A TOBIT MODEL OF THE DEMAND FOR FARMLAND

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The market for farmland has often been a subject of interest to agricultural economists, as evidenced by numerous studies that have investigated factors determining rural land values (Aines; Reynolds and Timmons; Ruttan; Scofield). Despite the wealth of literature concerned with land values, little is known about who owns and exercises entrepreneurial control over land resources in the U.S. Consequently, there is a lack of understanding concerning the decision to purchase farmland. Lewis has suggested that better understanding of landowner investment decisions is important in determining and implementing effective land-use policy. Also, Wunderlich has noted the importance of understanding land ownership with regard to land-use decisions. Long et al. (p. 44) have suggested that "if policies are to be designed to influence private landowners' decisions, then it seems imperative that the factors affecting landowners' decisions and the decision process be better understood."

This study investigates the demand for farmland, while accounting for the process underlying the decision to purchase farmland. The failure to account for the initial decision to purchase or not can lead to bias in estimated demand parameters (Heckman; Tobin). A theoretical and empirical model of farmland purchase behavior that accounts for the initial purchase decision is considered. First, theoretical considerations are addressed. Next, results of an empirical analysis of land purchases by farmers is presented. A Tobit model is employed to account for both the initial decision to purchase farmland and the amount of farmland purchased by the individual.

THEORETICAL CONSIDERATIONS

The decision to purchase and own farmland can be considered within the general framework of the theory of the firm. Assume a profit function for a given production period of the form

$$(1)\quad \pi = ph(x, z) - r_1x - r_2z - f$$

where x is land; z represents all other inputs in the production function h, which is assumed well-behaved and twice differentiable; p is the output price; r_1 and r_2 are factor prices; and f is some level of fixed costs. Let $x = x^* + c$ where c is some fixed or given (endowed) amount of land owned by the firm at the beginning of the production period, so that x^* represents the level of land purchases during the production period. Then application of the Kuhn and Tucker conditions for profit maximization yields

$$(2)\quad \partial\pi/\partial x = p(\partial h/\partial x) - r_1 \leq 0,\quad x^*(\partial\pi/\partial x^*) = 0$$

$$\partial\pi/\partial z = p(\partial h/\partial z) - r_2 \leq 0,\quad z(\partial\pi/\partial z) = 0.$$

Assuming $z > 0$, so that $\partial\pi/\partial z = 0$, yields the following profit maximizing condition:

$$(3)\quad \frac{\partial h/\partial x}{\partial h/\partial z} = \frac{r_1}{r_2}.$$

Of course, if $x^* > 0$, then $\partial\pi/\partial x^* = 0$ and (3) becomes the familiar strict equality between the rate of technical substitution and the input price ratio, so that an interior solution (i.e., $x^* > 0$) results. If $x^* = 0$, then $\partial\pi/\partial x^* > 0$, and (3) is a strict inequality, or $\partial\pi/\partial x^* = 0$ and (3) is a strict equality. All three cases are shown in Figure 1, where P_1, P_2, and P_3 are isoquant curves for different production processes. The corner solution case, $x^* = 0$ and $\partial\pi\partial x^* = 0$, is shown for production process P_2, while $x^* = x_1 - c$ for production process P_1. Assuming that $x^* \geq 0$, or that land cannot be sold during the production period, $x^* = 0$ for P_3 since $\partial\pi/\partial x^* > 0$.

An important implication of these results is that changes in the price of land or factors affecting the nature of the production function can have a two-fold effect on the quantity of farmland demanded. First, the *amount* of land purchased by firms for which condition (3) results in an interior solution will change. Second, the *number* of firms for which (3) results in an interior solution will change, along with the amount of farmland they purchase. Referring to Figure 1, this second effect can be envisioned for an individual firm as a shift in the relevant isoquant below or above the fixed or endowed amount of land c. For example, if the firm's relevant isoquant shifted from P_3 to P_1, it would be profitable to

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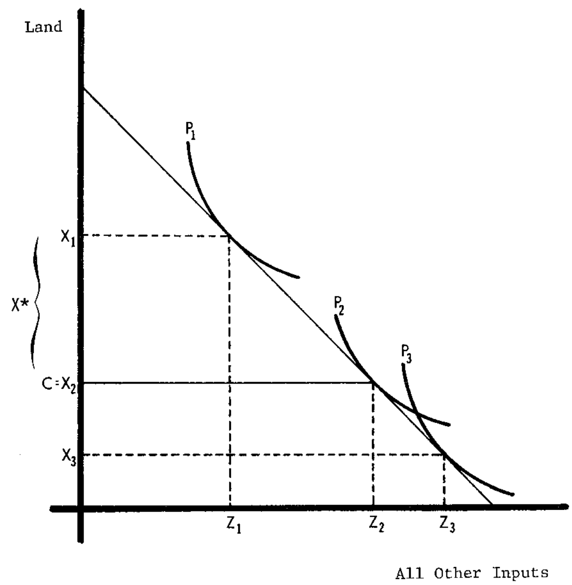

FIGURE 1. The Use of Land and All Other Farm Inputs

purchase farmland of an amount $x^* = x_1 - c$. (Alternatively, a shift from P_1 to P_3 would result in a decision to purchase no additional farmland.) Therefore, a model of farmland demand that did not account for the initial decision to purchase or not to purchase could underestimate the total effect of changes in demand factors on farmland purchase behavior for a given population of farm firms.

