Education and Innovation Adoption in Agriculture: Evidence from Hybrid Rice in China

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The continuous creation and introduction of new technology has been used as a standard for distinguishing a modern agricultural system from a traditional one (Schultz 1964). However, the introduction of many new technologies has met with only partial success, as measured by observed rates of adoption. Constraints to the rapid diffusion of a new technology may arise from many sources, such as lack of credit, inadequate farm size, unstable supply of complementary inputs, and so on (Feder, Just, and Zilberman). This paper examines the role of education in a farm household's decision regarding adoption of F_1 hybrid rice seed in the context of the Chinese economy.

A new agricultural technology may reflect high yield, low cost, or other desirable traits. However, the changes in the production process involved in the adoption of a new technology may bring risks due to imperfect information and the possibility of committing errors. Since education enhances one's ability to receive, decode, and understand information, Schultz (1964, 1975) and Nelson and Phelps, among others, have hypothesized that education may facilitate the diffusion of new technology. That is, farmers with a relatively high level of education may have a higher probability of adopting new technologies than those with relatively little education.

A number of empirical studies have examined the linkage between adoption of new agricultural technology and education. Some of the evidence is summarized by Feder, Just, and Zilberman. In those studies, the likelihood of adopting a new technology was found to be positively related to the education level of farmers. A recent study by Duraisamy also found that in India the level of using high-yielding rice varieties in India is positively related to education level. The above theory and evidence suggest that a farmer's education level may be an important factor in the adoption of F_1 hybrid rice in China.

China is the only country in the world in which F_1 hybrids are commercially used in production. Several studies have estimated the profitability of hybrids as compared to conventional varieties (He *et al* 1984, 1987a, 1987b). The yield advantage of hybrids over conventional varieties is about 15%. Because China's economy is centrally planned, governmental intervention has often been used in promoting certain technologies. As a result, just how important economic considerations are in the adoption decision regarding F_1 hybrids at the farm level is a controversial question (Wiens; Barker and Herdt, p. 61). An earlier study of my own (Lin 1990), using aggregate panel data, found profitability to be an important factor in explaining differences across regions and over time in the diffusion of hybrids after the household-based farming system reform, but not in the pre-reform period.[1] However, due to the aggregate nature of the data set used in that study, direct conclusions about the role played by education and other household characteristics could not be drawn.

For the purpose of this study, cross-section production data collected at the end of 1988 from a sample of 500 households are used. The main purpose is to determine the role of education in a household's decision regarding adoption and intensity of use of F_1 hybrids. In addition, other potentially relevant variables, such as the farming experience and sex of the household head and the availability of credit, are included.

The paper is organized as follows: The next section presents a simple behavioral model, which treats the adoption decision as a portfolio selection problem. The model is followed by a description of the areas covered by the study and the data set. The subsequent section presents the empirical analysis. The last section summarizes the results and discusses their implications.

A Portfolio Selection Model of Technological Adoption

In order to analyze the impact of education on the adoption decision regarding F_1 hybrid seeds, this section constructs a formal behavioral model in which the adoption of new technology, represented by the use of F_1 hybrid seed, is treated as a portfolio selection problem. The objective of a farm household is to maximize its expected utility. Following the convention of portfolio selection literature, I assume that a household only cares about the mean and variance of its income.[2] For simplicity, a farm household is assumed to grow a single crop, rice, on a unit of land. There are two alternative technologies -- conventional rice (CR) and F_1 hybrid rice (HR). CR is assumed to have a low yield, but the output is certain to each household. The output level, however, may be different from household to household due to the difference in some household characteristics. HR, on the other hand, has a higher expected yield but the output level is uncertain to each household. The variance of the output level will be assumed to depend on the *i*th household head's education level and other household specific variables that affect the household's ability in dealing with new technology.[3]

Following Jamison and Lau's convention (p. 197), if CR is used on all of the *i*th household's land, its income can be written as a function of variables representing the economic environment and a specific household factor, in the form

$$(1) \quad Y_{i,C} = M_C(E) + \epsilon_{i,C},$$

where E is a vector of independent variables representing the prices of rice, seeds, chemical fertilizers, pesticides, and so on, and $\epsilon_{i,C}$ is a variable representing the *i*th household's specific capacity for producing CR.[4] Similarly, the mean income from using HR on all its land can be written as a function of the same independent variables, and a specific household factor, in the form

$$(2) \quad Y_{i,H} = M_H(E) + \epsilon_{i,H}.$$

The variables $\epsilon_{i,C}$ and $\epsilon_{i,H}$ cannot be directly observed, but it is assumed that their joint distribution over the whole population can be described by a probability density function. Therefore, the *i*th household's mean income with r_i proportion of its land producing HR can be expressed as

$$(3) \quad Y_i = \{M_C(E) + \epsilon_{i,C} + r_i \cdot [\ D(E) + (\epsilon_{i,H} - \epsilon_{i,C})]\},$$

$$\text{where } D(E) \equiv M_H(E) - M_C(E).$$

If a household allocates all its land to produce CR, there will be no variance in its income, as the output level of CR is assumed to be constant to each household. If a household allocates all its land to produce HR, the variance in the household's income will be assumed to have the following functional form:

$$(4) \quad V_i = V_{i,H}(e_i,\ Z_i,\ E),$$

where e_i is the *i*th household head's education level; and Z_i is a vector of other household specific variables, such as the availability of credit and extension service to the household.[5] If a household allocates r_i proportion of its land to produce HR, the variance in its income will thus be

$$(5)\ Vi = r_i^2 \,.\, V_{i,H}(e_i,\ Z_i,\ E).$$

From expression 5, we find that the variance of a household's income is positively related, and increases at an increasing rate, to the proportion of land that the household allocated to HR.

