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Shifting from Green Revolution to environmentally sound policies: technological change in Indonesian rice agriculture

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This study analyses technological change in Indonesian rice agriculture. An analysis of data compiled by the Indonesian Central Bureau of Statistics shows that rice agriculture has undergone technological progress with non-neutral technological change that has been capital and labour saving and chemical intensive. Recent agricultural policy reforms, which include the dissemination and implementation of environmentally friendly technology, however, appear to have been successful in reducing chemical use.

Keywords: rice economy; biased technological change; Green Revolution; chemical-intensive technology; environmentally friendly policy

JEL classifications: Q18, O13, O33, C51

Introduction

Rice is the most important staple food in Indonesia, with more than 200 million people relying on rice as staple food. It is thus a politically strategic commodity, and either a shortage in the domestic rice market or highly fluctuating prices have the potential to create political instability. Since the early 1970s, Indonesian rice policy has sought to attain food self-sufficiency through price support, price stabilisation and public investment. This policy has made the central government a player in the rice market. The policy includes: (1) setting a reasonable floor price to stimulate production; (2) establishing a ceiling price that assures an attainable price for consumers; (3) maintaining sufficient range between these two prices to provide traders and millers a reasonable profit margin after holding rice between crop seasons; and (4) keeping a balanced price relationship between domestic and international markets.

The efforts to reach food self-sufficiency have been conducted by improving agricultural technology. During the Green Revolution, several new varieties of rice were introduced to farmers (Cleaver 1972). This was accompanied by massive extension campaigns and grower subsidies of \$725 million of which approximately 40% was allocated for pesticides (Barbier 1989). Various programmes called ‘bimbingan masal = BIMAS’ (mass guidance), ‘intensifikasi khusus = INSUS’ (special intensification) and ‘SUPRA INSUS’ (super special intensification) were implemented to intensify production and support the

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Green Revolution (Widodo 1989). A national research station was established in collaboration with national universities and international research institutions. The government also allocated expenditures to developing new rice varieties, agricultural extension and agricultural infrastructure for irrigation.

A drawback of the intensification of rice production has been negative externalities associated with increasing chemical use (Cleaver 1972, Byerlee 1992). These include pest resistance and, subsequently, pest resurgence (Barbier 1989, Conway and Barbier 1990), negative human health impacts (Kishi *et al.* 1995, Murphy *et al.* 1999, Pawukir and Mariyono 2002, Kishi 2005) and environmental contamination (Bond 1996, Pretty and Hine 2005). These externalities are the publicised justification for the Indonesian Government's gradual shift away from promoting chemical intensive agriculture to more environmentally sound agricultural practices (Rolling and van de Fliert 1994), in particular, integrated pest management (IPM).

IPM comprises a package of technologies that utilise natural predators and the careful timing and dosage of chemical pesticides to control pests. The adoption of IPM was one of the most important contributions to decreased use of pesticides in Indonesian rice agriculture. An IPM programme was established to disseminate knowledge of IPM to farmers, using the 'learning by doing' method through sending farmers to farmer's field schools (FFS) (Feder *et al.* 2004a). A major stimulant for the widespread dissemination of IPM technology was the prohibition of 57 problematic pesticide brands and the removal of subsidies on pesticides by 1990 (Untung 1996).

During the first few years of the IPM programme, pesticide use at farmer level dropped by approximately 50%, while rice production increased by around 10% (Pincus 1991). In addition, the work of Irham (2001, 2002) shows that the programme has not only diminished pesticide use but enhanced farm household's income. This is supported by evidence cited by Useem *et al.* (1992) and Untung (1996) who claim that the Indonesian IPM programme has been successful in reducing pesticide use and escalating rice production.

Kuswara (1998a, 1998b), Paiman (1998a, 1998b) and Susianto *et al.* (1998) also highlight cases of successful IPM implementations. In West Sumatra, Utama (2003a, 2003b) show that IPM graduates were more technically efficient than non-graduates. This means that IPM graduates could produce the same level of output, with lower level of inputs, including pesticides. Irham (2002, p. 75) sums up the national impact study of the Indonesian IPM programme conducted in 1999 as follows: 'at least the farmers can maintain the current yield with lower cost of pesticide'.

Despite the claims on behalf of the IPM, its success has been disputed by Feder *et al.* (2004a, 2004b) who claim the Indonesian IPM programme has been unsuccessful in reducing pesticide use. They argue that there is no statistically significant evidence that IPM has been diffused among farmers or has generated environmental or health benefits. The main criticism of the analysis of previous IPM impact studies is selection bias resulting from lack of adequate econometric procedures.

Thus, there are two conflicting points of view regarding analysis of IPM. The first mostly uses a descriptive and simple statistical approach of case studies to identify the impact of IPM and has found in favour of IPM and its ability to reduce pesticide use. The second viewpoint uses an econometric approach with a number of samples randomly drawn from farmers that have graduated from FFS. An alternative to both approaches is to use aggregate data based on the total number of graduated farmers, and cumulative impacts of environmental policies from national to local levels, to determine the effects of IPM. Such an approach needs to examine not only the dissemination of technology but also trends in pesticide use. The elimination of pesticide subsidies and prohibition of 57 brands of

pesticides in rice might also contribute to a reduction in pesticide use. In theory, the effect of policy on the use of chemicals, particularly pesticides, can be analysed using a concept of technological change, which, itself, can be affected by policy (Martin and Warr 1994), where technological change is represented by movements in the production frontier over time (Jansen and Ruiz de Londoño 1994).

