Edmonds, Christopher M.

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Foreword

The ERD Working Paper Series is a forum for ongoing and recently completed research and policy studies undertaken in the Asian Development Bank or on its behalf. The Series is a quick-disseminating, informal publication meant to stimulate discussion and elicit feedback. Papers published under this Series could subsequently be revised for publication as articles in professional journals or chapters in books.

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Abstract

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 mid-1990s. The study relies on econometric analysis of household-level longitudinal farm survey data covering about 150 farms from eight villages in the Mekong River Delta from1994 to 1998. A model is developed that combines spatial factors in a neoclassical production framework to examine changes in land use and agricultural technology. Estimates make use of panel data estimation procedures that control for the effect of unobserved variables. Major findings emerging from the study are that the transportation costs involved in moving agricultural input and output between farms and markets significantly effect farm land use and production decisions. Greater transport costs reduced the likelihood that farms adopt intensive cropping patterns or cultivate nonrice crops. Improvements in roads and waterways both reduce transport costs in the area. Results suggest the quality of local water management infrastructure is much 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 policy aiming to increase rice production or alter land use in the Mekong Delta in the future. Unfortunately, lack of information on the costs of alternative infrastructure investments limits the policy conclusions that can be drawn from the study.

I. INTRODUCTION

The increase in rice production in Viet Nam during the 1990s represents one of the recent success stories of Asian agricultural development. The increase in national production took the country from having a large deficit between rice demand and supply to becoming the third largest rice exporter worldwide. This expansion contributed to the country's high rate of GNP growth by providing urban areas with cheap food and generating foreign exchange earnings. 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 Viet Nam is widely known, there have been few studies of the changes in market and physical infrastructure that prompted farm-level changes in rice production techniques and land use, and led to the 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 reviews a microeconomic model developed to explore the relationship between biophysical and socioeconomic characteristics and to derive 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. Hypotheses are examined using available data. 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 implications for other areas in Asia making the transition between rainfed and irrigated agriculture.

This paper begins by characterizing the changes in the agricultural environment and the household-level responses to these changes as captured in farm survey, GIS, and provincial level statistics. Two important developments in the study area during the 1990s were the "deepening" and geographic extension of market reforms started in 1988, and the installation of new water control and transport infrastructure. This latter development increased both the area protected from saline water intrusion and the reach of irrigation for dry season rice cultivation. The major changes in policies, institutions, and infrastructure relevant to rice agriculture during the 1990s are also briefly considered. Our review of the biophysical characteristics of surveyed villages relied on GIS data compiled by the International Rice Research Institute (IRRI) and collaborating research institutions in Viet Nam. We capture farm-level changes in rice output and land use from a longitudinal household survey (1994 to 1997). The survey data were collected by the Institute of Agricultural Sciences (IAS) of Viet Nam 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 our estimates, we use data covering 149 farms from eight villages in three Mekong River Delta provinces. 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.

The paper presents a model that combines spatial factors in a neoclassical production framework to examine 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 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.

