Farm-Level Fertilizer Demand in Java: A Meta-Production Function Approach

Mark M. Pitt

This paper models seed variety choice and the demand for variable inputs as jointly determined by profit-maximizing cultivators. The approach parallels that of Hayami and Ruttan, who postulated that changes in the output-fertilizer price ratio induce movements along a meta-fertilizer response function, the envelope of individual variety-specific response surfaces. Ignoring the possibility of seed variety switching leads to underestimates of fertilizer demand elasticities. In addition, estimation with samples reflecting a single seed variety may involve serious selection bias. A two-stage procedure which adjusts for selectivity bias is used to estimate the model with farm-level data from Java.

Key words: fertilizer demand, high-yielding varieties, Indonesia, Java, meta-production function, profit function, sample selection bias, seed variety adoption.

Input demand equations have been estimated with farm-level data from developing countries in numerous recent studies. Demand relationships in these studies were typically estimated from a sample of farms in which a common variety of seed was planted. For example, Sidhu derived input demand elasticities for wheat in the Indian Punjab by estimating Cobb-Douglas profit functions for old and new variety cultivators. More recently, Sidhu and Baanante have estimated a translog profit function for another sample of Mexican wheat variety cultivators in the Indian Punjab.

These and other studies neglect the possibility that cultivators can respond to price changes not only by adjusting their use of variable inputs but also by switching to different seed varieties. This ability to switch varieties is of particular relevance in the analysis of fertilizer demand because of the substantially higher fertilizer responsiveness of the new high-yielding varieties (HYVs) compared with traditional varieties (TVs). The importance of seed switching has been much discussed in the agricultural technical change literature (Binswanger and Ruttan), primarily in the context of HYV adoption, so it is surprising that it has been neglected in estimating variety-specific fertilizer demand elasticities.

Hayami and Ruttan postulated that changes in the relative price of fertilizer will induce cultivators to switch to seed varieties of differing fertilizer intensiveness so as to maximize profits with respect to a meta-production function. The meta-production function is the envelope containing the production surfaces of all potential seed varieties, irrigation systems, and cultivation techniques. Figure 1 illustrates a meta-fertilizer response surface, S^*, representing the locus of technically efficient fertilizer-output combinations for a particular agroclimatic environment and fixed level of other factors such as irrigation. A different meta-fertilizer response function is associated with each combination of agroclimatic environment and factors of production. The meta-fertilizer response surface S^* encompasses seed variety fertilizer response functions such as S_1 and S_2.

With a fertilizer-rice price ratio of P_1, the profit-maximizing farmer would be at F^*_1 on the meta-response function using seed type 1. A decrease in the price ratio to P_2 without allowing for switching (that is, not permitting movement along the meta-response surface) results in an increase in fertilizer use to F_2, which is a point inside the meta response sur-

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face. Allowing for seed variety switching eliminates this problem since the new fertilizer-output combination will be at F^*_2 with seed type 2—on the meta-response surface. Note that fertilizer response to price is larger for movements along the meta-response surface than along the seed variety specific surface. Fertilizer demand models which do not jointly consider seed variety choice and fertilizer demand will underestimate response to price.

There is another troubling aspect of variety specific fertilizer demand and profit/cost function studies. In these studies, farmers who plant seed varieties other than those investigated are systematically excluded from the sample. The reason is simply that the profit to be obtained from planting Mexican wheat varieties, for example, is not observed from cultivators who plant other varieties. Hence, least squares estimation may be selectivity biased. The bias comes about because cultivators who would obtain lower-than-average HYV profit, given prices and fixed factors select TV seeds, thus truncating the observed HYV profit distribution. The nature of this bias, appropriate estimation methods, and a test for the existence of selectivity bias are discussed below.

In this paper, a model which allows for the simultaneous determination of seed variety and fertilizer use is proposed. Simple, two-stage estimation procedures which adjust for selectivity bias are discussed and applied to the model using a sample of Javanese paddy cultivators.

