# Rice Production, Land Use Dynamics, and Infrastructure Development in Viet Nam's Mekong River Delta

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This study examines the role of infrastructure development and technical change in explaining increases in agricultural production and changes in land use in the Mekong Delta Region of Viet Nam during the 1990s. The study analyzes longitudinal farm survey data from eight villages. A model is developed that combines spatial factors in a neoclassical production framework to examine changes in land use and agricultural technology. Major findings are that the transportation costs involved in moving agricultural input and output between farms and markets significantly affect farmland use and production decisions. Greater transport costs reduced the likelihood that farms would adopt intensive cropping patterns or cultivate nonrice crops. Results also suggest that quality of local water management infrastructure is more important than transport costs in explaining the increased intensity of land use and level of production observed in the Mekong Delta during the 1990s. A simulation model is developed to highlight the implications of findings for future policy aimed at increasing rice production or altering land use in the Mekong Delta.

## I. INTRODUCTION

The increase in rice production in Viet Nam during the 1990s represents a recent success story in Asian agricultural development. The increase in national production took the country from having a large deficit between rice demand and supply domestically, to becoming the third largest rice exporter worldwide. This expansion has contributed to the country's high growth rate by providing urban areas with cheap food and generating foreign exchange. Increases in rice production in the Mekong River Delta, which supplies about half of Viet Nam's total rice production, averaged about 6.3 percent per year during the 1990s according to official statistics. Although the rapid growth in rice production in

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Viet Nam is well documented, there have been few studies of the changes in farming practices and in market and physical infrastructure that prompted the changes in rice production and land use, and led to production increases.

Both biophysical and socioeconomic constraints influence land use decisions and limit the production activities of farming families in the Mekong River Delta. Infrastructure development and changes in economic policies modify both types of constraints. This makes understanding these constraints essential to developing technologies and advising on policies to increase agricultural production and spur economic development in the region. Integration of traditional econometric techniques with data organized in a geographic information system (GIS) offers a promising method for modeling constraints. This paper models the relationship between biophysical and socioeconomic characteristics and derives hypotheses concerning the importance of local infrastructure development, market expansion, new technology adoption, and changes in input application in the mid-1990s in explaining production changes observed in the Mekong Delta. Different areas in the Delta can be understood as being emblematic of different levels of agricultural development in the transition from rainfed to irrigated rice agriculture. This makes it a useful case to study, and findings carry broader implications for other areas in Asia that are making the transition between rainfed and irrigated agriculture.

During the years considered in this study, Viet Nam underwent profound changes in its agricultural and land policies. Beginning in 1988 with the adoption of Resolution 10 by the Politburo, Viet Nam undertook an ambitious program of decollectivization of its agriculture and liberalization of agricultural markets. Resolution 10 established farm households as autonomous economic entities in rural areas, and permitted farm families to own capital and land. Land formerly held in agricultural cooperatives was assigned to individual farms under long-term lease agreements.

In 1993, the Seventh Party Congress adopted Resolution 5 and the Road to Industrialization, which strengthened earlier reforms and adopted measures to promote rural industry and migration of workers out of employment in traditional agriculture. Investments in technology transfer (particularly in dissemination of higher-yielding varieties) and water management infrastructure spurred continued rice production increases. Terms of land leases were lengthened, and farms were given the right to exchange, transfer, lease, inherit, and mortgage land. Resolution 5 also sought to renovate and modernize remaining agricultural cooperatives and state-owned industries. During this same period, accompanying economic reforms lowered trade restrictions (although export quotas on rice remained) and led to devaluations in the national currency. Price controls were gradually relaxed on selected inputs and products over the course of the 1990s, and new agricultural firms entered into input and output markets. Marketing channels expanded to more remote rural areas under more competitive conditions than existed previously.[1] The prices of rice and the major chemical inputs to rice production evolved as a result of these market changes, and with changes in local supply/demand and fluctuations in the world price.

The years covered by the panel survey used in this study were marked by large increases in rice production and rice exports. The number of firms permitted to export rice increased and increases in supply both in Viet Nam and worldwide led to real price declines in rice during 1996 and the first half of 1997, but the government subsequently increased regulation of the operations of rice exporters, leading to increases in real prices despite continued growth in production.[2]

While the above description applies to Viet Nam as whole, this study focuses on land use change in the Mekong Delta region of the country. This region differs from the rest of the country in several important respects. Interviews with farmers in the Mekong Delta suggest that the process of agricultural collectivization progressed less in this region than elsewhere in the country. Agricultural cooperatives functioned largely as a legal formality in the Mekong River Delta region, leaving household farms as the ex facto productive unit earlier. There appeared to have been greater willingness among Mekong farmers to apply ex officio land tenure arrangements in deference to tradition. As a result, the effect of Resolution 10 in that region was lesser here than in other regions of Viet Nam. The Delta had long represented one of the most important agricultural regions in the country, and farms in the region tended to be larger and relatively more commercial (as opposed to subsistent) in production orientation.

This study also characterizes the agricultural environment and the household-level responses to changes in this environment brought about through infrastructure development as captured in farm survey, GIS database, and provincial-level statistics. Two important developments in the study area during the 1990s were the "deepening" and geographic expansion of market reforms as agents began expanded operations to more remote areas, and new water control and transport infrastructure was installed. New infrastructure development increased both the area protected from saline water intrusion and the reach of irrigation for dry season rice cultivation.

The paper develops a model that combines spatial factors in a neoclassical production framework to examine the changes in land use and agricultural technology that led to the increased output. Estimable forms of the production, land use, and revenue functions implied by the model are derived. Econometric models make use of panel data estimation procedures that control for the effect of unobserved variables. Estimations on single years of the survey use instrumental variable and system of equation estimators to correct for endogeneity bias in

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[1] For more detail regarding the institutional changes and new actors in rice marketing channels that emerged over the course of the study period in the Mekong Delta, see Institute of Agricultural Sciences (1997).

[2] Earlier studies that have examined the consequences of agricultural decollectivization and market liberalization in Viet Nam include Pingali and Xuan (1990), and Minot and Goletti (1998).

estimates of the effect of variables that are simultaneously determined with the outcomes of interest (e.g., cropping intensity, choice, and production level). The paper concludes by discussing estimation results. A simulation model is developed to highlight policy implications of findings.

