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Adoption of crop management technology and cost-efficiency impacts: the case of Three Reductions, Three Gains in the Mekong River Delta of Vietnam

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"Three Reductions, Three Gains" is a crop management technology designed by the International Rice Research Institute to reduce production costs, improve farmers' health, and protect the environment in irrigated rice production in southern Vietnam through the reduced use of seeds, nitrogen fertilizer, and pesticides. It was vigorously introduced to farmers by the Ministry of Agriculture and Rural Development in early 2000 through traditional extension work and mass media. Probit adoption analysis of farm survey data provided evidence that extension education is the main determinant of adoption. Stochastic frontier cost analysis showed that adopters were more cost–efficient. Adoption improved per capita incomes, albeit marginally.

Keywords: crop management technology, probit adoption model, stochastic frontier unit cost model

The importance of rice in the Asian diet, life, and socio-political economy cannot be overemphasized. Most Asians,[1] especially the rural and urban poor, normally have three meals of rice daily; thus, per capita annual consumption ranges from 90 to 200 kg or about 50–80% of caloric intake. Rice farming is a part of Asian heritage in which tilling small parcels of land is more often than not passed from one generation to the next regardless of tenancy or ownership of lands. For some of these farmers, rice farming is the only way to secure food for their families. The rural and urban poor, comprising about 70% of the Asian population, spend at least a third of their income on rice.

Keeping rice prices low on the one hand and the soaring prices of farm inputs (such as petroleum-based fertilizer, fuel, and labor) on the other limited poses a challenge to researchers and governments to develop technologies and economically sound programs that boost yield and/or minimize production costs. These technologies and programs are common requisites to achieving local, national, and global food

[1]Some exceptions include those living in northern China, northern India, Pakistan, and Bhutan.

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security[2] and alleviating poverty. Although research into rice varietal improvement is still paramount, there has been increased attention toward improving crop management strategies. Broadly speaking, these crop management strategies can be categorized as (1) those aimed at increasing yield while largely maintaining input use, and (2) those aimed at reducing input requirements without sacrificing yield. The technology of interest here, which is commonly referred to as "Three Reductions, Three Gains" (3R3G), falls into the second broad category. In essence, it is a knowledge-based crop management technology aimed at lowering the cost of growing rice in irrigated systems (through reduced quantities of seeds, nitrogen fertilizer, and pesticides) while maintaining yield, and improving farmers' health and better protecting the environment (through a reduced reliance on agrochemicals[3]).

The 3R3G project evolved from an integrated pest management (IPM) project in which the concept of not spraying for pests in rice fields the first 40 days after sowing was developed. This concept was based on research findings that showed that early spraying was unnecessary as any damage from leaf-feeding insects (the prime cause of early spraying) did not affect yield (Heong et al 1994). Given the strength of the research findings, a "No Early Spraying" (NES) media campaign was funded and reached around 92% of the 2.3 million farmer households in the Mekong Delta in Vietnam. As a result, the number of insecticide sprays per season dropped by 70% from 3.4 to 1.0 (Huan et al 1999). This was a remarkable change as farmers responded positively to the challenge posed by the media campaign.

The success of the NES experiments, combined with the knowledge that farmers in the Mekong Delta were applying high seeding rates (200–300 kg ha^{-1}) and nitrogen applications of around 150–300 kg ha^{-1}, motivated the Irrigated Rice Research Consortium (IRRC), with funding support from the Swiss Agency for Development and Cooperation (SDC), to conduct on-farm research in the province of Can Tho in 2001 to determine the amount by which seed and fertilizer use could be reduced. In the following year, the Plant Protection Division (PPD) under Vietnam's Ministry of Agriculture and Rural Development (MARD) validated the results of the experiments in 11 provinces with matching funds from the Danish International Development Agency (DANIDA). This study, involving 951 farmers, showed that seeds, fertilizers, and insecticides can be reduced by 40%, 13%, and 50%, respectively, resulting in marginal yield increases and increased profits of US\$44–58 ha^{-1} (corrected figures from Huan et al 2005). As a result, the pesticide management practice of NES was packaged with lower seed rates and lower nitrogen use and became known locally as *Ba Giảm, Ba Tăng* (3R3G). (See Table 1 for information on 2002 data on farmers' practices and the scientist-based recommended target rates.) By February 2005, a national committee was established by MARD to develop plans to scale up implementation of 3R3G. In 2006, MARD allocated about \$230,000 to 64 provinces, specifically for *Ba Giảm, Ba Tăng* implementation.

[2]In some instances, a nation is food-secure but still has pockets of severe food insecurity.

[3]Concerns about the environmental and health consequences of the injudicious use of agrochemicals are extensively discussed in the literature. See, for example, Nguyen and Tran (1997).

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Table 1. Three Reductions, Three Gains (3R3G) technology targets seed, fertilizer, and pesticide use rates.[a]

Item	Farmers' practice in 2002[b]	Target for dry season (winter-spring)	Target for wet season (summer-autumn)
Seed (kg ha^{-1})	200–350	70–100	100–120
Fertilizer	150–300	120	100
Nitrogen (kg ha^{-1})	No data available	30	30
Phosphorus (kg ha^{-1})	No data available	30	50
Potassium (kg ha^{-1})			
Insecticide	Spray 10–15 days after planting	NES first 40 days after planting	
Fungicide	"Calendar" spraying	Use fungicide when blast symptoms are visible at booting stage (at 60 days after planting)	

[a]These are scientist-based recommended rates. The Ministry of Agriculture and Rural Development was aware that achieving these rates will take a few years so that annual targets were adjusted accordingly. [b]Elicited from Plant Protection Division provincial, district, and village directors during key informant interviews in June 2006 and March 2007.

The national program used standard extension activities combined with a quite elaborate and creative mass media campaign. Through a multistakeholder participatory planning process, a campaign package was developed to reach and motivate large numbers of rice farmers in the Mekong Delta (Huan et al 2005). It consisted of communication media (TV, radio, print, and demonstrations) and materials (soap operas, leaflets, pamphlets, and farmer field days) geared toward increasing farmers' ability and motivation to modify their resource management practices by adopting the relatively knowledge-intensive technology. The strategy was to change farmers' attitude toward input use from one of "more is better" to one of "less is more sensible" through a number of information-delivery systems. In particular, these included billboards along main roads, soap operas aired on national radio and television stations,[4] and public amplifiers installed along village roadsides that replayed radio broadcasts at daybreak as farmers walked from home to their rice fields. It became nearly impossible for a farmer not to hear about 3R3G.

The principal IRRI scientists[5] from the 3R3G project received recognitions and awards from the Vietnamese government and the SDC, suggesting that the technology

[4]Funding support for various radio and television soap operas came from the Rockefeller Foundation and the World Bank ($131,800), with IRRI as project proponent. One specific radio program is "Chuyen Que Minh" or "My Homeland," which is well described by Escalada and Heong (2007).
[5]The principal IRRI scientists of 3R3G, Drs. K.L. Heong and M. Escalada, received three awards—2003 golden rice award by the MARD of Vietnam, 2005 best innovation award by Can Tho city government of Vietnam, and second prize in the 2005 success stories competition of the SDC.

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succeeded in making a difference in terms of farmers' (and environmental) well-being. A farm-level impact survey was then begun to provide credible evidence of technology adoption and economic impact. The specific objectives of this chapter are to

(a) estimate the adoption rate of 3R3G and analyze determinants of adoption;
(b) compare farm-level performance of adopters and nonadopters with respect to input use, yield, cost, and income; and
(c) analyze the difference in cost efficiencies that could be attributed to 3R3G adoption.

The study area and sample households

Mekong River Delta

A turning point in Vietnam's rice history occurred in 1989 when the country was transformed from an importer to an exporter of rice. In 2004, Vietnam's rice area of more than 7 million ha covered 75% of the country's cultivated land and produced 36 million tons of rough rice. Production exceeded domestic demand and 4 million tons of milled rice were exported in the same year. Vietnam became a leading rice-exporting country by the mid-1990s.