A Simultaneous Equation Seed Choice and Fertilizer Demand Model

Cultivators are assumed to choose between HYV and TV varieties of rice seed so as to maximize profits. Associated with every combination of fixed factors and variable factor prices is a variable profit (and optimal fertilizer use) for the two seed varieties. Cultivators will choose to plant HYV seeds if the variable profit obtained by doing so exceeds that obtained by planting traditional varieties.

The general model consists of two regimes described by the simultaneous equations,

$$(1) \qquad \pi_{hi} = \mathbf{P}_i\boldsymbol{\beta}_h + \mathbf{K}_i\boldsymbol{\gamma}_h + \epsilon_{hi},$$

$$(2) \qquad \pi_{ti} = \mathbf{P}_i\boldsymbol{\beta}_t + \mathbf{K}_i\boldsymbol{\gamma}_t + \epsilon_{ti}, \text{ and}$$

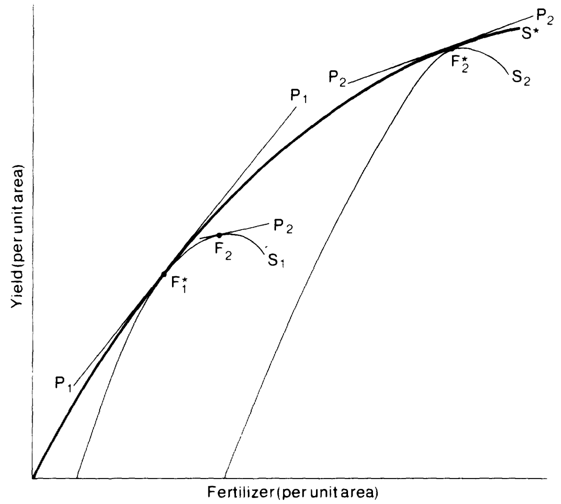

Figure 1. Optimal fertilizer application along a meta-response surface

$$(3) \qquad I^* = (\pi_{hi} - \pi_{ti})\,\lambda - \epsilon_i,$$

where $\mathbf{P}_i$ is a vector of variable factor prices; $\mathbf{K}_i$ is a vector of fixed factors; π_{hi} and π_{ti} represent variable profits under the HYV and TV regime, respectively; $\boldsymbol{\beta}_h$, $\boldsymbol{\beta}_t$, $\boldsymbol{\gamma}_h$, $\boldsymbol{\gamma}_t$, and λ are vectors of parameters; and $\epsilon_h \sim N(0, \sigma_h^2)$, $\epsilon_t \sim N(0, \sigma_t^2)$, and $\epsilon_i \sim N(0, \sigma_\epsilon^2)$. Equations (1) and (2) are variable profit functions. Equation (3) is the selection criterion function, and I^* is an unobserved variable. A dummy variable, I_i is observed. It takes the value of 1 if a plot is planted with HYV, 0 otherwise: that is,

$$(4) \qquad I_i = 1 \text{ if } I^*_i \geqq 0, \quad = 0 \text{ otherwise.}$$

Since HYVs and TVs are mutually exclusive, they cannot be observed simultaneously on any one plot. Thus, observed variable profit π_i takes the values

$$(5) \qquad \pi_i = \pi_{hi}, \text{ iff } I_i = 1; \quad \pi_i = \pi_{ti}, \text{ iff } I_i = 0.$$

The population regression function for equation (1) may be written as

$$(6) \qquad E(\pi_{hi}|\mathbf{P}_i, \mathbf{K}_i) = \mathbf{P}_i\boldsymbol{\beta}_{hi} + \mathbf{K}_i\boldsymbol{\gamma}_{hi}.$$

This function could be estimated without bias from a random sample of the population of paddy cultivators. The regression function for the incomplete sample (HYV cultivators only) may be written as

$$(7) \quad E(\pi_{hi}|\mathbf{P}_i, \mathbf{K}_i, \text{sample selection rule}) = \mathbf{P}_i\boldsymbol{\beta}_{hi} + \mathbf{K}_i\boldsymbol{\gamma}_{hi} + E(\epsilon_{hi}|\text{sample selection rule}).$$

