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RISK, SCHOOLING AND THE CHOICE OF SEED TECHNOLOGY IN DEVELOPING COUNTRIES: A META-PROFIT FUNCTION APPROACH*

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The determinants of rice seed variety choice are studied in a framework in which cultivator's variety specific profit, risk preferences, uncertainty and schooling affect variety choice. The econometric model takes the form of a simultaneous equation switching regimes model with random profit functions (the meta-profit function). Adoption of high yielding varieties in Indonesia is found to be positively associated with profitability, likelihood of flooding, quality of irrigation conditional on relative profit, and availability of credit, and negatively associated with likelihood of drought and land wealth. Schooling significantly affects variety specific profit and input demand but not variety choice.

1. INTRODUCTION

The spread of high yielding rice varieties (HYV's) has ushered in an era of agricultural transformation in Asia. In Indonesia, the adoption of these new seed varieties contributed importantly to a spectacular increase in Indonesia's rice production over the last decades—rice output grew at an annual rate of 4 percent during the 1970's and almost 6 percent in the 1980's. While experimental plots have demonstrated that under optimal conditions the mean yield of HYV rice far exceeds that of traditional varieties (TV's), many Asian cultivators do not plant HYV's. In Indonesia, the HYV revolution has been particularly slow to spread to many areas outside of Java and partly as a consequence the distribution of the gains derived from HYV's has been uneven. Accounting for differences in adoption rates is therefore of some interest.

Differences in prices and fixed factors of production are one explanation for inter-farm differences in seed variety adoption. If cultivator's seed technology choices are the result of profit maximizing behavior, then varietal choice will depend on the determinants of profit: variable factor prices, the prices of (variety-specific) output, and the level of fixed factors including the agro-climatic environment. Different profit functions exist for each variety, reflecting the differences in their biological technology. If seed variety choice is itself part of the cultivators profit-maximization problem, then there exists a single profit function—the meta-profit function—which treats variety choice as a variable input and from which all

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variety-specific profit functions can be derived by treating seed variety as fixed. The meta-profit function is dual to the meta-production function introduced by Hayami and Ruttan (1985) and has all the usual properties of profit functions. By Hotellings lemma, the slope of the meta-profit function is minus the demand for variable inputs. Application of Le Chatelier's principle demonstrates that treating seed variety choice as fixed, as most studies do, results in underestimates of (the absolute values of) input demand and output supply elasticities. The introduction of constraints—in this case, the fixing of seed variety choice—cannot increase the opportunity to substitute other inputs. Response to prices and fixed factors is therefore greater for movements along the meta surface than the individual variety-specific profit surfaces.

In rural areas of developing countries, characterized by costly information, climatic uncertainty and imperfect markets for risk, it may be inappropriate to model seed variety choice as solely the result of unconstrained profit-maximization. For example, cultivators may not be allocatively efficient with respect to the meta-profit function if costly or scarce information precludes the use of new seed technologies. Although many economists have devoted special attention to the role of education in improving allocative efficiency, its role in fostering the adoption of discrete new technologies has been less well modeled or documented. A notable exception is the paper of Rosenzweig (1981), who models the adoption-education association in the context of developing country farmers who are both agricultural decision-makers and employees. His empirical results suggest that in rural India, where information is scarce and valuable, education increases the efficiency of HYV technology adoption. A positive association between education and HYV adoption may not be a reflection of a higher rate of return to education in HYV cultivation but possibly a set of other factors unrelated to seed specific profitability such an association of education with the cost of acquiring new technology, access to credit, and risk preferences. It is difficult to ferret out the role of education in fostering technology adoption beyond its effect on relative seed specific profitability.

Risk preferences and the response of each variety's yield to weather and other random influences have also been considered important determinants of seed variety choice. The ability of rice varieties to withstand extremes in climate and pest infestation has long been a concern of plant breeders (IRRI 1978). The importance of the timing and extent of the monsoon in wet rice agriculture is well known. Allowing for risk preferences to affect cultivator decision-making complicates estimation of profit functions by making unlikely the separability between consumption and production decisions typically relied upon for profit function estimation (Singh, et al. 1986).

This study makes use of a large sample survey of Indonesian farm households to investigate the determinants of seed variety choice by estimating seed variety specific profit functions and a meta-profit function which allow for risk preferences, uncertainty and schooling to affect the cultivators seed variety choice. In Section 2 of this paper we consider the ways in which schooling may influence the choice of seed variety. Section 3 discusses the influence of risk and uncertainty on seed variety choice. Section 4 sets out the complete econometric model and methods of estimation. The econometric model takes the form of a simultaneous equation switching regimes model with random profit functions. The maximum likelihood method applied is complicated by endogenous regressors and heteroskedastic errors. Section 5 describes the data and Section 6 discusses results. The final section is a summary.