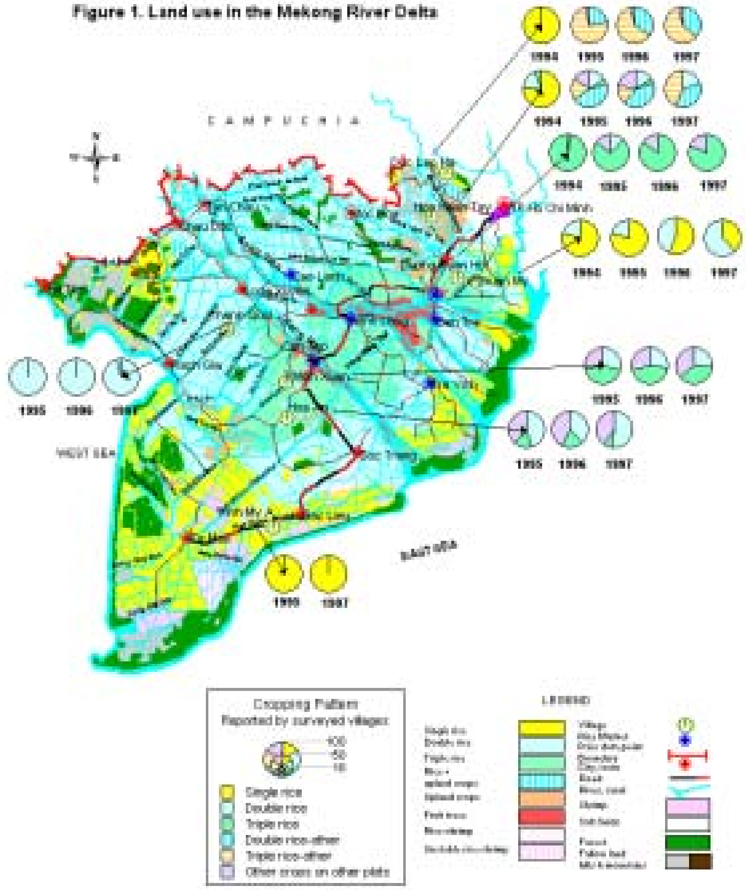
## II. DESCRIPTION OF THE STUDY AREA

The study area is described according to the following biophysical characteristics: location of rice producers and accessibility of markets, soil types, level and temporal distribution of rainfall and temperatures, and seasonal flooding or saltwater intrusion on farmland. Figure 1 superimposes land use as reported by farms in the eight surveyed villages on a land use map for the Mekong Delta (circa 1996). The figure indicates the high correspondence between farmland use captured from remote sensing presented on the map and that reported by farms completing the longitudinal survey. Compared to the other major agricultural regions of Viet Nam, the Mekong Delta is most similar to the Red River Delta in the North. The Mekong Delta has higher rainfall and is warmer than the Red River Delta. In contrast to the rest of the country, these two areas feature relatively flat terrains and abundant supplies of surface water for irrigation—in fact seasonal flooding and inundation is a problem in both areas. In addition, low lying and coastal land in the Mekong Delta is subject to seasonal saltwater intrusion (see Tuong et al. 1991).

Broader characterization of the farming systems in the Mekong Delta can be drawn from examination of the survey and other data collected in the study. Appendix Table 1 summarizes a number of farm characteristics. Rice remains the dominant crop cultivated in the region and farming activities can be characterized as being focused on rice in most of the study area, but surveyed farms also reported cultivation of fruit tree and row crops (i.e., a wide variety of nonrice crops were reported including peanuts, cassava, cashews, dragon fruit, various vegetables, and sugarcane). In addition to crop cultivation, many surveyed farms (particularly farms with greater resources) raised poultry or small livestock. Moreover, many surveyed households reported off-farm work or engagement in micro-entrepreneurial activities (i.e., home-based light manufacturing or retailing activities). There is widespread hiring of nonfamily labor to assist in farm operations during peak periods of labor input demand (i.e., transplanting and harvest).

The pie charts superimposed on Figure 1 describe the evolution of cropping patterns across surveyed farms in the eight study villages. The figure also shows the broader land use patterns in the study area as mapped in 1996. These include fishery (fish or shrimp) and forestry activities on lands not well suited to crop cultivation (e.g., saltwater intruded). As indicated in the figure, farms in most

**Figure 1. Land use in the Mekong River Delta**




Source: Base land use map from V.Q. Minh, Soil Science Department, College of Agriculture, Can Tho University, Vietnam; villages, roads, and village-level land use trends by the author.

villages displayed increases in the intensity of land use over time, evolving from monocropping to double, or triple, cropping of their land. Coincident with the rise in multicropping over time, rice output per surveyed farm increased while the average level of rice produced per growing season fell. Subsistence production of rice among surveyed farms remains important, with just under half of the rice output going to home consumption on average across households and years of the survey, but the share of rice sold to the market increases across the years covered in the study.

In terms of the technology applied in agriculture in the study area, farms employ a blend of traditional and modern agricultural technology. For example, most still rely on water buffalo for plowing, but over 70 percent use modern seed varieties and there is widespread use of chemical fertilizers. There was also evidence of advancing adoption of modern technologies (e.g., use of motor tillers for plowing grew more common) over time.[3]

Surveyed farms were asked about the principal occupation of the household head, and more than 95 percent of the respondents indicated farming, with the remainder engaged in fishing, commerce, construction, or service occupations. Seasonal work off-farm as agricultural laborers is common among members of farming households cultivating only one or two crops per year. Individuals other than the household head were more likely to report off-farm work and to report work outside of agriculture (e.g., employment in construction or service jobs). Many farms reported receiving loans through the government agricultural credit program. However, information collected on these activities was uneven across surveyed villages.

Accessibility to markets appears to play a key role in determining the land use and rice cropping intensity adopted by farms. Accessibility indicators were calculated for the eight surveyed villages based on travel distances and travel times between single markets (the nearest local market to the farm and Ho Chi Minh City) and average distances/times for transport between the farm and all surrounding markets.[4] A mix of road and canal/river transport is used to transport production inputs and outputs in this area—depending upon the village and good involved—so distance and time measures can differ greatly. The study combined survey data with input from key informants knowledgeable about agricultural markets and distribution networks to generate estimates of travel time, and calculated travel distances along common routes using GIS. The paper measures accessibility from two perspectives—a supply perspective, (i.e., service areas from the point of view of a facility, such as the serviceable area of a tube well), and a demand perspective. Study estimates made use of accessibility measured from a demand perspective (i.e., the ease of reaching or accessing services, economic and social opportunities by a user, or how many markets are within a given travel time or travel effort). Particular emphasis was placed on the issue of

[3] A more detailed review of environmental and socioeconomic conditions in the Mekong is provided in Edmonds et al. (2001).