For simplicity and ease of interpretation, the utility function is assumed to be separable, and have the following specific form:

$$(6)\ U_i = Y_i - C(V_i) = Y_i - C(r_i,\ e_i,\ Z_i,\ E),$$
$$\text{where } C_1 > 0,\ C_{11} > 0,\ C_{12} < 0, \text{ and } C(0,\ e_i,\ Z_i,\ E) = 0.$$

The specifications of C(.) in the second line of expression (6) imply that, given other variables, the utility loss increases and at an increasing rate with the ratio of land allocated to HR, that education reduces the utility loss of adopting HR, and that there is no utility loss if HR is not adopted. These characteristics can be justified by the previous assumptions that the income variance increases and at an increasing rate with the proportion of land used in HR, education reduces the variance of HR output, and the output of CR is constant. The optimization problem for a household can thus be expressed as follows:

$$(7)\quad \underset{0\leq\, r_i\, \leq 1}{\text{Max}}\ U_i(r_i|\ e_i,\ \epsilon_{i,C},\ \epsilon_{i,H},\ Z_i,\ E)$$
$$= \{M_C(E) + \epsilon_{i,C} + r_i.[\ D(E) + (\epsilon_{i,H}-\epsilon_{i,C})]\} - C(ri|\ e_i,\ Z_i,\ E).$$

This expression postulates that, given the *i*th household head's education level, specific ability in producing CR and HR, and other exogenous variables in the household as well as economy, the household will allocate its land to HR in a way that its utility is maximized.

<u>The Probability of Adoption</u>

Before solving for the optimal proportion of land used for HR, r_i^*, we will first consider the probability that the *i*th household will allocate part of its land endowment to HR, that is, r_i will be greater than zero. Expression (7) indicates that the necessary condition for $r_i > 0$ is $r_i.[D(E) + \epsilon_{i,H}-\epsilon_{i,C}] - C(r_i|\ e_i,\ Z_i,\ E) > 0$. Therefore, whether a household adopts HR depends only on the value of $r_i.[D(E) + \epsilon_{i,H}-\epsilon_{i,C}] - C(r_i|\ e_i,\ Z_i,\ E)$. As shown in figure 1, the necessary and sufficient condition for $r_i > 0$ is

$$(8) \quad C_1(0|\ e_i,\ Z_{i,\ E}) < D(E) + \epsilon_{i,H}-\epsilon_{i,C}$$

where $C_1(0|\ e_i,\ Z_i,\ E)$ is the first derivative of $C(r_i|\ e_i,\ Z_{i,}\ E)$ evaluated at $r_i= 0$. The adoption indicator of the *i*th household, $A_{i,}$ takes the value of

$$(9) \quad A_i = \begin{cases} = 1 \text{ if } C_1(0|e_i,\ Z_i,\ E) < D(E) + \epsilon_{i,H}-\epsilon_{i,C}, \text{ HR is adopted;} \\ = 0 \text{ if } C_1(0|e_i,\ Z_i,\ E) \geq D(E) + \epsilon_{i,H}-\epsilon_{i,C}, \text{ HR is not adopted.} \end{cases}$$

Thus, the probability that a household drawn randomly from the population, with education of household head, other characteristics and environment variables given, would adopt HR equals

$$\begin{aligned} P_i = Pr(A_i=1) &= Pr[C_1(0|e_i,\ Z_i,\ E) < D(E) + \epsilon_{i,H}-\epsilon_{i,C}] \\ &= Pr[C_1(0|e_i,\ Z_i,\ E) - D(E) < \epsilon_{i,H}-\epsilon_{i,C}]. \end{aligned}$$

This probability depends on the difference of the functions $C_1(0| e_i, Z_i, E)$ and $D(E)$ and $\epsilon_{i,H}-\epsilon_{i,C}$. $C_1(0| e_i, Z_i, E)$ is specified as a linear function of e_i, that is

$$C_1(0| e_i, Z_i) = a_0 e_i + \mathbf{a}_1 Z_i + \mathbf{a}_2 E,$$

where a_0 is an unknown parameter, and $\mathbf{a}_1$ and $\mathbf{a}_2$ are both row vectors of unknown parameters. Similarly, D(E) is a linear function of E,

$$D(E) = \mathbf{b}E$$

where **b** is a row vector of unknown parameters. We will denote the difference in the individual household factors as ϵ_i, that is,

$$\epsilon_{i,H}-\epsilon_{i,C} \equiv \epsilon_i$$

Then, the probability of the *i*th household adopting HR equals

$$(10) \quad P_i = Pr(A_i=1) = Pr\ [\epsilon_i < \mathbf{b}E - a_0 e_i - \mathbf{a}_1 Z_i - \mathbf{a}_2 E]$$
$$= F\ (\mathbf{b}' E - a_0 e_i - \mathbf{a}_1 Z_i),$$

where $\mathbf{b}' = \mathbf{b} - \mathbf{a}_2$, and F(.) is the cumulative distribution function.