2. EDUCATION AS A DETERMINANT OF SEED VARIETY CHOICE

Education may influence seed choice through a number of mechanisms. Education may affect profitability by enhancing the technical efficiency of production (Lockheed, et al. 1980), that is, given any set of inputs, output is increasing in education. More generally, education can be thought of as a fixed factor of production shifting variable profit functions and hence altering seed choice. Education may also augment skills used in allocating resources in the most profitable manner, particularly if the technology is complex (Nelson and Phelps 1966, Schultz 1975 and Welch 1970). Huffman (1977) has demonstrated that investments in education improve the allocative performance of US corn farmers. In this allocative role, education need not affect the technical efficiency of production. Thus, even if not a factor of production, education is a determinant of realized (but not potential) profit. Education may also reduce the informational costs associated with adopting a new technology, particularly when the new technology involves significant change in cultivation technique, in much the same way as agricultural extension acts to publicize the advantages and requirements of new technologies (Rosenzweig 1981). In this role, education affects the choice of seed variety but not necessarily the profit obtained from the seed variety chosen. As a limiting case, learning about new seed varieties has a cost which is decreasing in education, but once informed about a seed variety the cultivator may allocate resources perfectly. Education is then a determinant of meta-profit but not necessarily of seed specific profit and its effect can only be discerned by estimating a meta-profit function which conditions on seed specific profit.[2]

3. RISK, SEPARABILITY AND SEED VARIETY CHOICE

A number of studies have found that farmers in developing countries are risk averse (Binswanger 1981, Scandizzo and Dillon 1979, Antle 1987). A major source of risk to farmers in the unpredictability of the agro-climatic environment. Production and consumption demand are generally no longer separable if house-

[2] Rosenzweig distinguishes schooling from ability and considers the possibility that they are correlated but only one may be causally associated with innovation. For example, if schooling is positively correlated with (unobserved) ability, and ability influences innovation but schooling does not, educated farmers will be more innovative even though schooling does not structurally influence adoption.

Rosenzweig also notes the possibility that market substitutes do not exist for cultivator's time input as farm manager. In this case, even though schooling may reduce the cost of innovating, highly schooled farmers may be less innovative if the new technology reduces their ability to substitute away from farm production to work in better paying off-farm employment. Likewise, schooling may be positively associated with innovations even though it does not reduce the cost of innovation. This point is considered again below.

hold's care about risk and there is uncertainty. Lacking separability, the households objective is no longer one of maximizing profits in farm production since input choices now affect the riskiness of output and increases in risk affect utility. It is the expected utility of profits which is to be maximized and this expected utility depends on the form of preferences.[3]

In the absence of separability, seed variety and input demand choices can be characterized as the solution to the dynamic problem of an agricultural household operating in an uncertain environment with incomplete markets for future contingencies. However, as described below, the nature of wet paddy cultivation is such that risk influences the choice of seed variety much more than input choices once seed variety is chosen.[4] This results in a tractable empirical model in which cultivators act to maximize profits *conditional* on their varietal choice but for which uncertainty, risk and institutions which act to ameliorate the effects of risk are determinants of seed choice.

This partial separability is achieved if variety choice precedes input choices in time and all uncertainty is resolved by the time input choices are made. This assumption is not unrealistic for wet rice agriculture in Indonesia. Cultivators must plant rice seeds in seed beds 20 to 30 days prior to transplanting the seedlings into the paddy field. Typically, seed bed preparation occurs prior to the normal (mean) arrival date of the monsoon. The timing of the monsoon is thus the most important component of a cultivators uncertainty about future weather conditions.[5] By the time the seedlings are ready for transplanting, much of the cultivator's uncertainty regarding the timing of the monsoon is resolved.[6]

At the time the cultivator chooses a seed variety he is uncertain as to the state of nature during the time his paddy is growing in the field. Cultivators know the distribution of possible output outcomes for each seed variety, and because it is assumed they know input and output prices with certainty, they also know the distribution of variable farm profits associated with each seed choice. Profits will vary over time depending on the actual states of nature encountered. Households which maximize discounted expected lifetime utility may enter the credit market as borrowers and savers so as to smooth their consumption stream. Households are likely to borrow if agro-climatic conditions have been disadvantageous and to save

[3] A sufficient condition for separability is a complete set of markets for all relevant commodities. The breakdown in separability when there is risk is a reflection of absent or imperfect markets for contingent claims—that is, the inability to insure incomes against different states of nature. If markets exist for future contingencies, then risk can be perfectly diversified away and separability will hold. The existence of a complete set of such markets in developing countries is, of course, highly unrealistic.

[4] In neighboring Philippines, Roumasset (1976) found that the level of one key input, fertilizer, did not substantially increase financial risk among rice cultivators.

[5] The same is apparently true in India. Binswanger and Rosenzweig (1989) claim that village folklore suggests that the timing of the monsoon is the most important aspect of weather and uncertainty. Using panel data, they regressed farm profits on the monsoon onset date and five measures of rainfall. The onset date of the monsoon significantly affected farm profits whereas the other five measures of rainfall did not significantly add to the explanatory power of the regression.

[6] The same recursiveness results if uncertainty takes the form of a purely additive shock to yield. The variance (and higher moments) of this shock may differ by seed variety, thus influencing seed variety choice. Input choices conditional on a seed variety are unaffected as the shocks do not enter into the first-order conditions for profit maximization.

when conditions have been good. The interest rate (and access to credit) affects the ease and cost of consumption smoothing and hence influences the cultivators choice of seed variety in much the same way as crop insurance. If HYV's have a higher variance of profit outcomes than do TV's, higher interest rates or credit market transactions costs may tend to favor TV cultivation because of the reduced need to smooth consumption if they are chosen as compared to HYV's. Thus, we might expect that rates of HYV adoption vary with the variability of weather conditions—which increase the variance of profit outcomes—and with interest rates and access to credit—which allow cultivators to smooth consumption variability over time.

