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Pesticide Productivity in Green Revolution Rice Production: A Case Study of Vietnam

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Introduction

The use of pesticides in the Green Revolution has become increasingly controversial. While the benefits of pesticide use in terms of preventing crop losses and increasing food grain production have been well recognized, its unwanted side effects on human health and environment have become a major concern. Two types of problems have been recognized traditionally. First, pesticide use may exacerbate pest problems rather than reduce them. Insecticides have also been found to disrupt the natural habitats and the food web structures of natural enemies of rice insect pests in Southeast Asia, creating pest outbreaks that can lead to increased use of and dependence on pesticides (Barrion et al., Bottrell and Weil, Cohen et al., Heong et al., Schoenly et al., Settle et al., Way and Heong). Pesticides may also create new, less tractable pest problems when suppression of a primary pest allows the expansion of populations of what had formerly been secondary pests. For example, major outbreaks in the 1970s of the rice brown plant hopper, a secondary rice pest before 1964, were attributed to the overuse of insecticides (Kenmore, Kenmore et al., Heinrichs and Mochida). Second, pesticides may have detrimental effects on human health and wildlife. Increased use of pesticides has resulted in greater incidence of pesticide poisoning in developing countries. Many cases of poisoning have been reported to result from spillage of pesticides during storage and transportation and from misuse of pesticides during application (Oka 1983, Oka 1988, Aros). Adverse effects of pesticide use on farmers' health have in turn reduced labor productivity (Antle and Pingali, Rola and Pingali). Pesticide residues have been found in food supplies and in water bodies used for drinking, bathing, and clothes washing throughout Southeast Asia putting farmers and the general population at risk of pesticide poisoning due to direct and indirect exposure (Mustamin, Oka 1988, Tayaputch).

More recently, a third type of problem has attracted attention: The possibility that pesticides harm vertebrates and crustaceans growing in rice fields. These organisms are often harvested for food and constitute an important source of protein in farmers' diets. They may also provide a form of biological control against pests in rice fields. Fish, for example, eat harmful insects and their larvae (Wu, Amaritsut et al.). The use of pesticides for weed, insect, and disease control in waters of tropical countries has increased mortality of aquatic animal species such as fish, frogs, mollusks, and crustaceans that have traditionally been harvested for food from paddies along with rice (Cagauan, Grist, Miller et al., Niimi). Pesticides can harm these species by direct poisoning and indirectly by disrupting their food sources and habitat, causing them to starve, emigrate or cease to reproduce (Bottrell and Weil).

Economic evaluations using crop budgets conducted during early years of Green Revolution rice production in Southeast Asia showed that farmers typically overapplied pesticides (Waibel, Herdt, Kenmore et al., Smith et al.). The subsequent introduction of resistant rice varieties was shown to reduce profit-maximizing pesticide application rates still further (Herdt, Kenmore, Smith et al.). More recent econometric studies that examine adverse health affects in addition to rice productivity similarly indicate that current pesticide application rates on rice in Southeast Asia tend to be higher than optimal (Antle and Pingali).

The government of Vietnam and the International Rice Research Institute (IRRI) have jointly introduced two programs aimed at reducing farmers use of pesticides. The earliest was an integrated pest management (IPM) that provided extensive training for extension agents and farmers about the plant physiology, rice ecosystem dynamics, methods of pest sampling, and determination of pesticide treatment thresholds. Shortly afterwards, they introduced a farmer participatory research (FPR) program that asked farmers to refrain from spraying insecticides during the first 40 days after planting. At the end of each season, yields from the experimental fields were compared to historical yields and yields of non-participants (for a more extensive description see IRRI). Participation in the FPR program did not require formal training; rather, it was designed as a demonstration project that would allow farmers to draw conclusions from their own experiences about the value of cutting pesticide use. Heong et al. found no statistically significant difference between the rice yields of FPR participants and non-participants. However, their analysis did not control for input use or for harvests of aquatic animals.

This paper evaluates pesticide productivity in rice production in Vietnam under traditional methods and under the FPR program. In contrast to previous assessments of pesticide productivity in Green Revolution rice, all of which have treated rice fields as single output systems involving only the production of grain, we use a multi-product approach that includes harvests of aquatic animal foods in addition to rice. In contrast to previous assessments of the impacts of pesticide use on fish, the multi-product approach we use includes impacts on rice productivity as well as on aquatic organisms.