[4] The average travel distance index $D_i$ for an origin location $i$ is the mean travel cost between the origin location (e.g. village) and a number ($J$) of target locations (e.g., markets):

$$D_i = \sum_{j-1}^{J} d_{ij} / J$$

where: $D_i$ is the average distance (in kilometers) between farm $i$ and the target market(s), and $d_{ij}$ is the length/distance of the line segment $k$ (in kilometers) between the village and market $j$.

physical accessibility as a measure of the degree of market integration and its influence on the economics of agricultural production.

Spatial economic models emphasize the importance of the spatial location of economic agents relative to market centers, economic infrastructure, and to one another in determining the economic activities pursued by the agents. They offer a good framework for considering the effects on land use of the biophysical characteristics and changes in such characteristics due to infrastructure development. Accessibility indicators included in the model are used to predict farmers' land use and production decisions. Survey and secondary data (official statistical and information generated using GIS used to characterize the demographic characteristics and resource endowments of surveyed farms, and to examine changes in agricultural and market development in the Mekong River Delta in the 1990s, are summarized in Appendix Table 1.

## III. LAND USE MODEL

The model applies a von Thünen framework and builds on the work of Chomitz and Gray (1996) to examine the effect of travel distances between farms and markets on cropping patterns and land use intensity of farms.[5] Model formulation begins by assuming that farmers will use land for the activity that generates the highest rent given the physical characteristics of the plot (local climate, basis of land tenure, labor available for farming), and farm-gate input and output prices that depend upon the cost of transport. A revenue function for each alternative use of the plot can then be defined:

$$R_{ik}=P_{ik}Q_{ik}(P_{ik},C_{ik},Z_i)-C_{ik}X_{ik}(P_{ik},C_{ik})+u_{ik} \qquad (1)$$

where $R_{ik}$ gives the rent on plot/point *i* in use *k*
$P_{ik}$ is the price of output/crop k at plot/point *i* (farm gate price of *k*)
$Q_{ik}$ is the potential output of crop *k* at plot/point *i* (potential production)
$C_{ik}$ is a vector of prices of inputs needed for production of crop *k* at plot/point *i*
$Z_i$ is a vector of plot characteristics that determine its productive efficiency in crop *k*
$X_{ik}$ is the optimal input level for production of crop *k* per unit at land at point *i*
$u_{ik}$ is a random disturbance term

[5] Von Thünen's (1826) original theory also explained nonagricultural land use, predicting that nonagricultural land would be from the center point around which land applied agriculture would be focused. The villages from which data for this study are drawn are all remote rural villages (the nearest is about 40 kilometers or 80 minutes away from Ho Chi Minh City) where land (aside from homesteads) was observed being applied exclusively in agriculture.

The farm gate prices of inputs and outputs in the revenue equation depend upon the distance of the farm from the market.[6] The model assumes that the net prices of inputs increase and the net prices farms can obtain for output decrease as farms move further away from markets.

A functional relationship between the level of input applied to farming and the amount of output produced by the farm is specified, wherein the level of output produced depends upon input levels, agroclimatic conditions, and other fixed land characteristics. Using the production function and the expressions for net revenue associated with cultivation of each crop, the relationships between the factors determining net revenue and production and the demand for inputs by the farm can be derived. The demand for inputs for crop *k* cultivated at location *i* is a function of the cost of the inputs, the farm gate price of the output, the characteristics of the plot, and the efficiency of production of crop *k* on the plot.

Using the expressions for input demand, production, and the effect of travel distances on revenues, an expression for the net returns associated with cultivation of crop *k* on parcel *i* that incorporates the effects of travel cost and the production technology of the farm is defined. Two travel distances are considered in the model. $D_i$ is the distance between the homestead and the farming plot or plots operated by the family, and $T_i$ is the average distance between the homestead and the input/output market(s) accessible to the farm. Both distances are relevant in the model since various inputs used in farming (e.g., labor, fertilizer, seed, etc.) and the outputs produced are transported between homesteads, farm plots, and markets over the course of a production season. The expression generates the hypothesis that the likelihood a plot will be applied to cultivation of a particular crop, and its intensity of use, will fall as the distance between the plot and the output/input market increases. At the extreme, very distant plots will not be cultivated, while plots located closest to markets are expected to be used for intensive commercial farming.

An expression for net revenue from cultivation of crop *k* on plot *i*, which is amenable to estimation from earlier equations can then be formed:

$$ln(R_{ik}) = a_{0k} + a_{1k} ln(D_i) + a_{2k} ln(T_i) + a_{3k} ln(z_{1i}) + a_{4k} ln(z_{2i}) + \ldots + a_{Nk} ln(z_{Li}) + u_{ik} \quad (2)$$

[6]Land use and output levels can also be modeled as direct functions of prices, but reported prices do not reflect the costs incurred by remote farm households in procuring inputs or in marketing output—costs that strongly influence the net price perceived and considered by households in making their production and marketing decisions. The high incidence of subsistence farming and homogeneity in observed market prices for both common agricultural inputs and outputs across farms in the eight survey villages also makes use of prices implied by market distances preferable. For example, the coefficient of variation for the price of different grades of rice sold by surveyed farms ranged from 1.9 to 6.4 percent (also see standard deviations for prices reported on Appendix Table 1). Theoretical explanation of subsistence farming activity as a result of high transaction costs associated with remote rural markets can be found in de Janvry et al. (1991).

Adding technical assumptions concerning the distribution of error terms (*uik*) and the correlation of errors, the probability of any crop *k* being cultivated on plot *i* can be assumed to be distributed according to the multinomial logit distribution. This provides the basis for using the multinomial logit model in empirical tests of the model. If one is able to rank the alternative land uses—as is possible when the sample is limited to farms cultivating rice and the model is applied to explain rice cropping intensity—the model can be modified to take the form of an ordered logit model.

Under the model, the coefficients on distances ($D_i$ and $T_i$) are expected to be negative, while those on productivity-enhancing land characteristics ($s_{ik}$) are expected to have a positive sign. The magnitude of the estimation coefficients will depend upon per unit costs of transportation of different crops and the relevance of a particular land characteristic to the production of a particular crop. Whether the crop being cultivated on the plot is destined for commercial or subsistence use will also affect the influence of distance on the likelihood that a particular crop is produced and its cropping intensity—subsistence crop production being less influenced by distance.

## IV. ESTIMATION STRATEGY AND RESULTS

The model provides the basic framework applied in analyzing farm survey data, and establishes the multinomial logit and ordered probit estimators as appropriate for estimating land use and cropping intensity. The form of the estimation equation is given by equation (2) above. The key variables of interest in estimates are the distances between the homestead and the farming plots, and the distances between the homestead and markets accessible to the farm. The effect of farm accessibility to markets would be expected to have its greatest effect on commercial farm cultivation of perishable crops such as fruits or vegetables and the cropping intensity and inputs applied.

