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ENVIRONMENTALLY ADJUSTED PRODUCTIVITY GROWTH OF INDONESIAN RICE PRODUCTION [1]

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ABSTRACT

Productivity of Indonesian rice agriculture needs to grow substantially to ensure national food security. 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 social efficiency effects. Environmentally adjusted productivity growth is less than conventional productivity growth. Some policies to increase the environmentally adjusted productivity growth are proposed.

Keywords: *internalizing environmental cost, total factor productivity, rice production, scale effect, efficiency*

INTRODUCTION

The agricultural sector is a dynamic sector with many conflicting issues. 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 & Vindigni, 2000).

Agricultural growth in developing countries, including Indonesia, showed a marked decline up to the late 1990s, even though, during the Green Revolution, there was a high agricultural growth. This indicates that productivity level during the Green Revolution has not been sustained (Teruel & 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

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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 slow down agricultural growth.

Indonesian rice agriculture is facing a challenge of population growth leading to increased demand for food. This will require continually increasing productivity to ensure national food security, despite the fact that productivity growth is slowing and the availability of land for future expansion is limited. Enhancing productivity does not necessarily mean jeopardising environmental quality, however. Concerns relating to environment have been focused on sustainable agricultural development. 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 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

In most previous studies on growth that develop the neo-classical Solow-Swan models, it is strongly assumed that producers operate on full economic efficiency, in which they perform the best practice methods of application of state-of-the-art technology and at profit maximization. However, due to various circumstances, the producers do not operate 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 (1996: 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 & 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. 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. Last, this study analyses the impact of environmental problems by taking environmental costs into account.

METHODOLOGY

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. Following Kalirajan's (2004) approach of decomposition of total factor productivity, the general structure of the primal approach is illustrated in Figure 1, in which a single output is produced using a single input[2].

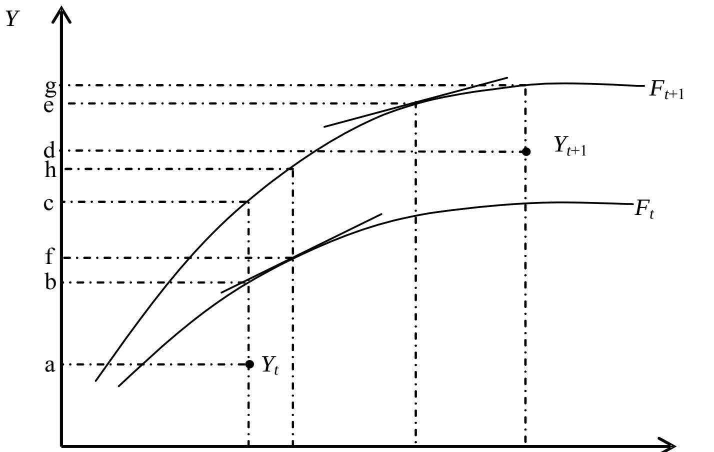

Figure 1. Decomposition of output growth with inefficient producers

[2] 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 & 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.

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. The production is technically inefficient and allocation of input is still below allocatively efficient level. 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, but allocation input exceeds allocatively efficient level. The increase in output from Y_t to Y_{t+1} represents output growth. 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 rate of output growth is $Y_{t+1} - Y_t$. The output growth is decomposable as follows:

$$\begin{aligned}\dot{Y} = d - a &= (b-a) + (f-b) + (c-f) + \\ &\qquad (h-c) + (d-h) \\ &= ((b-a)-(g-d)) + ((f-b)-(e-g)) + \\ &\qquad ((c-f)+(h-c)) + (e-h) \\ &= \Delta TE + \Delta AE + TC + \dot{X} \end{aligned} \tag{1}$$

Scale effects resulting from input growth need to be taken into account. Total factor productivity growth is output growth unexplained by input growth, and then total factor productivity growth is expressed as:

$$T\dot{F}P = \Delta TE + \Delta AE + TC^* + \Delta SE \tag{2}$$

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.