Vietnam's Mekong River Delta is at the end of the world's 12th longest river. Arising from the Himalayas, the Mekong River supplies the tropical wetlands of Vietnam with rich alluvial deposits, making the soil sufficiently fertile that the area is home to 15 million people. The intense green of cultivated rice paddies can be seen across the river, threaded through by an intricate web of irrigation and drainage canals.[6] The Mekong River Delta has 13 provinces that altogether accounted for about 52% of total national rice output of 36 million tons in 2005. Generally, two rice crops are grown per year. The national average yield in 2005 was 4.89 tons ha^{-1}.

Vietnamese households

Household surveys were completed in the provinces of An Giang and Can Tho in August 2006 and in Soc Trang in May 2007. For each province, as many as three districts and three villages per district were selected. Sample sizes at each geographical level were proportionate to rice area. Farmers interviewed were chosen at random in each village. Thus, a stratified simple random sampling procedure was used to select 200 farmers in each province (Table 2). The questionnaire used was well structured and designed to collect input-output data and information on the knowledge and perceptions of farmers with regard to 3R3G in particular and to rice farming in general. The data were collected for two seasons—the dry season (winter-spring, from December 2005 to April 2006) and the wet season (summer-autumn, from May to July 2006)—by the staff of the Faculty of Economics at An Giang University, An Giang Province, Vietnam.

Vietnamese farming households covered in the survey were typically Asian—for one, averaging 5 in the number of members. Heads of households were middle aged,

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[6]Source: European space agency accessible at http://earth.esa.int/cgi–bin/satimgsql.pl?pf=473.

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Table 2. Sample distribution, demographic profile, and farm characteristics of selected provinces of the Mekong River Delta, crop years 2005-07.[a]

Item	An Giang	Can Tho	Soc Trang	All
Sample distribution				
Dry season 2005-06	166	169		
Wet season 2006	166	169	172	507
Dry season 2006-07			172	
Demographic profile				
Ave. age (years)	46	48	46	47
Ave. education (years)	6	7	6	6
Ave. farm experience (years)	21	24	23	23
Ave. household size (number)	5	5	5	5
Farm characteristics				
Farm size (ha)	2.16	2.18	1.76	2.03
Tenure (number)				
Owner	163	161	170	500
Lessee	3	2	2	7

[a]Two hundred farmers were interviewed in each province. Transplanted farms and those with incomplete information were deleted from the analysis.

engaged in rice farming most of their adult years, and, although their seven years of formal schooling may not get them white-collar jobs, they were adequately educated to comprehend and follow simple written or oral instructions (Table 2). Farm sizes were rather small, averaging 2 ha and mostly owned.

The farm survey was complemented by farmers' focus group discussions (FGD), key informant interviews (KII) of seed growers, and collection of price data from agricultural chemical retail shops in all the provinces.

Analytical framework

Pathway to higher farm profits

The 3R3G technology is not a physical good (such as in the case of a new high-yielding rice variety) but rather a package of input management recommendations that farmers can use in their profit-maximizing or input use and decision-making process (Fig. 1). The 3R3G technology capitalizes on the synergistic effects of reducing three inputs together without sacrificing yield, that is, if seed rates are lowered, less fertilizer is required, which, individually and jointly, makes the crop less attractive to pests, thus reducing the need for insecticides for the whole cropping season. Further, the adoption of NES also discourages pest population buildup because not only is early spraying unnecessary in terms of yield benefits (as stated above) but, by destroying pest preda-

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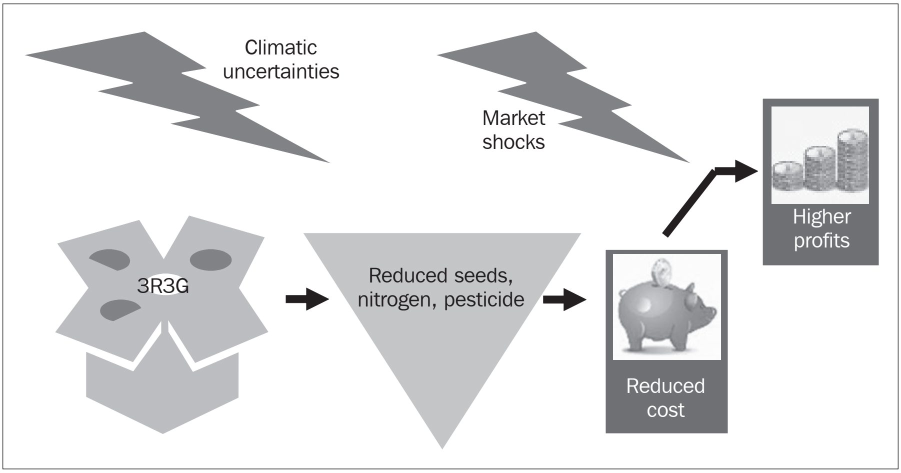

Fig. 1. Pathway to higher farm profits for "Three Reductions, Three Gains" technology.

tors, it can lead to pest resurgence problems. In other words, the more a farmer sprays, the more a farmer may need to spray. As such, the benefits of the 3R3G technology package should be manifested in reduced input use intensities without yield loss and, therefore, reduced costs and higher profits.

Uptake of 3R3G by the Vietnamese MARD first occurred at the provincial level and then at the national level. Perhaps part of the reason of the ministry's interest in 3R3G was that it complemented other (much larger) R&D programs aimed at increasing the use of seeders and certified (good) seeds. As the proceeding discussion will show, seed reduction was the component that contributed most to overall gains from 3R3G.

In addition to the development and promotion of other technologies, the adoption of one or more of the components of 3R3G was influenced by a range of biotic and abiotic stresses. For example, the marked resurgence of an insect called brown planthopper in the Mekong Delta in crop year 2005 could have had a significant negative impact on farmers' willingness to reduce insecticide use. In addition, farmers will react to changes in the price of inputs or output in terms of increased or reduced input use.

Definition of adopters and nonadopters

A requisite for measuring impact is being able to establish "with and without" technology scenarios. In this case, it is done by establishing and comparing two groups of farmers who have similar characteristics, except with respect to their uptake of 3R3G. The two groups are the "adopters" and "nonadopters." Since 3R3G is basically a suite of crop management technologies containing three components, it is possible for some farmers to fully adopt all three components and others to partially adopt one or a paired

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combination of the components. The analyses done in this study do not differentiate partial from full adopters; they are merged into one group—adopters.

The **nonadopters** group is composed of farmers who did not practice any of the recommendations because they

(a) have never heard about 3R3G,
(b) have heard about 3R3G but do not believe in the principal recommendations, or
(c) have heard about and believed in the principles of 3R3G but were not willing to take the risk and therefore did not change their farming practices according to the 3R3G recommendations.

The **adopters** group is composed of farmers who have stated that they

(a) have heard about 3R3G,
(b) believed in the principal recommendations, and
(c) were willing to take the risk and took up one or more of the 3R3G recommendations and lowered their use of (1) seed, (2) nitrogen, and/or (3) pesticides.

Determinants of adoption

To establish the success or failure of 3R3G promotion in the region, adoption rates need to be measured and factors influencing adoption identified. Of particular interest is the extent by which mass media and traditional extension work influenced adoption and how adoption may have varied among provinces in the Mekong Delta. Based on the interviews of key MARD personnel from the provincial to village level, the provinces in the region were motivated by a common 3R3G goal but differed in the manner of resource allocation and intensity or coverage of extension work among others.