Our study utilizes data from an original survey of rice production in the Mekong Delta during 1996 and 1997. We use nonparametric methods (data envelopment analysis) to obtain a piecewise linear representation of the joint rice/aquatic animal production technology for each of two growing seasons. We use statistical tests based on these representations to address the question of whether pesticide use has harmful effects on production (i.e., negative marginal productivity) and to evaluate whether the FPR program improved the technical and cost efficiency of pesticide use in rice production.

Rice Production in the Mekong Delta

Rice is the major annual crop in Vietnam. In recent years, rice has become Vietnam's principal agricultural export and a chief source of foreign exchange. Vietnam has become the second largest exporter of rice in the world, trailing only Thailand.

The Mekong River Delta is the most fertile rice growing area of Vietnam and accounts for nearly half percent of Vietnam's total rice production. Up to three rice crops can be produced per year. Rice cultivation is largely rainfed in the region, so rice planting is limited to the rainy months, which typically begins in April and lasts until November, allowing farmers to plant only two rice crops a year (in the Summer-Autumn and Winter-Spring seasons). Two general types of rice varieties are grown. Traditional long duration varieties generally require longer growing seasons but produce higher quality grain. Modern short duration varieties require shorter growing periods but produce lower quality rice. Short duration variety rice is normally grown in the Winter-Spring season to take advantage of the longer daylight hours and shorter maturation time. Long duration rice varieties are usually planted in the Summer-Autumn season when shorter daylight hours require the cropping season to be longer. Households that live closer to rivers or have access to irrigation can plant a third rice crop of short duration varieties. Those with adequate capital and access to water sometimes plant watermelons or vegetables in the third season instead of a short duration rice crop. Otherwise, fields are left fallow during this third season.

Traditional rice variety seeds are typically germinated in rice nurseries. Seedlings are subsequently transplanted. Rice fields are usually cleared prior to transplanting. Paddy straw and stubble are often burned during this stage to improve field sanitation and kill weed plants and weed seeds. The field is then fallowed for one or two days before farmers plow or harrow. Fields are then flooded, usually by rainfall, with some farmers supplementing water supplies by irrigation. Farmers who are able to control their water supply maintain the water level at about one foot. The water is then drained, leaving fields wet for transplanting. Transplanting is labor intensive and has to be completed within a very short period in order to ensure uniform crop maturity. For this reason, transplanting is generally done cooperatively in groups, mainly women, who transplant each others' fields in turn. Fertilizers are broadcast. Weeds can be pulled by hand or treated with herbicides. Insecticides and fungicides are applied periodically during the season, typically by one person using a backpack sprayer. Additional broadcast applications of fertilizers are often made during the season as well. Rice is harvested by hand when mature, then threshed and dried in the open. It is then packed and hauled to a mill to the the husk removed. When rainfall is heavy and drying is infeasible, farmers often sell their entire harvest to millers on site.

Modern rice variety seeds are sown by broadcast rather than grown in nurseries and then transplanted. Water is let into the field as the seeds germinate. Seedlings that have been sown too close together are uprooted and replanted to ensure sufficient space for adequate growth. Otherwise, modern short duration varieties are cultivated in the same way as traditional long duration varieties.

Mekong Delta farmers typically have fishponds near their homes. They stock these ponds with small fish purchased from local stores, feed the fish, and then harvest them for home consumption. The process continues all year round. Most households rely on these ponds for most of the fish they consume; only a few purchase fish of edible size from local markets. Some farmers also harvest fish from their rice fields. Fish enter rice fields along with irrigation water and are caught with a hook and line during the season and with nets at the end of the season when fields are drained. Fish in rice fields are not fed. Farmers also catch eels, frogs, mice, and snakes from their rice fields. Everything caught is used for home consumption.

Data

The data used in the study comes from two household surveys administered to 310 rice-farming families in Tan Tru District of Long An Province of the Mekong River Delta under the auspices of the International Rice Research Institute (IRRI) and the Sub-department of Plant Protection of Long An. Five extension agents from the Plant Protection Station in Tan Tru District administered the survey under the supervision of one of the authors. The agents monitored rice and aquatic animal food harvests of approximately 30 rice-farming households from each of the 11 villages in the District during the1996 Autumn-Winter and 1997 Summer-Autumn seasons.

Socioeconomic characteristics of participating households were recorded at the beginning of the study. Participating households were asked to keep daily logs of rice-farming and aquatic animal harvesting activities as well as input and output prices. Enumerators collected that information on two occasions, one early during each growing season and the other after harvest.