As shown, the probability of the *i*th household adopting HR seed is the value of the cumulative distribution function of F evaluated at $\mathbf{b}'E - a_0 e_i - \mathbf{a}_1 Z_i$. The exact distribution of F depends on the population distribution of the random variable ϵ_i. If ϵ_i is identically and independently distributed as the normal distribution over the population, the unknown parameters $\mathbf{b}'$, a_0, and $\mathbf{a}_1$ can be estimated by the probit regression model, which yields consistent and asymptotically efficient estimates. Since $C_{12} < 0$ implies that $a_0 < 0$, a larger e_i thus implies a higher probability of adopting HR seed.

the Optimal Adoption Intensity

The *i*th household's optimal proportion of land used in the production of HR can be obtained by solving expression (7). The first-order condition for an optimum requires

$$(11)\quad D(E) + \epsilon_{i,H} - \epsilon_{i,C} - C_1(r_i |\ e_i,\ Z_{i,\,E}) = 0.$$

Equation (11) implies that, for the optimality to hold, the decision maker equates the utility gain from adopting HR with the utility loss due to adopting this new technology at the margin. The second-order condition requires that $-C_{11} < 0$, which holds according to the basic assumptions.

The effect of education on the optimal proportion of land used for HR is implicitly defined in equation (11). From the implicit function theorem, we can obtain the following relation:

$$(12)\quad dr_i/de_i = -C_{12}/C_{11} > 0.$$

The optimal proportion of a household's land used for HR is thus implied in expression (11). To be specific, the optimal proportion can be expressed in a functional form as follows:

$$r_i^* = r\ (e_i |\ \epsilon_i,\ Z_i,\ E),$$

where $\epsilon_i = \epsilon_{i,H} - \epsilon_{i,C}$, as previously defined, is assumed to be identically and independently distributed as the normal distribution over the population. We will assume that the function is linear in e_i, Z_i, and E, that is,

$$(13)\quad r_i^* = c_0 e_i + cZ_i + dE + \epsilon_i$$

where c_0 is an unknown parameter, and c and d are row vectors of unknown parameters. Since $0 \leq r_i \leq 1$, the dependent variable r_i is censored. The tobit regression model with lower bound zero and upper bound 1 will yield consistent and asymptotically efficient estimates of the unknown parameters in expression (13).

The discussion so far focuses solely on the effect of a household head's education on the probability and intensity of adopting HR. It is also possible to investigate the impacts of other household characteristics and environmental variables under the present framework. For example, an increase in the price of rice will increase the relative profit of HR over CR and, therefore, increase the probability and intensity of adopting HR. Changes in the price of purchased inputs may also affect the probability and intensity of adopting HR if the requirements of purchased inputs differ between CR and HR. The availability of credit may facilitate adoption if more purchased inputs are used for HR and a household's liquidity becomes a constraint. Furthermore, most farm households are obliged to sell a certain quota of rice at below-market price to the government. In cases where the quota is a binding constraint, a household may adopt hybrid rice simply for its higher yield, even though it may not be as profitable as conventional rice. However, a full-length discussion of the impacts of these other variables is beyond the purview of this paper.[6]

The Data and Study Setting

The data come from a cross-section survey of 500 households in five counties in Hunan Province which was carried out during December 1988 and January 1989. Hunan Province is located on the middle reaches of the Yangtze River in South China. It has a semi-tropical climate. The average temperature is 4-7 ^{0}C in January and 26-30 ^{0}C in July, with 260 - 300 frost-free days. Annual rainfall is about 1,300 mm to 1,700 mm. Most of the rain fall is concentrated in May, June, and July. Of the total land area of 211,000 square km, mountains make up 51.2%, hills 29.2%, plains 13.1%, and water surface 6.4%. The province has 2.56 million hectares of cultivated land, 82% of which is irrigated. The per capita cultivated area is 0.05 hectare, below the national average. The total population is 5.8 million, of which 4.8 million is agricultural. From the proportion of agricultural population in total population, and from the per capita gross values of agricultural output and industrial output, Hunan can be considered in China to be a predominately agricultural province (see table 1). Rice is its most important crop. In 1987, 57% of the total cultivated acreage (or 82% of the grain acreage) was planted with rice, and, of the rice acreage, 46.5% was planted with hybrid seed.