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

$$\dot{Y} = \dot{A} + S_X \dot{X} + S_Z \dot{Z} \tag{3}$$

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:

$$T\dot{F}P = \dot{Y} - S_X \dot{X} - S_Z \dot{Z} = \dot{A} \tag{4}$$

In this case, total factor productivity growth is the same as the rate of 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 technical and allocative efficiency in producing outputs.

Following a primal method proposed by Kumbhakar & 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:

$$Y_{it} = f\left(X_{it}, Z_{it}, t; \beta\right)\exp\{-u_{it}\} \tag{5}$$

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

$$\dot{\varphi} = \frac{\partial \varphi_{it}}{\partial t} = \frac{\ln \exp\{-u_{it}\}}{dt} \tag{6}$$

$\dot{\varphi}$ can be interpreted as the rate at which a producer shifts towards or away from the production frontier, keeping everything else constant. Taking log and totally differentiating equation (5) and then differentiating with respect to t, yield:

$$\dot{Y} = \frac{\partial \ln f(\bullet)}{\partial t} + \frac{\partial f(\bullet)}{\partial X}\frac{X}{f(\bullet)}\frac{\partial \ln X}{dt} + \frac{\partial f(\bullet)}{\partial Z}\frac{Z}{f(\bullet)}\frac{\partial \ln Z}{dt} + \frac{\partial \ln \exp\{-u\}}{\partial t} \tag{7}$$

where $\dot{Y} = \dfrac{\partial \ln Y}{\partial t}$ is output growth, $f(\bullet) = f\left(X, Z, t; \beta\right)$ is the deterministic kernel of the stochastic production frontier, $\dfrac{\partial \ln f(\bullet)}{\partial t} = \dot{A}$ is the rate of technological change, $\dfrac{\partial \ln X}{dt} = \dot{X}$ is the growth rate of input X, $\dfrac{\partial \ln Z}{dt} = \dot{Z}$ is the growth rate of input Z, $\dfrac{\partial f(\bullet)}{\partial X}\dfrac{X}{f(\bullet)} = \theta_X$ is output elasticity with respect to input X, $\dfrac{\partial f(\bullet)}{\partial Z}\dfrac{Z}{f(\bullet)} = \theta_Z$ is output elasticity with respect to input Z, $\dfrac{\partial \ln \exp\{-u\}}{dt} = -\dfrac{\partial u}{\partial t} = \dot{\varphi}$ is the rate of change in technical efficiency. Substituting the expression for $\dot{Y}$ into equation (4) yields:

$$T\dot{F}P = \Delta TC + (\theta - 1)\left(\frac{\theta_X}{\theta}\dot{X} + \frac{\theta_Z}{\theta}\dot{Z}\right) + \left(\frac{\theta_X}{\theta} - S_X\right)\dot{X} + \left(\frac{\theta_Z}{\theta} - S_Z\right)\dot{Z} + \dot{\varphi} \tag{8}$$

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 $\dfrac{\theta_X}{\theta}$ and $\dfrac{\theta_Z}{\theta}$ is called normalised output elasticity with respect to input X and Z respectively. 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. 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; in other words, $MRTS$ 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 components of technological change, scale effect, allocative efficiency, and technical efficiency[3].

[3] 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 is constant returns to scale over time, the scale effect is zero.

Internalization of Environmental Cost. 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. Pretty & Waibel (2005) point out that the environmental costs associated with agrochemicals should be internalised into production costs. 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 & Turner, 1990; Tietenberg, 1998). 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 $\hat{S}_X = \dfrac{W_X X + EC}{W_X X + EC + W_Z Z} > S_X$ and the share of expenditure for input Z will be $\hat{S}_Z = \dfrac{W_Z Z}{W_X X + EC + W_Z Z} < S_Z$, 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:

$$T\dot{F}P_E = \Delta TC + (\theta - 1)\left(\frac{\theta_X}{\theta}\dot{X} + \frac{\theta_Z}{\theta}\dot{Z}\right) + \left(\frac{\theta_X}{\theta} - \hat{S}_X\right)\dot{X} + \left(\frac{\theta_Z}{\theta} - \hat{S}_Z\right)\dot{Z} + \dot{\varphi} \quad (9)$$

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. 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 negative effect of agro-chemical use.