The association of wealth with HYV adoption is ambiguous. If risk aversion and wealth are positively associated, as Quizon, et al. (1984) found among Indian farmers, wealthier farmers are less likely to adopt the more uncertain seed variety, presumably HYV's. Countering this effect, it also seems likely that access to credit is increasing in wealth, with increased access to credit favoring the more uncertain variety.[7]

Irrigation, by providing the cultivator with some control over the availability of water, reduces uncertainty. In summarizing a set of studies commissioned by the International Rice Research Institute, Anden-Lacsina and Barker (1978) concluded that irrigation was a critical factor in the adoption of HYV's because they tended to require greater water control than TV's. It is then expected that irrigation quality would be positively associated with HYV adoption conditional on its effects on profit.

4. A SIMULTANEOUS EQUATION VARIETAL CHOICE AND INPUT DEMAND MODEL

The nature and timing of the uncertainty facing cultivators permit us to specify and estimate variable profit functions for each seed variety. The variety choice decision rule is approximated as a linear function of the relative profitability of the alternative varieties and other regressors. The linearized seed variety decision equation is

$$I_i^* = \lambda(\Pi_{hi} - \Pi_{ti}) + z_i\gamma + \psi_i \quad (1)$$

where i indexes farm plots, Π_{hi} and Π_{ti} are (log) maximum variable farm profit from planting HYV and TV seed varieties respectively, z_i is a vector of other variables influencing varietal choice, λ is a parameter, γ is a vector of parameters and ψ_i is an error term. I_i^* is an unobserved latent variable. What is observed is a dichotomous variable I_i which takes the value of 1 if HYV seed is adopted and zero otherwise. That is,

[7] Two more channels by which education might affect innovation can now be suggested. First, the cost of credit is likely to be positively associated with income, and income is likely to be positively associated with schooling. That is, if educated farmers are higher paid in the labor market, they may have more and lower cost access to credit which will influence adoption rates. Second, education may interact with tastes for risk. Binswanger (1981) finds that (predicted) schooling is negatively associated—but not statistically significant—with risk aversion among a sample of Indian farmers.

$$I_i = 1 \quad \text{if} \quad I_i^* \geq 0 \qquad (2)$$
$$= 0 \quad \text{otherwise.}$$

In addition, since on any plot of land only one seed variety is chosen, one of the pair (Π_{hi}, Π_{ti}) is unobserved for every plot.

Variable profit function are represented by transcendental logarithmic (translog) flexible functional forms (written in matrix form):

$$\Pi_{ki} = \alpha_k + P_{ki}(\delta_k + \varepsilon_{ki}) + K_i\kappa_k + \tfrac{1}{2}P_{ki}\beta_k P'_{ki} + P_{ki}\theta_k K'_i + \tfrac{1}{2}K_i\psi_k K'_i + \eta_{ki}, \qquad k = HYV, TV, \qquad (3)$$

where P_{ki} is a row vector of the logarithms of J variable input/output prices, some elements of which depend on k, K_i is a row vector of log fixed factors, α_k is a scalar parameter, δ_k and κ_k are vectors of parameters, β_k, θ_k and ψ_k are matrices of parameters, η_{ki} is an error term and ε_{ki} is a vector of error terms. What distinguishes the specification (3) from most others in the literature is the manner in which stochastic terms enter. The coefficients on the variable input/output prices P_{ki} have both a fixed component δ_k and a variable component ε_{ki}. As a subset of its parameters are (plot specific) random parameters, the specification (3) represents a random profit function. The set of errors $\nu_{ki} = \{\eta_{ki}, \varepsilon_{ki}\}$ are assumed to be distributed as joint normal with zero mean and unrestricted covariance $\Sigma_{\nu k}$

$$\Sigma_{\nu k} = \begin{pmatrix} \sigma_{\eta\eta} & \sigma_{\eta\varepsilon_1} & \cdots & \sigma_{\eta\varepsilon_J} \\ \sigma_{\eta\varepsilon_1} & \sigma_{\varepsilon_1\varepsilon_1} & \cdots & \sigma_{\varepsilon_1\varepsilon_J} \\ \vdots & \vdots & & \vdots \\ \sigma_{\eta\varepsilon_J} & \cdots & \cdots & \sigma_{\varepsilon_J\varepsilon_J} \end{pmatrix}, \qquad k = HYV, TV. \qquad (4)$$

The errors ε_{ki} and η_{ki} are not the "random shocks" which are the source of uncertainty to the cultivator. Rather, these errors represent inputs unobserved by the econometrician but known by the cultivator. Characteristics of the plot and region such as soil composition and acidity, slope, and altitude importantly affect yield and are known by the cultivator but unknown by us. The agronomic and managerial abilities of the cultivators are also unknown by us but they are not random shocks to the cultivating household. If the unobservables affect input demands through the additive errors ε_{ki}, then, integrating back to the profit function, they must interact with prices as in (3). The uncertainty of rice production is of an intertemporal nature: it reflects the time-period specific deviations from the mean timing and abundance of rainfall, sunshine, humidity, and other random natural phenomena. In the analysis of a cross-section of rice plots, this time specific random shock is not statistically identifiable.[8]

[8] The assumption that random (weather) shocks are additive to profit would require the addition of the price of rice (times an unknown constant term representing a purely temporal shock) to the antilog of the right-hand side of equation (3). This additional nonlinear price of rice term vanishes if the mean random shock were realized in the time period observed.