Socio-economic information collected included the number of household members, as well as the gender, age, education, marital status, and occupation of each. Whether the head of the household had received IPM training was also reported, as was whether the household had participated in the FPR program. Information collected on land use included the number of plots planted in rice, the size of each plot, the quality and elevation of each plot, and the number and method of irrigation as well as the type of farming practices employed on each. Information collected on planting practices included the sowing method, the type and amount of seeds used, and unit price for each variety of seed planted.

Information collected on labor included the type and amount labor employed broken down by the type and timing of tasks. Planting time tasks reported included cleaning seeds, clearing fields, preparing seedbeds, managing irrigation water, plowing, harrowing, broadcasting, transplanting, and replanting. Growing season tasks reported consisted mainly of time spent applying chemicals (reported separately for herbicides, insecticides, fungicides, fertilizers, and micronutrients) plus hand weeding. Harvest time tasks reported included harvesting, threshing, collecting, winnowing, hauling, drying, and storing. Amounts of labor performed by family members, by hired workers, and by neighbors under the cooperative exchange labor system discussed above were reported separately for each task. Farmers were also asked to report the wage they would pay a hired worker for each task.

Information was collected on the total time spent using hand implements (plowing shovels, threshing boards, pesticide applicators, hoes, sickles, scythes, and harvesting knives), machinery used for pumping, plowing, and harrowing, and draft animals (water buffaloes or oxen). Farmers were asked to report a commercial rental rate for each item. Information collected on other variable inputs included the amounts, times of application, and prices of fertilizers, micronutrients, individual pesticide chemicals, and gasoline. The pesticide use data were used to confirm whether each household had actually followed the FPR guidelines by refraining from spraying during the first 40 days after planting.

Finally, farmers reported the quantities of modern and traditional rice varieties produced and aquatic animals harvested for food from their rice fields, all measured by weight. Prices received for rice sold and amounts of rice retained for home consumption were also reported.

Data on characteristics of the general population of Mekong Delta rice farmers a year or so prior to this survey are available in a report by IFPRI. The households participating in this survey seem comparable in terms of household size, number of adults, landholding, rice yields, and shares of cash expenditures allocated to most inputs (Table 1). The farmers in Tran Tru spent relatively more on fertilizers and less on seeds than the Mekong Delta average. Mean input usage and outputs levels of the farmers participating in this survey are given in Table 2.

Methodology

We investigate two questions: (1) whether pesticides have harmful effects on the productivity of rice/aquatic animal production systems and (2) whether the FPR program enhances the efficiency of rice/aquatic animal production. We adopt a non-parametric approach, primarily because it handles multiple outputs more naturally than parametric methods. Specifically, we use data envelopment analysis (DEA) to construct a piecewise linear approximation of the rice/aquatic animal food production technology. We use DEA-based statistical tests developed by Banker and by Brockett and Golany to test formally (1) whether pesticides exhibit negative marginal productivity and (2) whether FPR participants are more technically and cost efficient than non-participants.

A general specification of the multi-product rice/aquatic animal production technology is as follows. Let $x \in \Re_+^N$ be a vector of the N inputs employed to produce the vector of M outputs $y \in \Re_+^M$ by the J farmers in the survey sample. The production process is characterized by the technology set $T = \{(x, y) \in \Re_+^{N+M} : \text{x can produce y}\}$. We assume that T satisfies the standard fundamental properties of nonnegativity of the input set, non-emptiness and nonnegativity of the output bundle, closedness, boundedness and convexity. A technology set satisfying the preceding assumptions plus the standard assumptions of free disposability of inputs and variable returns to scale can be represented as $T^S(x,y) = \{(x,y): y_{jm} \leq \sum_{j=1}^{J} z_j y_{jm},\ m = 1,\ldots,M,\ x_{jn} \leq \sum_{j=1}^{J} z_j x_{jn}, n = 1,\ldots,N,$ $\sum_{j=1}^{J} z_j = 1$, j = 1, …, J}, where the $z_j \geq 0$ weight the observed output and input levels (Fare, Grosskopf, and Lovell).

We concentrate on input oriented representations of this technology for two reasons. First, we are interested in pesticide productivity. Second, we cannot observe a complete set of output prices because aquatic animals are harvested exclusively for home consumption. Let V(y) denote the set of inputs that can produce the output vector y, i.e., V(y) = {x: (x,y) $\in$ T}. A piecewise linear approximation of the technically efficient frontier of this input set can be found by solving the linear programming problem

$\theta_j^S = \{\min \theta : (\theta_j x_j, y_j) \in T^S, \theta_j^S \in [0,1], j = 1,.., J\}$ for each farmer j (Fare, Grosskopf, and Lovell). The problem solves for the largest possible radial contraction of each farmer's input bundle consistent with achieving the farmer's observed output bundle. The scaling factor $\theta \leq 1$ is equivalent to the Farrell measure of technical efficiency. Efficient input combinations have $\theta = 1$. Inefficient input bundles have $\theta < 1$, indicating that the farmer's observed output bundle can be produced using a convex combination of other farmers' input bundles featuring strictly less of at least one input.