The objectives of this current study are to estimate an aggregate production frontier over time for Indonesian rice agriculture and to identify the impact of the Green Revolution on the non-neutrality of technological change at the national level. The use of aggregate data is expected to eliminate selection bias, because the aggregate data consist of both IPM-trained and non-IPM-trained farmers. Given that environmental concerns are likely to relate to the policy, an important contribution of this study is to provide information on whether changing from the Green Revolution to environmentally sound policies has generated ambient benefits.

This study uses established provincial data on the production system for rice during and after the Green Revolution.

The paper is developed as follows. The next three sections outline the following: (1) the development of environmentally sound policy in Indonesian rice agriculture; (2) the methodology and underlying theory employed in this paper; and (3) the econometric specification and major data sources used. The paper concludes with a summary of the findings and the key policy implications.

The following section describes major trends in the rice sector in Indonesia. Estimates of production function and analyses are then presented.

IPM programme and dissemination of IPM technology

The Indonesian Government started implementing the IPM programme with a support from the UN Food and Agriculture Organization in May 1989. Initially, IPM technology was disseminated among rice-based farmers through a pilot project. The IPM programme provides an ideal case to contrast extension for sustainable agriculture with that supporting high-external-input agriculture.

This programme was a realisation of the Presidential Decree (INPRES 3/86), which banned 57 brands of problematic pesticides from rice cultivation and declared IPM as the national pest control strategy. This policy measure progressively reduced the subsidies on pesticides, which were previously 85% of the sale price, to zero in 1990 (Untung 1996). These policy measures created a favourable climate for the implementation of Indonesia's National IPM Programme.

In the first phase of the IPM programme (1989–1992), there was a large-scale attempt to systematically introduce sustainable agricultural practices nationally. In total, around 200,000 farmers were trained intensively, and many more received some form of extension advice. The intensive training was called FFS. Locations of FFSs were purposively selected on the basis of easy accessibility and the presence of active farmer groups. Farmers participating in the school were also selected for the programme and were usually more prosperous and better informed in the selected villages.

The FFS, a process of learning by doing, was the core of the Indonesian IPM programme. The World Bank along with a number of development agencies promoted the FFS, since it is a more effective method to extend science-based knowledge and practices (Feder *et al.* 2004a). The method used a participatory approach to provide assistance for farmers to develop their capability in terms of analytical skills, critical thinking and creativity so that they could make better decisions (Braun *et al.* 2000). In short, the objective of the FFS was to enhance human resource development, in which farmers become experts of IPM

in their own 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. The training involves not only pest control but also other aspects of farming such as balanced and efficient fertiliser application, efficient use of irrigation, crop rotation and soil conservation.

To be effective an FFS needs sufficient material and financial supports. As it is cited by the *Agro-Chemical Report* (2002), a unit cost of the FFS in 1996–1997 fiscal years was, on average, \$599. It constituted an honorarium for the facilitator, preparation and coordination expenses, facilitator's transport, materials, refreshments, compensation of land used for field trial, stipends for participants and field day and ceremonial expenses.

The second phase of the IPM programme (1993–1999) was sponsored by the World Bank. In this phase, the programme was scaled up. In 1994, the pilot FFS activities were taken over by the National IPM Training Project funded by the World Bank (1993). The project promoted IPM and improved cultivation of rice and other food and horticultural crops. More regions were covered and more participants involved. However, the target was not to reach all Indonesian farmers but rather to train a small fraction of farmers, which could then spread IPM knowledge by farmer-to-farmer diffusion. During the implementation of the second phase of the project, villages where FFSs were carried out were still subjectively selected, with the same criteria as before, by the project management in collaboration with agricultural services officials at both the provincial and district levels.

Methodology

Underlying theory

Technological change refers to improvement in technology, which is defined as a stock of available techniques or a state of knowledge from which production possibilities can be enhanced (OECD 1995). Solow (1957, p. 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 labo[u]r force, and all sorts of things will appear as “techn[olog]ical change.”’ Inference about the effect of improvement in technology is indirect and is generated by making comparison of changes in inputs and outputs (Mundlak 2000). A frequent representative measure of changes in technology is the use of a time index (Millan and Aldaz 1998). In this framework, the production function changes over time, but at a certain point in time, there is only one production function. The movement of the production frontier represents a process in which new technology is invented and institutionalised in production (Jaffe *et al.* 2000). This generally consists of three interlinked components: research and development; adoption and diffusion; and institutionalisation of the socio-economic, legal and political circumstances for the first two components (Knudson and Larson 1989).

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. Technological change can be Hicks-neutral or non-neutral. Technological change is Hicks-neutral if it leads to savings of all production inputs in the same proportion and is biased if technological change results in greater savings of one factor over others. Non-neutral technological change can be input saving or input augmenting; that is, it permits substitution of one input for other inputs (Mundlak 2000).