The exogenous or predetermined *z* variables in equation (2) are other household or farm characteristics expected to influence household land use decisions, and include characteristics of the biophysical environment where farms are located, family characteristics, and variables capturing market conditions in surveyed villages. Standard microeconomic production and supply analysis guide the selection of variables and expectations regarding their signs, but these are not reviewed in the interest of brevity. Different sets of right hand side variables are employed in estimates, depending upon the relevance of variables to the left hand side variable. In some estimates, the number of right hand side variables had to be reduced in order for the estimator to solve. These difficulties resulted from missing data and the relatively small sample size of the panel survey.

Data examined in this study draws from GIS data compiled by the International Rice Research Institute (IRRI) and collaborating research institutions in Viet Nam. Farm-level changes in rice output and land use are captured from a longitudinal household survey (1994–1997). The survey data were collected by the Institute of Agricultural Sciences of Vietnam (IAS) and Unité d'Economie

Générale, Faculté Universitaire des Sciences Agronomiques de Gembloux, Belgique, for a separate study of rice marketing channels in southern Viet Nam. In the estimates, data covering 149 farms from eight villages in three Mekong River Delta provinces are used. Because of nonreporting of some villages and to a lesser extent farm attrition from the survey, the sample size varies over time. Sampled villages represent a range of agroecological and production situations. Estimates use both cross-section and panel data-based estimation procedures. Panel data estimation procedures provide more robust estimates because they can account for the effect of unobserved variables and have the potential to measure more precisely the effect of changes in explanatory variables. The empirical analysis also uses cross-sectional data-based estimators for two reasons. Panel data estimators cannot accommodate the use of time-invariant right hand side variables in estimation equations, and many of the right hand side variables of interest were invariant or observed only a single time during the years of the survey.

In the estimates, cropping patterns and land uses are defined by cardinal rankings (e.g., monocropping, double cropping, etc.) and according to the type of crop cultivated. Crops are divided into broad categories: (i) rice; (ii) upland row crops (e.g., sugarcane, potato, vegetables); and (iii) fruit trees or perennial fruit crops (e.g., dragon fruit) or trees maintained by farms for fuel (e.g., eucalyptus). For ease in applying panel data estimators, it is useful to define cropping patterns and land use intensity as binary outcomes.

Appendix Table 2 reports the results of three estimations that used a random effects probit estimation procedure: (i) farm cultivation of nonrice crops, (ii) farm cultivation of fruit trees or other perennial crops, and (iii) cultivation of two or three rice crops per year. Because household-specific error terms are included in the models, the number of right hand side variables that could be considered in panel estimates was limited. The variables considered are: the on-farm land–labor ratio (acres per full-time equivalent family worker), age of household head, rice variety cultivated, and farm investment in dikes or land leveling. It is expected that households with lower land-labor ratios are more likely to farm land more intensively. Older farm operators and farmers with lower levels of educational attainment are expected to be more traditional and hesitant to adopt new technologies and cultivation of nontraditional crops. The rice variety planted by farms clearly influences the feasible cropping intensity. Dummy variables are used to define the seed variety cultivated by farms (e.g., short-duration modern varieties, long-duration traditional varieties).

Overall, the three models were each highly statistically significant. Several measures of the overall performance of the models in explaining land use are shown at the bottom of Appendix Table 2. Psuedo-R2 measures vary between 44.7 and 6.4 percent across measures and models. Lastly, the table reports land use categories correctly predicted by each model, and the distribution of actual versus predicted land use. All three models performed well in predicting farmland use decisions.[7]

The estimates of whether the farm cultivated a nonrice crop show that the land–labor ratio and the head of household's age both had statistically significant negative affects on farm cultivation of nonrice crops. Use of medium- or long-duration rice varieties and farm investments in water management infrastructure were found to increase significantly the likelihood of farm cultivation of a nonrice crop.[8] The estimated marginal effect of a one percent increase in the land–labor ratio of farms is a reduction of 4.0 percent in the likelihood that the farm cultivated more than a single crop per year. An increase of 10 years in the age of the household head was associated with only a 0.2 percent decrease in the likelihood the farm cultivated a nonrice crop. Farm use of medium- or long-duration modern rice was associated with an 8.4 percent increase in the likelihood the farm grew a crop besides rice. The signs of the estimation coefficients are consistent with the expected signs.

Farm-level investments in land leveling and water management were estimated to have a statistically significant effect on the likelihood that the farm cultivated tree crops, while older farm operators where significantly more likely to cultivate tree crops. Farms that invested in land leveling or other soil improvement or in water management infrastructure were, respectively, 35.9 and 30.6 percent less likely to cultivate a tree crop. The negative effect of the investments to improve the farm on tree crop cultivation is consistent with the understanding that such investments act as substitutes to tree crop cultivation in addressing water scarcity or poor soil quality.

Farms with a large amount of land per family worker were significantly less likely to cultivate three rice crops. A one percent increase in the land-to-labor ratio was associated with a 14.6 percent decrease in the likelihood of triple cropping. Farm use of medium- or long-duration varieties of rice was also found to have a positive statistically significant effect on the likelihood of triple cropping, although—surprisingly—use of short-duration varieties did not. Farms planting medium or long-duration varieties were 33.7 percent more likely to grow three crops of rice a year.

Summarizing results from land use estimates, farm size—particularly the relative abundance or scarcity of family agricultural labor in relation to the land operated by the farm—is found to play an important role in driving farmland use as expected. Farms with scarce labor relative to their farm size are less likely to cultivate land intensively. The choice of rice variety and corresponding crop

[7] The parameter *Rho* indicates the significance of farm specific error estimates. Because rice variety choice is endogenous with the choice of cropping pattern, estimates are open to endogeneity bias under the present specification. Unfortunately, data needed for suitable estimation procedures to control for endogeneity could not be identified.

[8] The random effects probit estimator is nonlinear, so estimation coefficients cannot be interpreted directly. The marginal effect of a change in a right hand side variable on the probability that a farm chose a particular land use at the mean values of the right hand side variables must be estimated using an approximation algorithm (see Greene 2003).

maturation periods are closely related to broader land use choices of farms. Investments in farmwide and plot-level improvements in water management were also clearly linked to land use choices. One of the benefits of dike construction appears to be the opportunities it creates for farms to cultivate nonrice crops. In the absence of such investments, farms appeared to adopt land use options (i.e., fruit trees and other perennial crops) with greater immunity to the effects of poor water management. Lastly, the statistical significance of the estimation parameter *Rho* suggests that unobserved farm characteristics (e.g., farm operator knowledge and motivation, or land fertility traits) significantly influence land use choices. This underscores the complexity and idiosyncrasy of the land use choices of farms. The age variable included in the regression is highly correlated with farming experience; unfortunately other few variables were available to capture the characteristics that account for the significance of *Rho*.

