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ABSTRACT

This paper investigates the determinants of rice seed variety choice in Indonesia with respect to a meta-profit function. Varietal choice is modeled as depending on the profitability of high yielding varieties of seed relative to traditional varieties of seed, the schooling of cultivators and factors associated with yield uncertainty and risk aversion. Careful attention is paid to the stochastic structure of the estimated simultaneous equations switching regimes model. The maximum likehood method applied to Indonesian farm-level data is complicated by endogenous regressors and heteroskedastic errors. Adoption of high yielding varieties was found to be positively associated with its relative profitability, the likelihood of flooding, quality of irrigation conditional on its effect on relative profit, and the availability of credit, and negatively associated with land owned and the likelihood of drought. Schooling was not found to be a significant determinant of variety choice. Sources of interregional differences in cultivator behaviors in Indonesia were calculated as an application of the estimated model. Interregional differences in employment in rice cultivation but not HYV adoption were largely due to differences in wages.

THE DETERMINANTS OF RICE VARIETY CHOICE IN INDONESIA

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The spread of high yielding rice varieties (HYV's) has ushered in an era of agricultural transformation 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 Indonesian cultivators do not plant HYV's. 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.

If cultivators seed technology choices are the result of profit maximizing behavior, then adoption will depend on the determinants of profit: variable factor prices, the output price, the level of fixed factors including the agro-climatic environment, and the nature of the alternative biological seed technologies. The meta-profit function, dual to the meta-production function introduced by Hayami and Ruttan (1985), is useful in analyzing the seed technology choices of profit maximizing cultivators. The meta-variable-profit function describes the (normalized) profits associated with tangencies of the price ratio hyperplane to the meta-production function. The meta-production function is the envelope containing the production surfaces of all seed varieties. By Hotelling's lemma, the slope of the meta-variable-profit function is minus the demand for variable inputs. Two-dimensional (one input) meta-variable-profit functions are pictured in Figure 1. Given fixed factors K_1, the difference between seed variety specific variable profit functions $\pi_1(P,K_1)$ and $\pi_2(P,K_1)$ is solely attributable to their different biology. Different levels of fixed factors such as climate, irrigation quality and soil type are associated with a different (and not necessarily homothetic) set of variable profit functions, such as $\pi_1(P,K_2)$ and $\pi_2(P,K_2)$. In Figure 1, seed 1 is the profit maximizing choice at prices P_o and fixed factors K_1. Seed 2 is profit maximizing with the same prices but fixed factors K_2. Note that input response to price is larger for movements along the meta surface than the individual profit surfaces. Input demand and output supply elasticities which do not consider seed variety switching will be underestimated.

The figure demonstrates that variation in varietal adoption can result from variation in relative prices (movements along a meta-variable-profit function) and variation in fixed factors (shifts in meta-variable-profit functions). In island Indonesia, both prices and fixed factors such as soil quality, climate and irrigation, are known to significantly vary inter-regionally. By estimating the meta-variable-profit function sources of the interregional variation in variety choice can be decomposed among the fixed and variable factors of production.

Many economists have devoted special attention to the role of education in improving allocative efficiency. However, the role of education 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 county 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.

It is difficult to ferret out the role of education in fostering technology adoption conditional on its effect on seed specific profitability. A positive association between education and HYV adoption may not necessarily reflect a higher return of profit to education in HYV cultivation but possibly a set of other factors unrelated to seed specific profitability such as the association of education with the wage the decision-making cultivator can earn in the labor market, access to credit, risk preferences, and the cost of acquiring new technology.

Risk preferences and the response of each variety's yield to weather and other random influences have also been hypothesized to be 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. Indonesia is climatologically diverse, the propensity to drought and flood varies greatly even within the island of Java. 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. Careful attention is paid to the stochastic structure of the estimated simultaneous system of equations. In section 2 of this paper we consider the ways in which schooling may influence the choice of seed variety. In section 3 we allow for risk preferences and uncertainty to influence seed variety choice and discuss restrictions which greatly simplify estimation. Section 4 sets out the complete econometric model and methods of estimation. The maximum likehood method applied is complicated by endogenity of regressors and heteroskedasticity of errors. Section 5 describes the data and section 6 discusses results. Section 7 decomposes interprovincial variation in seed choice, profit and input demand. The final section summarizes our results.

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, 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 (as in Figure 1) and hence altering seed choice. Lockheed et al (1980) summarize a number of studies of the farm efficiency effects of education. 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.[1]

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 households 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.[2]

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. Even if one would characterize the solution to this dynamic programming problem, empirical implementation would likely be intractable.[3] However, rather than remaining exclusively in the domain of a static model without uncertainty, as is typically the case in the estimation of production structures, we impose restrictions which allow for risk to influence the choice of seed variety but not input choices once seed variety is chosen. 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 greatly at variance with the nature of wet rice culture 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 perhaps the most important component of a cultivators uncertainty about future weather conditions. By the time the seedlings are ready for transplanting, much of the cultivator's uncertainty regarding the timing of the monsoon is resolved.