A probit analysis for a binary choice model for adoption was used to determine farmer/farm characteristics and technology transfer strategies that best influenced adoption. Two statistical packages[7] that can be used to estimate the parameters of the model using survey data are LimDep 8.0 and Stata 9.2. Both packages give exactly the same results, including the option to compute for marginal effects. The marginal effect measures how the probability of adoption is increased or decreased with an incremental increase in the explanatory variables or, in the case of a dummy, a discrete change from 0 to 1. The estimating equation for the binary choice adoption model specified in probit form is

$$\Pr(D_{3R3G} = 1) = \acute{\alpha} + \beta_1 Ext + \beta_2 TvRad + \beta_3 Exp + \beta_4 School + \beta_5 F_S + \beta_6 D_{p1} + \beta_7 D_{p2} + \varepsilon$$

where the dependent variables (left-hand side) and explanatory variables (right-hand side) of the above equation correspond to

[7]It is not necessary to use both Stata and LimDep; either one should be sufficient. However, this study benefited from the exercise of running the model using both because it allowed identifying and correcting errors in transferring data from Excel (original setup) to Stata and LimDep when the results differed. This turned out to be a good practice.

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D_{3R3G}	=	3R3G adoption dummy (1 if adopter, 0 otherwise)
Ext	=	received education regarding 3R3G from extension workers (1 if yes, 0 otherwise)
TvRad	=	received education regarding 3R3G from TV and/or radio (1 if yes, 0 otherwise)
Exp	=	experience in rice farming (years)
School	=	formal schooling (years)
F_s	=	farm size (ha)
D_{p1}, D_{p2}	=	province dummies for An Giang and Can Tho, respectively
ά, B_i	=	parameter to be estimated for the ith regressor (where i = 1, ..., 7)
ε	=	random error

Comparison of input rates, yield, costs, and income

The first step in finding evidence of economic impact is to look at farm-level data and examine changes in practices (input use) and performance (yield, costs, and income). An independent t-test on the mean difference to compare adopters and nonadopters was done using SPSS software.

Unit cost function

The 3R3G is an input-reducing technological innovation that directly reduces variable cost per fixed factor[8] and variable cost per unit of output (unit cost). Better information or increased know-how set the adopters apart so they would have the predisposition to use inputs judiciously and more efficiently. This can be modeled in two ways, by specifying an 3R3G adoption dummy in an average unit cost function (model 1) and estimating the coefficients via ordinary least squares (OLS) using SPSS.

Model 1: Average unit cost function with adoption dummy via OLS

$$C = ά + \beta_1 Y + \beta_2 Y^2 + \beta_3 D_a + \beta_4 D_{p1} + \beta_5 D_{p2} + \beta_5 F_s + \varepsilon$$

Or, a frontier cost function can be specified without the adoption dummy (model 2), coefficients estimated via maximum likelihood estimation (MLE) using FRONTIER 4.1,[9] efficiency scores (automatically generated as an output) established, scores sorted by adoption, and an independent t-test done on mean difference using SPSS. The cost (in)efficiency scores are to establish whether the adopters indeed perform better than the nonadopters.

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[8]Gabre-Madhin et al (2003) argued that this type of innovation when adopted "on a wide scale" affects the aggregate supply curve by shifting it to the right as producers offer more for sale at any price. Further, in the study of firm behavior in the manufacturing industry, Olive (2002) proved the validity of average variable cost as a proxy for short-run marginal cost.

[9]Frontier 4.1 is a computer program written specifically to estimate stochastic frontier functions. A free download is available at www.uq.edu.au/economics/cepa/frontier.htm, including an electronic copy of the manual or guide, which discusses the mathematical specification and estimation procedure.

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Model 2: Stochastic frontier unit cost function without adoption dummy via MLE

$$C = \acute{\alpha} + \beta_1 Y + \beta_2 Y^2 + \beta_3 D_{p1} + \beta_4 D_{p2} + \beta_5 F_s + (v + u)$$

where

C	=	per unit cost (total cost/rice output, US$/t)
Y	=	yield (t/ha)
Y^2	=	square of yield
D_a	=	3R3G adoption dummy (0, 1)
D_{p1}, D_{p2}	=	province dummies for An Giang and Can Tho (0, 1)
F_s	=	farm size (ha)
$\acute{\alpha}$, β_i	=	parameter to be estimated for the ith regressor (where i = 1, …, 5)
u	=	one-sided error representing inefficiency
v	=	random error term

In both models, the unit cost function is convex and quadratic in yield—the expected signs of the coefficients are negative ($\beta_1 < 0$) for the yield term and positive ($\beta_2 > 0$) for the squared term.

Results

All farms considered in the analyses were direct seeded; the few transplanted farms were dropped from the analysis. Also excluded from the analysis in the wet season were farms with incomplete output information because interviews were done prior to harvesting. The following discussion refers to Tables 3 to 10.

Awareness and adoption

An entertainment-education (E-E) media format and traditional extension work promoting 3R3G succeeded in creating more than 80% awareness regarding the teachings and benefits of reducing the three key inputs—seed, fertilizer, and pesticides (Table 3). Even those who have not participated in farmers' training and demonstration trials were able to enumerate the reduction teachings heard or seen repeatedly over the radio, TV, village amplifiers, and billboards. The E-E approach, which delivered the reductions message through scripted talk shows and countryside drama, was both educational and entertaining. It was also effectively used for its precursor, integrated pest management (IPM) (Heong et al 2008). The media campaign was an effective tool in creating an attitudinal change from "more is better" to "less is more sensible" among farmers. During focus group discussions, farmers demonstrated open mindedness and expressed willingness to reduce seed rate in a little plot and then "wait and see" whether it worked. For most, it was still "to see is to believe."

However, it takes more than awareness to affect practices. It is necessary that farmers acquire the minimum know-how and skills to apply them. Equally important is that they should be sufficiently convinced that such a change will work to their advantage—this is where "hard-core" extension work through direct, personal, and

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Table 3. Awareness and adoption rates (%) of 3R3G as reported by farmers, selected provinces of Mekong River Delta, crop years 2005-07.[a]

Item	An Giang	Can Tho	Soc Trang	ALL
Awareness	86	84	95	89
Practice change				
• Reduced seeds	48	34	56	46
• Reduced nitrogen/fertilizer	35	25	40	33
• Reduced insecticide/pesticide	40	26	40	35
Adoption level				
I: "One reduction"	6	8	13	9
II: "Two reductions" (any two-combination)	13	7	14	11
III: "Three reductions"	30	21	32	28
Adopters (one, two, and three reductions)	49	36	59	48
Nonadopters	51	64	41	52
Total number of respondents	166	169	172	507

[a]Percent was based on total number of respondents.

frequent interaction of agricultural technicians with farmers plays an important role. The media campaign, however, made it easier for the technicians to convince farmers to assume risks of yield loss associated with input reductions. Farmers were encouraged to reduce inputs gradually, season after season, until the optimum targets were reached. This eventually led to adoption. Other important considerations for adoption are farmers' assessment of risks imposed by the vagaries of weather, incidence of migratory pests, and fluctuations in input/output prices. It can be expected that, all else being equal, natural disasters causing floods, pest migration into the area, and unstable prices singularly, or in combination, discourage farmers from reducing seed, fertilizer, and pesticides.

Adopters and nonadopters were almost equally represented on the sample farms covered in the survey. More than half of the adopters are actually full adopters. Of the three reductions, reducing seed had the highest adoption rate. This is a positive outcome because if farmers are able to reduce seed rates, then adoption of the other two components may ensue naturally as there is less pest pressure and fertilizer requirements decline (Heong 2006). The success of the seed component was likely to have been due to the complementary programs of the MARD, namely, the provision of a reliable supply of affordable, good-quality seeds and the promotion of mechanical seeders. The adoption rate of lower seed application was highest in Soc Trang (56%), followed by An Giang (48%) and Can Tho (34%). Interprovincial differences possibly reflect variation in the assessment of the size of risks of yield loss as seed rates are reduced. Another probable reason that needs further investigation is the limitation

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Table 4. Multiple sources of information regarding 3R3G, selected provinces of the Mekong River Delta, crop years 2005-07.