In this paper, let Y be the output produced using environmentally detrimental input X and usual input vector Z for the following production technology: $Y_t = f_t(X_t, Z_t, T; \beta)$. Distinguishing both inputs requires an understanding of environment-related technological

change. In agricultural practices, the environmentally detrimental input is harmful chemicals, which consist of inorganic fertilisers and synthetic pesticides (Bond 1996, Reinhard *et al.* 2002).

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

Figure 1 shows isoquants Y_t , for each time t , representing a certain level of output using some level of inputs X_t and Z_t . In this case, cost minimisation holds because the marginal rate of technical substitution (MRTS) is equal to (coincides with) the price ratio of both inputs, $\bar{P}_t$. However, suppose there is an exogenous improvement in technology or positive technological change 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 inputs no longer yields maximised profit because MRTS is not equal to $\bar{P}_t = \bar{P}_{t+1}$. Cost minimisation 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. In mathematical form Figure 1 can be

Figure 1. Input- X -saving technological change.

represented with a functional form of production function as follows:

$$Y_t = \beta_0 X_t^{\beta_X + \beta_{tX}T} Z_t^{\beta_Z + \beta_{tZ}T} e^{\beta_t T + \beta_{tt} T^2}, \quad (1)$$

where β s are technology parameters and T is a time index. This production function is able to capture two distinct technological changes: pure and non-neutral technological changes. The former, which is represented by β_t and β_{tt} , means that the same level of output can be produced with a lower level of inputs, and the proportion of inputs is constant. The latter, which is represented by β_{tX} and β_{tZ} , allows MRTS to vary over time. The MRTS derived from the production function can be expressed as follows:

$$\text{MRTS} = -\frac{\partial X_t}{\partial Z_t} = -\frac{\partial Y_t / \partial Z_t}{\partial Y_t / \partial X_t} = -\frac{(\beta_Z + \beta_{tZ}T)X_t}{(\beta_X + \beta_{tX}T)Z_t}. \quad (2)$$

The impact of technological change on MRTS is given by partially differentiating with respect to the time index, that is,

$$\frac{\partial}{\partial T} \text{MRTS} = -\frac{(\beta_X \beta_{tZ} - \beta_Z \beta_{tX})X_t}{(\beta_X + \beta_{tX}T)^2 Z_t}. \quad (3)$$

With constant proportion of X and Z , MRTS will increase if $\beta_{tX} < 0$ and $\beta_{tZ} \geq 0$, or in general $\beta_{tX} \ll \beta_{tZ}$. Technological change is said to be input- X -saving if $\beta_{tX} \ll \beta_{tZ}$ such that the MRTS at the same proportion of input use increases in modulus.

Empirical work

This approach to measuring technical change can be applied to a farm using the inputs land A , capital K , labour L , material M and chemicals X to produce a single output Y . The technology is characterised by a production function:

$$Y = F(A, K, L, M, X, W, T; \beta), \quad (4)$$

where W is a dummy variable for wetland (rice agriculture) and T is a time index. 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 the following intensive form:

$$y = f(k, l, m, x, W, T; \beta), \quad (5)$$

where $y = Y/A$, $k = K/A$, $l = L/A$, $m = M/A$ and $x = X/A$.

With these inputs, taking the natural logarithm of Equation (1) results in a simplified translog frontier production technology that assumes inputs are separable from each other but not from time. The specification is expressed as follows:

$$\begin{aligned} \ln y = & \ln \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_W W + \beta_x \ln x + \beta_{tk} T \ln k + \beta_{tl} T \ln l \\ & + \beta_{tm} T \ln m + \beta_{tx} T \ln x + \beta_t T + \beta_{tt} T^2. \end{aligned} \quad (6)$$

In this case, technological change not only affects total factor productivity but also affects the elasticity of production with respect to all inputs. The rate of technological change is

$$d \ln y / dT = \beta_{tk} \ln k + \beta_{tl} \ln l + \beta_{tm} \ln m + \beta_{tx} \ln x + \beta_t + 2\beta_{tt}T. \quad (7)$$

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 for a time-varying marginal rate of factor substitution. The sign on β_t determines whether there is technological progress or technological regress; the sign on β_{tt} determines whether or not technological change is taking place at an increasing or a decreasing rate. In addition, if β_{tk} , β_{tl} , β_{tm} and β_{tx} are positive, the technological change will be input augmenting (O'Neill and Matthews 2001).

Historically, Indonesian rice agriculture consists of two major and distinct policy periods of environmental concern. The first is the implementation of the Green Revolution in the period 1970–1988. The second is the dissemination and implementation of ecological technology in the period 1989–1999. During the Green Revolution, technological change in rice agriculture is expected to be chemical using, whereas during the implementation of ecological technology, technological change in rice agriculture is expected to be chemical saving.