The assumption that all uncertainty is resolved at the time of transplantation is not required 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. In this case, risk averse households will act as utility maximizers in the selection of seed variety and as profit maximizers once seed variety is chosen. With technology of the form $y_k = f_k(X) + \epsilon_k$, where y_k is output of seed technology $f_k()$, X is a vector of inputs, and ϵ_k is a mean zero random shock, profit is

$$\Pi_k = p_k(f_k(X)+\epsilon_k) - \Sigma_j w_j x_j, \quad k = \text{HYV,TV}$$

where p_k is the price of output, and w_j is the price of input x_j. It is obvious that the first-order conditions for profit maximization given k do not include the shocks ϵ_k. Importantly, the risk preferences of farm households do influence seed choice, that is the distribution of the ϵ_k's matter. The levels of variable inputs conditional on the seed variety chosen are the levels that would be chosen by purely profit-maximizing behavior.[4] The intuition is simply that, given a seed choice, varying input levels cannot ameliorate the effect on utility of a shock to farm profit because it cannot affect its distribution.[5]

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. The output (profit) of high yielding varieties relative to traditional seed varieties may vary over possible states of nature. For example, lateness of the monsoon or abundant rainfall may provide HYV's with a relative advantage while an early monsoon or drought may provide TV's with a relative advantage. 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 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.[6]

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 affects on profit.

4. A Simultaneous Equation Varietal Choice and Input Demand Model

The restrictions imposed on 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.[7] The linearized seed variety decision equation is

$$(1) \quad I^*_i = \lambda(\Pi_{hi} - \Pi_{ti}) + Z_i\gamma + \psi_i$$

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,

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

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):

$$(3)\quad \Pi_{ki} = \alpha_k + P_{ki}(\delta_k+\epsilon_{ki}) + K_i\kappa_k + 1/2\ P_{ki}\beta_k P_{ki}' + P_{ki}\theta_k K_i' + 1/2\ K_i\psi_k K_i' + \eta_{ki},\ k=HYV,TV$$

where P_{ki} is a row vector of log 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 $\upsilon_{ki} = \{\eta_{ki},\epsilon_{ki}\}$ are assumed to be distributed as joint normal with zero mean and covariance $\Sigma_{\upsilon k}$

$$(4) \quad \Sigma_{\nu k} = \begin{bmatrix} \sigma_{\eta\eta} & \sigma_{\eta\epsilon_1} & \sigma_{\eta\epsilon_2} & \cdots & \sigma_{\eta\epsilon_J} \\ \sigma_{\eta\epsilon_1} & \sigma_{\epsilon_1\epsilon_1} & \sigma_{\epsilon_1\epsilon_2} & \cdots & \sigma_{\epsilon_1\epsilon_J} \\ \sigma_{\eta\epsilon_2} & \sigma_{\epsilon_1\epsilon_2} & & & \vdots \\ \vdots & \vdots & & & \vdots \\ \sigma_{\eta\epsilon_J} & \cdots & \cdots & \cdots & \sigma_{\epsilon_J\epsilon_J} \end{bmatrix}$$

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 but are unknown to us but known by the cultivator. The agronomic and managerial abilities of the cultivators are also unknown by us but they are not random shocks to the cultivating household. The uncertainty of rice production is of an intertemporal nature: it reflects 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]

The benefit of this stochastic specification of the profit function is that it provides a theoretically consistent error structure for the derived demand equations and the variety choice equation (1). A consistent error structure is especially important in our context since the profit function errors enter the rice variety choice equation. The common approach of simply appending structurally unrelated additive errors to the share and profit equations obscures the relationship between unobservables which may affect input demands, profit and seed variety choice. If input demand error terms importantly reflect unobservables such as soil, cultivator and environmental conditions, then appending them additively necessarily implies that they interact with prices in the profit function.

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

$$(5) \quad S_{jki} = \delta_{jk} + P_{ki}\beta_{jk} + K_i\theta_{jk} + \epsilon_{jki}, \quad k=\text{HYV},\text{TV}$$

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 seed variety were determined exogenously rather than by optimizing cultivators, the set of share equations (5) for each seed variety could be consistently and jointly estimated by standard system techniques. Adding-up requires that one share equation be omitted from the estimation as it is not stochastically independent of the remaining shares. All parameters of the profit function except for α_k, κ_k and ψ_k are identified by just estimating share equations. All profit function parameters are identified if the profit function itself (2) is estimated along with share equations, however it would be necessary to adjust the estimation procedure in light of the heteroskedasticity of the profit functions composite error $(P_{ki}\epsilon_{ki} + \eta_{ki})$.

