture with taking environmental costs into account because the efficiency contributes to productivity growth of rice agriculture, where environmental cost is hypothesised to influence the productivity of rice agriculture.

Chapter 6

Environmentally Adjusted Productivity Growth

Abstract

Productivity of Indonesian rice agriculture needs to grow substantially. However, the environmental cost should be taken into account. This study aims to analyse productivity growth of rice by decomposing it into technological change, scale effects, allocative efficiency and technical efficiency. Environmental cost associated with the use of environmentally detrimental inputs is internalised to obtain environmentally adjusted productivity growth. The result indicates that total factor productivity growth is driven by technological change and allocative efficiency effects. Environmentally adjusted productivity growth is less than conventional productivity growth. Some policies to increase the environmentally adjusted productivity growth are proposed.

Keywords: total factor productivity, technological change, scale effect, efficiency, environmental cost.

Introduction

Indonesian rice agriculture is facing a challenge of population growth leading to increased demand for food. This will require continually increasing productivity, despite the fact that productivity growth is slowing and the availability of land for future expansion is limited. Increasing agricultural productivity is important because it has a number of substantial effects (Ahearn et al. 1998). First, it releases resources that can be used by other sectors, thereby generating economic growth. Second, higher levels of agricultural productivity result in lower food prices that increase consumers' welfare. And third, in the context of an open economy, productivity growth improves the competitive position of a country's agricultural sector. Irz et al. (2001) empirically identify the importance of agricultural productivity in relieving rural poverty alleviation. Against this background, it is clear that agricultural productivity measures provide a key indicator of the performance of a country's agricultural sector. This has long been recognised and now there exists a vast literature on agricultural productivity measurement. The aims of most productivity studies have been to monitor the performance of the agricultural sector including efficiency, to make performance comparisons across industries and countries, and finally, to help policymakers to design optimal policies to enhance productivity.

Enhancing productivity does not necessarily mean jeopardising environmental quality, however. Concerns relating to environment have been focused on sustainable agricultural development. The agricultural sector is a dynamic sector with many conflicting issues. Agriculture has gone through cyclical movements in the past decades. In the late 1960s and early 1970s, it was commonly expected that agricultural production would not be capable of keeping pace with the rising need for food. But during the mid 1970s, there was rapid growth in global food production, reducing the threat of an increasing gap between supply and demand for food. However, since the late 1980s, the optimism has been tempered, due largely to the persistent problem of insufficient food supply in major parts of the world and environmental and social concerns about intensive farming methods. As reported by the United Nations (1997) there is a greater recognition of the problem of food security in the medium and long term, as a result of the depletion of natural resources and of environmental and land degradation. Against this background the notion of sustainability of agricultural development in relation to food security is quickly gaining significance (Nijkamp and Vindigni 2000).

Agricultural growth in developing countries showed a discernible decline up until the late 1990s, even though, during the Green Revolution, there was high agricultural growth. This indicates that productivity level during the Green Revolution has not been sustained (Teruel and Koruda 2004). According to Kalirajan et al. (2001) there are two main reasons for slow growth of agriculture. First, there was no major breakthrough in developing agricultural technology in the 1990s. Second, there was a decline in the quality of the environment and land, which reduced the marginal productivity of inputs. The decline in the quality of the environment and land is most likely brought about by the excessive use of chemical inputs (Bond 1996; Paul et al. 2002). In other words, lack of technological progress and deterioration in productive efficiency are crucial factors that impede agricultural growth.

This paper aims to estimate productivity growth of rice agriculture, to determine what drives it, and to examine the impact of internalising environmental cost associated with the uses of agrochemicals. The next parts of the paper review developmental methods of measuring productivity and discuss the drawbacks due largely to strong assumptions. An improved method is used to provide better results in which some assumptions are relaxed. The results will be discussed, and conclusions drawn from the analysis.

Literature Review

Neo-classical productivity growth analysis has been widely studied after the publication of major works of Solow (1956) and Swan (1956) in the United States of America and Australia respectively. Even though both authors used different approaches to examine growth (Dixon 2003), they have inspired many economists to examine economic growth further. There is a large body of literature on the measurement and explanation of the productivity residual. Generally, there are two methods of measuring productivity growth. The first method needs functional form of production technology, and the second needs no functional form.

Related to the need for functional form of the production function, there are two basic approaches to the measurement of productivity. First the growth accounting approach relies on neoclassical production theory under constant returns to scale for the proposition that the output elasticities with respect to inputs are equal to the corresponding factor shares (Solow 1957), and thereby calculates the total factor productivity as an arithmetic residual after share-weighted input growth rates are subtracted from the growth rate of output. Second, the econometric approach estimates the parameters of elasticity from time series data and infers the magnitude of total factor productivity as an econometric residual after the estimated effects of all measurable inputs on output have been allowed for (Jorgenson and Griliches 1967). In both of these approaches, much attention has focused on the difficulties of appropriately measuring both inputs and outputs (Jorgenson and Griliches 1967; Griliches 1994).

Related to the method needing no functional form, Coelli (1996) uses linear programming with data envelopment analysis to measure productivity. Fox et al. (2003; 2006) propose a new method for analysing productivity of resource-based firms. This method decomposes productivity from a profit function. This is a deterministic approach that needs no functional form of the production function. In the case of agricultural production analyses, the deterministic approaches seem to be unsuited to the nature of agriculture which is very stochastic, due mostly to natural conditions which producers are not able to control.

In most previous studies on growth that develop the neo-classical Solow-Swan models, it is strongly assumed that producers operate on full technical efficiency, in which they perform the best practice methods of application of state-of-the-art technology. However, due to various circumstances, the producers do not operate on their frontier or at best practice, what the economy would produce if all innovations made to date had been fully diffused. In this interpretation, innovation would drive technological change captured in the production technology. The issue of diffusion would then arise in the form of the presence of firms producing at points inside the production possibility frontier. Stochastic frontier estimation techniques (Aigner et al. 1977) would be needed to measure the extent to which such sub-frontier behaviour is occurring. In this formulation, observed movements of the frontier – measuring technological change — comprise the combined impacts of the invention, innovation and diffusion processes.

The most popular method of productivity measurement is the index number approach, which is practical but needs a number of limiting assumptions, in particular that technological change is Hicks neutral (Hsieh 2000). The implications of that assumption have recently been the focus of attention by growth economists interested in evaluating the relative contributions of capital accumulation and technological progress. In agriculture, Coelli (1996a: 89) studies the neutrality of technological change in Australian agriculture, and concludes that 'material and services and labour were Hicks-saving relative to other input groups'. This finding is in line with the study of Michl (1999) stating that technological change is not always neutral. O'Neill and Matthews (2001) who study technological change in Irish dairy production show that technological change is input augmenting. In India, Murgai (2001) studies technical progress in relation to the Green Revolution. The conclusion that is reached by all the authors is, invariably, that if technological change is biased, then conventional total factor productivity growth is not a satisfactory measure of productivity growth and can lead to erroneous policy conclusions.

By using a frontier technique, Kalirajan et al. (1996) propose a method of decomposition of agricultural total factor productivity that has been applied in Chinese agriculture. The same technique is used in decomposing total factor productivity in Indian agriculture (Kalirajan et al. 2001; Kalirajan 2004). This is similar to an approach used by Sun (2004) and Kong et al. (1999) for decomposing total factor productivity growth into technological change and technical efficiency. The most differing points of view come from the production function and the stochastic model. Kalirajan et al. (1996; 2001), Kalirajan (2004) and Sun (2004) use varying coefficients of Cobb-Douglas frontiers, whereas Kong et al. (1999) use an error component translog production frontier.

However, a strong assumption still holds in those studies, that is, every producer is allocatively efficient. The methods have not accounted for returns to scale of production technology. Thus, the effect of allocative efficiency and scale effect resulting from input growth are missing. Bauer (1990) proposes an approach of decomposing total factor productivity which has theoretical and empirical advantages. In this approach, total factor productivity is decomposed into technological change, returns to scale and economic efficiency.

Empirically, this approach has been used to estimate total factor productivity in US airlines.

Technically, the approach of Bauer (1990) is superior to the approach of Kong et al. (1999) in terms of accuracy and consistency in decomposing total factor productivity. Kong et al. (1999) decompose total factor productivity with a time-continuous approach, but calculating the components with a time-discrete approach. The temporal pattern of technical efficiency that has been estimated using a technical inefficiency effect and the rate of technological change that has been formulated, are ignored. As a consequence of the inconsistency, one observation is lost. By using the same approach, Bauer (1990) decomposes total factor productivity into technological progress, economic efficiency and scale effect. The last term is not found in the model of Kong et al. (1999). In addition, the efficiency term estimated in Bauer's (1990) approach has also accounted for weakness of technical efficiency estimated in Kong et al. (1999) which assumes allocatively efficient producers.