The province is divided juridically into 105 counties in three types of geographic setting-- lake-plain, hill, and mountain. Among the five counties in the data set, the first two-- Tiaojiang and Xiangxiang-- are selected from the hill region, the next two-- Nanxian and Anxiang-- from the lake-plain region, and the last one-- Zhijiang-- from the mountain region. These five counties were selected from the provincial sample of 34 counties surveyed annually by the State Investigation Team. Table 1 indicates that the 1988 per capita GNPs of these five counties were all lower than the provincial average, but that their per capita gross values of agricultural output were all higher than the provincial average. However, their rice economies are considered typical, and their agri-climatic conditions and infrastructure are representative of their respective regions.

Samples of 100 households each from these five counties were surveyed.

These households were all included in the random samples surveyed by the State Investigation Team. Table 2 summarizes the key characteristics of the samples in each of the five counties. While households in the two hill counties, Tiaojiang and Xiangxiang, had the highest per capita income in 1988, households in the two lake-plain counties, Nanxian and Anxiang, had the largest farm size. The main reason for the large farm size in the lake-plain region is that a substantial amount of cultivated land has been newly reclaimed from Dongting Lake, one of the five largest lakes in China.

Education in this study refers to a household head's years of formal schooling, including general and vocational training. China's school system consists of primary, secondary, and tertiary level. Because of a strong urban bias in the school system, students in rural areas are at a disadvantage to compete with students in urban areas. Therefore, the dropout rate in rural primary school is high and only a small portion of primary school graduates continues higher education.[7] In the samples, only one household head completed college education and 93.3% of household heads have less than 10 years of schooling. The average years of schooling is 5.52, about the level of a primary school graduate, with a large variation across age cohorts. The average for the cohort of household heads with age less than 30 is 7.85, while for the cohort with age 50 or older the average is 3.91. The average years of schooling is 6.39 for the cohort of thirties and 5.37 for the cohort of forties. Thus the younger a household head is, on average, the better is his/her education.

F_1 hybrid seeds were released to farmers in 1976. The price of hybrid rice matched the price of conventional rice. However, the price of hybrid seed was set officially to be 10 times the price of conventional seed because initially the seed field produced about one-tenth the seed of a conventional rice field.[8] Increase in seed costs, however, are mitigated by reduced seed requirements due to low plant density necessary in hybrid rice production.[9]

The yield of F_1 hybrids is reported to be about 20% higher than the conventional rice. In the first two years the diffusion of hybrid rice in Hunan was very rapid, but it declined sharply in 1979 and stagnated until 1983 (see figure 2). Several factors may contribute to this fluctuation and stagnation: Substantial government intervention was used at the beginning stage. Because rice-growing environments were diverse but the range of available hybrid varieties initially was limited, crop failures occurred in a number of areas owing to lack of resistance to local diseases. In addition, the growing time of the early-released hybrids was rather long (135 days), and the cooking quality was also a concern. However, most of the aforementioned problems were largely solved by 1988, the time of the survey.[10]

The new household-based farming system was introduced in the study areas during 1981-2. Table 3 compares the percentages of households in each county that adopted and did not adopt F_1 hybrids at the time when the new farming system was introduced and in 1988. Except in Zhijiang, the majority of households did not adopt hybrids when the institutional change occurred. In contrast, most households in all five counties adopted hybrids in 1988. The higher incidence of early adoption in Zhijiang county probably reflects the fact that most households in Zhijiang grow only one crop of rice a year while in other four counties most households grow two crops of rice annually. Therefore, the early-released hybrids, with a rather long maturation period, could be integrated more easily into the cropping system in Zhijiang.

Among the 500 households in the sample, 78% reported to have increased their hybrid-planted acreage, while only 4.2% reported that their hybrid acreage was reduced. The main reason reported for increases in hybrid rice acreage was improvement in yield advantage (384 out 390 households reported this reason). The releases of new hybrid varieties with suitable maturation period, however, should have also contributed to the increase. Our survey shows that the actual growing time in 1988 for early, middle, and late hybrids averaged, respectively, 111 days, 152 days, and 122 days, compared to 109 days, 149 days and 125 days for conventional early, middle and late rice.

As for government support for the adoption of F_1 hybrids, 21.2% of households reported that chemical fertilizers were used as an award when the hybrids were first promoted, and another 2.6% reported that hybrid seed was subsidized. Currently, none of the surveyed households reported seed subsidies and only 4.4% of the households reported having fertilizer supports.[11]

The survey also asked about cooking quality of hybrid rice. The responses of the sample households indicate that this is no longer an issue. Among the 319 households growing both hybrids and conventional rice, 48% reported eating conventional rice for daily meals, while the other 52% reported eating hybrid rice. As for the rice used for special occasions like entertaining guests and celebrating festivals, 25.4% reported to prefer conventional rice, 39.8% to prefer hybrid rice, while the remaining 34.8% reported having no preference.

Of the 500 households surveyed, 495 devoted part of their land to rice. Detailed information on the number of households using hybrid and conventional seed in each of the five counties in 1988 is reported in table 4. While only a few (thirteen) among the 495 households planted hybrids in the early rice season, the majority of households adopted hybrid seed either in the middle season if only one crop of rice is grown, or in the late season if two crops of rice are grown each year. A substantial portion of the households in each county planted both hybrid and conventional rice in a single crop season. This practice will enable us to investigate not only the problem of dichotomous choice but also the optimal allocation of land to the production of hybrids.