Province	Agric. technician	Radio and TV	Others[a]	No response	Number reporting
	Row percentage, %				
An Giang					
Adopters	49	43	7	–	81
Nonadopters	14	51	8	27	85
Both	31	47	8	14	166
Can Tho					
Adopters	43	54	2	2	61
Nonadopters	18	56	1	25	108
Both	27	56	1	17	169
Soc Trang					
Adopters	40	36	20	5	101
Nonadopters	20	48	21	11	71
Both	31	41	20	8	172
All					
Adopters	44	43	11	2	243
Nonadopters	17	53	9	22	261
Both	30	48	10	13	507

[a]Includes co-farmers, relatives, and input suppliers.

imposed by access to certified, registered, or commercial seeds at "affordable" prices, which are of higher quality than seeds harvested by farmers in the preceding season. Indeed, the farmers indicated that they will continue to reduce seed rates as cheaper quality seeds and mechanical seeders become increasingly available. In other words, indications are that uptake of the seed component of the 3R3G crop management package is enhanced by the outputs of the complementary MARD programs.

Determinants of adoption

The process of adoption may follow a complicated path; for simplicity, the decision to adopt is defined earlier to be a binary choice that allows the specification of a probit adoption model. From the enormous data collected, the items of interest are narrowed to only those hypothesized to influence a farmer's decision to adopt and these are the main source of 3R3G information (extension and mass media, which are mutually exclusive sources), length of experience in rice farming, formal schooling, and farm size. The location effect represented by province dummies was included in the model to statistically validate differences in the overall effectiveness of implementing the 3R3G

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Table 5. Probit regression: determinants of 3R3G adoption, selected provinces of the Mekong River Delta, crop years 2005-07.

Item	Coefficient	z/χ^2 value	Level of significance	Mean	Marginal effect*
Intercept	–0.862	–3.780	0.000		
Sources of 3R3G information					
Extension education[a]	0.822	6.890	0.000	0.491	0.319
Radio and TV[a]	0.151	1.100	0.271	0.732	0.060
Demographic characteristics					
Farm experience	0.007	1.260	0.209	22.558	0.003
Formal schooling	0.059	3.080	0.002	6.355	0.023
Farm size	0.000	0.020	0.988	2.032	0.000
Location effects					
An Giang[a]	–0.220	–1.510	0.131	0.327	–0.087
Can Tho[a]	–0.527	–3.600	0.000	0.333	–0.206
Log-likelihood, χ^2 (df = 7)	–308.867	84.250	0.000		
Pseudo R^2 (McFadden)	0.120				
Number of observations	507				

[a]These were estimated using Stata 9.2 and LimDep 8.0, which yielded the same results. Marginal effects were evaluated at the mean for continuous variables and at discrete change from 0 to 1 for dummies (*).

program across provinces. Using LimDep 8.0 and Stata 9.2, the results of maximum likelihood estimation and computed marginal effects are presented in Table 5.

Pervasive awareness regarding the technology was made possible by radio and television programs in an education-entertainment format as well as talk shows. Awareness preconditioned farmers for adoption. Conceivably, mental appreciation of the merits of the technology as they are entertained altered risk preference to the extent that farmers were more willing to take small lots of risk associated with yield loss when seed rates, fertilizers, and pesticides were reduced by a small proportion at a time.[10] As a stand-alone, however, it did not prove statistically significant in the final decision to adopt. Traditional extension education through individual or one-on-one visits, group meetings called by agricultural technicians, and participation in training/field trials proved more effective in influencing adoption. Probit analysis shows a 32% increase in the probability of adoption for farmers who received 3R3G education via extension work.

[10]The various works of Escalada and Heong (2004) and Heong et al (2008) pointed out the success of mass media campaigns and the significance of the education-entertainment process in creating favorable attitudes and changing rice farmers' practices on the use of insecticides, seeds, and fertilizers in Vietnam.

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Of the three demographics specified in the model, only formal schooling positively and significantly increased probability of adoption, although by a small margin of 2%. The logic behind lower fertilizer requirements and lower insect pest pressure following a seed rate reduction is arguably more appealing to more educated farmers, all other things being equal.

Of special note are the apparent counterintuitive results for location effects. Can Tho is the center of rice breeding research, education, and training in southern Vietnam as it houses the Cuu Long Rice Research Institute (www.clrri.org/en/function.htm). Moreover, most of the newer production management technologies in rice such as 3R3G in 2001 are pilot-tested in this province. Yet, rates of awareness and adoption were below those in the other two surveyed provinces (see Table 3). These results suggest that the promotion of 3R3G in Can Tho was not as successful as it was in An Giang or Soc Trang. The succeeding discussion on economic payoff provides some insights into the lower awareness and adoption rates.

Changes in input use and yield

The following discussion compares input use between adopters and nonadopters found in Tables 6A (dry season) and 6B (wet season). Reference is also made to the target recommendations in Table 1.

Results from the household surveys reveal that farmers have two equally important goals—to maximize yield and to maximize net income. Unlike formal businesses in which the entrepreneur usually conducts a feasibility study and keeps business records, farmers base their decision on recall of past seasons' yields and incomes plus some erstwhile unorganized records of costs incurred for the season. In making decisions regarding input use, they first consider the recommended rates provided by technicians and sales representatives from pesticide and fertilizer companies. Then, depending on current input prices and their cash and credit position, they will determine how closely they can follow the recommended rates. Often, long experience in farming provides a cognitive evaluation of economic optima that will maximize net income. Furthermore, there are compelling natural events and noneconomic considerations in input-use decisions. The interplay of these events and considerations compromises the integrity of *changes in input use* as an indicator of impact unless one can isolate changes that are purely attributable to 3R3G.

Seeds. On average, adopters in An Giang reported the lowest seed rate (151 kg ha^{-1}) during the dry season of 2005-06, whereas the highest seed rate (220 kg ha^{-1}) was reported by farmers in Can Tho in the wet season (Tables 6A, 6B). These rates are both well above the science-based recommendation of 100 kg ha^{-1} (Table 1). Most of these adopters indicated that they would continue reducing seed rate in increments of about 10–20 kg ha^{-1} every season conditional on favorable weather or climatic conditions and for as long as there would be no indication of a forthcoming significant yield loss. This is consistent with the overall MARD strategy of allowing farmers to slowly achieve a seed rate target year-by-year. As such, the continued fall in seed cost over time needs to be considered in an analysis of a temporal flow of benefits from the adoption of 3R3G recommendations.

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Table 6A. Average per hectare input use, yield, cost, and income comparisons, adopters vs. nonadopters of 3R3G, selected provinces of the Mekong River Delta, dry season.[a]

Item	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance
	An Giang, 2006				Can Tho, 2006			
Number of cases	81	85			61	108		
Seed rate (kg ha^{-1})	150.58	185.58	–35.00	0.000	196.39	213.25	–16.86	0.002
Elemental nitrogen (kg ha^{-1})	105.32	116.24	–10.92	0.024	100.48	98.65	1.83	0.755
Elemental phosphorus (kg ha^{-1})	29.66	31.59	–1.93	0.336	26.96	27.94	–0.98	0.667
Elemental potassium (kg ha^{-1})	54.49	47.98	6.50	0.093	40.08	38.84	1.24	0.750
Herbicide cost (US$ ha^{-1})	14.93	14.93	0.00	1.000	12.93	13.81	–0.88	0.490
Insecticide cost ($ ha^{-1})	19.32	28.21	–8.89	0.019	16.42	29.03	–12.60	0.047
Fungicide cost ($ ha^{-1})	45.04	46.74	–1.70	0.746	31.02	40.74	–9.72	0.010
Molluscicide cost ($ ha^{-1})	11.35	12.10	–0.75	0.721	9.83	11.56	–1.73	0.311
Yield (t ha^{-1})	7.71	7.55	0.16	0.186	7.65	8.00	–0.34	0.043
Cost: labor ($ ha^{-1})	179.85	184.66	–4.80	0.487	161.49	172.51	–11.02	0.099
Cost: materials ($ ha^{-1})	298.94	331.41	–32.47	0.004	256.39	289.91	–33.52	0.010
Cost: total ($ ha^{-1})	478.80	516.07	–37.27	0.005	417.88	462.42	–44.54	0.005
Cost: per unit ($)	62.65	68.84	–6.19	0.001	55.09	58.48	–3.39	0.108
Income: gross ($ ha^{-1})	1,169.27	1,101.55	67.72	0.001	1,163.89	1,244.81	–80.93	0.007
Income: net ($ ha^{-1})	690.47	585.48	104.99	0.000	746.01	782.39	–36.39	0.207

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Table 6A continued.