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 <u>observationally</u> equivalent cultivator who possess' less of these unobserved characteristics. Note that the switching condition (2) can be equivalently written as

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

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

$$(6) \quad \omega_i = \lambda(P_{hi}\epsilon_{hi} + \eta_{hi} - P_{ti}\epsilon_{ti} - \eta_{ti}) + \psi_i$$

obtained by substituting the stochastic profit functions (4) for the terms Π_{hi} and Π_{ti} in (1), and $\bar{\Pi}_{ki}$ is the unconditional expectation of profit,

$$\bar{\Pi}_{ki} = \Pi_{ki} - (P_{ki}\epsilon_{ki} + \eta_{ki}).$$

Note that the conditional expectation of the regression residual can then be expressed as follows

$$(7) \quad E(\eta_{ki}|I_i=1) = E(\eta_{ki}|\omega_i \geq -(\lambda(\Pi_{hi} - \Pi_{ti}) + Z_i\gamma)$$

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 (Lee (1976), Heckman (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 in presented in the appendix.

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 1980) 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 1980), carried out as part of the 1980 Population Census (Sensus Penduduk). For every village 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 non-bank 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 units per village.

Although the SUSENAS survey lacks a complete inventory of the total monetary value of each households 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 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 is not a problem for 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 seed variety switching equation.[9]

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 (non-flow) measures of factor input (irrigation quality, heads years of schooling, Java location and planting season). The specifications are the same for both HYV and TV except that we make use of separate prices for HYV rice and TV rice. The seed variety switching equation have as regressors the (log) difference in variety-specific variable farm profits, two measures of the variability of the environment, 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. Variable means and standard deviations are reported in Table 1.

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 (5) and sets of input demand equations (6) are presented in appendix Table A-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 $\Sigma_{\upsilon k}$. 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 appendix Table A-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 variables the <u>less</u> 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 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 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 mean HYV profitability relative to mean 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. The effects of an increase in the schooling of the head of household by one year (from the mean) on rice cultivation are illustrated in Table 3. 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 4 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. Th 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

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

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

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 <u>and</u> also differ from the mean traits of the cultivators of the seed they have adopted. Hence, the mean characteristics of both groups change.

Table 4 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 see 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, 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.[10]

The signs of all the profit elasticities with respect to input and output prices are all consistent with theory. The rice price and wage rate are quantitatively the most important, with the meta HYV rice price elasticity almost one. Education effects are small and positive and fertilizer price effects are small and negative. An additional year of education (Table 3) increases HYV profit by 1.30 percent, TV profit by 2.32 percent and meta profit by 1.64 percent.[11]

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. Sources of Interregional Variation in Rice Technology in Indonesia

Inter-province differences in cultivator behavior have been decomposed among the exogenous variable using the estimated seed variety switching equation and profit functions. The decompositions compare the seed variety choices, profits, input demands and rice outputs of cultivators having the mean characteristics of the full sample with a cultivator having the mean characteristics of the 19 provincial subsamples. This exercise is illustrated for two sets of provinces: four provinces having high rates of HYV adoption (labeled "high HYV"), and five provinces having low rates of HYV adoption (and labeled "low HYV"). The four provinces with high levels of HYV adoption are located on the island of Java, which is densely populated and intensively cultivated. The three provinces with low rates of HYV adoption consist of three provinces on Sumatra and two provinces on Kalimantan (Borneo), both islands are relatively sparsely populated. The values presented in Table 5 represent the percentage change in each set of provinces' endogenous variables (the column headings) of having (in turn) the national average value for each of the exogenous variables (the row headings), all other values unchanged. Note that the columns do not sum to the total percent difference between any set of provinces and the national average. The quadratic form of the profit function means that there are interaction effects -- the profit terms contains products of each pair of exogenous variables. As a consequence the effect of having two variables change simultaneously can be less or greater than the sum of the effects of changing one at a time.

The values in the first row of Table 5 predict that if the low HYV provinces had irrigation quality equal to the national average there would be increases in the proportion of farmers in these provinces using HYV's (+25.2 percent), variable farm profit (+7.9 percent), labor demand (+1.1 percent), fertilizer demand (+32.2 percent) and rice output (+7.2 percent). Unmeasured factors specific to Java location -- captured by the Java dummy variable -- are consistently important sources of inter-provincial differences. Differential rates of HYV adoption are also explained by the differences in the propensity to drought. If credit facilities in these provinces were as prevalent as the national average (see the rows for banks and other credit), there would also be very significant increases in HYV adoption (14.4 percent and 12.8 percent for banks and other credit institutions respectively) and, as a consequence, in the use of fertilizer. The higher wage rates of provinces outside of Java have very little impact on HYV adoption, indeed if wages were the national average HYV usage would fall slightly. Nevertheless, if the wage in these provinces were the national average, farm profit would increase 10.4 percent and and labor demand would rise 19.0 percent. If the wage in the province of Central Java were the national average wage, employment in paddy cultivation in Central Java would fall by 27.8 percent, profit by 16.5 percent and rice yield by 9.25 percent. At the other extreme, if the wage in North Sulawesi province were the national average wage, employment in rice cultivation in North Sulawesi would rise by almost 75 percent.