Applying Hotelling's lemma to the profit functions (3) results in profit share equations having additive errors

$$(5) \qquad S_{jki} = \delta_{jk} + P_{ki}\beta_{jk} + K_i\theta_{jk} + \varepsilon_{jki}, \qquad j = 1, 2, \ldots J;\ k = HYV,\ TV,$$

where j index's inputs/output so that S_{jki} is the profit share of j in the production of seed variety k in plot i. Additionally, the subscripts j denote the relevant rows (or columns) of the parameter matrices β_k and θ_k and the error vector ε_{ki}. Input shares derived from profit functions are negative, the output share is positive, and the shares sum to unity.

If cultivators choose seed varieties according to the decision rule given by (1) and (2), that is, maximize relative to a a meta-profit function, then estimation of the profit function parameters by standard techniques will result in selectivity biased estimates. Bias exists if the expected value of the regression function residual conditional on seed choice is not zero, for example if $E(\eta_{ki}|I_i = 1) \neq 0$. Bias comes about because those farmers who possess higher-than-average levels of those unobserved factors related to (say) HYV profitability will more likely choose HYV cultivation than an *observationally* equivalent cultivator who possess' less of these unobserved characteristics. Note that the switching condition (2) can be equivalently written as

$$(2') \qquad I_i = 1 \quad \text{if} \quad \omega_i \geq -(\lambda(\overline{\Pi}_{hi} - \overline{\Pi}_{ti}) + z_i\gamma)$$
$$= 0 \quad \text{otherwise},$$

where ω_i, the composite error of the switching equation, is

$$(6) \qquad \omega_i = \lambda(P_{hi}\varepsilon_{hi} + \eta_{hi} - P_{ti}\varepsilon_{ti} - \eta_{ti}) + \psi_i,$$

obtained by substituting the stochastic profit functions (3) for the terms Π_{hi} and Π_{ti} in (1), and $\overline{\Pi}_{ki}$ is the unconditional expectation of profit, $\overline{\Pi}_{ki} = \Pi_{ki} - (P_{ki}\varepsilon_{ki} + \eta_{ki})$. Note that the conditional expectation of the regression residual can then be expressed as follows

$$(7) \qquad E(\eta_{ki} \mid I_i = 1) = E(\eta_{ki} \mid \omega_i \geq -(\lambda(\Pi_{hi} - \Pi_{ti}) + z_i\gamma), \qquad k = HYV,\ TV,$$

and since η_{ki} is by definition (6) a part of ω_i, they will in general be correlated, resulting in sample selection bias. Note as well that error term (6) of the seed variety switching equation is heteroskedastic and has a variance which depends quadratically on both P_{hi} and P_{ti}.

Two-stage estimation methods have been proposed (Heckman 1976, Lee 1976) to estimate single regression equations with selected samples. Our problem is a generalization of the simultaneous equations switching regimes model considered by Lee (1978) in that we have endogenous variables (Π_{hi} and Π_{ti}) on the right-hand side of the switching equation. The generalization is that the regimes (seed specific profit functions) consist of *sets* of regression equations having a correlated and heteroskedastic error structure rather than single regression equations with homoskedastic errors. Rather than generalize Lee's inefficient three-step simultaneous equations estimator to our problem, we have estimated our model by the method of maximum likelihood. The derivation of the likelihood is in an appendix available from the authors.

5. DATA

The basic data used to estimate the meta-profit function are from the data tapes of the 1980 National Social Economic Survey of Indonesia (SUSENAS) carried out by the Central Bureau of Statistics (*Biro Pusat Statistik*) of the Government of Indonesia. The survey provides data on input and output quantities and values for the plots controlled by the surveyed households. Kabupaten (district) level prices for HYV rice, TV rice, fertilizer and wages were calculated by averaging the values reported by all respondents in each season. There are approximately 300 kabupaten's in Indonesia. The survey distinguished three seasons: wet monsoon, dry monsoon and other. A total of 8449 wet rice (*padi sawah*) plots distributed throughout the country were used in the estimation, each plot cultivated by a different farm household. Indonesia exhibits large spatial price variation reflecting the difficult topography, island geography and poor infrastructure of the country. In addition, prices vary seasonally.

The survey provides the area of cultivated land controlled by the household under various types of irrigation. These data were aggregated into an irrigation quality index in the manner of earlier work reported in Pitt (1983) and Sumodiningrat (1982). Other fixed factors consist of the area of the plot in hectares, and the schooling in years of the head of the household. Schooling and irrigation quality are not strictly "factors of production" (as is area) since they are quality measures rather than flows of factor services. Homogeneity of fixed factors is imposed on area only, with the result that the estimated relationship is a profit-per-hectare function. To capture some of the importance differences in topography and soil quality among the regions of Indonesia, a dummy variable having the value of one if a plot is located in Java-Madura is included. With similar reasoning, a dummy variable for planting season is also included.