FACTORS AFFECTING THE DEMAND FOR FARMLAND

Theory of the firm yields the result that input demand is dependent on the nature of the production function and input and product prices. If land is viewed as an ordinary input in the farm production function, then the input demand function for land can be derived in a straight-forward manner from the first-order conditions for profit maximization. However, some discussion is warranted concerning the relevant factors appearing in an input demand function for farmland.

The price of land would enter the demand function from the first-order conditions for profit maximization. Size of the farm should also appear in the demand function to account for the existence of economies of size in farming (Farris and Armstrong; Hall and LeVeen). From a cost of capital perspective, previous purchases of farmland may also be a determinant of current land purchase decisions. The greater the level of recent prior purchases, *ceteris paribus*, the higher the firm's current leverage ratio and cost of debt leading to a reduction in current demand for additional farmland.

Age of the farmland owner may also influence land purchase behavior. It is arguable that the demand for additional farmland would follow a life-cycle pattern, with greater demand during the middle-age years than during younger or older-age years. Younger owners may be less likely to purchase land because of cash flow problems (Lewis), while older persons may tend to have shorter planning horizons and be more risk averse. Alternatively, it is arguable that the demand for farmland may be greater during younger and older-age years than during middle-age years. Younger individuals entering into farming have to purchase a "critical mass" of land and have capital resources to establish a viable enterprise (Boehlje). During the middle-age years, owners may be less likely to purchase additional farmland because family responsibilities and child-rearing expenses are greater than in younger or older-age years. Furthermore, relative to middle-age owners, younger owners may be more financially aggressive regarding expansionary plans, while older individuals may purchase land to increase farm size if grown children remain on the farm as business partners in an expanding management capacity. In sum, farmland purchases probably follow a life-cycle pattern; however, whether purchases are greater or lower during middle-age years is not clear.

Finally, the level of off-farm income may influence farmland purchase decisions. Two effects appear possible. First, higher levels of off-farm income may be associated with a decrease in the demand for farmland because the individual would have less time to devote to farming. Alternatively, higher levels of off-farm income could lead to an increase in the demand for farmland since from a capital structure standpoint, the individual may be able to achieve a lower cost of debt. For these reasons, the level of off-farm income appears important with regard to farmland purchase decisions, although the direction of the influence of off-farm income on farmland demand is not entirely clear.

EMPIRICAL MODEL

In this section, an empirical model of farmland purchases, given the theoretical considerations discussed earlier, is presented. Estimation of the model gave rise to the empirical consequences of bias that result from using nonrandomly selected samples to estimate behavioral relationships. The problem was first considered by Tobin, and more recently by Amemiya and Heckman. Sample selection bias occurs when a sample is chosen on the basis of some observed or unobserved variable(s). In the case at hand, assume that only those individuals who purchased farmland were included in the sample. The criteria for sample inclusion would be whether land purchases were greater than zero during the study period considered, or in other words, if condition (3) results in an interior solution. Estimated coefficients of a model based on such a sample will be biased (Tobin), because ordinary least squares regression based on such a sample does not consider the initial decision of whether or not to purchase farmland, but rather only how much land is purchased once the decision to purchase is made.

If the sample includes only observations on individuals who purchased farmland during the study period, the model under consideration is

$$(4) \quad y_i = X_i\beta + u_i, \quad \text{if } u_i > -X_i\beta, \qquad (i = 1 \ldots T) \quad y_i = 0 \quad \text{otherwise}$$

where y_i is purchases of farmland, X_i is a (1 x k) vector of exogenous regressor values, β is a (k x 1) vector of parameters, and u_i is a random error term that is normally distributed with mean zero and variance σ^2. Such a model was first considered by Tobin, who proposed an iterative procedure for determining the maximum likelihood estimates. The ordinary least squares estimator does not consistently estimate the structural parameters of the Tobit model in (4) since

$$(5) \quad Ey_i = X_i \beta F_i + \sigma f_i$$

where F_i and f_i are the cumulative distribution function and density function of a normal random variable that is respectively evaluated at $X_i\beta/\sigma$.[1] The ordinary least squares estimator assumes $Ey_i = X_i\beta$.