The reason for early hybrids not being adopted by most households may arise from the fact that the yield advantage of early hybrids with suitable maturation period was not significant compared to early conventional varieties. Table 5 reports the means and standard deviations of inputs and outputs for hybrid and conventional rice from the samples. While the mean yields of hybrids were significantly higher than those of conventional varieties for middle and late rice, the difference is not statistically significant for early rice. Hybrid rice's yield advantages are partly offset by added requirements for chemical inputs and more expenditures for seed. As indicated in table 5, significantly more chemical inputs (chemical fertilizers and pesticides) were devoted to hybrids as compared to conventional varieties. Also, although cultivation of hybrids required only about one-third to one-fourth as much seed as conventional varieties, the price of hybrid seed is fixed as 10 times that of conventional seed. Therefore, the advantage of growing hybrids compared to conventional varieties depends largely on the prices of chemical inputs and seed, even for middle and late rice. However, hybrid rice does not require more labor input than conventional rice.

Empirical Analysis

Functional Form Specification

In the theoretical section, it was argued that the probability as well as the intensity of adopting F_1 hybrid seeds in rice production for a randomly selected household are functions of the household head's education, and other variables representing the household's characteristics and the economic environment. It is clear from the theoretical model that the functions for the dichotomous choice and for the optimal adoption decision should have the same set of explanatory variables. Table 6 presents the definitions, means, and standard deviations of the variables which will be used as regressors in the empirical analysis. Variables 1 to 4 are county dummies that represent some county-specific characteristics, which affect the adoption decision but are not observable to researchers.[12] Variables 5 to 7 are price variables, representing the economic environment. Theoretically, the prices of seed, fertilizer, and pesticide relevant to the decision to adopt hybrid seeds should be expected prices. Because data on expected prices are not available, the actual prices a household paid were used as proxies for expected prices.[13] If significant differences exist between expected prices and actual prices, the estimates of parameters may be biased. The price of rice is not included in the list because no cross-sectional variation in rice price existed. Since the information on wage, rent, and interest rate are not available, wage, rent, and interest rate are not include either. Variables 8 to 13 represent the household-specific characteristics, including endowments in landholding, labor, and capital, dummies for credit availability and state rice procurement quota, and the average education level of adult household members (excluding the household head).[14] The last group of variables was the household head's personal characteristics, including dummies for job type and sex, years of experience in agriculture, and years of education.

As for the dependent variables in the analysis, only the adoption decision with respect to middle rice and late rice is considered. Early rice is excluded because the data indicate that adapted early hybrids are not yet available. In the dichotomous choice model, a household is considered as an adopter if it grew either middle hybrids or late hybrids. In the model of optimal adoption decision, the dependent variable is the percentage of total rice acreage planted with hybrids in both the middle and late rice seasons.[15]

The theoretical model suggests that if the functional forms of D(E) and $C_1(0| e_i, Z_i, E)$ are linear, and the unobservable variable ϵ_i is identically and independently distributed as the normal distribution over the population, then probit is the appropriate method for estimating the unknown parameters in the dichotomous choice model. Similarly, if the functional form of $r(e_i| \epsilon_i, Z_i, E)$ is linear in the explanatory variables and ϵ_i has a normal distribution, then the two-limit tobit is the appropriate method for estimating the unknown parameters in the optimal adoption rate equation. Therefore, the probit and tobit model will be applied to estimate the following function:

$$
\begin{aligned}
(14) \quad X = {} & \alpha_1 + \alpha_2 C2 + \alpha_3 C3 + \alpha_4 C4 + \alpha_5 C5 + \\
& \beta_1 LnPs + \beta_2 LnPf + \beta_3 LnPp + \\
& \gamma_1 LnLand + \gamma_2 LnLabor + \gamma_3 LnCaptial + \gamma_4 CR + \gamma_5 Quota + \gamma_6 Avedu + \\
& \delta_1 Job + \delta_2 Sex + \delta_3 Agryrs + \delta_4 Eduhead + \epsilon_x ;
\end{aligned}
$$

X = AHR (dummy variable for the dichotomous choice) or PHR (percentage of acreage planted with hybrids).

The price variables and input endowments are the logarithms of their respective quantities. This is because under the assumption of Cobb-Douglas production functions, the logarithmic normalized production function is a linear function in the natural logarithms of the normalized prices and the fixed inputs, and is also linear in the characteristic variables (Jamison and Lau, p. 203).

Empirical Results

The empirical results are presented in table 7. The estimates of coefficients indicate that a household head's education level has a positive effect both on the probability of adoption and the intensity of adoption of F_1 hybrids, as predicted by the theoretical model. The estimates are different from zero at a .1% level of significance in the dichotomous choice model and at a 5% level of significance in the optimal adoption decision model. This evidence gives support in a Chinese context to Schultz's thesis about the role of education in decisions about the adoption of new technology.