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

$$\begin{aligned} \ln y = & \ln \beta_0 + \beta_k \ln k + \beta_l \ln l + \beta_m \ln m + \beta_x \ln x + \beta_W W + \beta_{tk} T \ln k \\ & + \beta_{tl} T \ln l + \beta_{tm} T \ln m + \beta_{tx} T \ln x + \beta_{Gtk} GT \ln k + \beta_{Gtl} GT \ln l \\ & + \beta_{Gtm} GT \ln m + \beta_{Gtx} GT \ln x + \beta_t T + \beta_{tt} T^2, \end{aligned} \quad (8)$$

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

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 two different intensification programmes (Green Revolution and ecological technology) and policies. Following Battese and Coelli (1992), a formal test for the hypothesis of non-existence of production frontier is formulated as follows:

$$H_0 : \gamma = \mu = \eta = 0; \quad H_1 : \text{at least } \gamma > 0. \quad (H-1)$$

A formal test for the hypothesis of absence in technological change is formulated as follows:

$$H_0 : \beta_t = \beta_{tt} = 0; \quad H_1 : \text{at least one not equal.} \quad (H-2)$$

A formal test for the hypothesis of neutral technological change is formulated as follows:

$$H_0 : \beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0; \quad H_1 : \text{at least one not equal.} \quad (\text{H-3})$$

A formal test for the hypothesis of no impact of the Green Revolution is formulated as follows:

$$H_0 : \beta_{Gtk} = \beta_{Gtl} = \beta_{Gtm} = \beta_{Gtx} = 0; \quad H_1 : \text{at least one not equal.} \quad (\text{H-4})$$

Given the importance of environmental issues, a particular hypothesis will be based on chemical input, x . It is expected that β_{Gtx} is positive, such that chemical-augmenting technological change has been occurring during the Green Revolution. A formal test for the hypothesis of solely chemical augmenting technological change is formulated as a single-sided hypothesis test:

$$H_0 : \beta_{Gtx} = 0; \quad H_1 : \beta_{Gtx} > 0. \quad (\text{H-5})$$

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

$$LR = 2 (LL_{H_1} - LL_{H_0}), \quad (9)$$

where LL_{H_1} is log-likelihood obtained from a model with an alternative hypothesis and LL_{H_0} is log-likelihood obtained from a model with a null hypothesis. The value of LR follows the distribution of χ^2 with a degree of freedom the same as number of the null hypothesis. *FRONTIER 4.1*, a computer programme created by Coelli (1996), is used to estimate the parameters of the stochastic frontier production function.¹

Data, source and variables

This study uses aggregate provincial data. The data are collected from a series available from the Indonesian Central Bureau of Statistics (BPS). The data are the averages of measures of rice agriculture operating in 1 ha of paddy land in each region across time. The data are therefore expected to be sufficiently representative of 1 ha of rice agriculture. Variables are aggregated based on type and function. The aggregation is made to avoid many missing variables. Particular emphasis is on the agro-chemical use because it strongly relates to the analysis of the Green Revolution and environmentally friendly policies. The definitions and unit measurements are provided in Table 1.

The summary statistics for those variables are given in the Appendices. It is important to note that tests for co-integration show that each variable (in logarithm), including time index, is co-integrated at same order. This means that there will be no spurious regression results (Greene 2003, Gujarati 2003).

Results and discussion

The rice yields and inputs are for the period 1979–1989. Different sets of policies are shown in Figure 2. The first (unshaded) period refers to the Green Revolution and the second (shaded) period to IPM.

Table 1. Definitions and unit measurement of variables.

Variable	Description and measurement
Yield (y)	Production of paddy per hectare (kg/ha)
Capital (k)	Uses of machinery and animals (IDR/ha)
Labour (l)	Cost of hired labour (IDR/ha)
Material (m)	Values of seed, irrigation and compost and other costs (IDR/ha)
Chemical (x)	Inorganic fertilisers consisting of Urea, KCl, TSP and ZA and chemical pesticides consisting of insecticides, herbicides and fungicides in various formulations (IDR/ha)

Note: Inputs are measured in monetary value at constant price 1983.
Source: Indonesian Bureau of Statistic (BPS) (1979–1999). There are 435 observations of provincial aggregate data. The data are aggregated from a number of farm households in each province sampled by the BPS.

The yield of rice initially falls at the beginning period. The most likely cause was the sporadic pest outbreaks in 1980–1981 resulting from pest resurgence. The figure suggests that there was no impact of the two different policies on the yield of rice. Namely, the yield of rice continued to trend upwards with the establishment of the IPM programme in 1989.

With respect to uses of materials and chemicals, the dynamics of both policies appear to have had similar pattern. During the Green Revolution, material and chemical uses grew progressively and then tended to fall moderately after 1989. This is a strong piece of evidence that the material and chemical use are strongly linked with the Green Revolution. Materials, which mostly consist of seed and irrigation costs, increased because of introduction of various new varieties of rice and expansion of irrigation systems. Chemical use consisting of inorganic fertilisers and synthetic pesticides accompanied the introduction of new varieties of rice. The new varieties were responsive to fertilisers and susceptible to pests. Without

Figure 2. Dynamics of yield and use of inputs. Source: Authors' calculation.