Tobin's estimator has been shown to be inconsistent, but a consistent estimation procedure has been proposed by Amemiya. Amemiya's estimator can be written

$$(6) \quad \begin{bmatrix} \hat{\beta} \\ \hat{\sigma}^2 \end{bmatrix} = \left(\sum_{i=1}^{T} \begin{bmatrix} X_i{}' \hat{y}_i \\ 1 \end{bmatrix} [X_i y_i, 1] \right)^{-1} \sum_{i=1}^{T} \begin{bmatrix} X_i{}' \hat{y}_i \\ 1 \end{bmatrix} y_i^2$$

where $\hat{y}_i = X_i (\sum_{i=1}^{T} X_i{}' X_i)^{-1} \sum_{i=1}^{T} X_i{}' y_i$.

Amemiya also provides the log likelihood function for this model:

$$(7) \quad L = - \sum_{i=1}^{T} \log F_i - (T/2)\log \sigma^2 - (1/2\sigma^2) \sum_{i=1}^{T} (y_i - X_i\beta)^2$$

so that maximum likelihood parameter estimates can be derived.

The estimator described in (6) or maximum likelihood estimates based on (7) do not alone indicate the effect of a change in X on y. As indicated by McDonald and Moffit, in Tobit models, it can be shown that

$$(8) \quad \partial E(y)/\partial X_j = F\beta_j$$

where X_j is the j'th independent variable in X and β_j the corresponding coefficient, and

$$(9) \quad \partial E(y|y > 0)/\partial X_j = \beta_j[1 - zf/F - f^2/F^2]$$

where $z = X\beta/\sigma$. The ordinary least squares estimator assumes: $\partial E(y)/\partial X_j = \partial E(y|y > 0)\partial X_j = \beta_j$. The derivative in (9) indicates the change in the amount of farmland purchased by firms, given that condition (3) results in an interior solution, while (8) indicates the total effect on farmland purchases, which also takes into account the change in the number of firms for which condition (3) results in an interior solution. Therefore, caution should be exercised in interpreting the results of Tobit models such as (4), since $\partial E(y)/\partial X_j$ does not equal β_j. These estimates should be corrected as in (8) and (9) to obtain the appropriate derivatives.

ESTIMATION

Following the procedure outlined above, the model described in (4) was estimated for Georgia farmers, using data gathered in a 1979 national survey of land ownership by the Soil Conservation Service. The sample of 89 observations included individuals who owned and operated a farm (as defined in the SCS survey) in Georgia during 1977 and made purchases of land during the period 1970–78. As discussed earlier, independent variables are reported market value per acre of farmland owned, total farm size (acres), total acres of land purchased between 1960–69, age of the farm owner, and off-farm income. Reported market value per acre from the SCS survey was used as a proxy for purchase price of the land for which data were not available. Off-farm income is represented as a set of dummy variables constructed to correspond to income ranges selected by respondents in the SCS "Land Ownership Study." Responses indicating "none" or "negative" off-farm income were deleted, and an intercept term was included in the model. To test the hypothesis that land purchases may follow one of the life-cycle patterns discussed earlier, age squared was included in

[1] The density function f_i and cumulative distribution function F_i for a normal random variable are defined as

$$f_i = (1/\sqrt{2\pi\sigma^2}) \exp [-½(X_i\beta/\sigma)^2]$$

$$F_i = \int_{-\infty}^{X_i\beta} (1/\sqrt{2\pi\sigma^2}) \exp [-½(\lambda/\sigma)^2]d\lambda.$$

the model. If one of the hypotheses is true, then opposite signs for the coefficients for age and age squared would be expected. The dependent variable was measured as acres of farmland purchased over the period 1970–78.

RESULTS

Ordinary least squares results for the model are presented in Table 1 (standard errors appear in parentheses); also presented are maximum likelihood estimates based on equation (7). Estimates were derived following the Newton-Raphson procedure, using the consistent estimator in (6) to obtain initial parameter estimates. Parameter estimates in both equations were all significantly different from zero, except for value per acre and previous land purchases in the ordinary least squares equation. All parameter estimates in the ordinary least squares equation are theoretically consistent in sign, in accordance with a priori expectations discussed earlier. The coefficients for age and age squared in the ordinary least squares equation imply that purchases of land were progressively lower during the study period for individuals up to age 47, and increased thereafter, supporting the second of the two possible life cycle hypotheses discussed previously. The negative signs for the income variables imply that individuals earning off-farm income are less likely to purchase farmland. This result supports the first of the two alternative hypotheses concerning the possible effects of off-farm income that were discussed earlier. R^2 for the least squares model was 0.48.