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 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 2, indicating that

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. This is consistent to technological change proposed by Solow (1957).

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[3].

The description and measurement of aggregated variables of input-output and technical inefficiency models from individual observations are given in Table 3. Table 4 shows the summary statistics for key variables across time. Table 5 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 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

[4] 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 & 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. 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

Note: See Table 3 for units of measurement.
Source: Author's calculation

Table 5. 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)

Note: Figures in parentheses represent standard deviations. See Table 3 for units of measurement.
Source: Author's calculation

Production Technology. By now, after introduction of transcendental logarithmic (translog) production technology by Christensen, *et al*. (1973), it becomes the fashionable functional form of a production function in estimating total factor productivity is the (Chen, 1997).[5] The stochastic frontier translog production technology is specified as:

$$\ln Y_{it} = \beta_0 + \sum_{k=1}^{5} \beta_k \ln X_{kit} + 0.5\sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} \ln X_{kit} \ln X_{jit} + \sum_{k=1}^{5} \beta_{kt} t \ln X_{kit} + \beta_t t + \beta_{tt} t^2 + v_{it} - u_{it} \quad (10)$$

The full translog production technologies captures more accurate estimates and more

[5] 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).

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 mean elasticities of output with respect to inputs are formulated as:

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

$$\theta_{X_k} = \frac{\partial \ln Y_i}{\partial \ln X_k} = \beta_k + \sum_{j=1}^{5} \beta_{kj} \ln X_{jit} + \beta_{kt} t \quad (11)$$

The mean output elasticities are then evaluated at the average level of each input and time period. 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:

$$\Delta TC = \partial \ln Y_{it} \big/ \partial t$$
$$= \sum_{k=1}^{5} \beta_{kt} \ln X_{kit} + \beta_t + 2\beta_{tt} t \quad (12)$$

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:

$$\varphi_{it} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 \quad (13)$$

The rate of change in technical efficiency is:

$$\dot{\varphi} = \frac{\partial \varphi_{it}}{dt} = \alpha_1 + 2\alpha_2 t \quad (14)$$

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

$$X_{kit} = a_0 e^{(r_1 + r_2 t)t} \quad (15)$$

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:

$$\ln X_{it} = \ln a_0 + r_1 t + r_2 t^2 \quad (16)$$

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

$$\frac{\partial \ln X_{it}}{\partial t} = r_1 + 2r_2 t \quad (17)$$

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. 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. 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:

$$EC = P\left\{f\left(X^{act}, Z\right) - f\left(X^{\min}, Z\right)\right\} \quad (18)$$

where P is prevailing price of output (see Mariyono, *et al*., 2010 for detail in estimating environmental cost).

RESULTS AND DISCUSSION

The estimation of stochastic frontier production technology is presented in Table 6. From the estimated frontier production technology, the four components of total factor productivity are calculated. 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 7. The next two components are: scale effects, which involve output elasticity with respect to each input and input growth of respective input; and allocative efficiency, which involves share in input costs without environmental cost and with environmental cost.

Table 6. Parameter estimates of stochastic frontier production function

		Model 1	
		Coefficient	z-ratio
TFP	β_0	8.0538	7.1[a]
Area (A)	β_1	1.2286	3.33[a]
Capital (K)	β_2	0.1513	2.81[b]
Labour (L)	β_3	-0.057	-0.19[n]
Material (M)	β_4	-0.1096	-0.98[n]
Chemicals (X)	β_5	0.0774	1.38[n]
0.5 A*A	β_{11}	0.051	1.61[c]
0.5 K*K	β_{22}	0.0076	3.49[a]
0.5 L*L	β_{33}	-0.0106	-0.62[n]
0.5 M*M	β_{44}	0.0051	1.72[c]
0.5 X*X	β_{55}	0.0057	6.97[a]
A*K	β_{12}	-0.006	-1.20[n]
A*L	β_{13}	-0.0158	-0.45[n]
A*M	β_{14}	-0.0602	-2.06[b]
A*X	β_{15}	0.0216	3.11[a]
K*L	β_{23}	0.0015	0.44[n]
K*M	β_{24}	-0.0095	-2.18[b]
K*X	β_{25}	-4.66E-05	-0.08[n]
L*M	β_{34}	0.0134	0.56[n]
L*X	β_{35}	-0.0042	-0.88[n]
M*X	β_{45}	-0.0104	-2.10[b]
t*A	β_{1t}	0.0217	0.44[n]
t*K	β_{2t}	0.0252	4.81[a]
t*L	β_{3t}	0.0276	0.82[n]
t*M	β_{4t}	-0.0548	-1.32[n]
t*X	β_{5t}	0.0891	7.32[a]
t	β_t	-0.3387	-0.67[n]
t^2	β_{tt}	0.2955	5.48[a]
	σ^2	1.097	5.92[a]
	γ	0.8811	38.48[a]
Log-likelihood		-645.56	
LR-test		137.47a	