A piecewise linear approximation of the allocatively efficient frontier of this input set can be found by solving the cost minimization problem $C(y_j,w_j) = \min \{w_j \bullet x: (x,y_j) \in T\}$, where w_j denotes the vector of input prices reported by farmer j and T denotes the technology specification. The solution to this problem is the minimum cost of producing the farmer's observed output bundle given the input prices faced by the farmer. The corresponding measure of cost efficiency is $\omega_j = C(y_j,w_j)/w_j \bullet x_j$, the ratio of the minimum cost of the output bundle to the farmer's observed expenditure. Efficient input bundles have $\omega = 1$. Inefficient input bundles have $\omega > 1$, indicating greater expenditures than needed to produce the farmer's input bundle (Fare, Grosskopf, and Lovell).

Weak Disposability and Negative Productivity

We use the concept of weak disposability of inputs to examine whether pesticides (or other inputs) have harmful effects on the joint production of rice and aquatic animal foods. This concept was introduced by Fare and Svenson to address the possibility of input or output congestion, in contrast to the standard assumption of free or strong disposability which does not permit congestion effects. Formally, a technology exhibits strong disposability if $x \in V(y)$ implies that any x' that differs from x only in having more of at least one input is also in V(y). Intuitively, adding more of any input results in nothing worse than the same output level, i.e., the marginal productivity of any input is always non-negative.

A technology is said to exhibit weak disposability if input bundles consisting of elements that are all proportionately greater than an input bundle in V(y) is also in V(y), $x \in V(y) \Rightarrow q\, x \in V(y), q \geq 1$. Intuitively, increasing the use of one input will decrease output unless other inputs are increased to counteract the deleterious effects of that input. Inputs exhibiting weak disposability thus essentially have negative marginal productivity.

A technology set satisfying the standard assumptions plus the assumptions of weak disposability of inputs, and variable returns to scale can be represented as folllows. Suppose that inputs 1, …, N_1 are weakly disposable while the remainder are strongly disposable. Then the technology set is $T^W(x,y) = \{(x,y)\colon y_{jm} \leq \sum_{j=1}^{J} z_j y_{jm},\ m = 1,\ldots,M,$

$$x_{jn} = \sum_{j=1}^{J} z_j x_{jn}, n = 1,\ldots,N_1,\ x_{jn} \leq \sum_{j=1}^{J} z_j x_{jn}, n = N_1 + 1,\ldots,N,\ \sum_{j=1}^{J} z_j = 1,\ j = 1,\ \ldots,\ J\},$$

where the $z_j \geq 0$ weight the observed output and input levels. T^W differs from T^S in that a strict equality holds for the constraints of the weakly disposable inputs, in contrast to the weak inequality holding for strongly disposable inputs. A piecewise linear approximation of the technically efficient frontier of this input set can be found by solving the linear programming problem

$q_j^W = \{\min q : (q_j x_j; y_j) \in T^W, q_j^W \in [0,1], j = 1,..,J\}$ for each farmer i (Fare, Grosskopf, and Lovell).

We use the statistical tests proposed by Banker (1993, 1996) to test formally whether inputs exhibit weak or strong disposability. If deviations from the efficient frontier are independently, identically distributed one-sided random errors whose density is monotonically decreasing, Banker (1993) shows that DEA corresponds to a maximum likelihood estimator of an arbitrary monotone, concave production function. If those random errors are distributed exponentially with mean $1+\sigma$, the test statistic for the null hypothesis that inputs are freely disposable against the alternative hypothesis that inputs are weakly disposable is $\sum_{j=1}^{J}(q_j^S - 1) \Big/ \sum_{j=1}^{J}(q_j^W - 1)$, which has an F distribution with (2J, 2J) degrees of freedom. If those random errors have a half-normal distribution with zero mean and variance σ_k (where k = S,W distinguishes the errors under the assumptions of strong and weak disposability, respectively), the relevant test statistic is $\sum_{j=1}^{J}(q_j^S - 1)^2 \Big/ \sum_{j=1}^{J}(q_j^W - 1)^2$, which has an F distribution with (J, J) degrees of freedom (Banker 1996).