Figure 3. Pesticide use and subsidy. Data source: Pemerintah Indonesia (1991).

the additional fertilisers and pesticides, the varieties of rice would not be superior to the traditional varieties (Cleaver 1972). After 1989, the use of materials dropped and chemical use peaked in 1992 and thereafter has fallen steadily.

After the Green Revolution, an environmentally friendly policy was applied. The policy consisted of prohibition of 57 brands of pesticides and elimination of pesticide subsidies, causing pest resistance and resurgence in rice, and dissemination of IPM technology (Rolling and van de Fliert 1994, Untung 1996). Despite the fact that all policy components did not work perfectly (Feder *et al.* 2004a, 2004b), it leads to moderate falls in material and chemical uses. The prohibition of pesticides might not work properly to reduce pesticide use on rice, because such prohibited pesticides have been substituted with other brands, which was highly recommended (Untung 1996). When the prohibition of was issued, there were political constraints in enforcing the regulation. Further, there was a resistance to moving from intensive practices to environmentally sound polices because of several high-ranking officers of Ministry of Agriculture being involved in pesticide suppliers (Oka 1997). This led to a black market of pesticides, which seemed to be the cause of only a moderate reduction in pesticide use. The most likely effective component was the elimination of pesticide subsidies in 1989. There was a strong link between uses of chemicals, particularly pesticides, with the government subsidies during the Green Revolution.

An equation using an estimated relationship between pesticide use and subsidies can be used to better understand the impact of subsidies on pesticide use.

Figure 3 shows that pesticide use increased along with the increase in subsidies. When the subsidies were reduced, the use of pesticides declined. Using a further simple regression, the result suggests that the use pesticides increased by around 84 tons when there was \$1 million increase in subsidies.

The delayed impact on pesticide use was due partly to a pilot IPM project during the first three years (1989–1992). A massive extension campaign starting from 1994 brought about

further declines in the use of pesticides. The small magnitude of declining chemical use was because of small fraction of farmers who applied the technology (Feder *et al.* 2004a).²

Results

From Figures 2 and 3, we can see many variations in yield of rice and use of inputs. In particular, the increase in rice yields was not driven by increases in all inputs. Some input declined and others rose, despite the fact that yield of rice rose steadily. This indicates that technological change has played an important role in driving the dynamic yields of rice.

The estimated parameters and model diagnostics for Equation (8) are presented in Table 2.

The table shows that the restriction of $\gamma = \mu = \eta = 0$ is rejected, meaning that the production function estimated using the frontier is different from that estimated using ordinary least squares. The estimated coefficient of the dummy variable for wetland is large and positive and statistically different from zero at the 5% level of significance. This means that total factor productivity, represented by the intercept in rice agriculture under

Table 2. Frontier yield function of rice.

ln y	Hicks-neutral		Biased		Effect of GR	
	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
ln β_0	7.5561	269.80 ^a	7.5016	220.35 ^a	7.4794	213.29 ^a
ln k	0.0016	4.60 ^a	0.0028	4.63 ^a	0.0021	2.57 ^b
ln l	0.0085	1.60 ^c	0.0323	3.95 ^a	0.0406	4.00 ^a
ln m	0.0079	1.42	0.0017	0.19	0.0093	0.81
ln x	0.0009	1.04	-0.0024	-1.80 ^b	-0.0044	-2.49 ^b
W	1.0398	15.33 ^a	0.9072	14.27 ^a	0.9082	14.48 ^a
T ln k			-0.0001	-2.56 ^b	-0.0001	-2.10 ^b
T ln l			-0.0027	-3.93 ^a	-0.0031	-3.76 ^a
T ln m			0.0005	0.54	-0.0005	-0.48
T ln x			0.0004	2.72 ^b	0.0004	2.68 ^b
GT ln k					-0.0001	-0.78
GT ln l					-0.0023	-1.83 ^c
GT ln m					-0.0002	-0.14
GT ln x					0.0005	1.89 ^c
T	0.0138	6.14 ^a	0.0218	6.64 ^a	0.0271	7.86 ^a
T ²	0.0002	2.31 ^b	0.0002	1.57	0.0000	-0.11
γ	0.9676	74.55	0.9546	53.28 ^a	0.9555	56.77 ^a
μ	0.3600	4.74	0.3259	3.17 ^b	0.3333	3.30 ^b
η	-0.0152	-8.47	-0.0175	-8.29 ^a	-0.0166	-8.25 ^a
Log-likelihood		940.17		954.60		971.88
Test for $\gamma = \mu = \eta = 0$		1150 ^a		1168 ^a		1193 ^a
Test for $\beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0$				28.86 ^a		
Test for $\beta_{Gtk} = \beta_{Gtl} = \beta_{Gtm} = \beta_{Gtx} = 0$						34.56 ^a

Note: Dependent variable is rice production per hectare (logged); W is dummy variable = 1 for wetland 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 (1986).

^aSignificant at 0.01.

^bSignificant at 0.05.

^cSignificant at 0.1.

Source: Authors' calculation.

intensification programmes, is much higher than that in non-intensification programmes. Thus, the rice yield in wetland is estimated to be almost double than that in dryland.