Item	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance
	Soc Trang, 2007				All			
Number of cases	101	71						
Seed rate (kg ha^{-1})	182.18	208.07	–25.90	0.000	175.21	202.95	–27.74	0.000
Elemental nitrogen (kg ha^{-1})	85.00	99.28	–14.28	0.004	95.66	104.48	–8.82	0.004
Elemental phosphorus (kg ha^{-1})	19.96	21.43	–1.46	0.414	24.95	27.36	–2.41	0.045
Elemental potassium (kg ha^{-1})	27.97	23.39	4.58	0.080	39.85	37.63	2.22	0.308
Herbicide cost ($ ha^{-1})	15.07	18.68	–3.61	0.111	14.48	15.48	–0.99	0.321
Insecticide cost ($ ha^{-1})	21.52	28.34	–6.83	0.024	19.50	28.58	–9.08	0.000
Fungicide cost ($ ha^{-1})	31.39	27.95	3.45	0.331	35.85	39.23	–3.38	0.172
Molluscicide cost ($ ha^{-1})	4.42	4.37	0.05	0.954	8.09	9.80	–1.71	0.076
Yield (t ha^{-1})	6.05	6.01	0.04	0.805	7.01	7.32	–0.31	0.008
Cost: labor ($ ha^{-1})	134.01	141.16	–7.15	0.113	156.19	167.99	–11.80	0.002
Cost: materials ($ ha^{-1})	227.88	257.53	–29.65	0.003	258.72	294.56	–35.84	0.000
Cost: total ($ ha^{-1})	361.89	398.69	–36.80	0.002	414.91	462.55	–47.64	0.000
Cost: per unit ($)	61.08	68.52	–7.45	0.001	60.10	64.51	–4.42	0.000
Income: gross ($ ha^{-1})	889.91	885.82	4.09	0.886	1,051.81	1,102.14	–50.34	0.010
Income: net ($ ha)	528.02	487.13	40.89	0.122	636.89	639.59	–2.70	0.879

[a]All monetary values are in 2006 prices.

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Table 6B. Average per hectare input use, yield, cost, and income comparisons, adopters vs. nonadopters of 3R3G, selected provinces of Mekong River Delta, wet season.[a]

Item	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance	Adopter (A)	Nonadopter (B)	Input/cost reductions (A – B)	Level of statistical significance
	An Giang, 2006				Can Tho, 2006			
Number of cases	81	85			61	108		
Seed rate (kg ha^{-1})	153.49	193.37	–39.88	0.000	202.23	219.83	–17.60	0.002
Elemental nitrogen (kg ha^{-1})	107.74	118.63	–10.89	0.045	108.17	102.63	5.54	0.354
Elemental phosphorus (kg ha^{-1})	30.14	31.06	–0.93	0.659	29.11	30.35	–1.24	0.615
Elemental potassium (kg ha^{-1})	55.49	49.02	6.48	0.101	44.72	45.26	–0.53	0.895
Herbicide cost ($ ha^{-1})	15.37	15.48	–0.10	0.951	12.72	14.59	–1.87	0.136
Insecticide cost ($ ha^{-1})	21.56	25.51	–3.95	0.349	17.74	27.46	–9.71	0.005
Fungicide cost ($ ha^{-1})	42.77	51.44	–8.67	0.137	30.94	40.91	–9.96	0.008
Molluscicide cost ($ ha^{-1})	8.47	9.61	–1.14	0.502	7.60	14.42	–6.81	0.007
Yield (t ha^{-1})	5.86	5.60	0.25	0.106	4.78	5.25	–0.47	0.002
Cost: labor ($ ha^{-1})	211.72	230.43	–18.71	0.067	167.88	183.66	–15.79	0.014
Cost: materials ($ ha^{-1})	293.71	328.66	–34.95	0.002	267.01	296.89	–29.88	0.013
Cost: total ($ ha^{-1})	505.43	559.09	–53.66	0.001	434.89	480.55	–45.66	0.002
Cost: per unit (US$/t)	89.28	104.18	–14.90	0.002	93.30	94.05	–0.75	0.835
Income: gross ($ ha^{-1})	910.31	849.75	60.56	0.015	709.77	788.60	–78.83	0.001
Income: net ($ ha^{-1})	404.88	290.66	114.22	0.000	274.89	308.05	–33.16	0.178

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Table 6B continued.[a]

Item	Adopter (A)	Non-adopter (B)	Input/cost reductions (A – B)	Level of statistical significance	Adopter (A)	Nonadopter (B)	Input/cost reductions (A – B)	Level of statistical significance
	Soc Trang, 2006				All			
Number of cases	101	71			243	264		
Seed rate (kg ha^{-1})	187.20	213.36	–26.16	0.000	179.74	209.57	–29.84	0.000
Elemental nitrogen (kg ha^{-1})	81.35	92.35	–11.00	0.016	96.88	105.02	–8.14	0.011
Elemental phosphorus (kg ha^{-1})	18.42	19.43	–1.00	0.487	25.01	27.64	–2.63	0.034
Elemental potassium (kg ha^{-1})	25.62	21.04	4.58	0.080	40.37	39.96	0.42	0.856
Herbicide cost ($ ha^{-1})	14.06	16.69	–2.63	0.221	14.16	15.44	–1.28	0.195
Insecticide cost ($ ha^{-1})	13.24	17.67	–4.43	0.028	17.15	24.20	–7.05	0.000
Fungicide cost ($ ha^{-1})	28.61	26.38	2.23	0.469	33.91	40.39	–6.48	0.012
Molluscicide cost ($ ha^{-1})	4.53	4.53	0.00	1.000	6.61	10.21	–3.59	0.001
Yield (t ha^{-1})	5.69	5.42	0.28	0.099	5.52	5.41	0.11	0.247
Cost: labor ($ ha^{-1})	127.73	129.38	–1.65	0.664	165.80	184.12	–18.32	0.001
Cost: materials ($ ha^{-1})	199.65	219.17	–19.52	0.039	247.91	286.22	–38.30	0.000
Cost: total ($ ha^{-1})	327.38	348.55	–21.17	0.060	413.72	470.34	–56.62	0.000
Cost: per unit (US$/t)	58.63	66.69	–8.06	0.001	77.55	89.96	–12.41	0.000
Income: gross (US$/ha)	685.55	669.74	15.81	0.536	766.55	776.32	–9.77	0.539
Income: net ($ ha^{-1})	358.17	321.19	36.98	0.131	352.83	305.98	46.85	0.002

[a]All monetary values are in 2006 prices.

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Fertilizer. Nutrient management in rice evolved from blanket recommendations of prescheduled and predetermined N-P-K (nitrogen-phosphorus-potassium) rates into a regimen that is site-specific and need-based.[11] Being site-specific, the rates (theoretically) vary with the inherent nutrient-supplying capacity of the soil and crop demand. These rates presume biological optima for all other inputs (including seeds) corresponding to a maximum yield level such that beyond these rates there will be no significant yield gains. Crop demand for these macro-nutrients is directly influenced by seed rate or plant density. Farmers in the Mekong historically sowed an excessive quantity of seeds, perhaps to mitigate the risk of losing seedlings to snails and losing yield to diseased seeds, weed competition, and flood—or due to a lack of awareness. High seed rates and high plant density led to high crop demand for nutrients or synthetic fertilizers. When seed rates are reduced, crop demand for these nutrients naturally diminishes, leading to lower rates of application, lower costs, and improved profits. Note that, for as long as fertilizer is not costless, the economic optimum rate is lower than the biological (production-maximizing) optimum rate. Furthermore, as fertilizer prices rise, all other things being equal, it is economically rational to reduce application rates. Hence, observed reductions in fertilizer could come from reduced crop demand resulting from reduced seed rates, or increases in fertilizer prices.