In general, there is a big debate on whether total factor productivity is needed in determining the big discrepancies in economic growth across countries (Chen 1997) regardless of the procedure used. Fellipe and McCombie (2003) raise an argument that the use of a production function to estimate and interpret total factor productivity as a rate of technological progress is problematic. This is because the production function estimation is usually estimated with data in value terms, rather than physical quantities. The production function estimated with such data will generate coefficients which are exactly the same as factor shares if the production function takes a Cobb-Douglas technology form (Chen

1997). Consequently, there is no difference between growth accounting and econometric estimation.

In the agricultural sector, the most significant weakness of the previous studies is that environmental problems associated with the use of environmentally detrimental inputs have not been taken into account. Based on the review of previous studies, the present paper will clearly be different in some aspects. First, this study relaxes assumptions of which producers are not allocatively and technically efficient. Second, this study allows non-neutral technological change and non-constant returns to scale. Third, the data used in this study are in physical quantities. Last, this study analyses the impact of environmental problems by taking environmental costs into account.

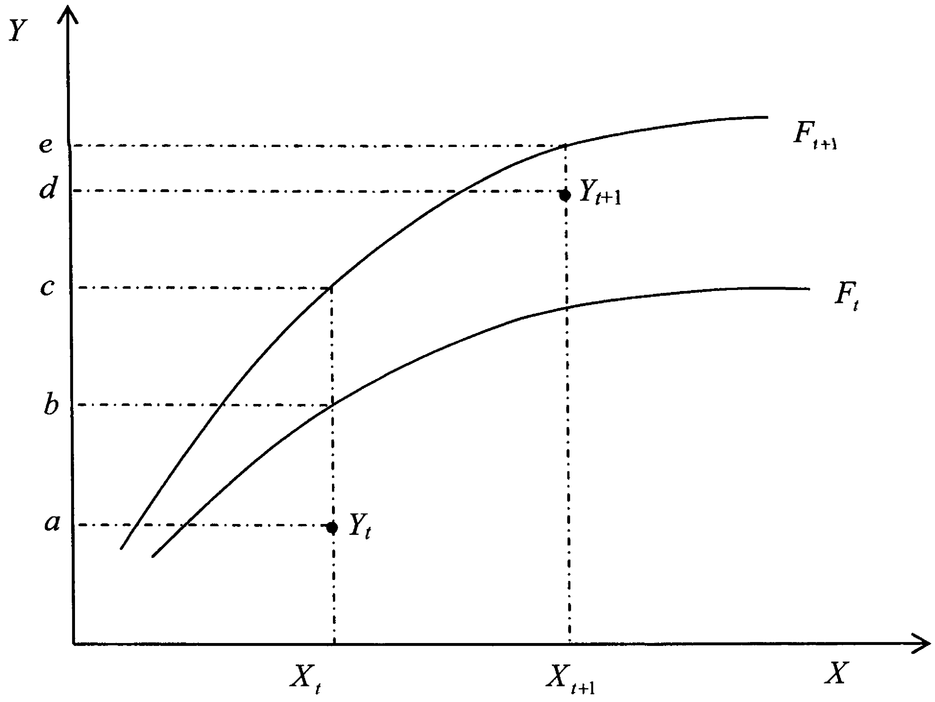
Theoretical Framework

Productivity refers to the rate at which production factors are transformed into output. Enhancement of productivity happens when more output results from given levels of inputs, or alternatively when the same level of output results from lower levels of inputs. Two approaches are usually used to measure productivity: partial productivity and total factor productivity. Partial productivity indices relate one or more outputs to a single input. There can be as many such measures as there are outputs and inputs. Total factor productivity indices relate aggregate output to a weighted sum of all inputs based on their relative importance in the production function (OECD 1995). Chen (1997) points out that the measurement of total factor productivity is crucially dependent on the specification of the relationship between inputs and output, the proper measurement of the factor inputs, and the weights assigned to the different categories of inputs in the aggregation of sub inputs. Total factor productivity can be estimated econometrically using primal and dual approaches. Estimation of stochastic frontiers with panel data is capable of decomposing productivity growth into technological change and technical efficiency (Greene 1993), and a primal method is more accurate in estimating efficiency, compared with a dual method (Thiam et al. 2001).

Productivity growth decomposition: diagrammatical approach

Following Kalirajan's (2004) approach of decomposition of total factor productivity, the general structure of the primal approach is illustrated in Figure 6.1, in which a single output is produced using a single input.

Figure 6.1. Decomposition of output growth



Let Y be a single output produced using a single input X with production technology F. At time *t*, the production frontier is F_t. The level of Y_t is produced using X_t, but the production is technically inefficient because the actual level of Y_t is below the production frontier. At time $t+1$, the production frontier moves upward from F_t to F_{t+1}. The level Y_{t+1} is produced using X_{t+1} with a new production frontier, but it is more technically efficient than before because the actual level of Y_{t+1} is closer to the production frontier. The increase in output from Y_t to Y_{t+1} represents output growth.

The rate of output growth is $Y_{t+1}-Y_t$. The output growth is decomposable as follows:

$$\begin{aligned}
\dot{Y} &= \left(Y_{t+1} - Y_t = d - a\right) = (b-a) + (c-b) + (d-c) \\
&= (b-a) + (c-b) + \left((e-c) - (e-d)\right) \\
&= \left((b-a) - (e-d)\right) + (c-b) + (e-c) \\
&= \mathit{\Delta} TE + TC + \dot{X} \qquad (6.1)
\end{aligned}$$

Total factor productivity growth, $T\dot{F}P$, is defined as output growth which is unexplained by input growth, thus $T\dot{F}P$ can be expressed as:

$$T\dot{F}P = \dot{Y} - \dot{X} = \mathit{\Delta} TE + TC \qquad (6.2)$$

It can be seen that when producers do not operate firms efficiently, total factor productivity growth is driven by change in technical efficiency and technological change.

In Kalirajan's decomposition, the producer is assumed to be allocatively efficient. Thus the technical efficiency actually represents economic efficiency in which allocative efficiency is equal to one (Sadoulet and de Janvry 1995). In agricultural countries, including Indonesia, agricultural practices are mostly driven by government agencies in terms of input distribution and technology (Tripp 2001). Producers use inputs as a technological package; and consequently allocative efficiency does not always exist. Economic efficiency needs to be broken down into technical efficiency and allocative efficiency.

Figure 6.2. Decomposition of output growth with inefficient producers

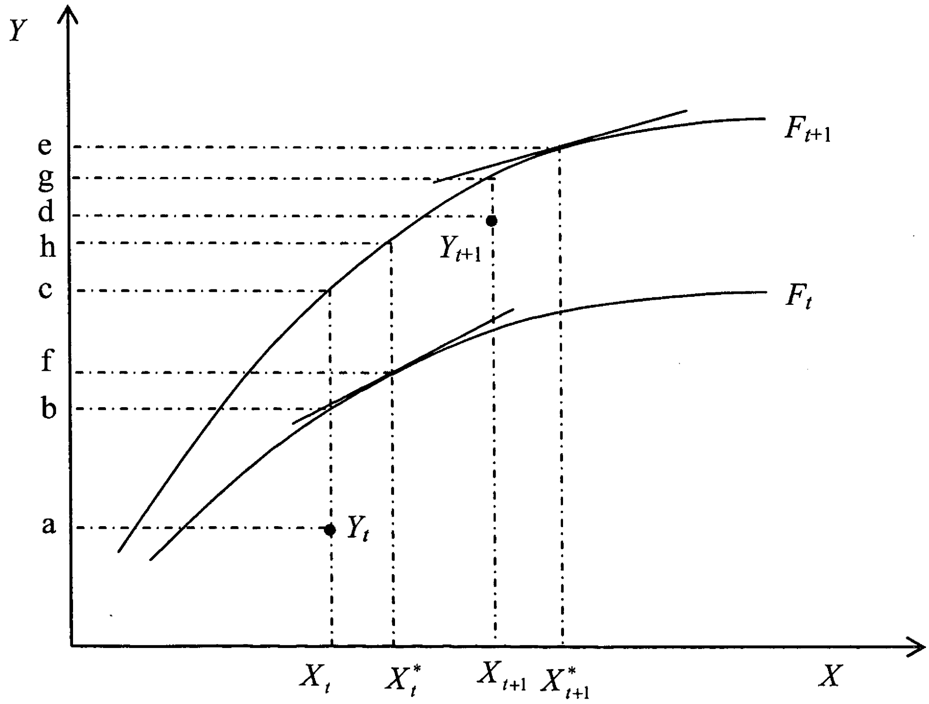


Figure 6.2 decomposes output growth of producers who have not been efficient, that is, the level of actual input use is still below the allocatively efficient level.[19] At time t, suppose the allocatively efficient level of input use is X_t^* where the marginal product of the input is equal to the relative price of the input. At time $t+1$, the allocatively efficient level is X_{t+1}^* where the marginal product of the input is equal to its relative price. The relative price at time t is not always the same as that at time t+1.