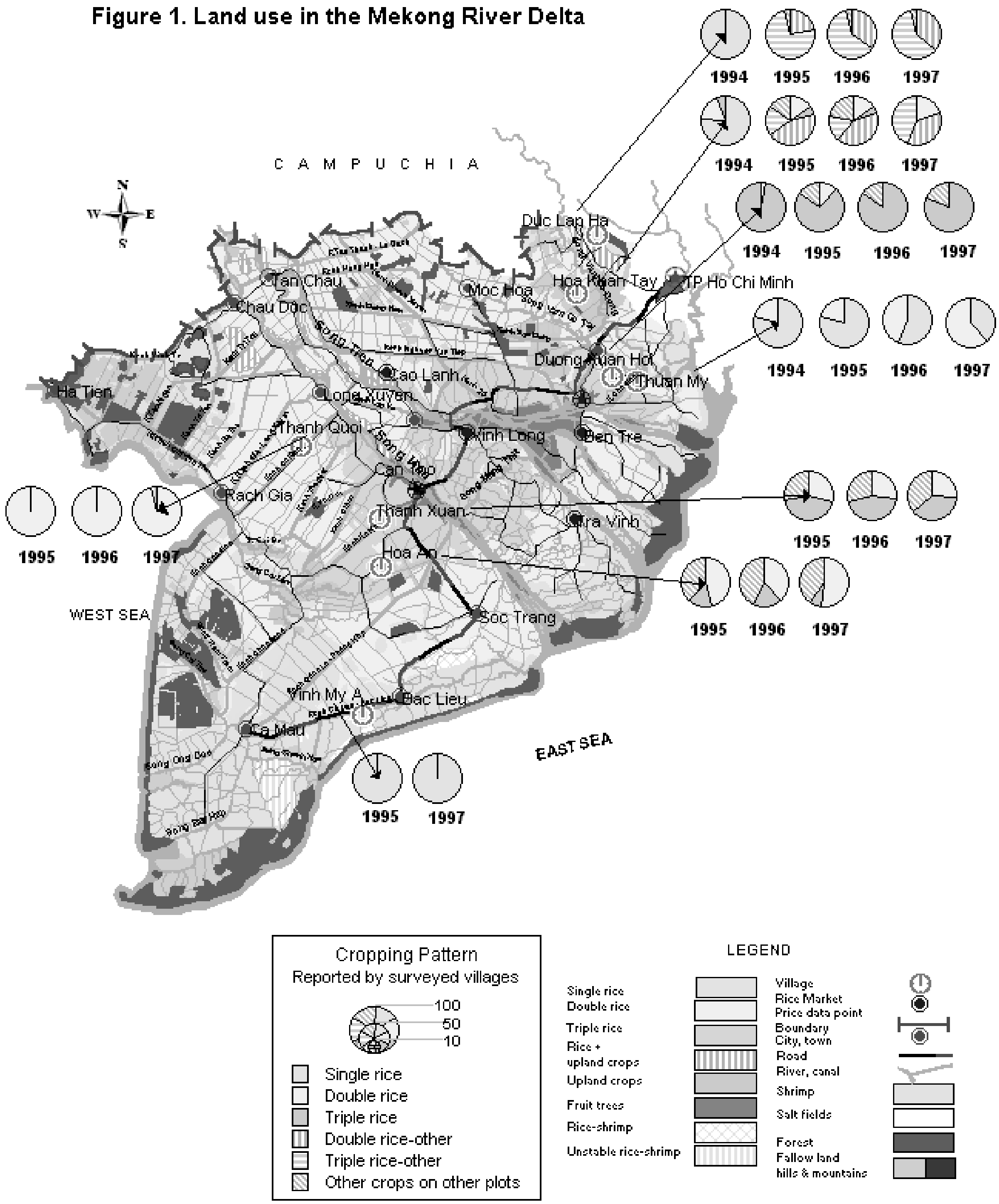
II. DESCRIPTION OF THE STUDY AREA

The study area was characterizied according to the following biophysical variables: location of rice producers and accessibility of markets, soils, rainfall and temperatures, and seasonal flooding and saltwater intrusion on farmland. Figure 1 in the Appendix 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 farm land use captured from remote sensing presented on the map and that reported by farms completing the longitudinal survey. The map also describes how land use in the surveyed villages changed over time.

Beginning in 1988 with the adoption of Resolution 10 by the Politburo, Viet Nam undertook an ambitious program of decollectivizing its agriculture and liberalizing agricultural markets. Resolution 10 established farm households as autonomous economic entities in rural areas, and farms were permitted to own capital and land. Land formerly held in agricultural cooperatives was assigned to individual farms under long-term lease agreements. Because agricultural cooperatives functioned largely as a legal formality in the Mekong River Delta region where household farms were the *ex facto* productive unit earlier, the effect of Resolution 10 in that region was lesser here than in other regions of Viet Nam.

In 1993, the Seventh Party Congress adopted Resolution 5 and the Road to Industrialization, which strengthen 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

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.

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.

Accompanying economic reforms lowered trade restrictions (although export quotas on rice remained) and devalued the national currency during this same period. 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. The prices of rice and the major chemical inputs to rice production evolved as a result of these market changes, and changes in world price and local supply and demand. The years covered by the panel survey used in this survey were marked by large increases in rice production and in rice exports. The number of firms permitted to export rice increased and some glutting of the market 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 prices despite continued growth in production.