We use these tests under both specifications of the random error to examine the type of disposability exhibited by each input in each of the two growing seasons. We then base the final specification of the rice/aquatic animal production technology in each season on the results of those tests.

Technical and Cost Efficiency of the FPR Program

We investigate whether the FPR program improved the efficiency of the joint rice/aquatic animal production system in each season in terms of both technical and cost efficiency using statistical tests proposed by Banker (1996) and by Brockett and Golany. We begin with Banker's tests, which can be used to test alternative specifications of the technology in addition to the comparative efficiency of FPR participants and non-participants. Let J_P denote the set of farmers who participated in the FPR program and J_{NP} denote the set of farmers who did not. Let $\theta = (\theta_1, \ldots, \theta_J)$ be the efficiency measures obtained from the final specification of the technology (i.e., with the disposability of each input specified according to the results of the statistical tests described in the preceding section). Let FPR denote the set of J_P farmers who participated in the FPR program and NFPR denote the set of J_{NP} farmers who did not. If the random deviations from the technically efficient frontier are distributed exponentially, the test statistic for the null hypothesis that participants and non-participants are equally technically efficient against the alternative hypothesis that non-participants are less technically efficient than participants is

$$\frac{\sum_{j\in NFPR}(q_j-1)}{J_{NP}} \Bigg/ \frac{\sum_{j\in FPR}(q_j-1)}{J_P}$$, which has an F distribution with $(2J_{NP}, 2J_P)$ degrees of freedom. If those random errors have a half-normal distribution with zero mean and variance σ_k (where k = P,NP distinguishes the errors of FPR participants and non-participants, respectively), the relevant test statistic is

$$\frac{\sum_{j\in NFPR}(q_j-1)^2}{J_{NP}} \Bigg/ \frac{\sum_{j\in FPR}(q_j-1)^2}{J_P}$$, which has an F distribution with (J_{NP}, J_P) degrees of freedom (Banker 1996).

We also apply these tests to the cost efficiency measures $\omega_1, \ldots, \omega_J$ to evaluate the null hypothesis that participants and non-participants are equally cost efficient against the alternative hypothesis that non-participants are less cost efficient than participants.

Brockett and Golany have argued that the tests proposed by Banker are prone to selection bias in that they cannot distinguish differences in efficiency due to differences in unobserved managerial skills of participants and nonparticipants from differences in efficiency due strictly to a policy or program. They propose a non-parametric test that can make this distinction. We used that test in addition to those proposed by Banker to examine whether the FPR program improved the technical of the multi-product rice/aquatic animal production system. In the first phase of the test procedure, efficiency measures are calculated for each group separately, i.e., relative to its own within-group frontier technology. Observed input bundles are then contracted radially using the estimated efficiency score to obtain an efficient input bundle for producing each farmer's observed output bundle. These efficient input bundles are then pooled into a single sample used to obtain overall efficiency scores $\theta_1^o, \ldots, \theta_J^o$ ($\omega_1^o, \ldots, \omega_J^o$ for the corresponding test of cost efficiency). These overall efficiency scores are then ranked in descending order (i.e., with one indicating the highest efficiency level) and used to calculate the standard normal test statistic $\frac{U - J_{NP} \cdot J_P}{\sqrt{\frac{J_{NP} \cdot J_P \cdot (J_{NP} + J_P + 1)}{12}}}$, where

$U = J_{NP} \cdot J_P + \frac{J_{NP} \cdot (J_{NP} + 1)}{2} - R$ and R is the sum of all rankings of FPR programs participants.

Specification of Inputs and Outputs

The empirical model includes three outputs: traditional rice varieties, modern rice varieties, and all aquatic animals harvested for food. Harvests of all three were measured in kilograms. Traditional and modern rice varieties were modeled as separate outputs because of significant differences in production methods, as noted above.

We included thirteen inputs in the empirical model: land, rice seed, six kinds of labor, three classes of pesticides, fertilizers and micronutrients, and fuel.

Farmers reported the size, elevation, and soil quality of each field they operated. Usage of all other inputs, however, was reported for each farmer's entire operation. Land was thus aggregated. The land variable used in the model gives the total hectares of land put under cultivation to all varieties of rice during the season.

Seeds, unlike output, were not distinguished by variety. The model includes kilograms of all seed planted as a single input.