Fertilizer rates were invariant between seasons despite the seasonally different recommended rates for nitrogen and potassium. However, variations occurred across locations (provinces): farmers' fertilizer rates in Soc Trang were usually lower than the recommended rates, whereas, in An Giang and Can Tho, fertilizer rates were either marginally below or marginally above the same recommendations. Between adopters and nonadopters, significant differences were most evident for nitrogen.

Adopters generally used less nitrogen than nonadopters except in Can Tho, where adopters applied more. The mean values for elemental nitrogen (85–116 kg ha^{-1}) were within the range of recommended rates (100–120 kg ha^{-1}).

For elemental phosphorus, adopters' rates in An Giang and Can Tho were not significantly different from those of nonadopters; the rates were, in fact, quite close to the science-based recommendations of 30 kg ha^{-1}. Soc Trang farmers, however, applied 10 kg below the recommended rate.

Although the recommended rates for potassium differ between seasons (30 kg ha^{-1} in the dry and 50 kg ha^{-1} in the wet), farmers' application rates were quite invariant. Dry-season averages for the provinces of An Giang and Can Tho exceeded the recommended rates by about 10–25 kg while in Soc Trang the rates were short by 2–7 kg. Wet-season averages for An Giang and Can Tho were close to the recommendations while in Soc Trang the rates were short by 25–30 kg.

Pesticides. Adopters of 3R3G spent less than nonadopters on pesticides, particularly insecticides. As mentioned earlier, 3R3G had its roots in NES. However, rather than promoting NES per se, the message delivered in the media campaign was one of a general reduction in the use of all pesticides, which further simplified the NES

[11]This is well described on the IRRI Web site at www.irri.org/ssnm (accessed September 2008).

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message, which was to refrain from applying insecticides within the first 45 days after planting.

Further discussions with farmers and district technicians revealed an active IPM program in the region prior to 3R3G. IPM taught farmers to assess pest situations, to use pesticides judiciously, and later to follow the NES rule. Since 3R3G can be regarded to have only reinforced the IPM teaching, then the benefit of a reduction in pesticide use cannot be fully attributed to 3R3G. However, any difference between the amounts spent between adopters and nonadopters can be largely attributed to 3R3G, as they were both exposed to IPM.

Changes in the three inputs targeted in the 3R3G campaign also affected, directly or indirectly, the use of other inputs, especially labor, although the aggregate effect is quite ambiguous. For example, sowing less seed will not likely alter the sowing labor requirement, while using less fertilizer and reducing the frequency of pesticide sprays could lessen labor usage. However, in the case of snail control, hand picking of snails was a common substitute for molluscicide application.

Yield. The national yield average for Vietnam in 2005 was 4.89 t ha^{-1}. Yields are higher in irrigated (favorable) areas than in rainfed (less favorable) areas. Southern Vietnam is a prime rice-growing area because of high alluvial deposits feeding the paddy soils along the trail and tail end of the Mekong River. The provinces along the river have fertile soils resulting in high yields. Between seasons, yields are much higher in the dry season because of greater solar radiation that results in more and heavier grains. This is supported by the survey data, which show that, in the dry season, average yields were 6–8 t ha^{-1}, whereas, in the wet season, average yields were 5–6 t ha^{-1}. Nevertheless, the wet-season yields were still higher than the national average.

As mentioned previously, 3R3G aims to reduce the use of seed, nitrogen fertilizer, and insecticides without sacrificing yield. Hence, it can be hypothesized that adopters' yield should not be statistically less than the yield obtained by nonadopters despite the input reductions. Effects of 3R3G on yields are inconclusive—no change for An Giang, a loss for Can Tho, and a gain for Soc Trang. Yield is therefore a poor partial indicator of 3R3G impact.

Economic payoff of adoption—cost and income comparisons

Rational business choices, even in rice farming, are often made based on a rule that says, "a cost saved is profit gained." Faced with ever-changing product and input prices and new crop management options, farmers change the mix of inputs with only one goal in mind—improve incomes and, in the case of three reductions, lower costs. This section examines the economic payoff of adoption by looking at overall farm performance using costs and incomes.

When costs are aggregated into two components—labor and materials—the resulting proportion of labor to material cost is 40–60. Labor cost consists of paid-out labor costs (including meals) plus imputed unpaid labor costs for which family/exchange labor is judged to be nonsupervisory and can be substituted with hired labor. Material costs include seed, fertilizer, pesticides, fuel, and oil. Roughly, seed, fertilizer, and pesticides account for about 8%, 30%, and 18% of total costs, respectively,

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quite invariant with respect to location (province), adoption, and season. Although the proportion of the three-reduction inputs put together is quite large (56% of total cost), the input/cost reductions were not large enough to affect the cost proportions (or cost structure).

A more insightful indicator of overall cost performance is in terms of unit cost, especially when this is compared with paddy (rough rice) price, for which the difference measures profit margins. The unit cost is equal to the total cost divided by total production. Adopters are hypothesized to exhibit a lower average unit cost; in fact, they do except in the case of Can Tho. Across provinces, mean differences between adopters and nonadopters were statistically significant—US\$4.42 t^{-1} in the dry season and \$12.41 t^{-1} in the wet season. Although the additional profit margin for individual farms is minimal, when extrapolated to all adopting farms, then aggregate benefits are significant.

On the basis of the unit cost, results suggest that it is more expensive to grow rice in the wet season than in the dry season because yields are lower in the wet season, whereas per hectare costs are relatively consistent. As such, the benefits of cost savings are amplified in the wet season when yields are low.

The economic payoff of adoption proved by the unit cost analysis did not come through the per hectare net income comparisons probably because the cost reductions were masked by lower farm-gate prices received by adopters. Farm-gate prices are sensitive to the timing of harvest. In general, rough rice sold either early or very late in the season receives higher prices. The expected higher per hectare income results, however, were evident only in An Giang for both seasons. Thus, unit cost stood out as the best indicator of 3R3G impact and a consistent measure of economic payoff.

Rice income and its implications for poverty reduction

Annual income from rice was computed by adding the two-season net incomes for the actual farm size of each household (Table 7). Adopters of 3R3G in An Giang and Soc Trang reaped statistically significant income gains. Adopters in Can Tho suffered some income losses (mainly because of lower yields) although these were not statistically significant.

To assess the ***possible*** impact of adoption on poverty reduction, per capita incomes were computed and compared to the poverty line—an estimate of the per person cost of procuring the 2,100 calories a day deemed necessary for human health. The World Bank \$1 per day[12] poverty line means that each person should have a disposable income of at least \$365 per year to buy enough food for a healthy living. Using survey data on net income from rice and average farm size and household size, annual per capita incomes were computed for each province (see footnote b of Table 7). This reveals the amount of money that can be drawn out of rice earnings to defray the cost of living of a household member. Per capita rice incomes computed for the three provinces surveyed in the region fall within the range of the poverty

[12]The Asian Development Bank recently raised the poverty line from \$1 per day to \$1.35 per day while the World Bank raised it to \$1.25 per day.

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Table 7. Annual income comparisons, adopters vs. nonadopters of 3R3G, selected provinces of the Mekong River Delta, crop year 2005-06–2006-07.