8. 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. Careful attention is paid to the stochastic structure of the estimated simultaneous equations switching regimes model. The maximum likehood method applied to Indonesian farm-level data is complicated by endogenous regressors and heteroskedastic errors. It was found that the adoption of a seed is positively associated with relative profit. Adoption of high yielding varieties was positively associatiated 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.

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. It was found that cultivators who would switch into HYV cultivation in response to a change in an exogenous variable have above average levels of unobservable traits positively associated with profit. The elasticities calculated report the percentage change in the <u>conditional</u> (on seed choice) <u>expectations</u> of endogenous variables in response to changes in the exogenous variables. The profit elasticities with respect to variables which do not enter the profit functions but do influence variety choice are nonzero becasue of their effect on seed switching. In addition, regional differences in cultivator behavior with respect to seed choice, employment and other variables were explained by application of the estimated model of cultivator behavior. Interregional differences in employment in rice cultivation but not HYV adoption were largely attributable to differences in wages.

Footnotes

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1. Rosenzweig distinguish's schooling from ability and considers the possibility that they are correlated and that one or the other may not be 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, he shows that 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 schooling does not reduce the cost of innovation.

2. 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.

3. A recent attempt to analyze risk with the framework of the agricultural

household model is the paper of Roe and Graham-Tomasi (1986). They found that if markets for future contingencies do not exist then very restrictive assumptions must be made about preferences, technology and the nature of risk (multiplicative yield risk) in order to obtain even a very special type of separability. Furthermore, parametric restrictions on estimating equations derived under the assumption of certainty do not apply when there is risk.

4. The restriction that risk does not affect input demands once seed variety is chosen is supported by the findings of Roumasset (1976). He found that fertilizer applications do not substantially increase financial risk among Philippine rice cultivators.

5. Here we ignore the implications of the non-negativity of yield on the realized distributions of the ϵ_k's and hence on risk.

6. 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 that (predicted) schooling is negatively associated - but not statistically significant - with risk aversion among a sample of Indian farmers.

7. It may be possible to analytically derive a functional form for the seed variety choice equation by judiciously choosing a functional form for the utility function. The functional forms required are quite restrictive and result in a nonlinear choice equation and, in any case, our interests are not in identifying the structure of preferences.

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.

9. Even without endogenous right-hand side regressors, identification can be an issue in reduced form switching regime models. The problem is to find exogenous regressors which affect choice of a regime but do not also affect the regime specific behavior. For purely profit-maximizing cultivators, the reduced-form seed variety switching equation would consist of all the same arguments as the seed variety specific profit functions, as in Pitt (1983). Two-stage selectivity bias estimation must rely exclusively on the specification of the error distribution for identification of the selection term. As the appropriate error distribution is not suggested by economic theory, identification is somewhat arbitrary. On the other hand, a theoretically justified set of exclusionary restrictions exists when estimating the set of input demand equations. By Hotelling's lemma, the input demand equations are necessarily of one lower order of polynomial than the profit equation, that is, they are the derivatives of the profit function. For a quadratic (or quadratic in the logs) profit function the seed switching equation is also quadratic but the input demands are linear. Thus identification can be achieved by the theoretically justified zero restrictions on quadratic terms in the input demands. The same arguments apply to problems in consumer demand.

10. The appendix (Table A-2) provides a parallel set of tables with the same set of elasticities as Table 4 except that the unconditional expectation of the error term -- zero -- is used. Inspection of both tables reveals the importance of self-selection and unobservables in the determination of farm

profit.

11. Consider the scenario considered by Rosenzweig and noted in footnote 1. 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.