If the conditional expectation of ϵ_{hi} is zero, a regression on the incomplete sample will provide unbiased estimates of $\boldsymbol{\beta}_{hi}$ and $\boldsymbol{\gamma}_{hi}$. However, it is not likely that both

$$(8) \quad E(\epsilon_{hi}|I_i = 1) = 0 \text{ and } E(\epsilon_{ti}|I_i = 0) = 0.$$

This would occur only in very special situations (Lee 1978). In our model, suppose that $\lambda > 0$, then it is likely that an observation of $I_i = 1$ will be associated with a positive value of ϵ_{hi} or negative value of ϵ_{ti}. That is, random factors associated with high HYV profit are likely to be associated with observed adoption.

Estimation

The variable profit functions of (1) and (2) are represented by transcendental logarithmic (translog) functions (Christensen, Jorgenson and Lau; Diewert). The translog form is much less restrictive than the Cobb-Douglas form. It does not maintain additivity or unitary Hicks-Allen elasticities of substitution. Other functional forms, such as the generalized Leontief (Diewert) or normalized quadratic (Lau) have the same property and might have sufficed. The translog variable profit function can be written as

$$(9) \quad \ln \pi = a_0 + a_{0i} \Sigma \ln P_i + \tfrac{1}{2}\Sigma_i\Sigma_j a_{ij} \ln P_i \ln P_j + \Sigma_m b_{0m} \ln K_m + \tfrac{1}{2}\Sigma_m\Sigma_j b_{mj} \ln K_m \ln K_j + \Sigma_i\Sigma_m c_{im} \ln P_i \ln K_m,$$

where π is variable profit (total revenue less total variable input costs), P_i and K_i are again variable factor prices (including the output price) and quantities of fixed factors. The parameters a_{00}, a_{0i}, a_{ij}, b_{0m}, b_{mj} and c_{im} are to be estimated. Furthermore, the following restrictions are required for symmetry and homogeneity: $a_{ji} = a_{ij}$, $b_{mj} = b_{jm}$, $\Sigma_j a_{ij} = 0$, $\Sigma_j b_{mj} = 0$, $\Sigma_i a_{0i} = 1$, $\Sigma_m b_{0m} = 1$, $\Sigma_i c_{im} = 0$ and $\Sigma_m c_{im} = 0$.

From the profit function (9), the following equation can be derived for a variable input (Diewert):

$$(10) \quad -S_i = a_{0i} + \Sigma_j a_{ij} \ln P_j + \Sigma_m c_{im} \ln K_m,$$

where S_i is the ratio of variable expenditures for the ith input to variable profit. In order to estimate the elasticity of demand for fertilizer, we need only estimate the parameters of equation (10).

Estimation of the variable profit functions (7) with selected samples is accomplished with the two-stage method described by Lee (1976) and Heckman. The objective is to find an expression that adjusts the profit function error terms so that they have zero means. A reduced-form seed selection equation is obtained by substituting the profit functions (1) and (2) into the seed selection equation (3):

$$(11) \quad I^*_i = \theta_0 + \mathbf{P}_i\boldsymbol{\theta}_1 + \mathbf{K}_i\boldsymbol{\theta}_2 - \epsilon^*_i.$$

By estimating (11) as a typical probit equation, it is possible to compute the probability that any plot has missing data on π_{hi} or π_{ti}. Of course, the probit reduced-form is of interest itself because it shows how prices and fixed factors affect the probability of adopting HYVs. If the joint density of ϵ_{hi}, ϵ_{ti} and ϵ_i is multivariate normal, then the conditional expectation on the right-hand side of (7) is

$$(12) \quad E(\epsilon_{hi}|I_i = 0) = \sigma_{1\epsilon^*}\left(-\frac{f(\phi_i)}{F(\phi_i)}\right),$$

where F is the cumulative normal distribution and f is its density function, both evaluated at ϕ_i. $F(\phi_i)$ is the probability that π_{hi} is observed. The two-stage procedure uses $-f(\phi_i)/F(\phi_i)$ and $f(\phi_i)/[1 - F(\phi_i)]$ as regressors in the HYV and TV profit function, respectively, to purge them of bias. Estimates of ϕ_i are just $\hat{\theta}_0 + \hat{\mathbf{P}}_i\hat{\boldsymbol{\theta}}_1 + \mathbf{K}_i\hat{\boldsymbol{\theta}}_2$, obtained from the estimated probit reduced-form equation (11).