Measures of the variability of the environment and the prevalence of credit institutions were taken from the data tapes of the 1980 Village Potential Census (*Potensi Desa*), carried out as part of the 1980 Population Census (*Sensus Penduduk*). For every village (*desa*) in Indonesia, the Census asked whether there had been a drought or flood in the prior five years. These responses were aggregated by us into kabupaten variables reflecting the proportion of villages in each kabupaten suffering from drought or flood in the prior five years. The Census also reported the number of banks and a variety of other types of agricultural credit institutions in each village. These nonbank credit institutions—cooperatives of various kinds in addition to money lenders—were summed and divided by the number of villages in the kabupaten. Our measure of the prevalence of banks was also expressed in terms of credit institutions per village.

Although the SUSENAS survey lacks a complete inventory of the total monetary value of each household's wealth, two important components of the wealth-holdings of agricultural households were measured and are used in our empirical analysis: ownership of land by irrigation quality and the value of the stock of livestock and poultry. Lacking data on land prices, we aggregated the data on land ownership by irrigation quality into a single index of land owned by applying the same weights used in constructing our irrigation quality index.

In addition to measures of the prevalence of credit, variability of the environment, and wealth, some of the arguments that appear in the profit function are also included in the seed variety switching equation (1). These are the irrigation quality index, schooling of the head of the household and the dummy variables for Java and season. The quality of plot irrigation, by providing the cultivator some control over water, is conjectured to reduce the variance of profits in response to variation in rainfall quantity and timing, thereby possibly altering the relative riskiness of seed varieties. Schooling may affect tastes for risk (Binswanger 1981), informational costs associated with learning new technologies and access to credit (Rosenzweig 1981). By including these variables as separate arguments in the seed variety switching equation we are allowing them to affect seed choice *both* directly and through their influence on seed variety specific profits. Note that standard conditions for the identification of right-hand side endogenous variables apply here—that is, at least one regressor in each profit function must not appear in the switching equation. Identification the effect of relative profit on seed choice (λ), is not a problem in our model since the quadratic form of the profit functions provide for identification (via the nonlinearity) even if we were to linearly include all profit function inputs and outputs in the vector z_i of the seed variety switching equation.

Even without endogenous right-hand side regressors, theoretically based identification of the parameters of the regime switched behavior is problematic in switching regime models. It is often difficult to find exogenous regressors which affect choice of a regime but do not also affect the regime specific behavior. Logically, if cultivators choose the seed variety which provides the maximum profit, then the determinants of the seed chosen (the selection equation) are also determinants of seed specific profit (the selected behavior). This same identification problem afflicts many other sample selection models in economics. Lacking exclusion restrictions, identification is typically achieved by the choice of an error distribution, such a normality. As normality (or any other) error distribution is not suggested by economic theory, identification of the parameters of the selected or regime-switched behavior relies essentially on an arbitrary functional form assumption.[9] However, a theoretically justified set of exclusion restrictions exists when estimating the set of input demand equations associated with a seed specific profit function. By Hotelling's lemma, the input demand equations are necessarily of one lower order of polynomial than the profit equation since they are the derivatives of the profit function. For a quadratic (or quadratic in the logs) profit function the seed variety switching rule (the difference between the variety specific profit functions) is also quadratic in prices and fixed factors but the regime specific input demands are linear. Thus the theoretically justified zero restrictions on quadratic terms in the input demands contribute to statistical identification. Note that these simple

[9] Recently, semi-parametric estimators have been developed that do not require the specification of a parametric probability distribution in the estimation of selection models. Pitt and Rosenzweig (1989) apply one such semi-parametric estimator to a selection model in which standard exclusion restrictions are implausible and test for the validity of the assumption of normality and other parametric distributions.

exclusion restrictions follow from profit maximization conditional on seed choice which follows from the assumption that uncertainty is resolved by the time inputs choices are made.

In summary, the estimated profit functions have three variable inputs/output (rice output, fertilizer and labor input), one fixed factor input flow (plot area) and four quality (nonflow) measures of factor input (irrigation quality, head's years of schooling, and dummy variables for Java location and planting season). The specifications are the same for both HYV and TV except that the prices of HYV rice and TV rice differ. The seed variety switching equation have as regressors the (log) difference in variety-specific variable farm profits, two measures of the variability of the weather, two measures of the prevalence of credit institutions, two measures of wealth, and four arguments of the profit functions: irrigation quality, schooling of the head of household, and dummies for Java location and planting season.

6. RESULTS

The maximum likelihood parameter estimates obtained from jointly estimating the complete model consisting of the seed variety switching equation (1), the profit functions (3) and sets of input demand equations (5) are presented in Table 1. The likelihood contains a great many parameters and proved very complex and cumbersome. The number of parameters to be estimated was reduced somewhat by dropping interaction terms between fixed factors and setting to zero those covariances not in the matrices $\Sigma_{\nu k}$. These profit function interaction restrictions do not greatly reduce the flexibility of the functional form as they do not enter into the derived demand equations. As for the covariance restrictions, the (composite) variance of the seed variety switching equation is still quadratic in the profit function errors and prices, except that there are no cross-regime covariances. Nonetheless, the maximum likelihood procedure still had to jointly estimate 60 free parameters.