We model labor as a set of six time-dated inputs differentiated according to the stage of production (time during the growing season when it was performed) and the specific types of tasks performed. Each type of labor is measured as the total amount of time spent by family members, hired workers, and neighbors under exchange agreements. The six kinds of labor included in the model are: pre-planting labor, rice planting labor , rice harvesting labor, aquatic animal harvesting labor, hand weeding, and chemical application labor (total time spent applying fertilizers, micro-nutrients, and pesticides). Hand weeding and chemical application labor are included separately in the model because both are potentially substitutes for chemical pesticides. Hand weeding is an obvious alternative to herbicide application. Farmers may be able to reduce the number of pesticide applications and/or pesticides used per application by taking greater care with (and thus spending more time on) chemical application.

The three major classes of pesticides (herbicides, insecticides and fungicides) are included separately in the model because pesticide productivity is the focus of this study and because there are likely substantial differences in their effects on rice and aquatic animal harvests. Each is measured in terms of the total weight of the active ingredients applied during the season.

Fertilizers and micronutrients are also measured in terms of the total weight applied during the season. Micronutrients were as fertilizer and only a few households applied them, they are included with fertilizers.

Finally, the total amount of gasoline (measured in liters) is also included in the model. Gasoline is the principal fuel used to power machinery.

Measures of the use of machinery, hand implements, and draft animals are omitted from the model in the belief that their effects are adeuqately captured by the labor, chemical, and fuel variables.

Each growing season is assumed to have a different production technology and is modeled separately.

Results

The test statistics and relevant critical values for the disposability if the inputs included in the model (derived using the specification described in the preceding section) are given in Table 3. The test statistics and relevant critical values for differences in technical and cost efficiency between FPR program participants and non-participants are given in Table 4.

Do Pesticides Impair Joint Rice/Aquatic Animal Productivity?

The crop science literature indicates that pesticides can impair productivity in terms of both rice and aquatic animal harvests. That literature, however, examines productivity in terms of a single output (either rice or aquatic animal harvests) and typically fails to account for input substitution possibilities. This study, by contrast, considers productivity in a multi-product framework that allows for input substitution. The results in Table 3 confirm those of the crop science literature. Banker's tests indicate all three classes of pesticides exhibit weak disposability in both growing seasons, indicating that they have negative marginal productivity at some observed usage levels in both the summer-autumn and autumn-winter seasons. As noted above, negative impacts of pesticides range from phytotoxic effects to impaired productivity caused by disruption of ecosystem balance, in particular, suppression of natural pest enemy populations. Our model, unfortunately, is unable to distinguish among these possible types of productivity impairment.

Banker's tests also indicate that planting labor exhibits weak disposability in both growing seasons, suggesting the occurrence of congestion due to overcrowding during planting. This result suggests the possibility of improving labor productivity by reducing the number of people conducting planting. Fertilizers also appear to exhibit weak disposability and thus negative productivity effects. A possible explanation is that fertilizers induced greater weed growth (Ho, Azmi et al.). Some crop science studies have found that applying more fertilizers without weeding can result in lower rice yields (Smith, Moody, Azmi et al.).

Efficiency Impacts of the FPR Program

We use both Banker's and Brockett and Golany's tests to examine whether FPR program participants exhibit greater technical and cost efficiency than non-participants. Both tests indicate no difference in technical efficiency between participants and non-participants in either growing season (Table 4). Both tests do indicate a statistically significant difference in cost efficiency in the 1996 autumn-winter season, albeit not in the 1997 summer-autumn season.

The apparent lack of difference in technical efficiency between FPR participants and non-participants suggests that the simple rule of thumb used in the FPR program (no spraying insecticides during the first 40 days after planting) may be insufficiently sophisticated to guarantee improvements in productivity. The fact that both types of test give the same results is evidence that participation in the FPR program suggests that this result is not due to selection bias, as might occur if farmers with greater management capacity tended not to participate in the FPR program. Thus, our results do not support a broad interpretation of the finding of the crop science literature. It may be true that the FPR program reduces the number of insecticide applications with no effect on yield, as Heong et al. claim. However, our results suggest that those reductions in the number of insecticide applications induced greater use of other inputs, so that the program did not increase overall multifactor productivity. In other words, our results do not support the contention on which the FPR program is based, namely that early season insecticide applications are completely superfluous.