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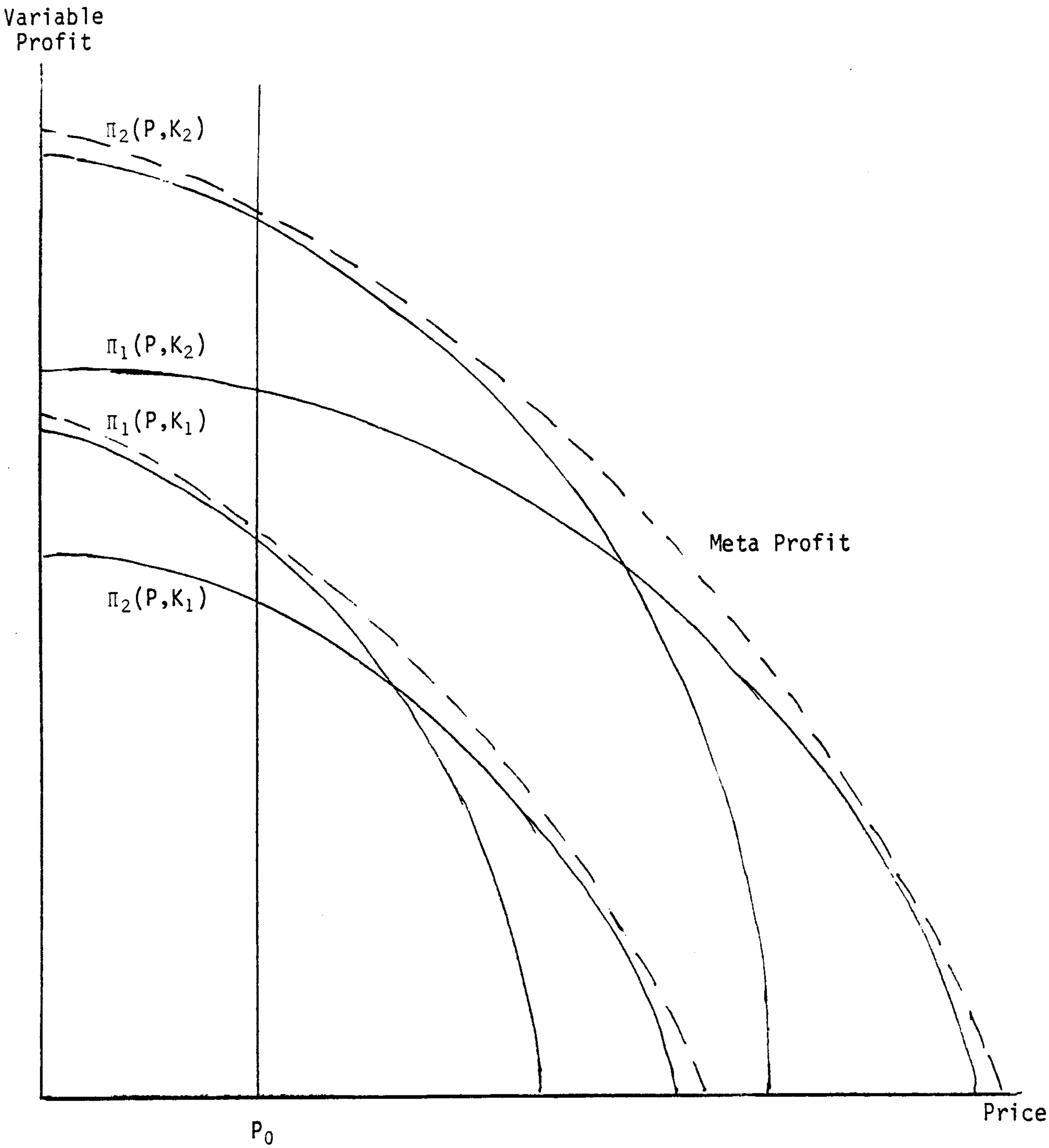

Figure 1

Meta Profit Functions

TABLE 1

DESCRIPTIVE STATISTICS

Variable	Mean	Std. Dev.
LABOR SHARE	-0.452	0.386
FERTILIZER SHARE	-0.055	0.060
LN (PROFIT/LAND) (Rp per .01 ha.)	7.640	0.637
IRRIGATION INDEX	0.574	0.215
LN (HEAD'S EDUCATION) (years)	1.070	0.786
LN (WAGE) (Rp per day)	6.427	0.432
LN (PRICE OF FERTILIZER) (Rp per kg)	4.341	0.093
LN (HYV RICE PRICE) (Rp per kg)	4.624	0.169
LN (TV RICE PRICE) (Rp per kg)	4.668	0.198
DROUGHT (EXPERIENCED=1,NOT=2)	1.692	0.174
FLOOD (EXPERIENCE=1,NOT=2)	1.762	0.164
BANKS (number per desa)	0.191	0.188
LN (OTHER CREDIT) (number per desa)	0.200	0.881
LAND OWNED (.01 ha.)	3.404	1.138
LN (LIVESTOCK) (Rp 1000)	5.318	5.432
JAVA (Java=1,otherwise=0)	0.523	0.499
SEASON (wet monsoon=1,otherwise=0)	0.167	0.373
PROPORTION HYV	0.599	0.490

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

Table 3

RESPONSE OF SEED VARIETY PROBABILITY, PROFIT, INPUTS AND OUTPUT WITH RESPECT TO A ONE YEAR INCREASE IN EDUCATION

(percent change, evaluated at the means)

HYV seed variety probability:	
Structural	0.246
Reduced form	-0.041
HYV profit	1.308
TV profit	2.321
Meta profit	1.640
HYV labor demand	-0.113
TV labor demand	1.094
Meta labor demand	0.320
HYV fertilizer demand	0.397
TV fertilizer demand	3.135
Meta fertilizer demand	0.957
HYV rice output	0.863
TV rice output	1.954
Meta rice output	1.213

Table 4

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

TABLE 5
Decomposition of the Differences in Seed Choice, Input Use and Rice Yield Between National Averages and Low HYV and High HYV Province's