Accessibility to markets plays 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 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. Indicators can be divided into two groups: Those that consider accessibility from the supply perspective, (i.e., service areas from the point of view of a facility, such as the serviceable area of a tube well), and measures of accessibility from the demand perspective. This study focused on accessibility from the 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 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) are 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. Table 1 summarizes selected descriptive statistics from the database used in this study.

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

Variable	Units	1994 (N=89)		1995 (N=149)		1996 (N=122)		1997 (N=105)		All years	
		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[1]	years					42.3	19.2			1	85
Age of the head of household[1]	years					53.0	15.4			21	85
Most educated HH member (primary)[1]	0/1 dummy					0.29	—		0	1	
Most educated member (secondary)[1]	0/1 dummy					0.57	—			0	1
Most educated member (post-seconndary)[1]	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[2]	0/1 dummy					0.51	—			0	1
Medium-slightly acid sulfate soil[2]	0/1 dummy					0.10	—			0	1
Saline soils with dry season saltwater[2]	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 m. 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[3]	'97 $US/kilo	0.13	0.03	0.17	0.04	0.14	0.02	0.15	0.02	0.09	0.30
Averagelocal market paddy price during year	'97 $US/kilo	0.14	0.01	0.18	0.02	0.15	0.01	0.14	0.01	0.12	0.20

(continued)

Table 1. (cont'd.)

Variable	Units	1994 (N=89) Mean	1994 (N=89) S.D.	1995 (N=149) Mean	1995 (N=149) S.D.	1996 (N=122) Mean	1996 (N=122) S.D.	1997 (N=105) Mean	1997 (N=105) S.D.	All years Min.	All years Max.
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)	'97 $US/kilo	0.244	0.028	0.236	0.022	0.248	0.016	0.219	0.023	0.123	0.337
Local market price urea (yearly average)	'97 $US/kilo	0.35	0.009	0.302	0.005	0.232	0.014	0.18	0.05	0.17	0.36
No mechanized tractor used[1]	0/1 dummy					0.3	—			0	1
Whether homestead with dry. court[1]	0/1 dummy					0.3	—			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 .5-1 m. lasting 3 months[2]	0/1 dummy					0.1	—			0	1
Brackish (>4g/l) water > 6 months[2]	0/1 dummy					0.1	—			0	1
Rainfed farm (no irrigation)[2]	0/1 dummy					0.1	—			0	1
Limited irrigation available[2]	0/1 dummy					0.1	—			0	1
Reliable irrigation on farm[2]	0/1 dummy					0.6	—			0	1
Market accessibility and travel distances											
Distance to nearest local market[2]	kilometers					19.8	4.6			12	28
Accessibility index distance nearest market[2]	kilometers					19.5	4.7			11	28
Accessibility index time all local markets[2]	minutes					130.2	70.2			51	255

Notes:
[1] 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.
[2] Soil, water availability, and accessibility measures where derived from GIS coverages available in Mekong Delta Provinces only.
[3] Calculated as the weighted average (by quantity of rice sold) sale price of rice reported by surveyed farms.

III. LAND USE MODEL

Building upon a von Thünen type framework and the work of Chomitz and Gray (1995), the effect of travel distances between farms and markets on cropping patterns and land use intensity of farms are modeled. Model formulation begins with the assumption 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.

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

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)

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 fixed characteristics of the plot that influence the land's production efficiency in use k

X_{ik} is the optimal input level for production of crop k per unit at land at point i

Q_{ik} is the potential output of crop k at plot/point i (potential production)

u_{ik} is a random disturbance term.

The prices of inputs and outputs in the revenue equation depend upon the distance of the farm from the market. It is assumed that the prices of inputs increase, and the 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. 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, while 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:

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

Adding technical assumptions concerning the distribution of error terms (u_{ik}) 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 farm commercial 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 also guides the selection of variables and our 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.

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) 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 wood (e.g., eucalyptus). In order to apply panel data estimators, it is necessary to define cropping patterns and land use intensity as binary outcomes.