Both Banker's and Brockett and Golany's tests do indicate that FPR participants were significantly more cost efficient than non-participants in the 1996 autumn-winter season, albeit not in the 1997 summer-autumn season. This result suggests that the other inputs participants apparently used in increased amounts (see above) during that season were more expensive than pesticides. The fact that the difference in cost efficiency occurred during the autumn-winter season but not the summer-autumn season suggests the possibility of a linkage with aquatic animal harvests. Most farmers grow mainly long duration traditional varieties of rice in the autumn winter season and short duration modern varieties of rice in the summer-autumn season. One would expect greater harvests of aquatic animals in the autumn-winter season because of its longer duration (which allows more time for fish and other organisms to mature to edible size). It is possible that reductions in FPR program participants' pesticide use lead to increases in aquatic animal productivity that permit reductions in aquatic animal harvesting labor. Further investigation would be required to determine whether this possibility is in fact true, however.

Conclusion

The use of pesticides in the Green Revolution rice has become increasingly controversial as their potential negative effects have come to light. During the early years of Green Revolution rice production, excessive reliance on pesticides destabilized rice ecosystems with adverse effects on productivity and farmers' health. Even after the introduction of more resistant varieties and more sophisticated pest management strategies, farmers are often believed to apply more pesticides than socially optimal given impacts on their health and the environment. More recently, the list of potential negative impacts of pesticides has been expanded to include adverse effects on fish, crustaceans, and other aquatic organisms harvested from rice fields that constitute an important source of protein in farmers' diets.

To date, studies of the adverse effects of pesticides on rice have considered only one output, rice, ignoring the joint production of aquatic animals harvested for food. The study reported here takes a multi-product approach. We use data from an original survey of joint rice/aquatic animal production in the Mekong Delta of Vietnam to investigate (1) whether pesticides impair productivity and (2) whether a farmer participatory research program introduced with the express goal of eliminating unnecessary insecticide applications improves technical and cost efficiency. We take a non-parametric approach (data envelopment analysis) because it handles multi-product technologies easily. We use statistical tests proposed by Banker and by Brockett and Golany.

We find that all three major classes of pesticides exhibit weak rather than free disposability, indicating that they can have negative impacts on productivity. We cannot distinguish whether those productivity impairments affect rice, aquatic animal harvests, or both (although the two are linked since aquatic animals also provide natural pest control). Further research would thus be necessary to determine more precisely the ways in which these productivity impairments occur.

We find no statistically significant difference in the technical efficiency of FPR participants and non-participants, indicating that farmers tend to make up for reductions in insecticide applications by increasing the use of other inputs. We do, however, find that FPR participants are more cost efficient than non-participants during the season in which farmers tend to grow traditional long duration rice varieties, suggesting a potential linkage to greater aquatic animal harvests. Further research is needed to determine the reasons for the lack of difference in technical efficiency and the observed difference in cost efficiency.

A major limitation of our results is that they apply only to single occurrences of the two main growing seasons. The study area experienced some flooding during each of those growing seasons, which may have influenced the results we obtain. In any event, investigation of these issues with additional data would be valuable.

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Table 1. Descriptive Statistics of Survey Data

	1996 Autumn-Winter	1997 Summer-Autumn
Number of households	302	306
Rice produced (Kilogram) :	2842.89	2940.41
Tradition varieties	2509.25	2124.21
Modern varieties	2666.66	2916.78
Households harvesting rice-animal food	74	106
Animal food harvested (Kilograms) :	18.52	8.11
Area of Land Cultivated (Hectares) :	0.74	0.74
of Very Good Quality and High Elevation	0.58	0.54
of Very Good Quality and Medium Elev.	0.69	0.69
of Very Good Quality and Low Elevation	0.51	0.54
of Good Quality and High Elevation	0.66	0.56
of Good Quality and Medium Elevation	0.52	0.60
of Good Quality and Low Elevation	0.49	0.37
of Average Quality and High Elevation	0.45	0.43
of Average Quality and Medium Elevation	0.51	0.43
of Average Quality and Low Elevation	0.48	0.51
of Poor Quality and High Elevation	0.49	0.73
of Poor Quality and Medium Elevation	0.30	0.30
of Poor Quality and Low Elevation	0.38	0.47
% of land not treated in the first 40 DAP	0.94	0.94
% of land treated in the first 40 DAP	0.06	0.06
% of land planted by broadcasting	0.35	0.91
% of land planted by transplanting	0.65	0.09
Total average seed use (Kilograms)	71.58	164.66
Traditional varieties	100.82	166.60
Modern varieties	39.05	98.57
Total average labor input (Hours)	640.91	510.26
Clean seeds	4.69	4.44
Clear fields	38.51	26.48
Prepare seedbeds	14.29	9.00
Pump water	17.03	11.46
Irrigate water	10.21	9.98
Plow by Machine	3.87	3.15
Plow with buffaloes/oxen	24.00	10.00
Harrow with Machines	4.20	4.29
Harrow by Hand Implements	2.00	n/a