The high t-ratios reported in Table 1 reveal the precision of our maximum likelihood estimates. Of particular interest are the high t-ratios of every argument in the seed variety switching equation with the exception of schooling. Higher profitability of a seed variety is positively associated with a higher probability of its adoption. The variables for prevalence of drought and flood suggest that HYV's are more likely to be adopted if the likelihood of drought is less and the likelihood of flooding is greater (the higher the value of these dummy variables the *less* likely the event occurs). Irrigation has a significantly positive effect on HYV adoption separate from its effect as a determinant of profit. This is in accord with the negative association of drought to HYV adoption—higher quality irrigation reduces the effect of drought. Increased availability of both types of credit is positively associated with HYV adoption as would be expected if HYV yields are more variable than TV yields. Schooling has a positive but statistically insignificant effect on HYV adoption conditional on profits. Java location and wet monsoon planting season both favor HYV use.

Curiously, the wealth variables have opposite signs. Larger ownership of land

TABLE 1

MAXIMUM LIKELIHOOD ESTIMATES OF THE SIMULTANEOUS EQUATIONS SEED VARIETY SWITCHING AND PROFIT FUNCTION MODEL

Variable*	HYV Profit Coefficient	HYV Profit *t*-ratio	TV Profit Coefficient	TV Profit *t*-ratio
Intercept	2.9168	67.63	2.8417	58.76
Irrigation index	0.2514	6.30	0.1108	1.81
Education (years)	0.0082	0.76	0.0435	2.97
Wage (Rp. per day)	0.0914	2.71	0.1211	2.96
Fertilizer (Rp. per kg.)	−0.0298	−4.72	0.0057	0.81
Wage × fertilizer	−0.0232	−9.36	−0.0037	−1.27
Wage × rice (Rp. per kg.)	0.3793	26.74	0.3748	23.14
Fertilizer × rice	0.0807	16.77	0.0124	2.63
Wage × irrigation	0.2732	10.60	0.0858	1.84
Fertilizer × irrigation	0.0058	1.53	−0.0350	−9.22
Wage × education	0.0200	2.98	0.0195	2.04
Fertilizer × education	0.0020	2.01	−0.0009	−0.98
Java (Java = 1, other = 0)	0.2543	12.19	0.1164	4.05
Java × wage	−0.1904	−13.89	−0.2257	−12.52
Java × fertilizer	−0.0420	−18.32	−0.0401	−19.66
Season (wet monsoon = 1, other = 0)	−0.1204	−4.39	0.0631	2.41
Season × wage	−0.0146	−0.80	0.0291	1.63
Season × fertilizer	−0.0033	−1.30	0.0053	2.61
var (η)	0.3670	59.92	0.3996	43.31
var (wage)**	0.1423	47.56	0.1779	34.40
var (fertilizer)	0.3281	44.97	0.1777	49.29
cov (η, wage)	−0.1014	−33.82	−0.1207	−23.94
cov (η, fertilizer)	0.0009	2.12	−0.0010	−2.29
cov (wage, fertilizer)	0.0087	26.04	0.0041	12.92
Seed variety switching equation:				
Relative profit (Rp/.01 ha.)***	0.4915	7.89		
Intercept	−1.8697	−8.11		
Drought (yes = 1, no = 2)	0.7940	7.81		
Flood (yes = 1, no = 2)	−0.2628	−2.37		
Banks (no. per desa)	0.7932	5.65		
Other credit (no. per desa)	0.1019	4.08		
Land owned (.01 ha.)	−0.0329	−2.04		
Livestock (Rupiah 1000)	0.0179	5.71		
Irrigation	1.5312	18.65		
Education	0.0145	0.66		
Java	0.3641	7.92		
Season	−0.3205	−6.56		
−Log Likelihood = 1729.737	number of observations = 8449			

*The variables education, wage, fertilizer, rice, profit, other credit, livestock and relative profit are in natural logarithms.

**Variable names for variances and covariances refer to the input demand equation errors ε_{ki}.

***Endogenous variable: log (HYV profit/TV profit).

reduces the likelihood of HYV adoption, consistent with risk aversion increasing in wealth. The positive association between the value of livestock holdings and HYV adoption may reflect the influence of diversity of income sources on a households' willingness to take on risk. Assets not employed in rice production, such as livestock, provide an income stream which is unlikely to covary closely with rice earnings.