The output growth is decomposable as follows:

$$\dot{Y} = d - a = (b-a) + (f-b) + (c-f) + (h-c) + (d-h)$$

---

[19] It could be the case that either the producer has not been efficient or the producer is no longer efficient.

$$=(b-a)+(f-b)+(c-f)+(h-c)+(e-h)-((e-g)+(g-d))$$

$$=((b-a)-(g-d))+((f-b)-(e-g))+((c-f)+(h-c))+(e-h)$$

$$=\Delta TE+\Delta AE+TC^{*}+\dot{X}^{*} \qquad (6.3)$$

In this decomposition, deviation of technological change and input growth from the actual level of input use has been adjusted with allocative efficiency. If the production technology exhibits constant returns to scale, growth in inputs does not have any impact on total factor productivity. However, the condition of constant returns to scale is not always the case. Scale effects resulting from input growth need to be taken into account. As defined before, total factor productivity growth is output growth unexplained by input growth, and then total factor productivity growth is expressed as:

$$T\dot{F}P=\Delta TE+\Delta AE+TC^{*}+\Delta SE \qquad (6.4)$$

where ΔSE is change in scale effect. When the production technology exhibits constant, increasing or decreasing returns to scale, the effect will be zero, positive or negative respectively.

Productivity growth decomposition: mathematical approach

From the neoclassical growth proposed by Solow (1957), the growth of output is decomposed as:

$$\dot{Y}=\dot{A}+S_X\dot{X}+S_Z\dot{Z} \qquad (6.5)$$

where $\dot{Y}=\frac{1}{Y}\frac{dY}{dt}=\frac{d\ln Y}{dt}$ is output growth, $\dot{X}=\frac{1}{X}\frac{dX}{dt}=\frac{d\ln X}{dt}$ is growth of input X, $\dot{Z}=\frac{1}{Z}\frac{dZ}{dt}=\frac{d\ln Z}{dt}$ is growth of input Z, $S_X=\frac{W_X X}{W_X X+W_Z Z}$ is the observed share of input X expenditure, $S_Z = \frac{W_Z Z}{W_X X + W_Z Z}$ is the observed share of input Z expenditure, and W_X and W_Z are prices of input X and Z respectively. The rate of change in technology is represented by $\dot{A} = \frac{1}{A}\frac{\partial A}{\partial t}$. Total factor productivity growth can be defined as the growth in output which is unexplained by growth in inputs, that is:

$$T\dot{F}P = \dot{Y} - S_X \dot{X} - S_Z \dot{Z} = \dot{A} \qquad (6.6)$$

In this case, total factor productivity growth is the same as the rate of improvement in technology or technological progress. Chen (1997) points out that this decomposition of productivity growth is the same as the growth accounting approach because Solow (1957) makes assumptions of Hicks-neutral technological change and constant returns to scale production technology. Another assumption not accounted for is economic (technical and allocative) efficiency in producing outputs.

In other production technology, the weights S_X and S_Z will change over time. In calculating total factor productivity growth at different points in time, different weights must be used (Chen 1997). Following a primal method proposed by Kumbhakar and Lovell (2000), this study decomposes total factor productivity growth into technological change, changes in technical and allocative efficiency and scale effect. To decompose productivity growth, a stochastic production function is used. The deterministic production frontier with environmentally detrimental input X and conventional input Z, technology parameter vector β, time trend t as a proxy for technological change, and output-oriented technical inefficiency $u \geq 0$ is represented as:

$$Y_{it} = f(X_{it}, Z_{it}, t; \beta)\exp\{-u_{it}\} \tag{6.7}$$

Technical efficiency is expressed as $\varphi_{it} = \frac{Y_{it}}{f(X_{it}, Z_{it}; \beta)} = \exp\{-u_{it}\} \leq 1$, which allows it to vary over time. A primal measure of the rate of change in technical efficiency is given as:

$$\dot{\varphi} = \frac{\partial \varphi_{it}}{\partial t} = \frac{\ln \exp\{-u_{it}\}}{dt} \tag{6.8}$$

$\dot{\varphi}$ can be interpreted as the rate at which a producer shifts towards or away from the production frontier, keeping everything else constant. Taking the log and totally differentiating equation (6.7) and then differentiating with respect to t, yield:

$$\dot{Y} = \frac{\partial \ln f(\bullet)}{\partial t} + \frac{\partial f(\bullet)}{\partial X}\frac{X}{f(\bullet)}\frac{\partial \ln X}{dt}$$

$$+ \frac{\partial f(\bullet)}{\partial Z}\frac{Z}{f(\bullet)}\frac{\partial \ln Z}{dt} + \frac{\partial \ln \exp\{-u\}}{\partial t} \tag{6.9}$$

where $\dot{Y} = \frac{\partial \ln Y}{\partial t}$ is output growth, $f(\bullet) = f(X, Z, t; \beta)$ is the deterministic kernel of the stochastic production frontier, $\frac{\partial \ln f(\bullet)}{\partial t} = \dot{A}$ is the rate of technological change, $\frac{\partial \ln X}{dt} = \dot{X}$ is the growth rate of input X, $\frac{\partial \ln Z}{dt} = \dot{Z}$ is the growth rate of input Z, $\frac{\partial f(\bullet)}{\partial X}\frac{X}{f(\bullet)} = \theta_X$ is output elasticity with respect to input X, $\frac{\partial f(\bullet)}{\partial Z}\frac{Z}{f(\bullet)} = \theta_Z$ is output elasticity with respect to input Z, $\frac{\partial \ln \exp\{-u\}}{dt} = -\frac{\partial u}{\partial t} = \dot{\varphi}$ is the rate of change in technical efficiency. Substituting the expression for $\dot{Y}$ into equation (6.6) yields:

$$
\begin{aligned}
T\dot{F}P &= \dot{A} + (\theta_X - S_X)\dot{X} + (\theta_Z - S_Z)\dot{Z} + \dot{\varphi} \\
&= \Delta TC + (\theta - 1)\left(\frac{\theta_X}{\theta}\dot{X} + \frac{\theta_Z}{\theta}\dot{Z}\right) \\
&\quad + \left(\frac{\theta_X}{\theta} - S_X\right)\dot{X} + \left(\frac{\theta_Z}{\theta} - S_Z\right)\dot{Z} + \dot{\varphi} \qquad (6.10)
\end{aligned}
$$

where $\theta = \theta_X + \theta_Z$ is the scale elasticity that provides a primal measure of returns to scale of the production frontier. The notation of $\frac{\theta_X}{\theta}$ and $\frac{\theta_Z}{\theta}$ can be called normalised output elasticity with respect to input X and Z respectively. The reason is that the sum of the normalised output elasticity with respect to both inputs will be exactly equal to unity for any returns to scale production technology. The effect of returns to scale is represented by notation of $(\theta - 1)$, which will be positive, negative, or zero if the production technology exhibits increasing, decreasing or constant returns to scale respectively. It is also reasonable to say that allocative efficiency of input use will be reached if normalised output elasticity with respect to all inputs is equal to the share in cost of the respective inputs. This is equivalent to a condition where $MRTS$ is equal to the price ratio of inputs.

This decomposition of total factor productivity is able to break down economic efficiency, as proposed by Bauer (1990), into allocative and technical efficiency. It can be seen in equation (6.10) that total factor productivity growth is decomposed into the technological change component, the scale component, the allocative efficiency component, and the technical efficiency component. If there is no technological change or change in the production frontier over time, the component of technological change will be zero. If technical efficiency is time-invariant, the decomposition implies that change in technical efficiency has no effect on total factor productivity. If the production technology has constant returns to scale over time, the scale effect is zero. Allocative inefficiency is represented by the deviations in normalised output elasticity and share of input cost. When all the gaps are zero, the uses of all the inputs are allocatively efficient, and there is no effect on total factor productivity growth. Lastly, if there is zero growth in inputs, the scale and allocative efficiency component will be zero, the growth in total factor productivity is only driven by technological change and technical efficiency. Therefore, if farms are always allocatively and technically efficient and the production technology has constant returns to scale, the total factor productivity growth is equal to the rate of improvement in technology or technological change.

Environmentally adjusted productivity growth

Chemical inputs have been known to be environmentally detrimental. Using chemical inputs where producers are technically inefficient will discharge extra pollution, leading to environmental cost. Growth of total factor productivity here has not taken the environmental cost into account. Pretty and Waibel (2005) point out that the environmental costs associated with agrochemicals should be internalised into production costs. El-Serafy (1989) suggests that environmental cost needs to be taken into growth accounting to obtain clean growth or, in environmental jargon, “green” growth. The environmental cost should be internalised into estimation of productivity growth to obtain the green growth. In the case of total productivity growth derived from economic production analysis in which economic inefficiency matters, internalising environmental cost needs an appropriate technique. When environmental cost is considered as a production cost in analysis of economic production, it should be included in the cost of the detrimental input. Internalising environmental cost into the cost of inputs will raise the production cost of inputs. The increase in production cost will influence allocative efficiency. After taking environmental costs into account, the outcome is considered as social efficiency (Grafton et al. 2004; Pearce and Turner 1990; Tietenberg 1998).