The coefficient estimates of the profit functions obtained from this two-stage procedure are consistent (Lee 1976). The correct asymptotic covariance matrix is very complicated. The formula used in calculating the asymptotic standard errors reported below is discussed in Lee, Maddala, and Trost.

Data

The data used in the estimation pertain to 616 individual farm plots of wet rice on the island of Java, Indonesia, in 1971. The data were collected by the Biro Pusat Statistik (Central Bureau of Statistics) of Indonesia, from which a sample was drawn representing six districts (*kabupaten*) distributed throughout the island.

The variables used are defined as follows:

plot area in hectares (L), the quality-weighted index of irrigation applied (W),[1] the money price of rice (P_r), and the money price of urea fertilizer (P_f). Very little factory fertilizer other than urea was applied.[2]

Estimation from a single cross-section is possible because of large spatial price variation reflecting the difficult topography and poor transportation infrastructure of Java. The sample mean rice/fertilizer price ratio is 61.25 with a standard deviation of 12.10. These statistics are consistent with village market prices separately collected by the national statistical agency.

Empirical Results

Maximum likelihood estimates of the probit reduced-form seed selection equation are presented in table 1. Translog profit functions not only imply that this reduced form is translog but that the parametric restrictions of the translog profit functions carry over to the reduced-form seed selection equation.[3] Table 1 presents coefficient estimates for a more general specification relaxing the restrictions

[1] The irrigation quality index applies weights of 1, .75 and .50 to irrigation classified as technical, semitechnical and simple, respectively. The weights reflect the opinion of local experts.

[2] Unfortunately, data was lacking on factors such as education and agricultural extension, which have been considered important determinants of seed choice. As they are likely to be uncorrelated with rice and fertilizer prices and fixed factors, no omitted variable bias arises from their omission.

[3] The right-hand side of the reduced-form probit equation (11) is the difference in the HYV and TV profit functions (9). Since both profit functions have identical sets of regressors and parametric restrictions, the coefficients on the reduced-form regressors are merely the differences between the HYV and TV profit function coefficients for the same regressors.

Table 1. Probit Reduced-Form Estimates of Seed Selection Equation

Exogenous Variable	Coefficients	Standard Error
Intercept	0.889	12.234
$\ln P_r$	−1.811	5.962
$\ln P_f$	1.811	5.962
$\ln W$	1.202	1.548
$\ln L$	−2.656	1.251
$\ln W \cdot \ln L$	−0.0458	0.287
$½(\ln W)^2$	3.025	1.325
$½(\ln L)^2$	0.0667	0.521
$\ln P_f \cdot \ln P_r$	−1.121	1.463
$½(\ln P_f)^2$	2.243	2.926
$½(\ln P_r)^2$	2.243	2.926
$\ln P_r \cdot \ln W$	−0.621	0.302
$\ln P_r \cdot \ln L$	0.621	0.302
$\ln P_f \cdot \ln W$	0.621	0.302
$\ln P_f \cdot \ln L$	−0.621	0.302

Table 2. Elasticities of the Probability of Planting HYVs at Sample Means

Exogenous Variables	Estimates
Rice price	0.911
	(4.28)[a]
Fertilizer price	−0.911
	(4.28)
Irrigation	1.457
	(4.05)
Area	−0.103
	(2.44)

[a] Approximate t-values are in parentheses.

$\Sigma_m b_{mj} = 0$ and $\Sigma_m b_{0m} = 1$. These restrictions would not hold if the fixed factor endowment enters the seed selection structural equation as separate arguments. That is, the land and irrigation endowments of plots affect seed choice directly as well as through their impact on relative varietal profitability. A likelihood ratio test supports this less restrictive specification [$\chi^2(3) = 17.20$].