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 on its land, 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 the head of household, 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. The rice variety planted by farms clearly influences the feasible cropping intensity. Dummy variables are used to define farms growing short-duration, modern varieties and medium- or long-duration varieties. 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. The parameter *Rho* indicates the significance of farm specific error estimates.

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 Table 2. Psuedo-R^2 measures vary between 44.7 and 6.4 percent across measures and models. Lastly, the table reports the share of land use categories correctly predicted by each model, and the distribution of actual versus predicted land use. This shows all three models performed well, predicting farm's land use decisions correctly.

Table 2. **Summary of Estimates of Land Use (Panel Data Estimators)**

LHS/Dependent Variable Estimation coefficient (Standard error of estimate)		Cultivates nonrice crop(s) 1994-97 (N=436)			Farm cultiv. fruit/other trees 1994-97 (N=436)			Farm triple crops rice (vs. 2 rice) 1994-97 (N=354)		
Land-labor ratio on farm		-1.058 *			0.056			-0.365 ***		
(hectares per HH 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		-0.131			-0.018			0.088		
modern varieties of rice		0.670			0.452			0.156		
Cultivated medium- or long-		2.221 ***			-0.334			0.846 ***		
duration modern rice varieties		0.775			0.364			0.172		
Farm invested in land leveling or		-0.116			-0.902 **			0.068		
other soil improvement		0.467			0.450			0.148		
Farm invested in dike construct-		0.646 *			-0.769 *			0.080		
ion or other water management		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

Notes:
*** 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
Estimates used the random effects probit estimator for panel data.

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 the probability that the farm cultivated a crop besides rice. 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.[1] The estimated marginal effect of a one percent

[1] 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 2000).

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 ten 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 outline in the previous section of the report.

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 substitute responses to tree crop cultivation in addressing water scarcity and 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—surprisinging—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.

To summarize the discussion of Table 2, across these estimates it was found that farm size, particularly the relative abundance or scarcity of family agricultural labor in relation to the land operated by the farm, plays an important role in driving farm land 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 maturation period of chosen varieties is closely related to broader land use choices of farms. Finally, investments in farm- or 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 significantly influence land use choices, which underscores the complexity and idiosyncrasy of the land use choices of farms.

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 3. 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

Table 3. **Summary of Estimates of Rice-cropping Intensity**

Left-hand side/dependent variable estimation coefficient (estimated standard error)		Rice-cropping intensity in 1994[a] (N = 60)	Rice-cropping intensity in 1995[a] (N = 114)	Rice-cropping intensity in 1996[a] (N = 114)	Rice-cropping intensity in 1997[a] (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 is 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.

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 ten 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.

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 by farm. 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 discussed next, are summarized on Table 4. Adjusted R^2 coefficient estimates across the production models ranged between 0.76 and 0.89. All four models were highly statistically significant overall. The cropping intensity had 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 all conform to expectations. The one exception involved the use of modern varieties, which had inconsistent effects on rice production across estimates. It had statistically significant

Table 4. **Rice Production Estimates (cross sectional estimators)**

Left-hand side/dependent variable estimation coefficient (estimated standard error)	Rice production in 1995[a] (N = 117)	Rice production in 1996[a] (N = 134)	Rice production in 1997[a] (N = 121)	Rice production in 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]

Notes:
*** 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
[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 specificat.
N.R. means household-specific intercepts are not reported.

negative effects in estimates carried out using data from 1995 and 1997 and a positive effect in 1996. One 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 farm land 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 5 and 6. Table 5 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. 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

Table 5. **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 6. **Simulation of Effects of Investments on Rice Production among Surveyed Farms (tons)**

	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
% 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.

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 6 details the changes in total rice production from the 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. Incorporating the estimates obtained in this research with other linear programming or general simulation models would be an important extension of this research.

VI. CONCLUSION

These 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 our expectation that greater transport distances reduce the cropping intensity and make the cultivation of nonrice crops less likely. However, results suggest the quality of the water management infrastructure is far more important in determining land use than transport infrastructure. 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, the age of the farm operator, the land-to-labor ratio of the farm, and rainfall influenced farm land use as predicted. Results suggest that investments in water management offer more promise in improving farm land 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 cost-price accounting study, and as a result encountered data constraints in analyses.

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