The decomposition of total factor productivity above, so far, has not taken into account the environmental cost associated with inefficiency in using environmentally detrimental inputs. The environmental cost should be included in the cost of respective inputs. If this is the case, the component of allocative efficiency in the decomposition of total factor productivity will change, because of changes in the share of input expenditure. The share of expenditure for input X will be $\hat{S}_X = \frac{W_X X + EC}{W_X X + EC + W_Z Z} > S_X$ and the share of expenditure for input Z will be $\hat{S}_Z = \frac{W_Z Z}{W_X X + EC + W_Z Z} < S_Z$

where EC is the environmental cost associated with inefficiency of environmentally detrimental input use. Consequently, the decomposition of environmentally adjusted total factor productivity will be:

$$T\dot{F}P_E = \Delta TC + (\theta - 1)\left(\frac{\theta_X}{\theta}\dot{X} + \frac{\theta_Z}{\theta}\dot{Z}\right)$$

$$+\left(\frac{\theta_X}{\theta} - \hat{S}_X\right)\dot{X} + \left(\frac{\theta_Z}{\theta} - \hat{S}_Z\right)\dot{Z} + \dot{\varphi} \qquad (6.11)$$

where $T\dot{F}P_E$ represents environmentally adjusted total factor productivity growth.

Internalising environmental cost therefore, could have either a positive or a negative effect, depending on the current position of allocative efficiency. For example, if production has not been allocatively efficient, internalising the environmental cost could possibly make production more allocatively efficient, and consequently enhance total factor productivity growth. Conversely, if either the production is no longer allocatively efficient or it is allocatively inefficient, internalising the environmental cost will reduce allocative efficiency, and consequently decrease total factor productivity growth. If the use of environmentally detrimental inputs grows faster than the conventional inputs, the impact of internalising the environmental cost into the cost of environmentally detrimental inputs diminishes the rate of total factor productivity growth, holding everything constant, and vice versa. This means that the increase in rate of use of environmentally detrimental inputs slows down the productivity growth. In this case, the non-point source pollution has a negative impact on productivity growth when the environmental cost is taken into account. Therefore the difference between total factor productivity growth with and without internalisation of environmental cost can be considered the rate of reduction of agricultural productivity associated with the amount of non-point source pollution.

Furthermore, it can be seen from the decomposition of total factor productivity growth that the increase in technical efficiency will have direct and indirect impacts on total factor productivity growth. The direct impact is observable, while the indirect impact comes from a decrease in environmental cost, because an increase in technical efficiency leads to an increase in environmental efficiency.

Methodology

By now, the fashionable functional form of a production function in estimating total factor productivity is the transcendental logarithmic (translog) production technology (Chen 1997). The full translog production technologies captures more accurate estimates and more precise technical efficiency, which will be subsequently used for calculating decomposition of productivity growth of rice production.

Given the estimated parameters in the production function, the rate of technological change is defined as the percentage change in output due to an increment of time in which all inputs are held constant, that is:

$$\Delta TC = {\partial \ln Y_{it}}/{\partial t} = \sum_{k=1}^{5} \beta_{kt} \ln X_{kit} + \beta_t + 2\beta_{tt} t \tag{6.12}$$

The rate of technological change consists of two components. First, biased technological change shown by $\sum_{k=1}^{5} \beta_{kt} \ln X_{kit}$; and second, pure technological change shown by $+\beta_t + 2\beta_{tt} t$. The biased technological change is producer specific, and, in contrast the pure technological change will be constant, increasing or decreasing at a constant rate, according to whether β_{tt} is zero, positive or negative respectively.

Following Cornwell et al. (1990) the temporal pattern of technical efficiency is modelled as a quadratic function of time, that is:

$$\varphi_{it} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 \tag{6.13}$$

The rate of change in technical efficiency is:

$$\dot{\varphi} = \frac{\partial \varphi_{it}}{dt} = \alpha_1 + 2\alpha_2 t \tag{6.14}$$

Input growth is considered to vary over time. The rate of growth of input is estimated using the expression:

$$X_{kit} = a_0 e^{(r_1 + r_2 t)t} \tag{6.15}$$

where a_0 is a proxy for initial level of X, $r_1 + r_2 t$ represents non-constant rate of input growth. Taking logarithm of both right and left hand sides gives log linear expressions:

$$\ln X_{it} = \ln a_0 + r_1 t + r_2 t^2 \tag{6.16}$$

and this can be easily estimated using OLS. The rate of input growth is obtained as:

$$\frac{\partial \ln X_{it}}{\partial t} = r_1 + 2r_2 t \tag{6.17}$$

Environmental cost associated with the use of environmentally detrimental inputs is estimated using an effect on production approach (Garrod and Willis 1999), that is the value of output that must be given up to minimise pollution or chemical waste.[20]

Results and Discussion

From the estimated frontier production technology, the four components of total factor productivity are calculated.[21] The first component is technological change, which consists of non-neutral and pure effects. The second component is rate of change in technical efficiency. Both components are described in Table 6.7. The next two components are: scale effects, which involve output elasticity with respect to each input and input growth of respective input; and

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[20] Estimation and discussions on environmental efficiency and environmental cost associated with agrochemical use are given in Chapter 5.

[21] The estimated production function and its discussion are given in Chapter 4.

allocative efficiency, which involves share in input costs without environmental cost and with environmental cost.[22]

The estimated translog production technology shows that γ is highly significant. This means that there is significant deviation of actual output to potential output which is brought about by technical inefficiency. In other words, the average translog production technology is significantly less than the frontier.

Technological change relates to time trend in the frontier production technology. A joint test for neutral technological change and pure technological change is rejected. This indicates that there are movements in production frontiers across time, representing technological change. The temporal pattern of estimated technical efficiency is represented as:

$$\varphi_{it} = 0.6177 + 0.0438 \cdot t - 0.0054 \cdot t^2 \qquad (6.18)$$

The joint test for time-invariant technical efficiency shows that $F^2_{356} = 3.85$; and it rejects at 5 per cent significance, meaning that technical efficiency is not time-invariant. Technical efficiency increases at a decreasing rate. The rate of change in technical efficiency is estimated as:

$$\dot{\varphi}_{it} = \frac{\partial \varphi_{it}}{\partial T} = 0.0438 - 0.0109 \cdot t \qquad (6.19)$$

The rate of change in technical efficiency and technological change in each year is given in Table 6.1.

The rate of change in technical efficiency in 1994, 1999 and 2004, was 0.0329, 0.0220 and 0.0111 respectively. The rate of change in non-neutral technological

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[22] Environmental cost is based on the effect of chemical input discharged into the environment calculated using formulas obtained from the estimation of environmental efficiency (Gang and Felmingham 2004). The discussion is given in Chapter 5.

change is positive but increasing, meaning that, technological change is, in total, input augmenting. The implication is that technological change leads to increases in input use. The rate of change in pure technological change is positive and increasing.[23] This indicates that given the same level of input use, rice production increases over time. This implies technological progress in Indonesian rice agriculture during the periods of 1994, 1999 and 2004. In total, technological change is positive and increasing. The impressive growth in technological change is an indication that farmers have adopted better technology in rice production, and this explains why the rate of change in technical efficiency is low.[24] The technological change that account for innovation and diffusion of agricultural technology can provide a significant multiplier effect on other sectors (Khan and Thorbecke 1988).

Table 6.1. Rate of change in technical efficiency and technological change

Year	Technical efficiency	Technological change		
		Biased	Pure	Total
1994	0.0329	0.397759	0.5910	0.988759
1999	0.0220	0.418854	1.1820	1.600854
2004	0.0111	0.437663	1.7730	2.210663

Source: Author's analysis

Scale effect and allocative efficiency relate to output elasticity with respect to each input. The output elasticity derived from translog production technology is not constant and dependent on the level of each input use. The output elasticity, which is calculated at the average level of each input use, is shown in Table 6.2. Together with input growth, the average output elasticity in each year will

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[23] A high rate of technological progress with a similar pattern of technological change has been shown by Villano and Fleming (2006) for rice agriculture in the Philippines.

[24] Jansen and Ruiz de Londono (1994) mention that technological progress represents movements in both average and frontier production function. In this case, farmers can operate farms closer to the frontier production, which is increasing over time.

be used to calculate scale effect and allocative effect. Input growth is estimated using regression of the logged input on quadratic time trends. The result of the regression is given in Table 6.3.