As for the effects of other independent variables on the probability of adopting hybrid seed, the estimates in column (1) indicate that a household head's number of years of experiences in agriculture, the existence of government procurement quota, and the size of a farm's cultivated land also have significantly positive impacts, and the price of hybrid seed has a significant negative impact. Other economic and household characteristic variables do not have significant effect. The positive impact of farm size on probability of adoption may arise from the economies of scale in acquiring information, credit, and/or hybrid seeds. As for the optimal adoption decision, column (2) of table 7 indicates that, besides a household head's education level and county dummies, a household's capital endowment is the only variable to have significant effect (at 10% level). This result implies that higher investment in fixed inputs increases the proportion of land used in hybrids.

Concluding Comments

This paper has focuses on the role of education in a farm household's decision about whether to adopt and the optimal intensity of adoption of F_1 hybrid rice in China. A simple behavioral model was developed in which adoption of new technology was treated as a portfolio selection problem, and the implications of the model were tested with data collected from a sample of 500 households from five counties in Hunan Province. The empirical results are consistent with the implications of the role of education in the theoretical model: A household head's level of education has positive and statistically significant effects on the household's probability and intensity of adopting of F_1 hybrid seed. Since technological change is the main force in agricultural development, the evidence in the paper supports arguments for increasing state investments in rural education in order to facilitate technological change in agriculture. In addition, a farm's size has a positive effect on the decision to adopt F_1 hybrids. This evidence suggests that the small farm size predominant following the household-based farming institutional reform may pose a restraint to technological change, and thus supporting the argument for further liberalization in land markets, in order to facilitate consolidation through land market transactions.[16]

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Notes

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[1] Farming activities were organized in a collective team system prior to the farming institutional reform in 1979. The collective system was replaced by an individual household-based system by 1983. For a theoretic and empirical study of this reform, see Lin (1988).

[2] This assumption requires that the utility function be quadratic, or/and that the outputs of new as well as old technologies have a normal distribution.

[3] These assumptions imply that the adoption of CR is riskless, and that HR is risky.

[4] That is, the first component, $M_C(E)$, is common to each household, and the second component, $\epsilon_{i,c}$, differs from household to household. The difference in

the second component may arise from several sources, like the quality of irrigation, fertility, and other micro-physical conditions of the household's landholding, the experience and ability of the household members, and so on.

[5] Since education enhances the ability of using new technology, the variance of HR output will be postulated to be inversely related to the educational level of the household head.

[6] The above model is obviously over-simplified. The framework could be further developed in many directions; however, the simplest form of the model is adopted in order to clearly illustrate its implications. For other models that treat technology adoption as dichotomous choice, see Jamison and Lau; as a portfolio selection problem, see Feder (1980), and Just and Zilberman.

[7] For an informative discussion of the issues and changes in China's rural education, see Perkins and Yusuf, Chap. 8.

[8] The production of F_1 hybrid seed involves a complicated three-line method: (1) locating a cytoplasmic male-sterile parent plant; (2) crossing it with a maintainer line to produce offsprings with sterility but with desirable genetic characteristics; and (3) crossing these seeds with a "restorer" line to produce F_1 seeds with normal self-fertilizing power. Initially the yield of hybrid seed fields was very low. The yield has been improved and reached one-third to one-half the yield of a regular field but the price ratio is still maintained.

[9] Due to high-tillering rate, F_1 hybrids require only one-third to one-fourth of conventional rice's seeding rate.

[10] The increase in the diffusion of hybrid rice after 1983 can partly be attributed to the improvement in a farmer's incentive for acquiring new innovation due to the change from the collective system to the household-based farming system (Lin 1990).

[11] This response may underreport the government's function in the promotion of F_1 hybrid rice, as government supports are mainly given to the seed research and distribution system, and not directly to individual households.

[12] The county dummies capture the effect of differences in a county's topology, rain fall, temperature, and other physical variables on a household's adoption decision. Since hybrid seed production, distribution, and extension services are organized by each county government, the county dummies will also capture the effect of differences in these government-provided services.

[13] The prices are derived from each household's actual expenditures on seeds, fertilizers and pesticides, dividing by the quantities of seeds, fertilizers, and pesticides. Because some portion of each of the inputs was rationed and some was purchased from markets, the derived prices are the average prices paid by a household.

[14] Since information on the availability of credit does not exist, the incidence of taking formal credit in the previous two years was used as a proxy for credit availability. However, this proxy may not reflect actual credit availability because the absence of borrowing may indicate that a household has enough funds of its own.

[15] Most households grow either middle or late rice, but not both.

[16] Although collectivization can solve the problem of farm size, it will reduce a farmer's incentives for farming as well as adopting new technology (Lin 1988, 1990), therefore, collectivization should be excluded as an alternative for solving the problem of farm size.

Table 1: Economic Profiles of the Study Areas

	Population		GNP Per Capita (Yuan)*	Gross Value Per Capita (Yuan)	
	Total (1,000)	Agri.		Agri.	Indus.
Nation	1,096,140	552,450	1,278	535	1,662
Hunan	59,157	50,356	987	512	983
Tiaojian	765	699	836	701	494
Xiangxiang	843	761	778	631	851
Nanxian	678	573	842	742	723
Anxiang	522	429	761	660	515
Zhijiang	316	286	713	621	479

Source: China Statistical Yearbook, 1989. p.28, p.51, p.87, p.742.
Hunan Statistical Yearbook, 1989. pp.375-8, pp.395-8, pp.407-10, pp.435-38, pp.491-2.