Measures of market accessibility and variables characterizing biophysical conditions in the surveyed villages used in estimates were fixed over time or observed at only a single point in time. This makes it impossible to examine the principal hypotheses of the model related to these variables using the panel estimators. Instead, cross-sectional estimates of cropping patterns and rice cropping intensity are used to estimate the effect of time invariant regressors. Rice cropping intensity is a categorical variable where the categories have a natural ordering, so an ordered probit estimator is used.

Rice cropping intensity estimates are significant overall in each of the four years, according to the goodness of fit measures reported on Table 1. Variables of particular interest in estimates are the measures of the distance between farming villages and the average travel time to all local markets, and the distance between homesteads and the plot or plots cultivated. The greater these distances, the lower the likely rice cropping intensity to be adopted by the farm. Estimation results generally support the model's hypotheses. Greater distances between farms and markets were associated with a reduced probability of intensive rice cultivation by the farm in 1995 and 1997, and estimated parameters were highly statistically significant. According to 1995 estimation results, a 10-minute increase in the average travel time between the farm and available local markets was associated with 14 and 21 percent decreases in the probability of cultivating two and three crops during the year, respectively. The distance between farms and local markets in 1996 had a positive and statistically significant effect on rice cropping intensity. This result appears to be related to the heavy rains and the sample of villages surveyed that year. The distance between plots and homesteads had a negative but not statistically significant effect on rice cropping intensity in 1995 through 1997.

Table 1. **Summary of Estimates of Rice Cropping Intensity**

| **Left-hand Side/Dependent Variable Estimation Coefficient (Estimated Standard Error)** | **Rice Cropping Intensity**[a] **in 1994 (N = 60)** | **in 1995 (N = 114)** | **in 1996 (N = 114)** | **in 1997 (N=77)** |
|---|---|---|---|---|
| Constant | 7.2873 | –17.884$^{***}$ | 16.599$^{***}$ | –34.870$^{***}$ |
| | (5.5589) | (4.217) | (4.678) | (11.088 |
| Average distance between homestead and plot or plots | 0.0011 | –0.131 | –0.062 | –0.025 |
| | (0.1183) | (0.138) | (0.139) | (0.185) |
| Average travel time to all accessible local markets | 0.0323 | –0.041 | 0.020$^{***}$ | –0.060$^{***}$ |
| | (0.0333) | (0.011) | (0.007) | (0.027) |
| Land–labor ratio on farm (hectares/household laborer) | 0.0308 | 0.689 | 0.356 | –0.100 |
| | (0.9918) | (0.521) | (0.464) | (0.834) |
| Years since family settled in current place of residence | 0.0064 | –0.007 | –0.003 | –0.012 |
| | (0.0110) | (0.007) | (0.007) | (0.014) |
| Maximum educational attainment of any family member | 0.0020 | 0.311 | 0.071 | 0.526 |
| | (0.5324) | (0.296) | (0.294) | (0.461) |
| Whether farm served by good-quality water control system | 2.2076 | 2.053$^{***}$ | 4.266$^{***}$ | 4.704$^{***}$ |
| | (1.5133) | (0.466) | (0.843) | (1.668) |
| Annual precipitation at locality where farm located | –0.0091 | 0.013$^{***}$ | –0.011$^{***}$ | 0.025$^{***}$ |
| | (0.0056) | (0.003) | (0.003) | (0.008) |
| *Mu* (1) | 0.3267$^{**}$ | 2.208$^{***}$ | 1.801$^{***}$ | 4.765$^{**}$ |
| | (0.1487) | (0.330) | (0.309) | (2.182) |
| Goodness of fit diagnostics: | | | | |
| Pseudo $R^2$: Cragg-Uhler | 0.432 | 0.633 | 0.521 | 0.768 |
| Maddela | 0.361 | 0.555 | 0.460 | 0.654 |
| McFadden | 0.248 | 0.386 | 0.288 | 0.556 |
| Likelihood ratio ($X^2$) test | 26.862$^{***}$ | 92.256$^{***}$ | 70.189$^{***}$ | 81.707$^{***}$ |
| (degrees of freedom) | 7 | 7 | 7 | 7 |
| % correctly predicted | 0.800 | 0.719 | 0.632 | 0.805 |
| Actual/predicted | 0 1 2 Tot. | 0 1 2 Tot. | 0 1 2 Tot. | 0 1 2 Tot. |
| 0 | 37 0 0 37 | 21 12 0 33 | 18 13 0 31 | 6 6 0 12 |
| 1 | 6 0 1 7 | 4 45 6 55 | 5 35 11 51 | 2 38 5 45 |
| 2 | 5 0 11 16 | 0 10 16 26 | 0 13 19 32 | 0 2 18 20 |
| Total | 48 0 12 60 | 25 67 30 114 | 23 61 30 114 | 8 46 23 77 |

[a]Model estimated using the ordered probit estimator.
$^{***}$Estimated coefficient statistically significant at 99% confidence level
$^{**}$Estimated coefficient statistically significant at 95% confidence level
$^{*}$Estimated coefficient statistically significant at 90% confidence level.

The availability of low-saline irrigation water to farms had a positive and statistically significant effect on the intensity of land use in all estimates. The magnitude of the effect of high-quality irrigation on cropping intensity was much greater than the effects of other explanatory variables included in the model. Rainfall levels had mixed effects on the cropping intensity of surveyed farms. In years with normal to high rainfall, increased rain was associated with increased cropping intensity. Rains in 1996 were particularly heavy and higher rainfall in that year was associated with significantly reduced levels of cropping intensity among surveyed farms likely due to flooding problems associated with the heavy rains. Results show rice variety selection was clearly linked to cropping intensity, with the adoption of modern short-duration rice varieties enabling more intensive rice cultivation. Farm-level investments in land leveling or dike construction increased the likelihood that farms adopted intensive rice agriculture. Other variables such as the level of education in the household, the age of the household head, or the farming experience of the family did not have consistent statistically significant effects.