Percentage change in:	LOW HYV PROVINCE'S[a]					HIGH HYV PROVINCE'S[b]				
	HYV SEED	PROFIT	LABOR	FERTILIZER	RICE	HYV SEED	PROFIT	LABOR	FERTILIZER	RICE
If provinces had national average value of:										
Irrigation	25.23	7.88	1.10	32.18	7.21	-2.48	-2.63	-.32	-3.52	-2.10
Education	.02	-.80	-.20	-.65	-.63	-.01	.56	-.01	.28	.37
Wage	-.56	10.42	18.96	-1.27	3.59	.57	-11.27	-18.94	-5.89	-6.14
Fertilizer price	.15	.12	.04	1.32	.03	-.01	-.20	-.09	-1.20	-.09
HYV rice price	-1.55	-.59	.20	2.24	-.03	1.35	6.71	3.11	3.23	1.07
TV rice price	7.98	-6.22	-3.39	2.30	-.11	-1.76	1.78	1.21	.51	.20
Drought	-5.77	-.16	.30	-2.83	-.38	-.07	.06	.05	.02	.02
Flood	-1.20	-.11	-.01	-.61	-.11	.16	-.01	-.01	.04	.00
Banks	14.44	.88	-.10	7.14	1.15	-3.68	-.09	-.03	-1.14	-.22
Other credit	12.80	.84	-.04	6.25	1.07	-2.05	-.06	-.04	-.64	-.12
Land owned	1.76	.10	-.04	.84	.14	-.42	-.01	-.00	-.13	-.02
Livestock	1.76	.02	-.10	.78	.09	-.48	.01	.01	-.14	-.02
Java	27.60	-10.08	11.37	87.05	-1.17	-8.15	3.46	-17.65	-24.95	-4.51
Season	11.11	.10	-.13	9.16	.74	-1.13	-.77	-.62	-1.02	-.78

a. Aceh, Jambi, Bengkulu, West Kalimantan and South Kalimantan.

b. West Java, Central Java, Yogyakarta, and East Java.

Appendix

Derivation of the Likelihood
for the Simultaneous Equation
Switching Regimes Model
with Random Profit Functions

For the model described by equations (1) to (5), if $I_i = 0$ the likelihood of the ith observation is

$$\text{(A1)} \quad \int_{-\infty}^{0} f(I^*_i, \Pi_{ti}, S_{1ti}, \ldots S_{Jti}) dI^*_i$$

and if $I_i = 1$, it is

$$\text{(A2)} \quad \int_{0}^{\infty} g(I^*_i, \Pi_{hi}, S_{1hi} \ldots S_{Jhi}) dI^*_i$$

where f and g are the multivariate normal density functions of I^*_i, profit (Π) and profit shares of J inputs ($S_1 \ldots S_J$) for TV and HYV rice varieties respectively.

The computation of the likelihoods, which involve multivariate normal densities, can be simplified by writing these joint densities as the product of a conditional and a marginal density:

$$\text{(A3)} \quad f(I^*_i, \Pi_{ti}, S_{1ti} \ldots S_{Jti}) = f_{I:\Pi,S}(I^*_i | \Pi_{ti}, S_{1ti} \ldots S_{Jti}) \times f_{\Pi,S}(\Pi_{ti}, S_{1ti} \ldots S_{Jti})$$

and

$$\text{(A4)} \quad g(I^*_i, \Pi_{hi}, S_{1hi} \ldots S_{Jti}) = g_{I:\Pi,S}(I^*_i | \Pi_{hi}, {}_{1hi} \ldots S_{Jti}) \times g_{\Pi,S}(\Pi_{hi}, S_{1hi} \ldots S_{Jhi})$$

where $f_{I:\Pi,S}$ and $g_{I:\Pi,S}$ are the conditional densities of I^*_i, conditional on profit and the shares, and $f_{\Pi,S}$ and $g_{\Pi,S}$ are the marginal distributions of profit and the shares.

The condition density $f_{I:\Pi,S}$ is univariate normal with mean μ_{ti}

$$\text{(A5)} \quad \mu_{ti} = \lambda(\Pi_{hi} - \Pi_{ti}) + Z_i\gamma + \Omega_{Iti}\Omega^{-1}{}_{tti}\left(\begin{bmatrix} \Pi_{ti} \\ S_{ti} \end{bmatrix} - R_{ti} \quad \Gamma_t \right)$$

where Ω_{Iti} and Ω_{tti} are submatrices of the residual covariance matrix (defined below), R_{ti} is the "stacked" left-hand side regressors of the complete TV profit and share equation system, Γ_t is the stacked matrix of regression coefficients, and S_{ti} is the stacked set of profit shares.