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

Table 7. 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

The estimated translog production technology shows that 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:

$$\varphi_{it} = 0.6177 + 0.0438 \cdot t - 0.0054 \cdot t^2 \quad (19)$$

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:

$$\dot{\varphi}_{it} = \frac{\partial \varphi_{it}}{\partial T} = 0.0438 - 0.0109 \cdot t \quad (20)$$

The rate of change in technical efficiency and technological change in each year is given in Table 7.

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 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.[6] 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.[7] The technological change that account for innovation and diffusion of agricultural technology can provide a significant multiplier effect on other sectors (Khan & Thorbecke, 1988).

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 8. Together with input growth, the average output elasticity in each year will 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 9.

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

[7] Jansen & 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.

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). The rate of input growth of each input is given in Table 10.

Table 8. 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.

Table 9. 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%

Table 10. 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

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 8, 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. The normalised elasticity resulting from output elasticity with respect to each input is given in Table 11.

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 12. 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.

Table 11. 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

Table 12. 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

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 13.

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.

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 14.

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.

Table 13. 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

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 10, there is variation in input growth. The total allocative and social efficiency effects are given in Table 15.

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

Table 14. 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

Table 15. 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

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 agro-chemicals, the effect of allocative efficiency was positive and increasing. In 1994, agro-chemicals 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 16 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.

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.

Table 16. Source of total factor productivity growth of rice agriculture (five-yearly)

Component	Conventional			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

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 & 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 & 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 & 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 social 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 social 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 to ensure national food security. 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. Two possible main reasons are no major breakthroughs in developing agricultural technology, and a decline in the quality of the environment and land. Lack of technological progress and deterioration in productive resources are crucial factors that slow agricultural growth. Thus analyses on "green" productivity growth are needed to recognise the sources of productivity and the impact of taking environmental problems into account.

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 internalized. Without taking environmental cost into account, the rate of growth in total factor productivity was 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 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 or "green 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 occurred in 2004, and this change reduced 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.

POLICY IMPLICATION

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. Improving technical efficiency can be conducted by sending farmers in agronomic training. Many studies show that agronomic training equipping farmers with knowledge and practices has enhanced farming efficiency.

Another policy that can improve productivity growth is to increase cultivated land area, which improves scale and social efficiency effects. Even though this is not an easy task because of massive agricultural land conversion in Java, land expansion can still be possible out-side Java where land is still available. In Java, it could be carried out by utilizing uncultivated land for dry land "gogo" rice farming. By now, seed technology has provided better cultivars of rice suitable in dry land.

One important long-run policy is to reduce dependency of Indonesian people on rice as a staple food. Indonesian people need to diversify their foods. If this is achievable, there is no need land expansion in Java; even, rice farmers are likely to change rice with other higher valued crops such as horticultural crops. Changing rice farming to horticultural crops makes it possible for farmers to increase welfare (Mariyono & Bhattarai, 2011).

During the 1st presidency of Susilo Bambang Yudhoyono, agricultural revitalization program fitted this implication of study. Increasing agricultural land (including for rice) is conducted outside Java; various high yielding cultivars of rice have been released; and training programs on agriculture have been launched (Mariyono, 2009). Currently, Indonesian agency food security promotes food diversification to provide more choice for people to eat.

CAVEATS

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 latest data used in this study 2004, which is eight years ago. Newly set data is needed to understand the current condition.

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.

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