As mentioned in the previous section, the Tobit coefficients for the maximum likelihood equation cannot be directly interpreted as the total effect on farmland purchases, given a change in the independent variables. The appropriate estimated derivatives following equations (8) and (9) are presented in Table 2. Both derivatives are estimated at the mean of all the independent variables. As shown by McDonald and Moffitt, the term $[1 - zf/F - f^2/F^2]$ in equation (9) represents the fraction of the mean total change in the dependent variable, farmland purchases, resulting from marginal changes in purchases on the part of individuals for which condition (3) yields an interior solution. For our sample, this proportion was calculated to equal 0.917, so that 91.7 percent of the mean change in farmland purchases, given a change in the independent variables, would be attributable to individuals for which purchases were observed to be greater than zero during the study period. Alternatively, 8.3 percent of the change would be generated by changes in the probability of purchasing any farmland at all. These results indicate that the correct derivatives based on equations (8) and (9) should differ little from the maximum likelihood results reported in Table 1.

Both corrected derivatives (Table 2) are quite similar and differ only slightly from the coefficient estimates in Table 1. For age, both estimated mean derivatives imply that farmland purchases decline up to age 43 and then begin to increase. All maximum likelihood derivative estimates indicate a somewhat greater responsiveness of mean farmland purchases relative to the ordinary least squares results, given changes in

TABLE 1. Empirical Results for Farmland Demand Model: Dependent Variable-Farmland Purchases in Acres, 1970–78

Independent Variable	Ordinary Least Squares	Maximum Likelihood
Intercept	4083.789 (1037.071)*	7493.640 (556.394)*
Value Per Acre	-.180 (.163)	-.940 (.119)*
Farm Size	.767 (.122)*	.976 (.064)*
Previous Farmland Purchased, 1960-69	-.125 (.103)	-.569 (.053)*
Age of Farm Owner	-82.302 (40.270)*	-185.295 (21.255)*
(Age of Farm Owner)^2	.878 (.426)*	2.173 (.229)*
Off-Farm Income		
$0 to $9,999	-2110.731 (382.121)*	-2949.930 (181.364)*
$10,000 to $19,999	-1955.674 (380.846)*	-3029.300 (185.999)*
$20,000 to $49,999	-1858.510 (392.663)*	-2592.900 (184.554)*
Over $50,000	-1938.343 (418.857)*	-3285.570 (223.135)*

* Significantly different from zero, $\alpha = .05$.

TABLE 2. Mean Estimated Derivatives for the Maximum Likelihood Estimator

Variable	$\partial E(y)/\partial X_i$ [a]	$\partial E(y \mid y > 0)/\partial X_i$ [b]
Value Per Acre	-.938	-.862
Farm Size	.974	.895
Previous Farmland Purchases, 1960-69	-.568	-.522
Age of Farm Owner	-184.924	-169.916
(Age of Farm Owner)^2	2.169	1.993
Off-Farm Income		
$0-$9,999	-2944.030	-2705.086
$10,000 to $19,999	-3023.241	-2777.868
$20,000 to $49,999	-2587.714	-2377.689
Over $50,000	-3278.999	-3012.868

[a] See equation (8)
[b] See equation (9)

the purchase price of land, farm size, previous purchases, and off-farm income. Furthermore, all derivative estimates are consistent with the theoretical considerations that are discussed earlier. Finally, as theoretically expected, the ordinary least squares estimates generally appeared to underestimate the effect of changes in exogenous factors on the demand for farmland in Georgia.

CONCLUSIONS

Factors affecting rural land values have been studied frequently, but little is understood about the causal factors explaining individual ownership of farmland. This paper represents an attempt to better estimate farmland demand by accounting for the process underlying the decision to purchase. A greater understanding of the decision to purchase and own farmland may have important policy implications in many areas, including rural economic development and land use policy. For example, policies affecting rural land values, such as differential assessment legislation, will affect farmland demand, and more accurate estimates of the impact on total farmland purchases should lead to more effectively designed legislation.

Given theoretical considerations, the demand for farmland was specified as a function of purchase price of the land, farm size, previous farmland purchases, age of the landowner, and off-farm income. These variables were considered in a model explaining 1970–78 farmland purchases in Georgia. The empirical procedure accounts for estimated parameter bias that would result from simply applying ordinary least squares to estimate the model.

Admittedly, the study suffers from shortcomings. First, possible aesthetic values associated with owning farmland and operating a farm were not considered.[2] Second, the model did not allow the possibility of selling farmland, but considered only the possibility of land purchases. Furthermore, the model failed to account for farmland rental, which is probably a reasonable substitute alternative to purchasing land for some individuals. However, results were consistent with a priori expectations and were encouraging regarding application of the maximum likelihood procedure relative to ordinary least squares. As theoretically expected, the ordinary least squares estimator generally seemed to underestimate the impact of changes in exogenous factors, such as purchase price and farm size, on farmland demand. These results appear to warrant additional research regarding the effect of these and other factors on farmland purchase behavior.

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[2] For a discussion of "land fundamentalism" and other attitudes regarding aesthetic values associated with owning farmland, see Smith and Martin.