Rice production estimates explained most of the observed variation in the levels of rice output across surveyed farms. Results of production function estimates, which are used in the simulation model, are summarized in Appendix Table 3. All four models were highly statistically significant overall. Adjusted $R^2$ coefficient estimates across the production models ranged between 0.76 and 0.89. Cropping intensity had a consistent and statistically significant effect on annual production levels in all estimates. Monocropping was associated with significantly lower levels of output and triple cropping was associated with significantly higher output levels compared to double cropping. The land area cultivated and the amount of rice seed used were also associated with significantly higher levels of output in all estimates. The amount of hired labor applied on the farm had a positive and statistically significant effect on output in all the estimates except the 1994 cross-sectional estimate. The level of fertilizer applied on the farm had a positive and statistically significant effect on rice output in 1996 and 1997. The amount of family labor applied on-farm was difficult to measure accurately from available data, but had a negative and significant effect on rice output in 1994 and a positive and significant effect in 1995. Pesticide application had a positive and statistically significant effect on output only in 1994.

The signs of these estimated coefficients largely conform to expectations. One exception involved the use of modern varieties, which had inconsistent effects on rice production across estimates. It had statistically significant negative effects in estimates carried out using data from 1995 and 1997 and a positive effect in 1996. One possible explanation for this is that the variable was imprecisely defined due to aggregation across many distinct varieties. A second reason is that due to collinearity with rice cropping intensities, the principal effect of modern variety use seems to have been to enable farms to pursue more intensive rice production. Considered together, the various estimates provide a clear indication of the factors driving farmland use, production, and marketing decisions.

## V. SIMULATION MODEL FOR EVALUATION OF INVESTMENTS

The implications of model estimates for evaluating the effect of development of different types of infrastructure can be better understood by generating a simulation model using estimation parameters. The results of a simulation model derived from empirical estimates are summarized in Tables 2 and 3. Table 2 shows the distribution of rice cropping intensities among surveyed farms. The actual distribution of farms in each of the four years of the survey is shown, along with the projected distribution under alternative scenarios.

Table 2. **Simulation of Effects of Investments on Distribution of Farm Rice Cropping Intensity**

| **Rice Cropping Intensity** | **Actual Distribution of Farms** | | | | **Simulated Distribution of Farms with Improvements in** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Transportation System—Reducing Travel to Market by 10 Minutes** | | | | **Land Consolidation—Reducing Distance from Home to Plot by 1 Kilometer** | | | | **Water Control Infrastructure—Increasing Area Covered by 10%** | | | |
| | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** |
| Monocropping | 37 | 33 | 31 | 12 | 36 | 21 | 26 | 12 | 40 | 29 | 33 | 12 | 15 | 13 | 0 | 12 |
| Double cropping | 7 | 55 | 51 | 45 | 7 | 62 | 51 | 45 | 6 | 57 | 51 | 44 | 8 | 67 | 52 | 38 |
| Triple cropping | 16 | 26 | 32 | 20 | 17 | 31 | 37 | 20 | 14 | 28 | 30 | 21 | 37 | 34 | 62 | 27 |

Table 3. **Simulation of Effects of Infrastructure Investments on Rice Production (in tons) among Surveyed Farms**

| | **Actual Production[a]** | | | | **Predicted Production for Travel to Market (–10 min)[a]** | | | | **Predicted Production for Distance from Home to Plot Reduced by 1 km[a]** | | | | **Predicted Production for Better Water Management Extension +10%[a]** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** | **1994** | **1995** | **1996** | **1997** |
| 1 × rice farm production | 25 | 22 | 11 | 7 | 24 | 14 | 10 | 7 | 27 | 20 | 12 | 7 | 10 | 9 | 0 | 7 |
| 2 × rice farm production | 5 | 41 | 24 | 28 | 5 | 47 | 24 | 28 | 5 | 43 | 24 | 28 | 6 | 50 | 24 | 24 |
| 3 × Rice Farm Production | 13 | 22 | 26 | 16 | 14 | 26 | 30 | 16 | 12 | 23 | 25 | 17 | 31 | 28 | 51 | 21 |
| Total rice production | 44 | 85 | 61 | 51 | 44 | 86 | 64 | 51 | 43 | 86 | 60 | 51 | 47 | 87 | 75 | 52 |
| Percent change in total production | | 0.4 | 3.0 | 5.2 | 0.0 | –0.9 | 1.0 | –2.1 | 0.4 | 7.6 | 4.9 | 31.5 | 2.6 | | | |

[a]Columns may not sum to total rice production due to rounding error.

One scenario involves improvements in travel networks between surveyed villages and local markets. The second considers the effect of land transport improvements or land consolidation that brings homesteads and farm plots closer. The third contemplates extension of water control infrastructure to an additional 10 percent of the surveyed farms. Using results of production function estimates, the implied changes in the share of farms that double- or triple-crop rice can be applied to calculate an implied increase in aggregate rice output across farms. The production estimates provide a measure of the average change in annual rice yield associated with mono, double, or triple cropping of rice. Table 3 details the changes in total rice production under the various scenarios. The simulation model shows a large effect of investments in irrigation extension on rice production, and more moderate effects obtained from improvements in the transportation system or land consolidation.

## VI. CONCLUSION

Research results generally support the hypothesis that the time and direct cost of transporting inputs and outputs between rural homesteads, farm plots, and markets influence the land use and production decisions of farming households. Estimation results confirm expectations that greater transport distances reduce cropping intensity and make the cultivation of nonrice crops less likely. However, results suggest the quality of water management infrastructure is more important than transport infrastructure in determining land use. The magnitude of the effect of having high-quality water management infrastructure dwarfed the effect of other variables. Other variables including the use of modern seed varieties, age of the farm operator, land-to-labor ratio of the farm, and rainfall influenced farmland use as predicted. Results suggest that investments in water management offer more promise in improving farmland use options and increasing rice production than transport infrastructure investments in the Delta. However, information on the relative costs of extending road and water management infrastructure is necessary before it would be appropriate to offer policy conclusions in this regard. This study relied on existing sources of data originally collected for a study of the rice production and marketing chain in Viet Nam, and as a result encountered considerable data constraints in analyses.