Note: * US$ 1 = 3.7 Yuan in 1988.

Table 2: Characteristics of Sample Farm Households

	Tiaojian (N=100)	Xiangxiang (N=100)	Nanxian (N=100)	Anxiang (N=100)	Zhijiang (N=100)
Mean farm size (mu*)	5.0	4.9	8.1	8.4	5.9
Mean household size (person)	4.28	4.26	4.59	4.60	4.20
Per capita income (Yuan**)	569	607	430	492	463
Share of income from:					
(i) Nonfarm activities(%)	39	21	19	20	29
(ii) Sideline and animal husbandry (%)	31	25	18	21	23

Note: * 15 mu = 1 hectare.

** In 1988, US$ 1 = 3.7 Yuan.

Table 3: Changes in Adoption of Hybrid Seeds

	Tiaojian (N=100)	Xiangxiang (N=100)	Nanxian (N=100)	Anxiang (N=100)	Zhijiang (N=100)
In 1981-1982					
Adopter	27	10	4	20	52
Nonadopter	63	90	96	80	48
In 1988					
Adopter	78	67	64	93	99
Nonadopter	22	33	36	7	1

Table 4: The Adoption of Hybrid and Conventional Rice in 1988

	Tiaojian (N=100)	Xiangxiang (N=100)	Nanxian (N=97)	Anxiang (N=99)	Zhijiang (N=99)
Early Rice					
Hybrid	4	7	0	0	2
Conventional	98	98	92	98	6
Both	2	5	0	0	0
Middle Rice					
Hybrid	0	1	8	8	99
Conventional	0	0	11	9	14
Both	0	0	0	2	14
Late Rice					
Hybrid	79	67	63	90	9
Conventional	35	49	78	51	0
Both	14	18	46	43	0

Table 5: Means & Standard Deviation - Hybrid and Conventional Rice

	Early Rice		Middle Rice		Late Rice	
	Conv. (N=392)	Hybrid (N=13)	Conv. (N=34)	Hybrid (N=116)	Conv. (N=213)	Hybrid (N=308)
Seed (kg/mu)	11.6	3.1	6.9	2.0	6.2	2.0
	(3.7)	(2.2)***	(3.1)	(0.9)***	(3.3)	(1.1)***
Fert.(Yuan/mu)	21.0	27.5	14.9	18.9	22.7	24.7
	(9.4)	(7.9)*	(8.4)	(10.4)*	(13.2)	(10.7)*
Pesticide (Yuan/mu)	5.1	7.3	4.1	6.2	5.7	7.3
	(4.7)	(2.7)	(3.5)	(4.1)*	(3.9)	(5.4)**
Labor (day/mu)	15.3	17.0	22.3	20.3	13.9	14.4
	(6.4)	(3.8)	(13.6)	(7.4)	(5.8)	(5.4)
Draft Animals (day/mu)	1.5	1.9	3.0	3.7	1.1	1.1
	(1.1)	(1.0)	(3.0)	(2.1)	(1.1)	(.7)
Machine (day/mu)	.5	1.3	1.4	.06	.6	.6
	(.8)	(1.4)**	(6.9)	(.31)*	(.8)	(.9)
Rice Output (kg/mu)	352.7	385.4	270.0	432.5	323.6	386.6
	(97.3)	(172.1)	(117.8)	(124.2)***	(90.2)	(85.3)***
Straw (kg/mu)	206.9	293.1	211.9	295.9	240.8	296.1
	(109.9)	(57.4)**	(92.4)	(89.6)***	(95.7)	(98.1)***

Notes: *, **, and ***, indicate respectively, that the means are significantly different at the 5%, 1% and 0.1% level of confidence.

Table 6: Variable Definitions, Means and Standard Deviations

<u>Dependent variables</u>:		
(1) AHR	Adoption dichotomous =1 if middle or late hybrid rice is adopted, 0 otherwise	.82 (.39)
(2) PHR	Percentage of middle and late rice area grown with hybrid seeds	.69 (.40)
<u>Independent variables</u>:		
(1) C2	County dummy variable =1 if Nanxian County, 0 otherwise	.20 (.40)
(2) C3	County dummy variable =1 if Anxiang County, 0 otherwise	.20 (.40)
(3) C4	County dummy variable =1 if Zhijiang County, 0 otherwise	.20 (.40)
(4) C5	County dummy variable =1 if Xiangxiang County, 0 otherwise	.20 (.40)
(5) Ps	Price of hybrid rice seed (Yuan/kg)	4.07 (.63)
(6) Pf	Price of chemical fertilizer (Yuan/kg)	.41 (.49)
(7) Pp	Price of Pesticide (Yuan/kg)	10.06 (2.49)
(8) LAND	Land area cultivated (in mu, 1 ha = 15 mu)	6.46 (2.97)
(9) LABOR	Number of Adults	4.39 (1.22)
(10) CAPITAL	Value of capital equipment (in Yuan)	459.22 (653.24)
(11) CR	Credit dummy=1, if formal credit used in the previous two years, 0 otherwise	.41 (.49)
(12) Quota	Rice procurement quota dummy variable= 1 if quota exists, 0 otherwise	.97 (.16)
(13) Avedu	Average education level of other adult household members (in years)	5.18 (2.27)
(14) Job	Job dummy of household head, =1 if nonfarm 0 if farm	.10 (.30)
(15) Sex	Sex of household head, =1 if female, 0 otherwise	.04 (.19)
(16) Agryrs	Household head's experience in agriculture (in years)	23.66 (11.61)
(17) Eduhead	Education level of household head (in years)	5.49 (2.58)