Little can be said about the magnitude of individual regressors on farm profit or

TABLE 2
ELASTICITIES OF THE PROBABILITY OF CHOOSING HYV SEED VARIETIES

	Structural	Reduced Form
HYV profit	0.291	—
TV profit	−0.291	—
Irrigation	0.522	0.601
Education	0.009	−0.001
Wage	—	0.031
Fertilizer price	—	−0.010
HYV rice price	—	0.447
TV rice price	—	−0.469
Drought	0.798	0.798
Flood	−0.276	−0.276
Banks	0.090	0.090
Other credit	0.060	0.060
Land owned	−0.019	−0.019
Livestock	0.011	0.011
Java	0.113	0.143
Season	−0.032	−0.045

seed choice from examining the parameter estimates themselves. Table 2 provides arc elasticities of the probability of selecting HYV seed varieties with respect to exogenous variables and profit. Two sets of elasticities are presented, labeled "structural" and "reduced form." The structural elasticities provide the effect of changes in (endogenous) profits on the probability of adopting HYV seeds as well as the effects of exogenous variables on this probability *net* of any effect they might also have on profit. For example, a structural elasticity of HYV adoption with respect to the wage does not exist since the wage only affects seed variety adoption through its effect on profits. The reduced form elasticities provide the effects of only exogenous variables on seed choice and includes both their structural effect (if any) and their effect on varietal choice through the profit functions.

Table 2 reveals that a 1 percent increase in HYV profits, or an equivalent decrease in TV profits, increases the probability of HYV adoption by .29 percent. Not surprisingly, irrigation has a large positive structural elasticity (.52), reflecting the relatively greater importance of water control in reducing the uncertainty of HYV cultivation resulting from the random nature of rainfall. Its reduced form elasticity is not much larger (.60), suggesting that irrigation influences the choice of seed technology more by reducing HYV profit uncertainty relative to TV profit uncertainty than by increasing HYV profitability relative to TV profitability.

The rice price elasticities seem large because each rice price affects only one variety-specific rate of profit. If both rice prices were to rise by the same proportion there would be almost no effect on varietal choice. Schooling, the wage and the price of fertilizer have fairly small effects on seed choice. Schooling does not seem to importantly influence either *relative* profitability or the choice of seed technology conditional on profit in our sample of cultivators. An additional year of education increases the probability of HYV use conditional on profits by .25 percent. The small effect of education on HYV adoption conditional on profit may reflect the fact that by 1980 HYV technology was no longer very new—education may be a more important determinant of the timing of *first* adoption rather than continued adoption.

Table 3 provides elasticities of profit, labor demand, fertilizer demand and rice supply with respect to exogenous variables. These elasticities report the percentage change in the conditional expectation of all endogenous variable in response to a 1 percent change in the exogenous variables. The use of conditional expectations, conditional on the seed variety chosen, is appropriate because the self selection of cultivators into seed variety regimes implies that the seed variety specific error terms do not have zero mean. As we argued earlier, cultivators who possess higher-than-average levels of unobserved (by us) traits related to HYV profitability will more likely choose HYV's than an observationally identical cultivator who possess' less of these unobserved characteristics. As a result, the HYV and TV error terms are truncated. In particular, in equation (7) we expressed the mean of the profit error term η_{ki} conditional on choosing the HYV variety as equivalent to conditioning on the seed variety switching equation error. With normally distributed errors, these conditional expectations are

$$\text{(8)} \qquad \text{HYV: } E(\eta_{hi} \mid I_i = 1) = \text{cov}\,(P_{hi}\varepsilon_{hi} + \eta_{hi},\, \omega_i)\,\frac{\phi(\zeta_i)}{\Phi(\zeta_i)}$$

$$\text{TV: } E(\eta_{ti} \mid I_i = 0) = -\text{cov}\,(P_{ti}\varepsilon_{ti} + \eta_{ti},\, \omega_i)\,\frac{\phi(\zeta_i)}{1 - \Phi(\zeta_i)},$$

where $\zeta_i = \lambda(\Pi_{hi} - \Pi_{ti}) + z_i\gamma$, which is just the expected value of the seed variety switching equation, and $\phi(\ )$ and $\Phi(\ )$ are the standard normal density and cumulative distribution functions respectively. The error terms ε_{ki} have conditional expectations of similar form. The implication is that profit elasticities with respect to variables which do not enter the profit function will nonetheless be nonzero because changes in those variables affect ζ_i and hence the conditional expectation of the profit function errors. For example, a change in the availability of credit will (with positive probability) induce some households to switch seed varieties, and those households that switch will likely have unobserved traits that differ from the mean traits of cultivators of the seed they have abandoned and also differ from the mean traits of the cultivators of the seed they have adopted. Hence, the mean characteristics of both groups change.

Table 3 has three columns representing elasticities for HYV cultivators, TV cultivators and the "meta" or total elasticity for each cultivator choice. The meta elasticity measures cultivator response along the meta-profit function rather than along the individual variety-specific profit functions. It differs from the latter in that it incorporates the changes in profit, input demands and output that arise from the switching of some proportion of cultivators from one seed variety to the other. For example, notice that the meta elasticity of profit with respect to irrigation quality is higher than either of the variety specific profit elasticities. Higher quality irrigation increases the profitability of both varieties but additionally induces a shift in cultivation in favor of the higher profit HYV varieties.