Keeping the use of inputs constant, rice agriculture underwent technological progress at a constant rate. The restriction of $\beta_{tk} = \beta_{tl} = \beta_{tm} = \beta_{tx} = 0$ is rejected, meaning that technological change is not Hicks-neutral. From the model of biased technological change, it can be seen that the technological change is capital saving, labour saving and chemical augmenting. This means that the use of capital and labour declined over time relative to materials and chemicals. It appears that modern chemicals and materials enabled farmers to reduce labour use. The higher proportion of materials and chemicals occurred because seed technology was developed to find varieties of rice responsive to inputs, including irrigation.

The restriction of $\beta_{Gtk} = \beta_{Gtl} = \beta_{Gtm} = \beta_{Gtx} = 0$ is rejected, meaning that there was a difference in biased technological change in the era of the Green Revolution and IPM policies. We can see that β_{Gtl} is positive and statistically different from zero at the 5% level of significance; β_{Gtx} is also negative and statistically different from zero at the 5% level. This means that during the Green Revolution, the technological change in rice agriculture was more labour saving and more chemical using. In other words, the technological change after the Green Revolution (post-1989) was more labour augmenting and less chemical augmenting.

Input use in Indonesian rice production was not Hicks-neutral. The non-neutral technological change implies that the marginal rate of technical substitutions did vary over time and resulted from time-varying output elasticity with respect to some inputs. The mean output elasticities with respect to inputs are given in Table 3.

With respect to labour, the output elasticity with IPM was greater than during the Green Revolution. Conversely, with respect to chemicals, the output elasticity with IPM was less than during the Green Revolution. However, note that the output elasticity with respect to each input was very small, even negative.³

It has been shown that technological change during the Green Revolution was more chemical intensive than during the environmentally friendly policy periods of the IPM. This finding is in line with a study of Murgai (2001) on technological progress in relation with the Green Revolution. The conclusion is that technological change was biased. During the Green Revolution, chemical input use was subsidised by the government and new rice-seed technology responsive to chemical fertilisers was introduced along with mass guidance. A study on technological change of the Philippine rice sector by Umetsu *et al.* (2003) also indicates that change in productivity of rice is related to the intensification caused by the Green Revolution, which promoted chemical use. All actions of government policies, such as subsidies, agricultural credit for inputs including chemicals and intensive training during the Green Revolution, were reflected by more chemical-using technological change.

Table 3. Mean output elasticities of inputs.

Agro-ecosystem	Factors				Total
	Capital	Labour	Materials	Chemicals	
Green Revolution	0.0011	-0.0034	0	0.0046	0.0023
After Green Revolution	0.0011	0.0096	0	0.0004	0.0111

Source: Authors' calculation.

The technological change after the introduction of IPM, in which environmentally sound technology was applied, was more labour using and less chemical augmenting. In the post-1989 era, the environmentally friendly technology has been addressed to reduce pesticide use and to correct fertiliser use. More labour-using technological change is reasonable because implementing the technology needs regular observations on rice agro-ecosystems (Untung 1996). As a result, more labour was devoted into rice production activities.

Practical policy implication

There are policy implications related to the findings. With respect to the elasticity of land that is greater than 0.9, the practical implication is that it is not recommended to increase the use of agricultural inputs in order to increase production. The most reasonable recommendation is to increase land use, as it can considerably increase the production. Such implications are strongly in line with the agricultural revitalisation programmed under the Presidency of Susilo Bambang Yudhoyono. 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 (Sinukaban 2005). Las *et al.* (2006) point out that the agricultural revitalisation also should not jeopardise the environment.

Conclusion

In Indonesia, rice is a politically and economically strategic commodity. It serves as a staple food for more than 200 million people. The rice sector occupies more than a half of rural people. Efforts to increase rice production have been conducted through many programmes and policies since 1960s. All policies and programmes related to rice production can be represented by a modernisation or technological progress in rice agriculture. The Green Revolution was the first breakthrough in enhancing rice production. Various intensification programmes were launched, and massive campaigns accompanied the introduction of new varieties of rice, inorganic fertilisers and synthetic pesticides. The actions resulted in a remarkable increase in rice production. But adverse impacts of chemical use on human health and the environment accompanying the success became an important concern. The policy then changed from environmentally damaging to environmentally sound, without sacrificing rice production. With the particular target of reducing use of chemicals, IPM, which is regarded as environmentally friendly technology, was disseminated to improve the existing agricultural practices. Pesticide subsidies were totally waived and 57 brands of problematic pesticides were banned from rice production. The results of such actions at a national level could be represented by a technological change.

Technological change in rice agriculture was non-neutral. Stochastic frontier analysis shows that the type of technological change during the Green Revolution was different from that during the era of environmentally sound policies. Technological change during the Green Revolution was less labour saving and more chemical using. More chemical-using technological change during the Green Revolution was mostly driven by development of seed technology.

The technological change after the Green Revolution and IPM, in which environmentally sound technology was applied, was more labour intensive and more chemical saving. In this era, environmentally friendly technology was addressed to use pesticides and fertilisers wisely. More labour-using technological change is because of implementing the technology that needs regular observations on rice agro-ecosystem.