Table 7: Probit Estimates for Dichotomous Adoption and Two-limit Tobit Estimates for Adoption Rate of Hybrid Seed

	Probit	Two-limit Tobit
Dependent Variable:	AHR (1)	PHR (2)
Independent Variable:		
Constant	-3.40	-.81
	(2.22)	(.73)
C2	-.43	-.38
	(1.68)	(2.26)
C3	-.56	-.85
	(1.37)	(3.15)
C4	.57	-.15
	(1.56)	(.60)
C5	5.69	.85
	(.02)	(2.82)
Ps	-.95	.14
	(1.71)*	(.34)
Pf	.21	-.20
	(.22)	(.35)
Pp	.47	.21
	(1.45)	(.86)
LAND	.74	.040
	(2.91)***	(.24)
LABOR	-.24	-.173
	(.76)	(.80)
CAPITAL	.05	.076
	(.86)	(1.88)*
CR	.17	-.08
	(1.04)	(.70)
Quota	.69	.44
	(1.79)*	(1.33)
Avedu	-.01	.015
	(.31)	(.59)
Job	.14	-.048
	(.52)	(.28)
Sex	.50	.43
	(1.21)	(1.53)
Agryrs	.02	.0025
	(1.78)*	(.44)
Eduhead	.16	.052
	(3.61)***	(1.91)**
Log Likelihood	-177.86	-426.73

Note: Figures in parentheses are absolute values of asymptotic t-statistics.

*, **, and *** indicate that the estimates are significantly different from zero at .1, .05, and .01 level of confidence.

Definitions of variables are provided in Table 6.

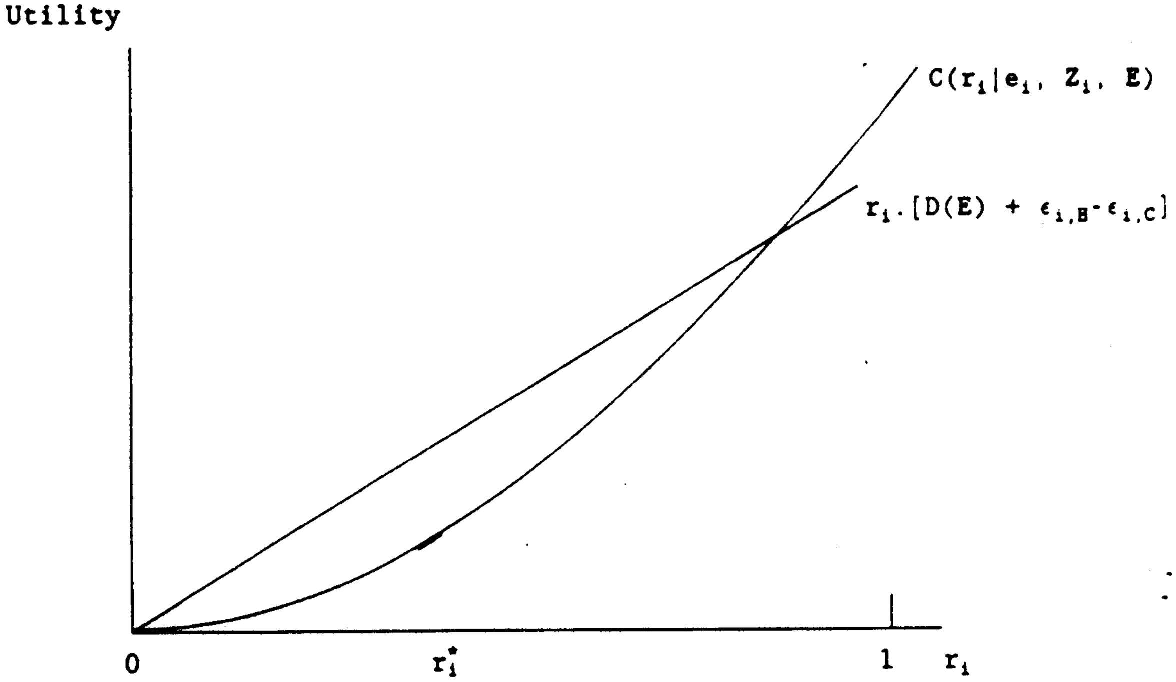

Fig.1: The Optimal Land Allocation to Hybrid Rice

Fig 2: Diffusion of Hybrid Rice in Hunan