Table 6.2. Output elasticity with respect to each input

Inputs	Year			Total
	1994	1999	2004	
Land	0.7207	0.6969	0.7432	0.7166
Capital	0.0343	0.0487	0.0315	0.0443
Labour	0.0000	0.0000	0.0000	0.0000
Material	0.1043	0.1028	0.1229	0.1077
Chemicals	0.0013	0.0884	0.1920	0.0923
Scale elasticity	0.8605	0.9368	1.0896	0.9608

Note: the output elasticity is evaluated at the average of all (ln) input use in 1994, 1999, 2004 and total.
Source: Author's calculation

Table 6.3. Regression of input (in logarithmic form) on time trend

Dep. Var.		Constant	t	t^2	
$\ln Land$	Coef.	-0.9473	-0.0899	0.0649	F=7.39[a]
	t-ratio	-4.03[a]	-0.33	0.93	R^2=0.02
$\ln Capital$	Coef.	-10.6166	6.6654	-2.4319	F=45.66[a]
	t-ratio	-5.97[a]	3.21[a]	-4.59[a]	R^2=0.10
$\ln Labour$	Coef.	1.3770	2.6447	-0.6430	F=54.16[a]
	t-ratio	6.17[a]	10.16[a]	-9.68[a]	R^2=0.12
$\ln Material$	Coef.	8.6592	1.4895	-0.2854	F=16.37[a]
	t-ratio	21.51[a]	3.17[a]	-2.38[a]	R^2=0.04
$\ln Chemicals$	Coef.	7.2044	-1.6099	0.6750	F=11.22[a]
	t-ratio	5.79[a]	-1.11	1.82[c]	R^2=0.03

Note: [a]) significant at 5%, [c]) significant at 10%
Source: Author's estimation

As mentioned above, input growth is expected not to be constant over time. All regressions are highly significant in overall tests, despite the fact that some coefficients are individually insignificant. This is because the time series trend is only three, and unbalanced. This condition leads to a strong correlation between linear and quadratic trends, resulting in a multicollinearity problem. Wooldridge (2003) states that severe multicollinearity brings about individual effects that tend to be insignificant since the standard error of the coefficient is very high. Since the joint tests show high significance, the coefficient is then used to calculate the rate of input growth in each year. The rate of input growth of each input is given in Table 6.4.

Table 6.4. Rate of input growth (five-yearly)

Inputs	Year			Average
	1994	1999	2004	
Land	0.0400	0.1699	0.2998	0.1699
Capital	1.8015	-3.0623	-7.9262	-3.0623
Labour	1.3587	0.0727	-1.2133	0.0727
Material	0.9186	0.3477	-0.2231	0.3477
Chemicals	-0.2599	1.0900	2.4400	1.0900

Source: Author's estimation

On average, inputs grow, except capital which decreases at 306 per cent during the period. Capital consisting of tractors and animals, dropped sharply because the economic crisis in 1997/1998. Agricultural machinery becomes more significantly expensive after the crisis. The highest rate of positive growth is agrochemicals, more than 100 per cent during the same period. In 1994, the rate of growth of all inputs was positive, except agrochemicals which declined at the rate of 26 per cent. The highest rate of growth was capital at 180 per cent. However, in the next period, the rate of capital growth drastically felt. On the other hand, agrochemicals dropped in 1994, while the rate of growth in 1999 and 2004 rose considerably. Labour and material inputs have the same pattern, initially high rates of growth, and then the rate falls in the next two periods, and becomes negative in 2004. The rate of land growth is continually positive and increasing over time.

The rate of input growth will contribute to scale effects and allocative efficiency effects. Scale effects are determined in three components: input growth, as it has been previously discussed; returns to scale, the sum of output elasticity with respect to all inputs; normalised elasticity, the ratio of output elasticity with respect to each input to the sum of output elasticity with respect to all inputs. As shown in Table 6.2, the translog production technology of rice agriculture exhibits decreasing returns to scale in 1994 and 1999, and increasing returns to scale in 2004. Overall, however, the production technology exhibits decreasing returns to scale.[25] The normalised elasticity resulting from output elasticity with respect to each input is given in Table 6.5.

Table 6.5. Normalised output elasticity

Inputs	θ_i/θ		
	1994	1999	2004
Land	0.8375	0.7439	0.6821
Capital	0.0399	0.0520	0.0289
Labour	0.0000	0.0000	0.0000
Material	0.1212	0.1097	0.1128
Chemicals	0.0015	0.0944	0.1762

Source: Author's analysis

The normalised output elasticity of each input has a similar pattern to the output elasticity. The important difference between normalised elasticity and output elasticity is that the sum of normalised elasticity is exactly equal to unity. The scale effect is given in Table 6.6. The scale effect in the first two points in time is negative. This is because there is decreasing returns to scale in those periods. In contrast, the scale effect is positive in the last point in time, because of increasing returns to scale.

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[25] A formal test for returns to scale has been done in Chapter 4. The test shows that the translog production function of rice agriculture does not exhibit constant returns to scale.

Table 6.6. Rate of change in scale effect and its components (five-yearly)

Inputs	$\frac{\theta_i}{\theta}\dot{X}_i$		
	1994	1999	2004
Land	0.033501	0.126391	0.204489
Capital	0.071809	-0.1592	-0.22914
Labour	0	0	0
Material	0.111342	0.038155	-0.02516
Chemicals	-0.00039	0.102857	0.429956
$\sum_i \frac{\theta_i}{\theta}\dot{X}_i$	0.21626	0.108208	0.380137
$(\theta-1)$	-0.1395	-0.0632	0.0896
$(\theta - 1)\sum_i \frac{\theta_i}{\theta}\dot{X}_i$	-0.03017	-0.00684	0.03406

Source: Author's analysis

The last component of total factor productivity growth is the allocative efficiency effect, which constitutes the gap between the normalised output elasticity and share in input cost. In this analysis, share in input cost is sorted into private cost and social costs. The private cost of input is the cost for which environmental cost associated with environmentally detrimental inputs is not taken into account. Conversely, the social cost of input is the cost for which environmental cost is internalised as input cost. Since the environmental cost is a negative externality, the social cost will be greater than the private cost. The share in both private and social costs is given in Table 6.7.

Let us first describe the share in private costs. Generally, labour and agrochemicals have a higher share in cost of production. In small-scale rice agriculture, this condition is reasonable. Small-scale rice agriculture is usually labour and chemical intensive. Chemicals are used to increase productivity of land, and labour is more suitable than tractors. This corresponds to the low share in cost of capital which is a less suitable input in small-scale rice agriculture. Land has the smallest share in cost, because most farmers studied here operate rice agriculture on their privately owned land. The cost related to land is land tax, which is relatively low in rural areas. The shares of land, labour and capital costs tend to increase, whereas the shares of agrochemicals and materials tend to decease. The dynamics of shares of cost is dependent on the price of inputs, and the level of use of these inputs.

Table 6.7. Share in cost of input use

	$S_X = \frac{W_X X}{W_X X + W_Z Z}$			$\hat{S}_X = \frac{W_X X + EC}{W_X X + EC + W_Z Z_X}$ and $\hat{S}_Z = \frac{W_Z Z}{W_X X + EC + W_Z Z}$		
	1994	1999	2004	1994	1999	2004
Land	0.0439	0.0121	0.1230	0.0439	0.0120	0.0901
Capital	0.0604	0.1049	0.2030	0.0604	0.1046	0.1660
Labour	0.2603	0.4669	0.4047	0.2602	0.4655	0.3175
Material	0.2799	0.2173	0.1237	0.2798	0.2156	0.0904
Chemicals	0.3555	0.1988	0.1456	0.3557	0.2023	0.3360

Source: Author's analysis

With respect to share of social cost, it is theoretically expected that the share of chemical cost increases and the share of other input cost decreases. This is because the environmental cost associated with agrochemicals, which is considered to be environmentally detrimental, is internalised into the cost of chemical inputs. In the first two points in time, the impact of internalisation of environmental cost is very low. But, in the last point in time, there is considerable change in those shares. This is an indication that in the last point in time, the environmental cost associated with chemical input is significant.

With positive rate of growth in inputs, allocative efficiency effect will be positive, negative or zero if the gap resulting from normalised output elasticity with respect to each input minus the share in cost of the corresponding input is positive, negative or zero respectively. The gap between normalised output elasticity with respect to each input is shown in Table 6.8.

Table 6.8. Average gap between normalised output elasticity and share of input cost

	Private: $\frac{\theta_X}{\theta} - S_X$			Social $\frac{\theta_X}{\theta} - \hat{S}_X$		
	1994	1999	2004	1994	1999	2004
Land	0.7936	0.7318	0.5591	0.7937	0.7319	0.5920
Capital	-0.0205	-0.0529	-0.1741	-0.0205	-0.0526	-0.1371
Labour	-0.2603	-0.4669	-0.4047	-0.2602	-0.4655	-0.3175
Material	-0.1587	-0.1075	-0.0109	-0.1586	-0.1059	0.0224
Chemicals	-0.3540	-0.1045	0.0306	-0.3542	-0.1079	-0.1598
$\sum\lvert\bullet\rvert$	1.5871	1.4636	1.1794	1.5872	1.4638	1.2288

Source: Author's analysis

As has been discussed in Chapter 5, allocative and social efficiencies are not the case here, and therefore allocative and social efficiency effects will affect the total factor productivity growth. Land has a positive gap, meaning that the use of land is low compared with other inputs. The gap decreases over time due to the increase in land tax. Capital, labour and materials have a negative gap. This means that the use of these inputs is economically excessive relative to land use. The negative gap for capital increases, whereas the negative gap for materials decreases over time and the gap for labour fluctuates. Chemicals have a negative gap in 1994 and become positive in the next two periods. After internalisation of the environmental cost associated with inefficient use of agrochemicals, the gaps change slightly. As expected, the gaps for land, capital, labour and materials increase because the shares of cost of these inputs fall. In contrast the gap for agrochemicals increases since the share of cost of chemical inputs becomes higher after internalisation of the environmental cost.