Item	Adopter (A)	Non-adopter (B)	Mean difference (A – B)	Level of statistical significance	Adopter (A)	Non-adopter (B)	Mean difference (A – B)	Level of statistical significance
		An Giang				Can Tho		
Number of cases	81	85			61	108		
Income: gross ($ ha^{-1})	2,079.58	1,951.30	128.28	0.001	1,873.66	2,033.42	–159.75	0.001
Cost: labor ($ ha^{-1})	391.57	415.09	–23.51	0.120	329.37	356.18	–26.81	0.021
Cost: materials ($ ha^{-1})	592.65	660.07	–67.42	0.001	523.40	586.79	–63.40	0.007
Cost: total ($ ha^{-1})	984.23	1,075.16	–90.93	0.001	852.77	942.97	–90.20	0.002
Income: net ($ ha^{-1})	1,095.35	876.14	219.21	0.000	1,020.89	1,090.44	–69.55	0.140
Average farm size (ha)	2.53	1.80	0.73	0.006	2.08	2.24	–0.16	0.737
Average household size	4.91	4.73	0.18	0.393	4.62	4.93	–0.30	0.173
Income: per capita ($)	594.48	384.34	210.14	0.002	497.22	561.21	–63.98	0.620
		Soc Trang				All		
Number of cases	101	71			243	264		
Income: gross ($ ha^{-1})	1,575.46	1,555.56	19.90	0.658	1,818.36	1,878.46	–60.11	0.052
Cost: labor ($ ha^{-1})	261.74	270.54	–8.80	0.258	322.00	352.11	–30.12	0.000
Cost: materials ($ ha^{-1})	427.53	476.70	–49.17	0.007	506.64	580.78	–74.14	0.000
Cost: total ($ ha^{-1})	689.27	747.24	–57.97	0.008	828.63	932.89	–104.26	0.000
Income: net ($ ha^{-1})	886.19	808.32	77.87	0.057	989.72	945.57	44.15	0.100
Average farm size (ha)	1.83	1.66	0.17	0.401	2.13	1.94	0.18	0.335
Average household size	4.74	4.93	–0.19	0.377	4.77	4.86	–0.09	0.442
Income: per capita ($)[b]	360.05	282.58	77.47	0.071	472.63	429.33	43.30	0.382

[a]All monetary values are in 2006 prices. [b]Income: per capita is [Income:net] multiplied by [average farm size] divided by [average household size].

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Table 8. Average unit-cost function (via OLS) results by season.

Item	Dry season		Wet season	
	Coefficient	Level of significance	Coefficient	Level of significance
Intercept	147.171	0.000	260.240	0.000
Yield	–18.469	0.000	–56.469	0.000
Square of yield	0.862	0.000	3.770	0.000
Adoption dummy	–5.385	0.000	–6.836	0.000
An Giang Province dummy	12.625	0.000	37.137	0.000
Can Tho Province dummy	4.228	0.009	23.384	0.000
Farm size	–0.531	0.031	–0.559	0.145
R^2	0.328		0.614	
Adjusted R^2	0.320		0.609	
F-value	40.761	0.000	132.556	0.000
Number of observations	507		507	

line. With an increase in per capita income of $77-210, adoption of three reductions had a positive influence on the well-being of households in An Giang and Soc Trang (statistically speaking). Whereas, in Can Tho, the per capita income of adopters was lower on average by $63, suggesting that the survey data and analysis employed failed to show any economic payoff of 3R3G adoption to farmers in this province.

From a livelihood perspective, rice farmers in the Mekong region have other sources of income such as livestock, fisheries, and off-farm employment so that incomes from rice account for about 20–40% of total household income (Hossain et al 2006, Ut et al 2000) and could even be less with rising employment opportunities from the burgeoning industrial/manufacturing and service sectors. Given rice income to buy enough food and the 60–80% of income from nonrice sources, it follows that rice farmers in the region live well above poverty.[13]

Cost efficiency

Results supporting the cost-reducing effect of 3R3G are quite robust based on the estimated coefficients of the two unit-cost models presented in Tables 8–10. All variables hypothesized to affect unit cost have coefficients bearing the expected signs

[13]It can be further said that the total and incremental changes in rice incomes due to 3R3G or any crop management technology for that matter are rather small to have a substantial poverty impact on households that experience growing income opportunities in the industrial, manufacturing, and service sectors. Also, poverty impacts, especially in this particular situation, are better assessed in the context of overall livelihood opportunities rather than improvements in rice incomes alone.

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Table 9. Stochastic frontier cost function (via MLE) results by season.[a]

Item	Dry season		Wet season	
	Coefficient	Level of significance	Coefficient	Level of significance
Intercept	136.992	0.000	200.410	0.000
Yield	–20.428	0.000	–43.890	0.000
Square of yield	1.013	0.000	2.787	0.000
An Giang Province dummy	13.703	0.000	34.309	0.000
Can Tho Province dummy	5.571	0.000	23.767	0.000
Farm size	–0.633	0.027	–0.983	0.026
Sigma-squared, σ^2	310.536	0.000	737.833	0.000
Gamma, λ	0.877	0.000	0.901	0.000
Log likelihood function	–1,949.496		–2,154.210	
LR[b] test of the one–sided error	47.666		76.014	
Number of observations	507		507	

[a]Mu (μ) and eta (η) were restricted to zero. [b]LR = likelihood ratio.

Table 10. T-test on mean difference of cost efficiency (CE) scores.

Item	Adopter ave. score (A)	Nonadopter ave. score (B)	Mean difference (A – B)	Level of statistical significance
Dry season				
An Giang	1.212	1.266	–0.054	0.020
Can Tho	1.243	1.331	–0.088	0.016
Soc Trang	1.235	1.326	–0.092	0.002
All	1.229	1.309	–0.080	0.000
Wet season				
An Giang	1.229	1.319	–0.090	0.004
Can Tho	1.222	1.333	–0.111	0.005
Soc Trang	1.455	1.491	–0.036	0.470
All	1.321	1.371	–0.050	0.043

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and are significant at least at the 5% level. Consistent with economic theory, unit cost is quadratic and convex.

In the first model, the effect of adoption was determined by specifying an adoption dummy to explain average variations in the unit cost. The OLS estimate (Table 8) shows that, on average, adoption reduced unit cost by \$5.39 t^{-1}, all other things being equal. Further, differences occur in the unit cost across provinces, which likely reflect differences in wages paid. Wage rates were highest in An Giang, which has more employment opportunities, followed by Can Tho and Soc Trang. Relatively larger farms have a lower per unit cost, which suggests economies of scale. In fact, as the province progresses, labor becomes increasingly scarce and more expensive, thus setting the stage for mechanization. Since investing in machinery makes more sense if farms are larger, some farmers interviewed reported having grouped to consolidate their lands with respect to farm operations to justify the acquisition of bigger tractors, large-capacity dryers, and threshers. Substituting machines for labor lowers unit cost.

The second model takes the cost-efficiency concept in a more intuitively appealing framework—the stochastic frontier approach. The model is re-specified by taking out the adoption dummy. The approach involves connecting the points of the most efficient farms to define a frontier cost curve. The next step involves assessing the inefficiency of the rest of the farms by calculating the distance of the less efficient farms from the frontier called "efficiency score." A computer algorithm makes this otherwise complex (maximum likelihood) procedure computationally possible and tractable. Efficient farms have scores closer to 1 whereas inefficient farms have scores much higher than 1. Finally, the mean efficiency scores of adopters and nonadopters are compared statistically.

In Table 9, the results of Model 2 (stochastic frontier unit cost) reinforce the results of Model 1 (average unit cost) discussed earlier except for a slight variation in the magnitude and improved level of significance of the coefficients. Gamma (γ) coefficients in both the dry and wet seasons are significantly different from zero, which means that inefficiencies exist (Coelli 1996). Average cost-efficiency scores in Table 10 indicate inefficiencies for both although the inefficiencies were greater for nonadopters. Finally, a t-test on the mean difference of cost-efficiency scores supports the OLS results that adoption improved cost efficiency.[14]

Conclusions

Three-reductions technology is a knowledge-based crop management innovation aimed at solving the excessive seeding rate and overuse of fertilizers and pesticides in southern Vietnam. IRRI used SDC funds and invested in on-farm research in the province of Can Tho in 2001, which the MARD of southern Vietnam quickly adopted

[14]Although it is tempting to conclude that the incidence of inefficiency for adopters indicates room for improving the technical content or delivery of 3R3G, given that only about 30% of the variation in the average unit cost is explained by the independent variables in the OLS model, it cannot be categorically stated that this is the case. The authors believe that the scores are best interpreted for their relative rather than absolute values. Besides, there will always be some inefficiency.