Haul seedlings to main fields	34.39	32.00
Uproot seedlings from seedbeds	36.54	30.67
Broadcast	5.87	4.54
Transplant	162.07	61.33
Replant	77.40	127.97
Apply herbicides	4.25	5.35
Apply insecticides	5.65	6.62
Apply fungicides	6.50	5.56
Apply fertilizers	12.68	11.49
Apply micronutrients	4.53	3.91
Handweeding	75.89	122.34
Harvesting	150.98	103.49
Threshing	26.71	n/a
Collecting	10.24	17.06
Winnowing	16.63	19.25
Hauling rice paddy to house	22.30	15.65
Drying	83.67	83.84
Storing	11.53	10.18
Total average capital input (Hours)	56.63	42.80
Buffaloes/Oxens	3.50	24.00
Plough machines	3.67	2.98
Harrowing machines	3.88	6.75
Threshing machines	3.98	3.56
Threshing boards	32.07	27.87
Pump machines	15.26	10.47
Pesticides applicators	14.29	10.35
Harvesting knives	30.76	19.67
Average pesticide input (Kg)	1.06	0.82
Herbicides	1.29	0.64
Insecticides	1.22	0.44
Fungicides	0.68	1.40
Fertilizers	231.82	192.63
Micro-nutrients	2.41	1.29

Table 2. Comparison of Survey Data with IFPRI Study of the Mekong River Delta

Demographics:	**Household Size**	**Number of Adults**	**Household Landholding**
Survey Sample	5.61	3.54	0.89
IFPRI Study	5.76	3.75	1.0

Rice Production	**Autumn-Winter**		**Summer-Autumn**	
Shares of Cash Expenditure	**Survey Sample**	**IFPRI**	**Survey Sample**	**IFPRI**
Fertilizers	0.46	0.31	0.42	0.32
Pesticides	0.04	0.09	0.09	0.07
Seeds	0.09	0.13	0.23	0.14
Machinery [a]	0.09	0.15	0.17	0.17
Other	0.32	0.32	0.09	0.30

Note: [a] Machines include plowing, harrowing, and/or pumping machines.
Sources: Data for MRD came from the International Food Policy Institute's (IFPRI) Survey on "Rice Market Monitoring and Policy Options Study" December, 1996.

Table 3. Test Statistics for Input Disposability for Autumn-Winter (1996) and Summer-Autumn (1997) Rice Seasons

	Exponential		Half-Normal	
Inputs	**1996**	**1997**	**1996**	**1997**
Land (1)	1.10	1.08	1.08	1.06
Seeds (2)	1.09	1.08	1.11	1.12
Pre-Planting Labor (3)	1.09	1.11*	1.14	1.12
Planting Labor (4)	1.16**	1.22**	1.16*	1.42**
Harvesting Labor (5)	1.06	1.09	1.09	1.15
Hand Weeding Labor (6)	1.06	1.08	1.10	1.14
Animal Food Harvest Labor (7)	1.07	1.02	1.08	1.02
Chemical Application Labor (8)	1.16**	1.52**	1.23**	1.72**
Gasoline (9)	1.17**	1.05	1.05	1.05
Herbicides (10)	1.71**	1.46**	1.82**	1.67**
Insecticides (11)	1.42**	1.35**	1.41**	1.44**
Fungicides (12)	1.23**	1.66**	1.30**	1.96**
Fertilizer (13)	1.17**	1.23**	1.17*	1.47**
Critical value for 1% significance level		1.15		1.21
Critical value for 1% significance level		1.11		1.16

** denotes significantly different from zero at a 1% level.

* denotes significantly different from zero at a 5% level.

Table 4. Test Statistics for Comparison of Technical and Cost Efficiency between FPR Participants and Non-Participants

	Growing Season		**Critical Value of Test Statistic**	
	1996	**1997**	**1% Significance Level**	**5% Significance Level**
Technical Efficiency				
Banker Exponential	0.00	0.00	1.15	1.11
Banker Half-Normal	0.00	0.00	1.21	1.16
Brockett and Golany	-1.29	-0.18	2.58	1.96
Cost Efficiency				
Banker Exponential	1.12*	0.02	1.15	1.11
Banker Half-Normal	1.27**	0.01	1.21	1.16
Brockett and Golany	-2.02**	0.84	2.58	1.96

** denotes significantly different from zero at a 1% level.
* denotes significantly different from zero at a 5% level.