The coefficients of table 1 cannot directly reveal the sign or magnitude of the change in the probability of planting HYV rice in response to changes in the exogenous variables. Table 2 provides this information as elasticities. The elasticities with respect to rice and fertilizer prices are of equal magnitude and opposite sign because of the zero homogeneity of variable input demands (10) in prices. Both elasticities are significantly different from zero (at the sample means) and suggest that seed selection is quite responsive

Table 3. HYV and TV Fertilizer Share Equations, Adjusted for Selectivity Bias

Exogenous Variables	HYV	TV
Intercept	0.3286[a]	−0.3636
	(0.1766)	(0.6946)
$\ln P_r$	−0.0834	0.0328
	(0.0372)	(0.1888)
$\ln P_f$	0.0834	−0.0328
	(0.0372)	(0.1888)
$\ln W$	−0.0156	0.0052
	(0.0065)	(0.0352)
$\ln L$	0.0156	−0.0052
	(0.0065)	(0.0352)
Selectivity variable[b]	0.1019	−0.0708
	(0.0364)	(0.2087)

[a] Standard errors in parentheses.

[b] Selectivity variable: $HYV = -f(\phi_i)/F(\phi_i)$, $TV = f(\phi_i)/[1 - F(\phi_i)]$.

Table 4. HYV and TV Variable Profit Functions, Adjusted for Selectivity Bias

Exogenous Variables	HYV Coefficients	HYV Standard Errors	TV Coefficients	TV Standard Errors
Intercept	15.979	10.411	16.538	6.829
$\ln P_r$	−2.911	5.049	−5.905	3.426
$\ln P_f$	3.911	5.049	6.905	3.426
$\ln W$	−1.590	1.045	1.077	0.823
$\ln L$	2.590	1.045	−0.077	0.823
$\ln W \cdot \ln L$	0.026	−0.455	−0.048	0.042
$\frac{1}{2}(\ln W)^2$	−0.026	−0.455	0.048	0.042
$\frac{1}{2}(\ln L)^2$	−0.026	−0.455	0.048	0.042
$\ln P_f \cdot \ln P_r$	−0.512	1.240	−1.726	0.874
$\frac{1}{2}(\ln P_f)^2$	0.512	1.240	1.726	0.874
$\frac{1}{2}(\ln P_r)^2$	0.512	1.240	1.726	0.874
$\ln P_r^1 \cdot \ln W$	0.383	0.252	−0.262	0.200
$\ln P_r \cdot \ln L$	−0.383	0.252	0.262	0.200
$\ln P_f \cdot \ln W$	−0.383	0.252	0.262	0.200
$\ln P_f \cdot \ln L$	0.383	0.252	−0.262	0.200
Selectivity variable[a]	0.941	0.283	−0.220	0.276

[a] Selectivity variable: $HYV = -f(\phi_i)/F(\phi_i)$, $TV = f(\phi_i)/[1 - F(\phi_i)]$.

to the fertilizer/rice price ratio as expected because of the much higher fertilizer responsiveness of HYVs. The elasticities with respect to irrigation and area are also significantly different from zero. The irrigation elasticity of 1.457 suggests that improvements in irrigation quality will induce substantial adoption of HYV varieties. The area elasticity, though small, indicates that plot size is negatively related to HYV adoption, *ceteris paribus*.

Table 3 provides estimates of the fertilizer share equations adjusted for selectivity bias. At the bottom of table 3, the coefficients and standard errors of the selectivity variables appear, $-f(\phi_i)/F(\phi_i)$ for the HYV fertilizer equation and $f(\phi_i)/[1 - F(\phi_i)]$ for the TV fertilizer equation. The selection variable is significantly different from zero at the .01 level of significance in the HYV fertilizer equation. This is evidence of pronounced selection bias in estimating the equations from a subsample of cultivators. On the other hand, there appears to be no significant selection bias in the estimation of the TV equation. Therefore, OLS estimation of this equation from a subsample of TV cultivators should be unbiased.[4]

Adjusted estimates of the profit function themselves are presented in table 4. Again, the selectivity variable is significantly different from zero at the .01 level of significance in the HYV profit function but not in the TV profit function. This is further evidence of potential bias from estimating production structures from subsamples of cultivators.