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in its agricultural programs by replicating the research in other provinces, promoting the three reductions on the radio and television in an entertainment format, and organizing small farmers' meetings with local government technicians for the mechanics of the three-reductions technology. Radio and television promoted awareness, but the extension work of local technicians remains the most significant determinant of farmers' decision to adopt. Contrary to expectations, Can Tho showed the lowest awareness and adoption rates. The low adoption could also be because of the lack of economic payoff to adoption in this province resulting from the yield loss associated with adoption.

Adoption of three reductions, partial or full, most significantly lowered seed rates, which were likely to have been made possible by the increased availability of certified and good seeds in addition to soft loans that enabled farmers to acquire mechanical seeders as part of the overall rice program in the region. Effects of three reductions on yield and net incomes are quite inconclusive; therefore, these are poor indicators of impacts. Unit cost is the most consistent and, hence, the best indicator of 3R3G impact—adopters showed lower unit costs. When the frontier approach was used, adopters were proved to be more cost efficient than nonadopters. Unit costs were also lower for larger farms, suggesting the presence of economies of scale. Finally, rice incomes were sufficient for households to purchase food to be healthy. Other sources of income such as nonrice ventures or off-farm employment are important in ensuring that these rice households remain a leap away from poverty.

Lessons learned

Facilitative nature of the E-E approach in technology dissemination

In promoting awareness and adoption of technologies, it was learned that mass media using the E-E approach facilitated the work of traditional person-to-person extension in as much as this prepared farmers mentally and psychologically in understanding, appreciating, and evaluating the pros and cons of 3R3G. Imagine how advertisements raise the curiosity, wants, and desires of consumers for products so neatly and alluringly presented in colorful images and sounds. E-E and mass media, similar to product advertisements, drive farmers to curiosity and want—at least they want to experiment to see whether the technology works. Extension workers can build on this "conditioning" and effectively motivate farmers to experiment and adopt. An in-depth investigation of these two would be most helpful for guiding technology diffusion programs in the future.

Establishing counterfactuals and attribution

In ex post impact analysis, the most challenging part methodologically is the establishment of a counterfactual or causal relationship between intervention and impact. It must address the general question, "What could have happened had there been no intervention?" In this study, the question is, "What could have happened to input use, yield, production costs, and farm income had IRRI not introduced 3R3G?" To answer this, the study surveyed a random sample of farmers in order to create comparable

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groups of adopters and nonadopters wherein the observed differences in their input use, costs, and incomes were equated to measures of impacts of the intervention.

However, just when the data had been analyzed and a report written, the authors learned that the random sampling procedure deployed does not ensure random assignment of "treatment" so there exists the possibility of *self-selection into treatment … or adoption decision … relevant to the process determining the outcome* (Faltermeier and Abdulai 2009). In other words, the adopters may be systematically different from nonadopters in that they may be more knowledgeable and innovative, less capital-constrained, less risk averse, and consequently have adopted superior technologies apart from 3R3G. When this happens, there is an upward bias in our impact measures as they also capture the benefits from other technologies the adopters were using concurrently. This is an example of an attribution problem, which is often referred to as the central problem in impact evaluations (Leeuw and Vaessen 2009).

Solutions to the problem of attribution and creating counterfactuals are becoming commonplace in economic literature as they continue to evolve. But, the econometric procedure is usually difficult to follow and not readily applicable to the specific cases at hand. An impact evaluator therefore needs to keep abreast of the methodological evolution and learn to adapt such to specific impact studies.

References

Coelli TJ. 1996. A guide to FRONTIER Version 4.1: a computer program for stochastic frontier production and cost function estimation. Centre for Efficiency and Productivity Analysis Working Papers No. 7/96. University of New England, Armidale, Australia. Free download of software and this article is available at www.uq.edu.au/economics/cepa/frontier.htm (accessed 24 Jul 2009).

Escalada MM, Heong KL. 2004. The case of using mass media: communication and behavior change in resource management. In: New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, 26 Sep.-1 Oct. 2004, Brisbane, Australia. Available at www.cropscience.org.au/icsc2004/symposia/4/2/356_escaladam.htm (accessed September 2008).

Escalada MM, Heong KL. 2007. Environmental radio soap opera for rural Vietnam. Paper presented at Radio Asia 2007, 19-22 June 2007, Singapore. Available at http://devcompage.files.wordpress.com/2007/12/mescaladaheong-asia-radio-paper.pdf.

Faltermeier L, Abdulai A. 2009. The impact of water conservation and intensification technologies: empirical evidence for rice farmers in Ghana. Agric. Econ. 40:365-379.

Gabre-Madhin E, Barrett CB, Dorosh P. 2003. Technological change and price effects in agriculture: conceptual and comparative perspectives. Discussion paper no. 62. Markets, Trade and Institutions Division, International Food Policy Research Institute, Washington, D.C. Available at www.ifpri.org/divs/mtid/dp/papers/mtidp62.pdf (accessed in August 2008).

Heong KL, Escalada MM, Huan NH, Ky Ba VH, Quynh PV, Thiet LV, Chien HV. 2008. Entertainment-education and rice pest management: a radio soap opera in Vietnam. Crop Prot. 27:1392-1397.

2010. Pp 289-316 Ch 19. In "Research to impact: case studies for natural resource management for irrigated rice in Asia." (eds) FG. Palis, GR Singleton, MC Casimero, B. Hardy. Los Baños (Philippines): International Rice Research Institute. 370 p.

Heong KL. 2006. Transforming research to benefit millions: the case of the 3R3G program in Vietnam. Division Seminar, Social Sciences Division, 23 June 2006, International Rice Research Institute, Los Baños, Philippines.

Heong KL, Escalada MM, Mai V. 1994. An analysis of insecticide use in rice: case studies in the Philippines and Vietnam. Int. J. Pest Manage. 40:173-178.

Hossain M, TT Ut, ML Bose. 2006. Livelihood systems and dynamics of poverty in a coastal province of Vietnam. In: Hoanh CT, Tuong TP, Gowing JW, Hardy B, editors. Environment and livelihoods in tropical coastal zones. Manila (Philippines): International Rice Research Institute and Penang (Malaysia): International Water Management Institute: CAB International. p 30-47.

Huan NH, Mai V, Escalada MM, Heong KL. 1999. Changes in rice farmers' pest management in the Mekong Delta, Vietnam. Crop Prot. 18:557-563.

Huan NH, Thiet LV, Chien HV, Heong KL. 2005. Farmers' evaluation of reducing pesticides, fertilizers and seed rates in rice farming through participatory research in the Mekong Delta, Vietnam. Crop Prot. 24:457-464.

Leew F, Vaessen J. 2009. Impact evaluations and development: NONIE guidance on impact evaluation. Washington, D.C. (USA): World Bank. Available at http://siteresources.worldbank.org/EXTOED/Resources/nonie_guidance.pdf (accessed 28 May 2010).

Nguyen HD, Tran TTD. 1997. Economic and health consequences of pesticide use in paddy production in the Mekong Delta, Vietnam. Ottawa (Canada): International Development Research Centre. Available at www.idrc.ca/uploads/user–S/10536137480ACF124.pdf (accessed September 2008).

Olive M. 2002. Is average variable cost a good proxy for short-run marginal cost and why is it important? Sydney: Macquarie University, Department of Economics. Available at www.econ.mq.edu.au/research/2002/8–2002Olive.PDF (accessed September 2008).

Ut TT, Hossain M, Janaiah A. 2000. Modern farm technology and infrastructure in Vietnam. Econ. Polit. Weekly 35:52(25-42).

Notes

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