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Notes

1. There is a strong criticism that an econometrically estimated production function will not provide unbiased estimators because of simultaneous bias resulting from endogeneity of inputs use (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 rationed. Furthermore, 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 regardless of the measurement of inputs. There is no need to cope with endogeneity of inputs as suggested by economists (e.g. Widawsky *et al.* 1998, Savvides and Zachariadis 2005) in estimating the production function or to convert the value of inputs into indices (e.g. Hadri and Whittaker 1999).
2. The data used in this study cover provinces, which are not the direct target of dissemination of technology. The technology had been disseminated in 12 of 27 provinces at the time.
3. This is an indication that the rice farm was very intensive. The sum of elasticity with respect to all inputs is less than 0.1. As mentioned before, the production function is assumed to exhibit constant return to scale, and the elasticity of rice production with respect to land is more than 0.9, which is very high. This result suggests that if the same level of inputs is applied into 2 ha of land, the rice production increases by 98%, or almost double. In some cases, agricultural output elasticity with respect to land was likely to be very high in Indonesia (Trewin *et al.* 1995, Sumaryanto *et al.* 2003), the Philippines (Villano and Fleming 2006), China (Yao and Liu 1998) and Ivory Coast (Sherlund *et al.* 2002). But for the case of Vietnamese rice agriculture, the highest output elasticity was not with respect to land (Che *et al.* 2001) but with respect to material inputs (Che *et al.* 2006).

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Appendix 1. Summary statistics for variables in wetland and dryland by major region.

Regions	Wetland					Dryland				
	Yield	Capital	Labour	Material	Chemical	Yield	Capital	Labour	Material	Chemical
Sumatra (150 ocean bottom seismometers [observations])	Mean	3667.86	4.32	62.96	24.81	340.85	0.87	1928.45	14.20	109.23
	SD	527.30	4.65	31.33	15.35	178.81	1.69	276.21	7.89	121.07
	Min	2298.00	0	6.82	3.55	1.77	0.	1251.00	0.92	0
	Max	4687.00	27.83	150.71	81.75	745.62	9.50	2439.00	75.06	404.19
Java & Bali (95 observations)	Mean	5029.26	10.43	130.19	28.45	688.49	2.52	2204.96	15.65	308.52
	SD	375.38	6.74	41.34	10.30	122.62	2.74	363.56	7.84	160.25
	Min	3875.00	0.64	54.39	9.03	364.53	0.00	1202.00	2.95	0
	Max	5786.00	35.07	311.38	51.96	916.81	15.52	2803.00	59.13	668.60
Kalimantan (76 observations)	Mean	2580.50	0.54	37.94	17.02	170.79	0.39	1673.80	26.29	28.67
	SD	297.09	0.90	22.03	7.77	108.69	0.90	229.63	6.59	48.85
	Min	1989.00	0	2.92	0.36	2.06	0	1125.00	1.41	0
	Max	3387.00	4.99	104.80	34.07	421.97	5.86	2209.00	80.86	228.58
Nusa Tenggara (38 observations)	Mean	3658.13	14.93	59.34	21.66	346.35	1.71	1785.82	25.00	38.11
	SD	607.89	5.32	32.96	11.13	227.33	2.06	272.56	17.15	45.35
	Min	2648.00	4.36	11.87	4.37	29.14	0	1229.00	3.79	0
	Max	4595.00	27.14	117.39	58.52	800.77	9.22	2259.00	62.06	211.32
Sulawesi (76 observations)	Mean	3647.72	9.38	66.55	33.61	303.97	2.54	1729.40	31.43	31.32
	SD	557.32	8.58	36.26	16.51	131.27	3.77	226.19	19.77	54.19
	Min	2227.00	0.00	8.83	3.49	14.26	0	1356.00	0.73	0
	Max	4766.00	37.22	195.82	71.49	547.12	17.64	2314.00	88.04	327.25
Indonesia (435 observations)	Mean	3770.84	6.80	73.58	25.51	381.09	1.51	1897.11	32.74	118.85
	SD	910.28	7.17	45.83	14.12	231.94	2.52	339.02	23.07	151.43
	Min	1989.00	0	2.92	0.36	1.77	0	1125.00	0.73	0
	Max	5786.00	37.22	311.38	81.75	916.81	17.64	2803.00	165.97	668.60

Note: See Table 1 for units of measurement.
Source: Authors' calculation.

Appendix 2. Summary statistics for variables in wetland by year.