Similarly, the conditional density function $g_{I:\Pi,S}$ is univariate normal with mean μ_{hi}

$$\text{(A6)} \quad \mu_{hi} = \lambda(\Pi_{hi} - \Pi_{ti}) + Z_i\gamma + \Omega_{Ihi}\Omega^{-1}{}_{hhi} \left\{ \begin{bmatrix} \Pi_{hi} \\ S_{hi} \end{bmatrix} - R_{hi} \quad \Gamma_h \right\}$$

where Ω_{Ihi} and Ω_{hhi} are submatrices of the residual covariance matrix (defined below), R_{hi} is the stacked left-hand side regressors of the complete HYV profit and share equation system, Γ_h is the stacked coefficient matrix and S_{hi} is the stacked set of profit shares.

The residual covariance matrix Ω_i is defined as

$$\text{(A7)} \quad \Omega_i = W'_i \; \Sigma \; W_i$$

where Σ is the covariance matrix of the full set of (homoskedastic) structural errors ν

$$\text{(A8)} \quad \Sigma = \begin{pmatrix} \sigma^2{}_\psi & \Sigma_{\psi h} & \Sigma_{\psi t} \\ \Sigma'_{\psi h} & \Sigma_{hh} & \Sigma_{ht} \\ \Sigma'_{\psi t} & \Sigma'_{ht} & \Sigma_{tt} \end{pmatrix}$$

where Σ_{hh} and Σ_{tt} are defined by (4), Σ_{ht} are the cross-regime covariances, that is, the covariance between the errors υ_{hi} and υ_{ti}, σ_ψ is the variance of the switching equation error ψ_i and $\Sigma_{\psi h}$ and $\Sigma_{\psi t}$ are the covariances between ψ_i and υ_{hi} and υ_{ti} respectively. The matrix W_i, which transforms the structural error covariance matrix into the (heteroskedastic) composite residual covariance matrix, reflects both the random coefficients of the profit function and the endogeneity of profit in the switching equation:

$$
\text{(A9)} \quad W_i = \begin{bmatrix}
1 & \lambda & \lambda P_{1i} \cdots \lambda P_{Ji} & \lambda & -\lambda P_{1i} \cdots -\lambda P_{Ji} \\
0 & 1 & P_{1i} \cdots P_{Ji} & 0 & 0 \cdots 0 \\
\cdot & 0 & & \cdot & \\
\cdot & \cdot & I_J & \cdot & 0_J \\
\cdot & \cdot & & 0 & \\
0 & 0 & \cdots\cdots 0 & 1 & P_{1i} \cdots P_{Ji} \\
\cdot & \cdot & & 0 & \\
\cdot & \cdot & 0_J & \cdot & I_J \\
0 & 0 & & 0 &
\end{bmatrix}
$$

where I_J is a JxJ identity matrix and 0_J is a JxJ matrix of zeros.

The matrix Ω_i can then be partitioned:

$$
\begin{bmatrix}
\Omega_{IIi} & \Omega_{Ihi} & \Omega_{Iti} \\
\Omega'_{Ihi} & \Omega_{hh} & \Omega_{hti} \\
\Omega'_{Iti} & \Omega'_{hti} & \Omega_{tti}
\end{bmatrix}
$$

Thus, Ω_{IIi} is the variance of the switching equation residual ω_i, given by equation (6). The submatrices Ω_{Ihi} and Ω_{Iti} are the covariances of ω_i with the set of residuals from the HYV and TV profit and share equation systems respectively.

The variance of the TV conditional density given by (A6) is

$$\tilde{\sigma}^2_{ti} = \Omega_{IIi} - \Omega_{Iti}\Omega^{-1}_{tti}\Omega'_{Iti}$$

and the variance of the HYV conditional density given by (A7) is

$$\tilde{\sigma}^2_{hi} = \Omega_{IIi} - \Omega_{Ihi}\Omega^{-1}_{hhi}\Omega'_{Ihi}.$$

Thus, the log likelihood can be written

$$\sum_{I=1} \left[\ell n \left(\Phi \left(\frac{\mu_{hi}}{\sigma_{hi}} \right) \right) - 3/2 \; \ell n(2\pi) - 1/2 \; \ell n|\Omega_{hhi}| \right.$$

$$\left. - 1/2 \left(\begin{pmatrix} \Pi_{hi} \\ S_{hi} \end{pmatrix} - R_{hi} \;\; \Gamma_h \right)' \Omega^{-1}{}_{hhi} \left(\begin{pmatrix} \Pi_{hi} \\ S_{hi} \end{pmatrix} - R_{hi} \;\; \Gamma_h \right) \right]$$

$$+ \sum_{I=0} \left[\ell n \left(\Phi \left(\frac{\mu_{ti}}{\bar{\sigma}_{ti}} \right) \right) - 3/2 \; \ell n(2\pi) - 1/2 \; \ell n|\Omega_{tti}| \right.$$

$$\left. - 1/2 \left(\begin{pmatrix} \Pi_{ti} \\ S_{ti} \end{pmatrix} - R_{ti} \;\; \Gamma_t \right)' \Omega^{-1}{}_{tti} \left(\begin{pmatrix} \Pi_{ti} \\ S_{ti} \end{pmatrix} - R_{ti} \;\; \Gamma_h \right) \right]$$

where Φ is the standard normal cumulative function. The variance σ^2_Ψ is not identifiable and is normalized to unity. All other variances and covariances and parameters are identifiable.