Appendix Table 1. **Sample Means from Data Set Used in Study**

| | | 1994 (N=89) | | 1995 (N=149) | | 1996 (N=122) | | 1997 (N=105) | | All Years | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Units** | **Mean** | **S.D.** | **Mean** | **S.D.** | **Mean** | **S.D.** | **Mean** | **S.D.** | **Min.** | **Max.** |
| Number of Reporting Villages | | 6 of 10 | | 10 of 10 | | 8 of 10 | | 9 of 10 | | | |
| Household Demographic Characteristics | | | | | | | | | | | |
| Years since family settled in area[a] | years | | | | | 42.3 | 19.2 | | | 1 | 85 |
| Age of the head of household[a] | years | | | | | 53.0 | 15.4 | | | 21 | 85 |
| Most educated HH member–primary[a] | 0/1 dummy | | | | | 0.33 | – | | | 0 | 1 |
| Most educated member–secondary[a] | 0/1 dummy | | | | | 0.58 | – | | | 0 | 1 |
| Most educated member–postsecondary[a] | 0/1 dummy | | | | | 0.04 | – | | | 0 | 1 |
| Total persons residing in household | individuals | 4.7 | 1.52 | 5.8 | 1.79 | 5.8 | 1.71 | 5.6 | 1.66 | 2 | 13 |
| Land/labor ratio in household | has./workers | 0.36 | 0.31 | 0.40 | 0.52 | 0.34 | 0.45 | 0.40 | 0.48 | 0 | 3.96 |
| Landholding and Biophysical Characteristics | | | | | | | | | | | |
| Total land owned by farm | hectares | 0.91 | 0.63 | 1.22 | 0.79 | 1.15 | 0.70 | 1.07 | 0.64 | 0.13 | 4 |
| Farming plots cultivated by family | number | 1.3 | 0.69 | 1.5 | 0.79 | 1.1 | 0.45 | 1.0 | 0.10 | 1 | 5 |
| Quality adjusted landholding size | quality adj. has. | 1.14 | 1.11 | 1.47 | 1.92 | 1.30 | 1.81 | 1.34 | 1.91 | 0.04 | 17.84 |
| Alluvial soil[b] | 0/1 dummy | | | | | 0.51 | – | | | 0 | 1 |
| Medium-slightly acid sulfate soil[b] | 0/1 dummy | | | | | 0.10 | – | | | 0 | 1 |
| Saline soils w/dry season saltwater[b] | 0/1 dummy | | | | | 0.21 | – | | | 0 | 1 |
| Rice Production, Marketing, and Land Use | | | | | | | | | | | |
| Paddy yield during winter-spring | kilos/hectare | 3841 | 1382 | 5288 | 1490 | 5670 | 1073 | 5023 | 1377 | 1053 | 9000 |
| Area cultivated to rice autumn-winter | hectares | 0.88 | 0.55 | 1.00 | 0.61 | 0.92 | 0.62 | 0.79 | 0.41 | 0.13 | 3.5 |
| Total yearly rice production in province | 1000 metric tons | – | – | 10529 | 5430 | 13792 | 3615 | 11539 | 5939 | 0 | 18032 |
| Rice cropping intensity | number | 1.8 | 0.79 | 1.9 | 0.69 | 1.9 | 0.76 | 2.1 | 0.58 | 0 | 3 |
| Cultivated nonrice/nonrow crop | 0/1 dummy | 0.12 | – | 0.55 | – | 0.59 | – | 0.56 | – | 0 | 1 |
| Paddy sold by farm during year | kilos | – | – | 5459 | 5901 | 5541 | 5486 | 5405 | 5106 | 0 | 32060 |
| Average sale price of paddy during year[c] | 1997 $US/kilo | 0.13 | 0.03 | 0.17 | 0.04 | 0.14 | 0.02 | 0.15 | 0.02 | 0.09 | 0.30 |
| Average local market paddy price during year | 1997 $US/kilo | 0.14 | 0.01 | 0.18 | 0.02 | 0.15 | 0.01 | 0.14 | 0.01 | 0.12 | 0.20 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Technology, Practices, and Inputs | | | | | | | | | | | |
| Traditional nonglutinous rice | 0/1 dummy | 0.18 | – | 0.11 | – | 0.11 | – | 0.07 | – | 0 | 1 |
| Modern short duration nonglutinous | 0/1 dummy | 0.20 | – | 0.35 | – | 0.37 | – | 0.43 | – | 0 | 1 |
| Modern medium/long duration nonglutinous | 0/1 dummy | 0.52 | – | 0.40 | – | 0.34 | – | 0.24 | – | 0 | 1 |
| Urea per hectare, year average | kilos/hectare | 160 | 87 | 160 | 74 | 169 | 71 | 149 | 73 | 0 | 533 |
| Price of urea, weighted yearly average | 1997 $US/kilo | 0.244 | 0.028 | 0.236 | 0.022 | 0.248 | 0.016 | 0.196 | 0.023 | 0.123 | 0.337 |
| Local market price urea, yearly average | 1997 $US/kilo | 0.355 | 0.009 | 0.302 | 0.005 | 0.232 | 0.014 | 0.187 | 0.005 | 0.175 | 0.369 |
| No mechanized tractor used[a] | 0/1 dummy | | | | | 0.28 | – | | | 0 | 1 |
| Whether homestead w/ drying court[a] | 0/1 dummy | | | | | 0.26 | – | | | 0 | 1 |
| Water Management Infrastructure (water) | | | | | | | | | | | |
| Land leveling carried out on farm | 0/1 dummy | 0.38 | – | 0.28 | – | 0.29 | – | 0.38 | – | 0 | 1 |
| Dike constructed by farm | 0/1 dummy | 0.48 | – | 0.36 | – | 0.34 | – | 0.39 | – | 0 | 1 |
| Interpolated annual rainfall at village | millimeters | 1251 | 66 | 1616 | 216 | 1863 | 107 | 1513 | 145 | 1174 | 2076 |
| Flooding 0.5-1 m. lasting 3 months[b] | 0/1 dummy | | | | | 0.12 | – | | | 0 | 1 |
| Brackish (>4g/l) water > 6 months[b] | 0/1 dummy | | | | | 0.13 | – | | | 0 | 1 |
| Rainfed farm (no irrigation)[b] | 0/1 dummy | | | | | 0.11 | – | | | 0 | 1 |
| Limited irrigation available[b] | 0/1 dummy | | | | | 0.10 | – | | | 0 | 1 |
| Reliable irrigation on farm[b] | 0/1 dummy | | | | | 0.61 | – | | | 0 | 1 |
| Market Accessibility and Travel Distances | | | | | | | | | | | |
| Distance to nearest local market[b] | kilometers | | | | | 19.8 | 4.6 | | | 12 | 28 |
| Accessibility index distance nearest market[b] | kilometers | | | | | 19.5 | 4.7 | | | 11 | 28 |
| Accessibility index time, all local markets[b] | minutes | | | | | 130.2 | 70.2 | | | 51 | 255 |

Note:
[a]Figures reported come from: (i) a baseline survey that did not include all households later interviewed for the longitudinal survey, and (ii) from interpolation or overlay of values generated from GIS coverages. Number of observations for particular variables can vary from general sample sizes reported.
[b]Soil, water availability, and accessibility measures were derived from GIS coverages available in Mekong Delta provinces only.
[c]Calculated as the weighted average (by quantity of rice sold) sale price of rice reported by surveyed farms.