Year		Yield	Capital	Labour	Material	Chemical
1979	Mean	3617.04	10.83	63.59	13.16	178.21
	SD	870.25	10.12	66.93	10.01	178.33
1980	Mean	3939.17	10.92	81.38	18.91	237.94
	SD	1000.15	9.39	62.78	9.60	202.98
1981	Mean	3221.30	11.13	73.26	17.58	280.05
	SD	775.77	9.02	48.62	6.06	220.96
1982	Mean	3440.83	11.03	82.25	16.46	317.64
	SD	800.59	10.80	46.66	5.66	210.53
1983	Mean	3567.09	10.29	70.77	17.24	360.95
	SD	834.02	9.39	42.04	8.97	229.90
1984	Mean	3569.57	6.79	57.99	19.08	328.44
	SD	852.13	5.29	39.97	8.39	255.37
1985	Mean	3601.09	6.79	66.69	27.39	330.34
	SD	851.80	5.29	39.24	9.39	234.61
1986	Mean	3676.48	6.79	64.90	27.76	350.96
	SD	870.00	5.29	34.37	12.80	217.41
1987	Mean	3650.17	3.00	68.32	27.96	395.18
	SD	884.37	2.93	38.00	15.49	206.23
1988	Mean	3738.17	6.03	72.37	35.47	431.86
	SD	909.86	5.29	40.74	19.55	257.83
1989	Mean	3836.30	7.07	78.55	33.26	455.28
	SD	929.76	6.52	37.36	15.15	242.95
1990	Mean	3889.52	4.27	72.37	24.17	446.04
	SD	944.09	4.71	41.99	12.52	238.56
1991	Mean	3950.83	6.03	75.89	31.74	474.81
	SD	939.63	5.23	47.27	15.84	203.95
1992	Mean	3970.65	7.52	84.39	31.31	467.44
	SD	940.90	7.39	51.18	18.55	218.33
1993	Mean	3982.04	6.19	76.82	29.21	444.97
	SD	947.27	6.56	42.57	14.72	208.23
1994	Mean	3992.74	4.75	74.33	30.61	437.52
	SD	952.53	4.94	44.35	13.09	211.24
1995	Mean	4018.65	4.26	78.21	29.10	447.91
	SD	937.83	4.86	50.41	11.94	219.83
1996	Mean	4080.22	2.94	80.07	31.89	420.38
	SD	928.08	2.93	48.76	14.19	194.48
1997	Mean	3916.67	2.27	76.09	22.01	439.97
	SD	913.90	3.85	42.73	10.25	241.03
Indonesia	Mean	3770.84	5.73	73.58	25.51	381.09
	SD	910.28	7.30	45.83	14.12	231.94

Note: See Table 1 for units of measurement. Dickey–Fuller test for residual -4.379 , $p > 0.01$.

Source: Authors' calculation.

Appendix 3. Summary statistics for variables in dryland by year.

Year		Yield	Capital	Labour	Material	Chemical
1979	Mean	1742.57	2.17	29.71	7.66	34.41
	SD	224.14	2.57	35.72	5.75	53.67
1980	Mean	1800.17	1.92	35.90	11.40	68.71
	SD	240.77	3.37	24.44	5.89	104.67
1981	Mean	1505.09	2.08	38.15	12.93	82.43
	SD	188.63	4.09	27.33	6.37	113.36
1982	Mean	1655.09	3.23	35.03	12.74	80.28
	SD	190.52	4.57	25.11	6.56	110.71
1983	Mean	1685.17	1.49	28.60	10.77	81.56
	SD	202.29	2.23	20.44	6.38	112.49
1984	Mean	1705.70	1.51	22.05	9.56	124.02
	SD	273.86	1.57	17.77	3.82	171.22
1985	Mean	1724.09	1.51	27.13	14.64	120.27
	SD	316.10	1.57	17.54	5.48	150.55
1986	Mean	1761.52	1.51	32.48	19.06	115.10
	SD	270.85	1.57	19.61	10.58	146.22
1987	Mean	1813.04	1.16	39.74	22.63	135.53
	SD	294.90	2.40	22.44	13.63	161.66
1988	Mean	1895.61	1.43	30.06	22.06	134.11
	SD	275.92	2.56	18.33	12.39	175.25
1989	Mean	1953.22	0.95	33.06	18.78	123.44
	SD	327.01	1.43	21.26	9.80	156.27
1990	Mean	2023.44	0.90	28.27	16.85	122.42
	SD	302.34	1.63	18.79	8.44	150.96
1991	Mean	2061.61	1.17	34.13	20.29	161.41
	SD	295.51	1.98	27.62	10.34	192.17
1992	Mean	2100.61	1.14	36.05	17.89	140.18
	SD	305.18	1.97	22.41	7.64	158.95
1993	Mean	2121.35	2.13	37.12	15.46	162.94
	SD	303.50	3.69	24.52	5.46	176.89
1994	Mean	2121.65	1.34	33.25	20.08	140.09
	SD	310.65	1.58	20.24	6.17	165.01
1995	Mean	2112.44	1.25	35.93	15.70	144.61
	SD	312.80	1.97	22.78	4.92	170.60
1996	Mean	2155.17	1.10	27.54	14.61	121.52
	SD	307.06	1.80	18.88	10.13	150.93
1997	Mean	2127.57	0.68	38.39	9.33	169.63
	SD	347.70	1.67	26.14	5.46	174.40
Indonesia	Mean	1897.11	1.27	32.74	15.42	118.85
	SD	339.02	2.50	23.07	9.04	151.43

Note: See Table 1 for units of measurements. Dickey–Fuller test for residual -3.744 , $p > 0.05$.

Source: Authors' calculation.