Even though the variables for drought, flood, banks, other credit, land owned,

TABLE 3
ELASTICITIES OF PROFIT, LABOR, FERTILIZER AND RICE WITH RESPECT TO INPUT AND OUTPUT PRICES, FIXED FACTORS AND OTHER DETERMINANTS OF SEED VARIETY SWITCHING

	Profit			Labor			Fertilizer			Rice Output		
	HYV	TV	Meta	HYV	TV	Meta	HYV	TV	Meta	HYV	TV	Meta
Irrigation	0.301	0.341	0.372	0.029	0.096	0.067	0.316	0.839	0.682	0.225	0.276	0.310
Education	0.044	0.077	0.055	−0.003	0.037	0.011	0.013	0.104	0.032	0.029	0.065	0.041
Wage	−0.384	−0.370	−0.376	−0.636	−0.785	−0.689	−0.079	−0.327	−0.118	−0.159	−0.187	−0.165
Fertilizer price	−0.061	−0.037	−0.054	−0.014	−0.031	−0.020	−0.232	−0.816	−0.359	−0.010	−0.030	−0.018
HYV rice price	1.349	0.136	0.994	0.625	0.032	0.424	0.250	0.096	0.409	0.093	0.102	0.147
TV rice price	0.098	1.274	0.446	0.020	0.786	0.286	0.048	1.054	0.062	0.074	0.113	0.033
Drought	−0.166	0.243	0.045	−0.034	0.057	0.016	−0.081	0.171	0.310	−0.125	0.183	0.064
Flood	0.058	−0.084	−0.016	0.012	−0.020	−0.006	0.028	−0.059	−0.108	0.043	−0.063	−0.023
Banks	−0.019	0.027	0.005	−0.004	0.006	0.002	−0.009	0.019	0.035	−0.014	0.021	0.007
Other credit	−0.013	0.018	0.003	−0.003	0.004	0.001	−0.006	0.013	0.024	−0.009	0.014	0.005
Land owned	0.004	−0.006	−0.001	0.001	−0.001	−0.000	0.002	−0.004	−0.008	0.003	−0.004	−0.002
Livestock	−0.002	0.003	0.001	−0.000	0.001	0.000	−0.001	0.002	0.004	−0.002	0.002	0.001
Java	−0.070	−0.097	−0.065	0.189	0.117	0.167	0.270	0.464	0.371	0.019	−0.016	0.024
Season	−0.015	0.005	−0.013	−0.017	0.005	−0.010	−0.011	−0.015	−0.031	−0.015	0.005	−0.014

and livestock do not enter the profit function they have nonzero elasticities through their effect on varietal choice and hence on the mean of the error representing unobserved traits of the cultivator and plot. Note the opposite signs of this subset of elasticities for HYV and TV cultivators, and the same signs for TV profit and the variables in the varietal choice equation (Table 2). This suggests that cultivators newly brought into HYV cultivation by changes in these (or other) variables are of below average profitability as HYV cultivators and of above average profitability as TV cultivators.

The signs of all the profit elasticities with respect to input and output prices are all theoretically consistent. The rice price and wage rate elasticities are quantitatively the largest and the meta rice price elasticity is almost one. Education effects are small and positive and fertilizer price effects are small and negative. An additional year of education increases HYV profit by 1.3 percent, TV profit by 2.3 percent and meta profit by 1.6 percent.[10]

Meta labor demand is responsive to the wage (elasticity = −.69) and rice prices. The demand elasticity for labor is slightly larger for TV then HYV cultivation (−.78 vs. −.64). An exogenous shift from HYV to TV cultivations increases employment, albeit only slightly. Factors which affect seed choice but not seed specific profit, such as additional credit facilities, induce more HYV cultivation (Table 2) and increase labor demand.

Fertilizer demand is relatively responsive to irrigation, its own price and the HYV rice price. The response of rice output to rice price increases is small (elasticities of .15 and .03 for HYV and TV prices respectively), smaller in absolute value than output response to the wage (−.16).

7. SUMMARY

This study makes use of a large sample survey of Indonesian farm households to investigate the determinants of seed variety choice with respect to a meta-profit function. Varietal choice is explicitly modeled as depending on relative profitability, and factors which influence yield uncertainty and risk. The maximum likelihood method applied to Indonesian farm-level data is complicated by endogenous regressors and heteroskedastic errors resulting from random profit functions. It was found that the adoption of a seed is positively associated with its relative profitability. Adoption of high yielding varieties was positively associated with the likelihood of flooding, quality of irrigation *conditional* on its effect on relative profit, and the availability of credit, and negatively associated with the likelihood of drought and land owned. Schooling was not found to be a significant determinant of variety choice.

[10] Consider the scenario considered by Rosenzweig and noted in footnote 2. Another type of market failure implying nonseparability occurs—no market substitutes exist for cultivators' time as farm cultivator. If the wage rate facing cultivators in off-farm employment is also increasing in schooling, then the predicted off-farm wage of the cultivator should be an argument in the seed variety choice equation otherwise its effect will be captured by the schooling variable. Using Indonesian farm household data Pitt and Rosenzweig (1986) found that the time household heads devote to cultivation does not affect farm profit, that is, market substitutes for cultivator time apparently do exist in Indonesian agriculture.

The profit, and labor and fertilizer demand elasticities demonstrate the importance of the meta-profit function model and careful attention to unobservables in obtaining accurate estimates of behavioral response. Cultivators who would switch into HYV cultivation in response to a change in an exogenous variable are found to have above average levels of unobservable traits positively associated with profit. We report elasticities for changes in the conditional (on seed choice) expectations of endogenous variables in response to changes in the exogenous variables.

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