We can see that there is improvement in overall allocative efficiency as well as social efficiency. After internalisation of the environmental cost associated with inefficient use of agrochemicals, the gaps change slightly. As expected, the gap for land, capital, labour and material increase because the shares of cost of these inputs fall. In contrast the gap for agrochemicals increases since the share of cost of chemical inputs becomes higher after internalisation of the environmental cost. The gaps will have total impacts on the total factor productivity growth if there is variation in input growth. As shown in Table 6.4, there is variation in input growth. The total allocative and social efficiency effects are given in Table 6.9.

Table 6.9. Average rate of change in allocative efficiency effect (five-yearly)

	Private: $\left(\frac{\theta_X}{\theta} - S_X\right)\dot{X}$			Social: $\left(\frac{\theta_X}{\theta} - \hat{S}_X\right)\dot{X}$		
	1994	1999	2004	1994	1999	2004
Land	0.0317	0.1243	0.1676	0.0317	0.1244	0.1775
Capital	-0.0370	0.1620	1.3797	-0.0370	0.1611	1.0867
Labour	-0.3537	-0.0339	0.4910	-0.3536	-0.0338	0.3852
Material	-0.1458	-0.0374	0.0024	-0.1457	-0.0368	-0.0050
Chemicals	0.0920	-0.1139	0.0746	0.0921	-0.1177	-0.3899
Total	-0.4127	0.1011	2.1154	-0.4124	0.0972	1.2545

Source: Author's analysis

Land and capital have positive allocative efficiency effects. This is because the gap for land is positive and land use grows positively. In 1994, capital has a negative allocative efficiency effect, after which the effect increases considerably. The considerable increase in allocative efficiency effect is due mostly to drastic falls in capital growth. Since the use of capital is no longer allocatively efficient, the negative growth causes allocative efficiency to rise. For the case of labour and materials, the allocative efficiency effects are negative in the first two points in time, but the effects increase. In 2004, the rate of labour and material growth was negative and at the same time there was an increase in cost of labour and materials resulting in decrease in allocative efficiency. For the case of labour, the increase was relatively high because the fall in labour growth was very high. For the case of agrochemicals, the effect of allocative efficiency was positive and increasing. In 1994, agrochemicals decreased and the gap was negative. In the next two points in time, both growth and gap were positive. The total effect is positive.

The allocative and social efficiency effects are considerable. The effects increase over time starting from a negative value. This indicates that there is improvement in allocative efficiency as well as social efficiency effects, particularly after the economic crisis in 1997/1998. The allocation of inputs is much more efficient after the crisis. Farmers become more conscious if some inputs are incorrectly allocated. They will adjust the use of inputs based on the productivity of such inputs.

Internalising environmental cost into cost of chemical input reduces the total impact. In 1994 and 1999 the decrease was quite small, but in 2004 there was a dramatic decrease in total impact of allocative efficiency, which dropped from 4.3712 to 3.5103. The sharp decrease resulting from the internalisation indicates very high environmental costs.

Table 6.10 shows the total factor productivity growth, which stems from growth in technological change, scale effect, allocative efficiency and technical efficiency. In absolute value, the total factor productivity growth is high, particularly for 2004. The largest contributor to total factor productivity growth is technological change, followed by the allocative efficiency effect, which comes from allocative efficiency and growth of inputs. With respect to the considerable magnitude of total factor productivity growth, it could be acceptable for the following logical reason. The time interval is five years, which is relatively long. If the total factor productivity growth is taken in yearly accounting, the growth becomes 0.1157, 0.3434 and 0.8742 for 1994, 1999 and 2004 respectively.

Table 6.10. Source of total factor productivity growth of rice agriculture (five-yearly)

Component	Without environmental cost			Environmentally adjusted		
	1994	1999	2004	1994	1999	2004
TC	0.9888	1.6009	2.2107	0.9888	1.6009	2.2107
Scale	-0.0302	-0.0068	0.0341	-0.0302	-0.0068	0.0341
AE	-0.4127	0.1011	2.1154	-0.4124	0.0972	1.2545
TE	0.0329	0.0220	0.0111	0.0329	0.0220	0.0111
TFP	0.5787	1.7171	4.3712	0.5791	1.7132	3.5103

Note: TC: technological change; Scale: returns to scale; AE: allocative efficiency; TE technical efficiency; TFP: total factor productivity

Source: Author's analysis

Based on this finding, technological change and allocative efficiency effects are the significant components of total factor productivity growth. In the previous studies on productivity growth using stochastic production technology which do not account for allocative efficiency effects, the estimates of total factor productivity growth are misleading. It could be an underestimation or overestimation, which is dependent on the level of allocative efficiency and input growth. Thus, in the previous studies, those effects are still unexplained.

This study shows impressive growth in total factor productivity. Slow growth in 1994 was due to ignorance of the agricultural sector at the time (Mellor et al. 2003). Since the economic crisis, the sector has become more central because of the fact that it is the only sector able to grow in the economic crisis. After that, the sector has had much more attention from the government, resulting in high growth in total factor productivity.

Productivity growth changes after internalisation of environmental cost into the cost of chemical inputs. The effect of internalisation of environmental cost is to increase total factor productivity growth for 1994. The positive impact of internalisation is due to an average improvement in allocative efficiency of input uses. In contrast, the effect of internalisation of environmental cost is to decrease total factor productivity growth for 1999 and 2004. The negative impact of internalisation is due to an average decrease in allocative efficiency of input uses. In 1994 and 1999 the change in total factor productivity growth resulting from internalisation of environmental cost was small, but in 2004 the change was very high. Overall, the impact of internalisation of environmental cost into the cost of inputs is to decrease total factor productivity growth.

It seems that the statement of Kalirajan et al. (2001) — growth in productivity of agricultural production in some developing countries is decreasing due partly to environmental degradation — is in line with this outcome. This is supported by Toruel and Koruda (2004) who highlight that technological change in Asian agriculture was exceptional, when the Green Revolution began, but has decreased sharply since. In the era of the Green Revolution, the use of agrochemicals is excessive and tends to be inefficient (Pimentel et al. 1993). For the case of Indonesian rice agriculture, the main cause of excessive use of agrochemicals is government subsidy (Conway and Barbier 1988; Barbier 1989). The excessive use of agrochemicals leads to environmental degradation, particularly land degradation, resulting in falls in soil fertility and, eventually, decreases in productivity of agriculture.

The total factor productivity growth after internalisation of environmental cost can be considered as the environmentally adjusted growth of total factor productivity. This measure is to some extent important because of current concerns of the global community regarding environmental protection. If the target of agricultural policy is to increase the environmentally adjusted growth, it will not jeopardise environmental quality much, particularly in the agricultural sector. The environmentally adjusted growth of total factor productivity can be enhanced by improving the rate of change in technical efficiency, technological change, scale effect and allocative efficiency effect.

The rate of change in technical efficiency is very small, and therefore it is realistic to increase this component. Enhancing technological change will be effective if the appropriate new technology is available, and the existing technology has been fully adopted by all farm operators. In other words, rice agriculture has been technically efficient. In fact, the rice agriculture has not been technically efficient. Shapiro (1983) and Belbase and Grabowski (1985) suggest that efforts to improve technical efficiency may be more cost effective than introducing new technologies as a means of increasing agricultural productivity. The effort to enhance technical efficiency has direct and indirect impacts on the environmentally adjusted total factor productivity growth. The direct impact is clear, that is, increases in technical efficiency will directly improve total factor productivity. The indirect impact is to increase total factor productivity through the decrease in environmental cost. When environmental cost falls, the share in cost of agrochemicals will increase and the share in cost of other inputs will decrease. The changes in shares then influence the (socially) allocative efficiency effect.

The case of scale effect, which also varies, needs careful policy formulation. Given the parameters of rice production technology, the scale effect can be improved by reducing or increasing the use of inputs. Referring to the increasing returns to scale of production technology in 2004, it is reasonable to increase the use of land, labour and chemical inputs which have positive normalised elasticity, and to reduce the use of capital and material inputs which have negative normalised elasticity.

However, the increase in use of inputs also influences socially allocative efficiency. For 2004, the increase in land use leads to increased social efficiency, but the increases in other inputs lead to decreased social efficiency. It is therefore, the increase in land use which will improve scale and social and allocative efficiency effects. The increases in both effects can also be achieved by reducing capital and material inputs. The increases in labour and chemical inputs will lead to opposite impacts on scale and social efficiency effects. The policy that is able to provide greatest net positive impact is preferable.