More efficient estimates could have been derived by estimating the profit function jointly with the share equation with Zellner's seemingly unrelated regressions estimator. However, this procedure is rather complicated because the estimated covariance matrix to be used in the generalized least squares must first be purged of bias and also because the asymptotic covariance matrix of the final GLS estimate is complicated to compute. In any case, Guilkey and Lovell have found that Zellner estimation of a translog system of equations did not perform any better than single-equation estimation.

[4] In general, the selectivity variable may be significant in any or both of the equations (Lee 1978).

Fertilizer Demand Elasticities

The price elasticity of demand for fertilizer allowing for seed switching is readily calculated from parameters of the probit seed selection equation and the two fertilizer demand equations. The expected demand for fertilizer by a representative cultivator having mean endowments of fixed factors and facing mean prices is

$$(13) \quad E(F) = E(F|I = 1) \text{ Prob } (I = 1) + E(F|I = 0) \text{ Prob } (I = 0),$$

where $E(F|I = 1)$ and $E(F|I = 0)$ are the demand for fertilizer under a HYV and a TV seed regime, respectively; and Prob (I = 1) and Prob (I = 0) are the probabilities of observing an HYV and a TV regime, respectively. The log derivative of this expectation with respect to the price of fertilizer is the total price elasticity of demand (η), which can be reduced to

$$(14)\quad \eta = \frac{\eta_h E(F|I = 1) \text{ Prob } (I = 1)}{E(F)} + \frac{\eta_t E(F|I = 0) \text{ Prob } (I = 0)}{E(F)} + \frac{\S_h [E(F|I = 1) - E(F|I = 0)] \text{ Prob } (I = 1)}{E(F)},$$

where $\S_h$ is the elasticity of the probability of choosing HYV seeds with respect to the price of fertilizer, and η_h and η_t are given by

$$(15)\quad \eta_i = -\frac{a_{ff,i}}{S_i} + S_i - 1, \quad i = \text{HYV, TV},$$

where S is the fertilizer share and a_{ff} is the estimated coefficient on the fertilizer price variable in the share equation (10). At the sample means, these elasticities are $\eta_h = -1.561$ and $\eta_t = -0.400$.

The sum of the first two terms of (14) is the total elasticity in the absence of seed switching. It is −1.042. The last term in (14) adjusts this elasticity for the change in the probability of HYV cultivation as a result of a fertilizer price increase. Only if fertilizer demand is the same irrespective of which seed is planted $[E(F|I = 1) = E(F|I = 0)]$ or if cultivators are unresponsive to fertilizer prices in making their seed choice ($\S_h = 0$) will the seed switching adjustment have no impact on the elasticity. In our case, the seed switching adjustment increases the elasticity by about 11% to −1.155.

Conclusions

This paper differs from other attempts to estimate the farm-level demand for variable inputs. The choice of seed variety and the demand for variable inputs was analyzed in a simultaneous equations framework. The approach parallels that of Hayami and Ruttan, who postulated that changes in the output-fertilizer price ratio induce movements along a meta-fertilizer response function which is the envelope of individual variety-specific response surfaces. Ignoring the possibility of seed variety switching leads to underestimates of farm-level fertilizer price elasticities of demand. In addition, estimation from samples reflecting a single seed variety may involve serious selection bias.

This model assumes that cultivators maximize profits in the joint determination of seed variety and fertilizer demand. A two-stage procedure which adjusts for selectivity bias is used to estimate the model. A t-test confirms the significance of selectivity bias in the estimation of the HYV fertilizer equation and profit function. The price elasticity of demand for fertilizer allowing for seed switching along the meta-response surface was calculated to be −1.155.

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