Appendix Table 2. **Summary of Estimates of Land Use (panel data estimators)**

| **LHS/Dependent Variable Estimation Coefficient (Standard Error of Estimate)** | **Cultivates Nonrice Crop(s) 1994–7 (N=436)** | **Farm Cultivation Fruit/Other Trees 1994–7 (N=436)** | **Farm Triple Crops Rice (vs. 2 rice) 1994–7 (N=354)** |
|---|---|---|---|
| Land-labor ratio on farm | -1.058 * | 0.056 | -0.365 *** |
| (hectares per household laborer) | 0.578 | 0.591 | 0.153 |
| Age of the household head | -0.050 *** | 0.014 ** | -0.003 |
| | 0.014 | 0.007 | 0.002 |
| Cultivated short duration modern varieties of rice | -0.131 | -0.018 | 0.088 |
| | 0.670 | 0.452 | 0.156 |
| Cultivated medium- or long-duration modern rice varieties | 2.221 *** | -0.334 | 0.846 *** |
| | 0.775 | 0.364 | 0.172 |
| Farm invested in land leveling or other soil improvement | -0.116 | -0.902 ** | 0.068 |
| | 0.467 | 0.450 | 0.148 |
| Farm invested in dike construction or other water management | 0.646 * | -0.769 * | 0.080 |
| | 0.381 | 0.449 | 0.149 |
| *Rho* | 0.787 *** | 0.970 *** | 0.812 *** |
| | 0.225 | 0.081 | 0.125 |
| Goodness of fit diagnostics: | | | |
| Pseudo $R^2$: Cragg-Uhler | 0.130 | 0.447 | 0.117 |
| Maddela | 0.064 | 0.317 | 0.079 |
| McFadden | 0.098 | 0.309 | 0.073 |
| Likelihood ratio ($X^2$) test | 28.693 *** | 166.549 *** | 35.846 *** |
| [degrees of freedom] | 1 | 1 | 1 |
| Pct. correctly predicted | 0.842 | 0.672 | 0.624 |

| Actual/Predicted | 0 | 1 | tot. | 0 | 1 | tot. | 0 | 1 | tot. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 342 | 17 | 359 | 107 | 126 | 233 | 136 | 39 | 175 |
| 1 | 52 | 25 | 77 | 66 | 137 | 203 | 94 | 85 | 179 |
| total | 394 | 42 | 436 | 173 | 263 | 436 | 230 | 124 | 354 |

Note: Estimates carried out using the random effects probit estimator for panel data.
***Estimated coefficient is statistically significant at a 99% confidence level.
**Estimated coefficient is statistically significant at a 95% confidence level.
*Estimated coefficient is statistically significant at a 90% confidence level.

Appendix Table 3. **Rice Production Estimates (cross sectional estimators)**

| **LHS/Dependent Variable Estimation Coefficient (Estimation Standard Error)** | **Rice Production in 1995[a] (N=117)** | | **in 1996[a] (N=134)** | | **in 1997[a] (N=121)** | | **1995-97[b] (N=372)** | |
|---|---|---|---|---|---|---|---|---|
| Constant(s) | 7.493 | *** | 4.642 | *** | 6.295 | *** | N.R. | *** |
| | 0.322 | | 0.765 | | 0.350 | | N.R. | |
| Single-cropped rice | -1.281 | *** | -3.479 | *** | -1.947 | *** | -0.416 | |
| | 0.253 | | 0.469 | | 0.271 | | 0.453 | |
| Triple-cropped rice | 0.608 | *** | 1.570 | *** | 0.972 | *** | -0.015 | |
| | 0.132 | | 0.257 | | 0.130 | | 0.226 | |
| Largest area planted to rice | 0.789 | *** | 0.469 | *** | 0.558 | *** | 1.090 | *** |
| in any season | 0.075 | | 0.194 | | 0.070 | | 0.254 | |
| Total household expenditure | 0.067 | | 0.483 | *** | 0.098 | *** | 0.210 | *** |
| on hired labor | 0.081 | | 0.077 | | 0.029 | | 0.052 | |
| Imputed value of family | -0.194 | ** | 0.429 | *** | 0.102 | | 0.176 | |
| labor applied on farm | 0.097 | | 0.165 | | 0.098 | | 0.127 | |
| Expenditure on fertilizer | 0.029 | | 0.205 | * | 0.151 | ** | 0.033 | |
| | 0.060 | | 0.108 | | 0.068 | | 0.072 | |
| Expenditure on pesticides | 0.096 | *** | 0.010 | | 0.016 | | -0.320 | |
| or herbicides | 0.038 | | 0.075 | | 0.034 | | 0.048 | |
| Average quantity of rice seed | 0.622 | *** | 0.735 | *** | 0.747 | *** | -0.419 | ** |
| used per season cultivated | 0.125 | | 0.236 | | 0.101 | | 0.192 | |
| Use of any modern variety | -0.123 | * | 0.226 | * | -0.119 | ** | 0.295 | |
| of rice seed | 0.067 | | 0.134 | | 0.058 | | 0.092 | |
| Year 1995 | – | | – | | – | | -0.010 | |
| | – | | – | | – | | 0.069 | |
| Year 1996 | – | | – | | – | | -0.103 | *** |
| | – | | – | | – | | 0.063 | |
| Goodness of fit diagnostics | | | | | | | | |
| Adjusted $R^2$ | 0.892 | | 0.755 | | 0.888 | | 0.835 | |
| F-ratio | 107.710 | *** | 46.450 | *** | 106.220 | *** | 12.210 | *** |
| [degrees of freedom] | [9, 107] | | [9, 124] | | [9, 111] | | [167, 204] | |
| Likelihood ratio ($X^2$) test | 270.097 | *** | 197.658 | *** | 273.827 | *** | 891.838 | *** |
| [degrees of freedom] | [9] | | [9] | | [9] | | [167] | |

Note: N.R. means household-specific intercepts are not reported.

[a]Estimated in logarithms using the ordinary least squares estimator.

[b]Estimated in logarithms using the fixed effects estimator for panel data. The results of the Hausman test (46.950*** with 11 d.f.) supported use of the fixed effects specification.

***Estimated coefficient statistically significant at a 99% confidence level.

**Estimated coefficient statistically significant at a 95% confidence level.

*Estimated coefficient statistically significant at a 90% confidence level.

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