Conclusion

Indonesian rice agriculture needs to grow in order to be capable of keeping pace with the rising need for food of the national population. Increases in agricultural productivity are still important because they have a number of substantial effects on economic development and rural poverty alleviation. It is clear that productivity measures provide a key indicator of the performance of a country's agricultural sector, which has long been recognised, and now there exists a vast amount of literature on agricultural productivity measurement.

Enhancing productivity does not mean jeopardising environmental quality, however, and formulating sustainable agricultural productivity growth is crucial, since agricultural growth in developing countries shows a discernible decline.

This indicates that productivity increase resulting from the Green Revolution has not been sustained. Two possible main reasons are no major breakthroughs in developing agricultural technology, and a decline in the quality of the environment and land. This decline is most likely due to excessive use of chemical inputs. In other words, lack of technological progress and deterioration in productive resources are crucial factors that slow agricultural growth. Thus analyses on productivity growth are needed to recognise the sources of productivity and the impact of taking environmental problems into account. The environmental problem is associated with the inefficient use of environmentally detrimental inputs.

Using an approach of total factor productivity growth, which is decomposed into technological change, technical efficiency, scale effect and allocative efficiency effect, the total factor productivity growth of rice agriculture is determined. Environmental cost, associated with the inefficient use of agrochemicals is then taken into account. Without taking environmental cost into account, the rate of growth in total factor productivity is low in 1994, but quite high in 1999 and 2004. Mostly, the rate of growth in total factor productivity is driven by an impressive rate of growth in technological change, followed by improvement in allocative efficiency effect. The high productivity growths in 1999 and 2004 were due to recovery from the economic crisis. Farmers have adopted better techniques and the uses of all inputs are much more allocatively efficient. Farmers have better allocated inputs.

After taking the environmental cost into account, the rate of growth in total factor productivity, overall, decreases. This is called environmentally adjusted total factor productivity growth. The growth is less than usual because the shares in costs of all inputs change and, consequently, allocative efficiency effects change as well. A high change in the allocative efficiency effect occurs in 2004, and this change reduces the rate of growth in total factor productivity by around 40 per cent. This is an indication of which environmental cost associated with the use of chemical inputs is significant.

Agricultural policy needs to improve environmentally adjusted productivity growth because such action will not seriously jeopardise environmental quality. The improvement of technical efficiency is the most suitable option because it impacts in two ways: directly adding to total factor productivity and indirectly impacting through reducing environmental cost given the technology of rice production. Another policy that can improve productivity growth is to increase cultivated land area, improving scale and social efficiency effects. Reducing the use of capital and material inputs has the same effect as increasing the area of land used for rice production.

Chapter 7

Policy Implications and Research Direction

Policy Implications

It is noteworthy that shifting from chemical intensive to more environmentally sound practices could reduce the intensity of chemical use. Promoting environmentally sound practices need more incentive since the current practices of rice production still indicate chemical intensive technological change.

Since rice agriculture is still technically inefficient, there is enough room for improvement in the productivity of rice farms, given the state of the art in agricultural technology. Increasing the scale of farms is capable of enhancing efficiency, as well as improving human capital, use of tractors on large farms and reducing exchange and voluntary labour. But this is not feasible in Java because of limited amounts of land and small farm size. Outside Java it is more likely, but the fertility and suitability of land for rice needs consideration.

Along with the growing concern for sustainable development, it is recommended that the policy should address improving social efficiency instead of allocative efficiency. Given fixed prices of all resource, land expansion is the most appropriate measure to improve the proportions in resource allocation. Since land is scarce, reducing use of other inputs is a way of improving allocative efficiency. Labour is excessively used, and the reduction of paid labour can save costs. However, reducing paid labour has a trade-off in technical efficiency. The best way to improve labour allocation is to reduce family labour devoted to rice farming in favour of non-farm sector employment. Improving allocative and social efficiencies means improvement in profitability leading to increase in rice income.

Agricultural policy needs to improve environmentally adjusted productivity growth because such action is expected not to reduce environmental quality. The improvement of technical efficiency is the most suitable option because this impacts in two ways: directly adding to total factor productivity and indirectly impacting through reducing environmental costs for given technology in rice agriculture. Another policy that can improve productivity growth is to increase land use so to as improve scale and social efficiency effects. Reducing use of capital and material inputs has the same effect as increasing land use.

Contributions of Study

The study provide useful contributions to the Indonesian government in revitalising agriculture in general and rice production in particular. The results are consistent with the planned actions to increase productivity of rice such as to increase farm size, to improve agricultural infrastructure, particularly irrigation facilities, and to improve farmers' skill. All actions can improve economic efficiency, as well as social efficiency. Eventually, the increases in efficiency improve sustainable productivity growth since the two components of growth are allocative and technical efficiency. This study is also expected to give a significant contribution to the literature on Indonesian agriculture in general, and on rice research and development in particular.

The understanding and measurement of sustainable productivity growth related to externalities are still in its infancy. The models proposed here are the starting points through which technical efficiency and environmental impact can be integrated. Environmental costs associated with the use of agrochemicals can be valued and the values internalised into the cost of production. Social efficiency of chemical use can be determined when the estimated values of environmental costs are available. Considering which environmental costs should be taken into account in growth accounting, this study tries to internalise the environmental costs into productivity growth. With identified limitations of this proposed approach, it is remarkable that when environmental costs are sufficiently large, the environmentally adjusted productivity growth is significantly reduced. This study is expected to provide a significant discourse to agricultural development defined in the important work of Mosher (1976: 46) as

> 'a trend in the technologies, organisations, activities and value of a culture that increasingly brings all of its present and potential farm-land into its most effective use, combined ... with increasingly agricultural production per farm worker'

to be sustainable.

Caveats

There are several limitations in this study that need elaboration. The first limitation is the approach. This study uses a primal approach, meaning that the production function is used in all parts of the study. The production function is estimated using data on hand, both at aggregate and farm levels. There is a strong criticism that an econometrically estimated production function will not provide unbiased estimators because of endogenous use of inputs (Kumbhakar 1988a; 1988b). This is particularly true if the output is fixed because of quotas or other restrictions, such that under the assumption of profit maximisation, the producer will choose a level of input for a given level of fixed output. In this case, the use of inputs is endogenous. This condition mostly happens in developed countries where the agricultural production quotas apply. However, it is unlikely to be the case in developing countries, because agricultural production is not constrained. Further, on small scale farms, farmers produce as much output as they can for a given level of inputs. In this case, output is endogenous because the level of output is determined by the use of inputs. Zellner et al. (1966), argue that when output is uncertain, such that farmers maximise expected profit, there is no constraint in estimating the production function because the use of inputs is no longer endogenous, meaning that estimating the production function econometrically will give unbiased estimators. The nature of agricultural production very well fits with the condition of expected profit maximisation, since output is strongly affected by the natural conditions such as weather and pest outbreaks. Coelli (2002) provides technical evidence that the use of the production function can provide unbiased estimators under the assumption of expected profit maximisation. There is no need to cope with endogeneity of inputs as suggested by economists (for example: Widawsky et al. 1998; Savvides and Zachariadis 2005) in estimating the production function.

The second limitation is data. In the analysis of technological change, the limitations relate to provincial aggregate data used to estimate the production frontier. In this case, the estimated production frontier fails to measure individual technical efficiency of each farm's operation. The efficiency measures represent the mean efficiency of all farms in each region (Kalirajan 2001). However, since the focus of analysis of technological change is on the movement in the production frontier, not the efficiency level, the use of aggregate provincial data is expected not to be a problem. The analysis of technical efficiency itself is estimated using farm level panel data, which are capable of identifying efficiency of every farm.

However, availability of panel data at the farm level is another constraint. A longitudinal survey on the same farm every year is not available. This study uses panel data with intervals of five years, which is quite long. As a consequence, the data set is an unbalanced panel because of conditions such as farmers having died, no longer operating the rice farm, or having sold the paddy land. Using an unbalanced panel is somewhat less effective than a balanced panel data, but is better than using cross-sectional data.

The sample size of the longitudinal survey is, to some extent, small because of resource constraints. Consequently, the sample may not well represent the overall condition of Indonesian rice agriculture. However, the sample is collected from the main islands of Indonesia, considered the rice bowl areas. It is expected that the sample is able to represent regional differences.

The sample is selected deliberately, that is, the selected rice growers are farmers specialised in rice production, and the rice production is based on the optimal planting season. The conditions, therefore, do not represent average rice cultivation. Lastly, the producers are surveyed longitudinally, or, they are a permanent sample. It is likely that the producers will be influenced by the survey, such that they change behaviour related to agricultural practices. The change in behaviour may vary across producers. If the producers want to show that their own rice production has made good progress, they will improve their practices. Conversely, if they want to get agricultural assistance, they will use worse practices. It is expected that the former offsets the latter, such that the behaviour is captured as white noise or disturbance error.