TABLE A-1

Maximum Likelihood Estimates of the Simultaneous Equations Seed Variety Switching and Profit Function Model

Variable	Coef	t-Stat
HYV profit function:		
Intercept	2.9168	67.63
Irrigation	0.2514	6.30
Education	0.0082	0.76
Wage	0.0914	2.71
Fertilizer	-0.0298	-4.72
Wage*fert	-0.0232	-9.36
Wage*rice	0.3793	26.74
Fert*rice	0.0807	16.77
Wage*Irrig.	0.2732	10.60
Fert*irrig.	0.0058	1.53
Wage*educ.	0.0200	2.98
Fert*educ.	0.0020	2.01
Java	0.2543	12.19
Java*wage	-0.1904	-13.89
Java*fert	-0.0420	-18.32
Season	-0.1204	-4.39
Season*wage	-0.0146	-0.80
Season*fert	-0.0033	-1.30
var(η)	0.3670	59.92
var(wage)	0.1423	47.56
var(fert)	0.3281	44.97
cov(η,wage)	-0.1014	-33.82
cov(η,fert)	0.0009	2.12
cov(wage,fert)	0.0087	26.04

TV profit function:

Intercept	2.8417	58.76
Irrigation	0.1108	1.81
Education	0.0435	2.97
Wage	0.1211	2.96
Fertilizer	0.0057	0.81
Wage*fert	-0.0037	-1.27
Wage*rice	0.3748	23.14
Fert*rice	0.0124	2.63
Wage*Irrig.	0.0858	1.84
Fert*irrig.	-0.0350	-9.22
Wage*educ.	0.0195	2.04
Fert*educ.	-0.0009	-0.98
Java	0.1164	4.05
Java*wage	-0.2257	-12.52
Java*fert	-0.0401	-19.66
Season	0.0631	2.41
Season*wage	0.0291	1.63
Season*fert	0.0053	2.61
var(η)	0.3996	43.31
var(wage)	0.1779	34.40
var(fert)	0.1777	49.29
cov(η,wage)	-0.1207	-23.94
cov(η,fert)	-0.0010	-2.29
cov(wage,fert)	0.0041	12.92

Seed variety switching equation:

Profit	0.4915	7.89
Intercept	-1.8697	-8.11
Drought	0.7940	7.81
Flood	-0.2628	-2.37
Banks	0.7932	5.65
Other credit	0.1019	4.08
Land owned	-0.0329	-2.04
Livestock	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

Table A-2

Elasticities of Profit, Variable Inputs and Rice Yield with Respect to Input and Output Prices, Fixed Factors and Other Determinants of Seed Variety Switching

(unconditional expectations)

	PROFIT			LABOR			FERTILIZER			RICE		
	HYV	TV	Meta	HYV	TV	Meta	HYV	TV	Meta	HYV	TV	Meta
Irrigation	0.427	0.157	0.451	0.090	0.071	0.115	0.381	0.669	0.724	0.323	0.139	0.371
Education	0.044	0.078	0.054	0.001	0.044	0.016	0.015	0.103	0.031	0.029	0.066	0.040
Wage	-0.466	-0.571	-0.493	-0.705	-0.922	-0.779	-0.149	-0.476	-0.197	-0.222	-0.341	-0.253
Fertilizer price	-0.072	-0.039	-0.064	-0.023	-0.033	-0.027	-0.281	-0.812	-0.387	-0.020	-0.032	-0.025
HYV rice price	1.542	0	1.157	0.723	0	0.497	0.417	0	0.553	0.238	0	0.243
TV rice price	0	1.616	0.413	0	0.956	0.311	0	1.296	0.026	0	0.370	0.033
Drought	0	0	0.138	0	0	0.041	0	0	0.382	0	0	0.137
Flood	0	0	-0.048	0	0	-0.014	0	0	-0.132	0	0	-0.047
Banks	0	0	0.016	0	0	0.005	0	0	0.043	0	0	0.016
Other credit	0	0	0.010	0	0	0.003	0	0	0.029	0	0	0.010
Land owned	0	0	-0.003	0	0	-0.001	0	0	-0.009	0	0	-0.003
Livestock	0	0	0.002	0	0	0.001	0	0	0.005	0	0	0.002
Java	-0.040	-0.140	-0.046	0.173	0.066	0.143	0.263	0.392	0.356	0.039	-0.054	0.035
Season	-0.024	0.019	-0.019	-0.019	0.010	-0.011	-0.017	-0.004	-0.035	-0.022	0.015	-0.019