The third limitation is the source of environmental impacts. This study only pays attention to environmentally detrimental inputs as a cause of externalities. This study also estimates an indirect measure of environmental costs through a production function. This is not a full representation of real environmental costs. In some studies on environmental degradation associated with intensive agricultural practices, however, there are other factors that can degrade the environment. One is soil erosion and soil compaction resulting from certain agricultural practices. The author expects that these other factors resulting in land degradation are interesting and challenging subjects to be modelled in future research on sustainability of agricultural productivity growth, both theoretically and empirically.

Chapter 8

Concluding Remarks

It has been known that agriculture plays an important role in the economy of many developing countries. At early stages however, agricultural development was subordinated to the central strategy of accelerating economic growth. This suggests that the irreversible path leading to resources coming out of rural communities paid no attention to the full growth potential of the agricultural sectors. Nowadays, it has been identified that agriculture is mutually connected with other sectors in shaping economic development. Ignoring the whole range of economic contributions of agriculture underestimates the returns to agricultural investments. A development consensus points out that good performance of the agricultural sector is fundamental to economic growth. Improving performance of the agricultural sector generates income. Consequently, economic growth is stimulated by more investments and expenditures as households' incomes increase. Improving performance of agriculture can significantly reduce poverty and hunger, since most people in developing countries live in rural areas and rely on agriculture for their livelihoods, and can subsequently improve health outcomes as malnutrition is reduced.

Rice is one of the important commodities in agricultural production and it has been of particular interest in Asian economic development. More than 90 per cent of rice in the world is produced and consumed in Asia. In Indonesia, rice is a staple food and represents the largest calorie source for more than 200 million people. In economies of Asia, rice is important because its production occupies more than 50 per cent of farmers and many more in the post production and supply chain of rice to consumers. Politically, rice is a strategic commodity. It can potentially influence political stability when it is in shortage and price fluctuates highly.

Growth in rice agriculture should trigger growth in other agricultural sectors and subsequently, economic growth. Growth in rice agriculture is capable of promoting income growth for households and communities, improving livelihoods and lifting not only farmers but also entire communities out of poverty, if the growth is based on efficiency, sustainability and social equity. Mismanagement of rice agriculture to improve productivity can threat sustainable production as agricultural resources are depleted and environment is degraded. Enhancement of rice productivity while conserving the natural resource base is the challenge for sustainable rural development.

In Indonesia, many efforts have been made to improve rice productivity as a key to agricultural growth such that it is the top national priority. Various techniques have been developed and disseminated to farmers through various intensive processes of institutionalisation. Two main environmentally related policies apply. The first relates to the application of chemical intensive technology. Since this policy is not in line with current concepts of sustainable rural development, the policy has shifted from chemical intensive, which is considered environmentally detrimental, to more environmentally sound technological change.

Current policy has returned attention to the agricultural sector after ten years of ignoring the sector in economic development. Realising that agriculture is able to promote economic growth and reduce poverty, while being resistant to the economic crisis, the policy revival for agriculture enhances its performance in national development without sacrificing other sectors. This action is well known as the revitalisation of agriculture. Again, rice is placed as the top priority. The efforts are to enhance sustainable rice productivity in order to support national food security and food safety.

This thesis studies technological progress with particular attention to environmental concerns related to the use of chemical inputs. Technological progress, which frequently represents agricultural modernisation, consists of technological change, technical efficiency and allocative efficiency. In the concept of sustainable rural development, it has been highlighted that environmental problems resulting from attempts to increase productivity growth should be taken into account. In response to such concerns, current concepts of environmental and social efficiencies are considered important components of technological progress. In this sense, achieving high productivity growth in rice must not jeopardise the quality of the environment. The productivity growth then must be related to the environmental costs associated with the inevitable use of agrochemicals.

Primal approaches of economic production are used in this study, meaning that technological progress, consisting of technological change and efficiencies, and productivity of rice are analysed using the concept of the production function. In this case, the idea of a stochastic production frontier applies, instead of a deterministic one, because of the nature of agriculture. The primal approaches are selected to be used in this study because of a more straightforward interpretation. Technological change is estimated using simplified translog production technology to cope with a severe multicollinearity problem resulting from aggregate data. Various rice policy schemes are analysed using a concept of environmentally biased technological change. The schemes constitute intensification, non-intensification programs, the Green Revolution and environmentally sound periods.

Efficiencies, consisting of technical, environmental, allocative and social terms, are estimated using full translog production technology to capture more precise estimates of technical efficiency and more accurate coefficients of production technology at the farm level, rather than restricted functional forms. Socio-economic factors are hypothesised to be sources of variation in technical efficiency among farms. By relaxing the assumptions of constant returns to scale in the production function, and technically and allocatively efficient producers, productivity growth is decomposed into growth of technological change, improvements in technical and allocative efficiencies, and change in scale effects. Using more flexible functional forms of production technology is expected to reduce biased estimates of productivity growth. Environmental costs associated with chemical use are taken into account to get environmentally adjusted productivity growth.

Technological change is estimated using aggregate panel data at provincial level. The data are collected from a database of structured costs of rice production. The data cover 23 provinces during the period 1979-99. The data provide output-input information on rice production in intensification and non-intensification programs. They cover two major periods 1979-89 and 1990-97 concerning environmentally related policies.

Efficiencies and productivity growth are estimated using farm level unbalanced panel data. The data are from a longitudinal survey conducted by the

Indonesian Centre for Agricultural Economics Research and Development (CASER), of the Ministry of Agriculture. The data consist of 358 irrigated rice farm operations in five regions of Indonesia during 1994, 1999 and 2004. The total number of observations is 817.

With aggregate provincial level and farm level panel data, *FRONTIER* 4.1 is used to estimate the simplified translog and full translog production functions respectively. Analyses on technological change, efficiencies and productivity growth are based on the estimated production functions. The results of the analyses are as follows.

Generally, technological change in rice agriculture is not neutral. With the passage of time, improvements in agricultural technology affect productivity of certain inputs used. The type of technological change is not the same for both spatial and temporal aspects. The results show technological regress at a decreasing rate. Technological change under intensification programs is more chemical-using than under non-intensification programs. Technological change during the Green Revolution is less labour-saving and more chemical-using. The development of seed technology, which is responsive to chemical fertilisers and susceptible to pest infestation, is the major cause of more chemical-using technological change.

The technological change after the Green Revolution, in which environmentally sound technology is applied, is more chemical-saving and more labour-intensive. In this era, environmentally friendly technology is employed to reduce pesticide use and adjust fertiliser use. More labour-intensive technological change is because the technology needs regular observations on rice agro-ecosystems. As a result, more labour is devoted to rice production activities.

Chemical saving technological change has been applied after the policy reform switch from chemical intensive to more environmentally friendly practices. Unexpected experiences related to adverse impacts of excessive chemical uses, particularly pesticides, have been behind the idea of reducing chemical use.

Variation in technical efficiency is a key source of variation in Indonesian rice production among farms. The average of technical efficiency is 0.6755, which is considered low. This means that, with the existing technology, rice production can still be increased with the same level of input use. The important sources of variation in technical efficiency are farmer's experience, educational attainment, size and number of plots of land, hired labour and mechanisation. More experienced and educated farmers lead to more technical efficiency because farmers will be more capable of implementing the existing technology. Mechanisation and hired labour lead to high technical efficiency because using tractors is less costly, and hired labour works more effectively. Regional characteristics in Java that positively affect technical efficiency include more technology and better irrigation management availability. In Java where various extension programs have been implemented, farmers operate rice farms with more technical efficiency than in other regions. Technical efficiency increases at a decreasing rate, meaning that rice farms in each region are getting more technically efficient.

Environmental efficiency is low, but increases slightly over time. Since environmental efficiency is strongly correlated with technical efficiency, factors affecting technical efficiency automatically influence environmental efficiency. Low environmental efficiency means that agrochemicals applied in the rice production system cannot be absorbed effectively, and this results in significant chemical waste. The waste leads to externalities being imposed on society. In terms of monetary value, or the cost of externalities, the values are relatively high. The levels of chemical waste and environmental costs are positively correlated with farm size. In regions where farm size is large, the levels of waste and environmental costs are higher.

Rice production is not allocatively efficient, meaning that the allocation of resources is not proportionately correct. Land use is far less than allocatively and socially efficient because observed cost of land is very low. This leads to relative overuse of other inputs. Despite under-utilisation of capital and material, reducing both inputs improves overall allocative efficiency. Allocative and social efficiency increases over time. Improvement in both mostly comes from land expansion and increase in cost of land. Cost of land is mostly represented by land tax, which is low in rural areas.

The rate of growth in total factor productivity was low in 1994, but quite high in 1999 and 2004. The rate of growth in total factor productivity is driven by growth in technological change and allocative efficiency effect. In 2004, the allocative efficiency effect was very high, and this resulted in high rates of growth in total factor productivity. Internalisation of environmental costs into production costs reduces the productivity growth. This is called environmentally adjusted total factor productivity growth. Internalisation of environmental costs apparently reduced productivity growth in 2004 by around 40 per cent. This is an indication that environmental costs associated with the use of chemical inputs are very high.

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